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Aggregate fluctuations in a trade and credit network economy

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AGGREGATE FLUCTUATIONS IN A TRADE AND CREDIT NETWORK ECONOMY

Jakub Miřtak

A Thesis presented for the degree of
Doctor of Philosophy in Economics



Banking & Finance Research Group
King's Business School
King's College London

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Declaration

The work in this thesis is based on research carried out at King's Business School, King's College London, United Kingdom. No part of this thesis has been submitted elsewhere for any other degree or qualification and it is all my own work unless referenced to the contrary in the text.

The contents of **Chapter 2** are joint work with Gulcin Ozkan (King's College London, King's Business School) and Aida Garcia-Lazaro (the University of Bath, Institute for Policy Research): all co-authors contributed equally. The paper version of **Chapter 2** has been published in the Journal of Economic Dynamics and Control under the title: "**Supply chain networks, trade and the Brexit deal: a general equilibrium analysis**" and was presented at the 50th Anniversary Conference of the Money, Macro & Finance Research Group in September 2019 at the London School of Economics under its primary title: "What will hurt the UK economy most after Brexit: restrictions on trade, capital or migration?".

A modified version of **Chapter 3** was presented at the 53rd Annual Conference of the Money, Macro & Finance Research Group in September 2022 at the University of Kent.

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As a disclaimer, I declare that the views expressed in this thesis are those of the authors and should not be attributed to the European Central Bank or the Eurosystem.

I declare that this thesis consists of 52,797 words.

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Contents

Declaration	2
Acknowledgments	3
Introduction	15
1 A model of a trade and credit network economy	22
1.1 Introduction	23
1.2 Model	25
1.2.1 Benchmark model	26
1.2.2 Model with Ricardian and non-Ricardian households	31
1.2.3 Model with supply chains	33
1.2.4 Model with long-term bonds	37
1.2.5 Model with credit linkages	39
1.3 Calibration	43
1.4 Comparative statics	49
1.4.1 TFP shocks	50
1.4.2 Labor supply shocks	53
1.4.3 Trade shocks	55
1.4.4 Government spending shocks	58
1.4.5 Monetary policy shocks	60
1.4.6 International spillovers	62
1.5 Welfare analysis	65
1.6 Sensitivity checks	71
1.7 Discussion	75
1.8 Conclusions	77
2 Supply chain networks, trade and the Brexit deal: a general equilibrium analysis	79
2.1 Introduction	80
2.2 Benchmark model	84

2.2.1	The benchmark specification	86
2.2.2	Benchmark model simulations	91
2.3	Migration, supply chains and the banking sector	98
2.3.1	Migration flows and heterogeneous labour	98
2.3.2	Supply chain networks	101
2.3.3	Banks	102
2.3.4	Calibration of the extended model	103
2.4	Policy experiments: frictions in migration and trade of goods and services	107
2.4.1	Migration	109
2.4.2	Frictions to trade in goods	113
2.4.3	Frictions to trade in services	114
2.4.4	Trade deals with non-EU countries	115
2.4.5	Comparative statics	117
2.5	Discussion	118
2.5.1	Model choice	118
2.5.2	Welfare analysis	121
2.6	Robustness checks	123
2.6.1	A fall in high-skilled labour inflows	123
2.6.2	Elasticity of substitution between domestic and foreign goods .	124
2.6.3	Composition of consumption baskets for low versus high-skilled households	124
2.6.4	Further sensitivity checks	125
2.7	Conclusions	125
3	Supply chains, financial linkages and international spillovers of monetary policy	127
3.1	Introduction	128
3.2	Two-country model with financial frictions	131
3.2.1	Households	131
3.2.2	Firms	133
3.2.3	Banks	136
3.2.4	Monetary and fiscal authorities	140

3.2.5	Clearing conditions	140
3.3	Extensions	141
3.3.1	Supply chains	141
3.3.2	Financial linkages	143
3.4	Calibration	148
3.4.1	Parameters of households	148
3.4.2	Parameters of producers	149
3.4.3	Parameters of banks	150
3.4.4	Parameters of government	151
3.4.5	Parameters of the trade and credit network	151
3.5	Conditional forecast	153
3.6	Network contagion	154
3.6.1	Spillovers of conventional monetary policy	155
3.6.2	Spillovers of asset purchases	160
3.6.3	Fear of floating	164
3.7	Sensitivity analysis	168
3.8	Discussion	170
3.9	Conclusions	171
	Concluding remarks	172
	Appendix A	190
A.1	Optimization problems of the benchmark model	191
A.1.1	The households' problem	191
A.1.2	The firms' problem	193
A.2	Optimization problems of Ricardian and non-Ricardian households . .	196
A.2.1	Ricardian households	196
A.2.2	Non-Ricardian households	198
A.3	Optimization problems with supply chains	199
A.3.1	CES technology	199
A.3.2	Leontief technology	201
A.3.3	Cobb-Douglas technology	204
A.4	Optimization problems with long-term bonds	206

A.5	Optimization problems with credit linkages	207
A.6	Sensitivity checks	211
Appendix B		219
B.1	Benchmark model	220
B.1.1	Households	220
B.1.2	Firms	224
B.1.3	Government	228
B.2	Extension (1): migration and heterogeneous households	229
B.2.1	Households	229
B.2.2	Firms	233
B.2.3	Government	235
B.3	Extension (2): supply chain networks	235
B.3.1	Importers	240
B.3.2	Government	240
B.3.3	Market clearing conditions	240
B.4	Extension (3): banks	241
B.4.1	Households	241
B.5	Calibration	244
B.5.1	Benchmark model	244
B.5.2	Extension (1): migration flows and heterogeneous households .	246
B.5.3	Extension (2): supply chains networks	247
B.5.4	Extension (3): banks	249
B.6	Trade relocation	252
B.7	Steady-state	255
B.7.1	Households	255
B.7.2	Banks	260
B.7.3	Government and market clearing	260
B.8	Sector classification	262
B.9	Sensitivity analysis	263
Appendix C		272
C.1	Optimization problems of the two-country model with financial frictions	273

C.1.1	The households' problem	273
C.1.2	The firms' problem	276
C.1.3	The banks' problem	279
C.1.4	Capital goods producers	284
C.2	Optimization problems of the model with supply chains	285
C.2.1	The firms' problem	285
C.3	Optimization problems of the two-country model with financial linkages	291
C.4	Sensitivity checks	296

List of Figures

1.1	Responses to US-originated TFP shock under alternative model configurations.	51
1.2	Responses to China-originated TFP shock under alternative model configurations.	52
1.3	Responses to US-originated labor supply shock under alternative model configurations.	54
1.4	Responses to China-originated labor supply shock under alternative model configurations.	55
1.5	Responses to 10% increase in US import prices under alternative model configurations.	56
1.6	Responses to 10% increase in Chinese import prices under alternative model configurations.	57
1.7	Responses to US-originated government spending shock under alternative model configurations.	58
1.8	Responses to China-originated government spending shock under alternative model configurations.	59
1.9	Responses to 100 basis points US interest rate hike.	61
1.10	Responses to 100 basis points Chinese interest rate hike.	62
2.1	Responses to bilateral non-tariff barriers to trade in goods across the UK-EU border in the benchmark model.	97
2.2	UK economy responses to migration and trade shocks.	110
3.1	Conditional forecast of the US conventional monetary policy path. . . .	157
3.2	Differences between the responses to the US conventional monetary policy with and without the endogenous responses of Turkish monetary policy.	159

3.3	Conditional forecast of asset purchases by the US Fed.	162
3.4	Differences between the responses to asset purchases by the US Fed with and without the endogenous responses of Turkish monetary policy. . .	163
3.5	Conditional forecast of the US conventional monetary policy path with the fear of floating.	165
3.6	Conditional forecast of asset purchases by the US Fed with the fear of floating.	167
A.1	Sensitivity analysis: elasticity of substitution between domestic and imported intermediate inputs. Responses to US-originated TFP shock.	211
A.2	Sensitivity analysis: elasticity of substitution between domestic and imported intermediate inputs. Responses to US-originated labor supply shock.	211
A.3	Sensitivity analysis: elasticity of substitution between domestic and imported intermediate inputs. Responses to a 10% increase in the US import price of traded goods.	212
A.4	Sensitivity analysis: elasticity of substitution between domestic and imported intermediate inputs. Responses to US-originated government spending shock.	212
A.5	Sensitivity analysis: elasticity of substitution between domestic and imported intermediate inputs. Responses to 100 basis points US interest rate hike.	213
A.6	Sensitivity analysis: elasticity of substitution between intermediate in- puts and value added. Responses to US-originated TFP shock.	213
A.7	Sensitivity analysis: elasticity of substitution between intermediate in- puts and value added. Responses to US-originated labor supply shock.	214
A.8	Sensitivity analysis: elasticity of substitution between intermediate in- puts and value added. Responses to a 10% increase in the US import price of traded goods.	214
A.9	Sensitivity analysis: elasticity of substitution between intermediate in- puts and value added. Responses to US-originated government spend- ing shock.	215

A.10 Sensitivity analysis: elasticity of substitution between intermediate inputs and value added. Responses to 100 basis points US interest rate hike.	215
A.11 Sensitivity analysis: share of Ricardian households in China. Responses to China-originated TFP shock.	216
A.12 Sensitivity analysis: share of Ricardian households in China. Responses to China-originated labor supply shock.	216
A.13 Sensitivity analysis: share of Ricardian households in China. Responses to a 10% increase in the Chinese import price.	217
A.14 Sensitivity analysis: share of Ricardian households in China. Responses to China-originated government spending shock.	217
A.15 Sensitivity analysis: share of Ricardian households in China. Responses to 100 basis points Chinese interest rate hike.	218
C.1 Sensitivity analysis: investment adjustment cost. Conditional forecast of the US conventional monetary policy path.	296
C.2 Sensitivity analysis: investment adjustment cost. Conditional forecast of asset purchases by the US Fed.	297
C.3 Sensitivity analysis: survival rate of banks. Conditional forecast of the US conventional monetary policy path.	298
C.4 Sensitivity analysis: survival rate of banks. Conditional forecast of asset purchases by the US Fed.	299
C.5 Sensitivity analysis: proportional advantage in absconding rate. Conditional forecast of the US conventional monetary policy path.	300
C.6 Sensitivity analysis: proportional advantage in absconding rate. Conditional forecast of asset purchases by the US Fed.	301
C.7 Sensitivity analysis: fraction of divertable funds. Conditional forecast of the US conventional monetary policy path.	302
C.8 Sensitivity analysis: fraction of divertable funds. Conditional forecast of asset purchases by the US Fed.	303
C.9 Sensitivity analysis: elasticity of substitution between local and export capital. Conditional forecast of the US conventional monetary policy path.	304

C.10 Sensitivity analysis: elasticity of substitution between local and export capital. Conditional forecast of asset purchases by the US Fed.	305

List of Tables

1.1	Calibrated structural parameters.	47
1.2	Shock parameters.	48
1.3	US-originated shocks: consumption equivalents of US households. . .	67
1.4	China-originated shocks: consumption equivalents of Chinese households.	68
1.5	US-originated shocks: consumption equivalents of Chinese households.	69
1.6	China-originated shocks: consumption equivalents of US households.	70
2.1	Calibrated parameters of the benchmark model.	92
2.2	Summary of consumption baskets of the four countries.	93
2.3	Calibrated parameters of extensions and shocks.	105
2.4	Summary of the supply chain parameters.	106
2.5	Responses to shocks - final model.	112
2.6	Steady-state values of the UK economy.	118
2.7	Responses to non-tariff barriers to trade in goods and services under four model specifications.	120
2.8	Welfare analysis.	122
3.1	Calibrated parameters.	152
B.1	Calibrated parameters of the benchmark model.	245
B.2	Benchmark model: composition of consumption in the four countries.	246
B.3	Calibrated parameters of extension (1): migration and heterogeneous households.	247
B.4	Calibrated parameters of extension (2): supply chains networks. . . .	248
B.5	Supply chains model: composition of consumption in the four countries	248
B.6	Summary of the supply chain parameters.	250
B.7	Supply chains model: the supply chain parameters; as percent of total supplies of type $s = \{1, 2, 3\}$	251

B.8	Calibrated parameters of extension (3): banks.	252
B.9	Summary of the supply chain parameters under NTBs to trade in goods relative to benchmark model; percentage points differences.	253
B.10	Summary of the supply chain parameters under NTBs to trade in ser- vices relative to benchmark model; percentage points differences.	254
B.11	Summary of the supply chain parameters under liberalised trade relative to benchmark model; percentage points differences.	254
B.12	Translation table for NACE Rev.2 classification.	262
B.13	Responses to shocks to the UK's net high-skilled migration (final model).	263
B.14	Sensitivity analysis: elasticity of substitution between domestic and foreign supplies (η_s).	264
B.15	Responses to shocks with different consumption baskets of high-skilled and low-skilled households (final model).	265
B.16	Sensitivity analysis: Calvo parameter (θ_p).	266
B.17	Sensitivity analysis: survival rate of banks (θ_b).	267
B.18	Sensitivity analysis: Taylor rule parameter (φ_π).	268
B.19	Sensitivity analysis: persistence of nominal interest rate (ρ_r).	269
B.20	Sensitivity analysis: investment adjustment cost (Φ).	270
B.21	Sensitivity analysis: share of low-skilled workers ($1-\rho_i^{hs}$).	271

Introduction

Changes in both the international financial system and the nature of international trade have significantly impacted the functioning of the global economy in recent decades, resulting in two stylized facts. First, the emergence of global supply chains with different stages of production taking place in different countries has generated global trade networks, altering the composition of international trade, a much greater share of which is now in intermediate inputs. Second, the scale of international financial integration has led to a global financial cycle significantly increasing the cross-country co-movement (see, for example, [Klein and Shambaugh, 2015](#); [Rey, 2015](#)).

Although global supply chains have been at the heart of the international economic architecture for some time, the role of trade networks in macroeconomic outcomes has only recently been incorporated formally (see, for example, [Acemoglu et al., 2012, 2015](#)). Furthermore, most of the existing work on trade networks examines dynamics in closed economies (see, for example, [Altinoglu, 2021](#); [Bigio and La’o, 2020](#); [Barrot and Sauvagnat, 2016](#); [Carvalho and Gabaix, 2013](#)). Similarly, there is very little existing work explicitly featuring network effects in finance from an open-economy general equilibrium perspective (see, for example, [Caliendo et al., 2019](#); [Altinoglu and Stiglitz, 2022](#); [Poutineau and Vermandel, 2015](#); [Ueda, 2012](#); [Kolasa and Wesołowski, 2020](#)). Given the overwhelming evidence for interconnectedness in both finance and trade across borders, it is clear that a comprehensive analysis of the behavior of an open economy requires explicit incorporation of both.

The emerging nature of international interactions has clear implications for aggregate fluctuations in open economies and the resulting policy responses to the global shocks and the spillovers of foreign-originated shocks. This is particularly the case given the frequency and the scale of international shocks driving domestic dynamics. Recent developments have pointed to the importance of global trade shocks origi-

nating, for example, from Brexit; or the supply chain disruptions in global trade; the demand and supply shocks - all acutely observed during the COVID-19 crisis; as well as the global financial shocks as observed during the Global Financial Crisis (GFC) of 2007-08 or the European sovereign debt crisis.

In principle, the problem of incorporating trade networks from a modeling perspective comes down to the choice between alternative functional forms of a production function. On top of the usual components like labor or physical capital, a production function with value chains includes intermediate inputs in the form of domestically-produced or imported (or both) supplies used to produce intermediate goods. Strong, yet not full, complementarity between labor and capital can justify a common practice of describing technology with labor and capital inputs using a Cobb-Douglas technology with a unit elasticity of substitution between labor and capital.¹

On the other hand, [Atalay \(2017\)](#), [Barrot and Sauvagnat \(2016\)](#), [Boehm et al. \(2019\)](#), and [Kehoe et al. \(2018\)](#) all suggest a low degree of substitutability between value-added and intermediate inputs in a closed economy. This would suggest a functional form of a production function with a degree of substitutability between value-added and supplies close to zero as the most appropriate, for example a Leontief function with zero elasticity of substitution. On top of several models utilizing a Leontief function to characterize technology with imported intermediate inputs (see, for example, [Steinberg, 2019, 2020](#); [Rubbo, 2020](#); [Reimer, 2011](#); [Nishioka and Ripoll, 2012](#); [Benz et al., 2014](#)), some authors propose production functions with the elasticity of substitution between value-added and intermediate inputs in an open economy higher than zero (see, for example, [Kaneda, 1982](#); [López, 2006](#); [Amiti and Konings, 2007](#); [Johnson, 2014](#); [Caliendo et al., 2017, 2019](#)).

Interestingly, although limited, firm-level evidence on the degree of substitutability between domestic value-added and intermediate inputs in an open economy also differs on the matter. In their analysis of manufacturing firms in China, [Feng et al. \(2016\)](#) find that production in Chinese processing zones can be specified by a Leontief production function. Conversely, [Peter et al. \(2020\)](#), using a 6-8 years time horizon, indicate that the short-run elasticities of substitution between value-added and inter-

¹The empirical evidence in [Gechert et al. \(2022\)](#) suggests, however, that the true elasticity of substitution between capital and labor can be significantly lower than one.

mediate inputs are consistent with the Leontief specification. However, the long-run estimates of 4.3 point to the degree of substitutability even greater than that resulting from the Cobb-Douglas production function. This is, in principle, supported by [Asturias et al. \(2019\)](#) in their analysis of the Indian manufacturing sector, who find that across-industry elasticities of substitution range from 1.2 to 1.99. The existing micro-level evidence, therefore, propounds that the elasticity of substitution between value-added and intermediate inputs increases with time horizon. Therefore, a Leontief specification can be adopted for analyses of the short-run phenomena. In contrast, a higher degree of substitution seems more appropriate in the medium- and long-run analyses.

One of the goals of this thesis, especially that of [Chapter 1](#), is to shed some light on the quantitative effects of adopting a production function with supply chains and the different degrees of substitution between value-added and intermediate inputs in an open economy. Specifically, [Steinberg \(2020\)](#) suggests that the long-run welfare costs of trade shocks are between 70% and 115.2% larger in the Cobb–Douglas version of his analysis of the possible consequences of NAFTA termination than in the baseline Leontief specification. In the analyses of the changes in long-run equilibria following from events such as NAFTA or Brexit, a higher than zero degree of substitution might be, therefore, more appropriate as implemented in [Caliendo and Parro \(2015\)](#) for NAFTA or [Garcia-Lazaro et al. \(2021\)](#) for Brexit - both assuming a unit elasticity of substitution between value-added and intermediate inputs.

On the other hand, there are several alternative approaches in developing financial networks in a general equilibrium framework (see, for example, [Diebold and Yilmaz, 2009](#); [Cabrales et al., 2015](#); or [Korniyenko et al., 2018](#) for evidence on extensive network effects in finance). The first is by introducing trade credit – inter-firm lending where trade in intermediate goods is financed by suppliers’ credit. As [Altinoglu \(2021\)](#) and [Luo \(2020\)](#) show for a closed economy, such a credit network distorts the propagation of shocks, altering the form and the scale of aggregate fluctuations. From an open-economy perspective, however, trade credit is less relevant in characterizing the financial linkages between individual countries.²

²Although, the evidence from [Chor and Manova \(2012\)](#) or [Crozet et al. \(2022\)](#) suggests that trade credit is not irrelevant in driving cross-country fluctuations.

Secondly, financial assets can be treated as inputs in a production function. This approach is adopted by [Caliendo et al. \(2019\)](#) in their analysis of the effects of Chinese-originated trade shocks on the US economy or [Punzi and Rabitsch \(2015\)](#) in their analysis of investor borrowing heterogeneity in a closed economy. Thirdly, financial linkages across countries can be represented by cross-border loans, as in [Poutineau and Vermandel \(2015\)](#) or [Cuadra and Nuguer \(2018\)](#). Finally, in their representation of cross-country financial linkages, [Kolasa and Wesołowski \(2020\)](#) use long-term bonds traded across borders, which is the method of representing cross-country financial linkages I adopt in [Chapter 1](#) of this thesis. In [Chapter 1](#), I further show how long-term financial assets and cross-border trade in financial assets alter the spillovers of domestically-originated versus foreign-originated shocks.

I argue, however, that more than the financial linkages in the form of cross-border trade in bonds is needed to replicate the cross-country business cycle co-movement found in the data. Sizable literature argues that the standard New-Keynesian models perform poorly in replicating the international business cycles (see, for example [Justiniano and Preston, 2010](#) or [Gornemann et al., 2016](#)). Motivated by these findings, in [Chapter 3](#) to increase the scale of cross-country financial linkages, I divide physical capital used in the production of intermediate goods into local and export capital. Local capital is backed by loans granted by domestic banks, while export capital is backed by loans granted by foreign banks. Therefore, banks in each country invest in domestic and foreign financial assets with important implications for cross-country co-movement.

The unprecedented level of interconnectedness of global trade and finance provides fertile ground for analyzing the global phenomena taking place on the world stage. [Chapter 2](#) derives the quantitative effects of the Trade and Cooperation Agreement (TCA) signed between the UK and the EU following the 2016 Brexit referendum. By calibrating a multi-country Dynamic Stochastic General Equilibrium (DSGE) model to the UK economy, the EU, and the third countries - accounting for an explicit configuration of the UK's trade links with advanced and emerging economies separately - we consider the global effects of permanent non-tariff barriers in cross-border trade in goods and services alike between the UK and the EU; a potential permanent reduction in tariff barriers in trade between UK and third countries that move the model economy

to new steady-state; and stochastic migration shocks.

Finally, [Chapter 3](#) presents the effects of US conventional monetary policy and the Fed's asset purchases in a two-country DSGE model. I calibrate the model to the US economy and Turkey to consider the spillovers of the US monetary policy to Turkey and the policy response in Turkey to the US monetary policy. Calibrating my framework with data from the US and Turkey yields several interesting findings on the pattern of international transmission of monetary policy shocks originating in the US and spilling over to an emerging economy such as Turkey.

To simulate the effects of the US monetary policy, I use a conditional forecast - a method of simulating the responses of model variables for a given constrained path of the US risk-free rate and asset purchases by the US monetary authority. I find that the financial channel is critical in driving aggregate fluctuations in Turkey following the adjustments of the US monetary policy. Allowing banks to invest in domestic as well as foreign assets significantly increases cross-country co-movement relative to its scale from [Chapter 1](#) with no financial linkages or with financial linkages limited to cross-border trade in long-term bonds. Second, I show that some degree of sensitivity to the exchange rate fluctuations in the emerging markets is desirable following the adjustments of the US interest rate. However, my results suggest that it generally disadvantageous for emerging markets to attach a high weight on the nominal exchange rate following balance sheet adjustments by the Fed.

This thesis is organized into three chapters. In [Chapter 1](#), I begin by building a model of a world economy with cross-country trade and financial linkages. One of the extended versions of the model with trade linkages and two household types is then used to assess the global economic consequences of the Trade and Cooperation Agreement (TCA) in [Chapter 2](#). Finally, the other model, which builds on a framework with supply chains from [Chapter 1](#), is used to examine the transmission of US conventional monetary policy shocks and asset purchases by the Fed to Turkey over the years 2003-23 in [Chapter 3](#). My analysis in [Chapter 1](#) employs stochastic simulations to analyze the responses to a number of standard shocks. The framework from [Chapter 2](#) uses stochastic simulations to mimic the effects of migration shocks and perfect foresight to simulate the effects of trade shocks. Finally, [Chapter 3](#) employs conditional forecasts to simulate the effects of the actual monetary policy by the US Fed over the

years 2003-23 in a two-country general equilibrium framework.

The effects of shocks originating in one country and spilling over to another are relatively small in a country indirectly affected by the shocks in [Chapter 1](#) even when cross-border trade in long-term bonds are taken into account. As shown in [Alpanda and Aysun \(2014\)](#) and [Georgiadis and Jančoková \(2020\)](#), standard DSGE models generally fail to replicate the large scale of cross-country business cycle co-movement found in the data. Therefore, to increase the cross-country co-movement and match it with the data one has to add cross-country correlations in the specifications of shock processes or introduce further assumptions like cross-country lending and borrowing by banks or global banks - a single financial entity that lends to more than one country.

In [Chapter 2](#), spillovers of shocks are achieved because of an international nature of shocks related to Brexit - migration and trade shocks, which directly affect both countries. [Chapter 2](#), therefore, generally abstracts from shocks affecting only one of the countries and spilling over abroad. Shocks, however, can also be highly asymmetric. An important example would be the bankruptcy of Lehman Brothers and the significant spillovers of the US-originated financial shock that resulted in the Global Financial Crisis. Without accounting for strong cross-country financial linkages, standard DSGE models - the examples of which are presented in [Chapter 1](#) - would be unable to replicate significant spillovers of the US-originated financial shock observed in the data.

In [Chapter 3](#), to increase the spillovers of US-originated monetary policy shocks to Turkey, I allow US banks to lend to both the US and Turkey. A significant part of the physical capital used in the production of intermediate goods in Turkey is, therefore, backed by dollar-denominated loans granted by US banks. Turkish banks are also allowed to hold dollar-denominated assets. The financial channel of this sort dramatically increases the spillovers of asymmetric shocks directly affecting one of the countries and spilling over to another.

Due to a relatively large number of features involved in the development of models in [Chapter 2](#) and [Chapter 3](#) - such as supply chains, two types of households, long-term bonds, financial linkages, financial frictions, and financial linkages - in [Chapter 1](#), I begin by building a multi-country model, starting from its benchmark specification and adding each feature of the extended model one at a time. I then present the

results, including welfare analysis, using a number of model configurations with fewer features in order to disentangle the impact of each major mechanism I employ in the extended configuration, including in the models I use for the analysis of Brexit in [Chapter 2](#) and spillovers of the US monetary policy shocks in [Chapter 3](#).

Models in both [Chapter 2](#) and [Chapter 3](#) also feature a banking sector. [Chapter 2](#) uses the framework from [Gertler and Kiyotaki \(2010\)](#), and [Chapter 3](#) is based on [Karadi and Nakov \(2021\)](#) in introducing financial frictions with the banking sector. I use [Chapter 2](#) to show the effects of incorporating banks on aggregate fluctuations in an open economy.

CHAPTER 1

A MODEL OF A TRADE AND CREDIT NETWORK ECONOMY

1.1 Introduction

In the first part of the thesis, I develop a multi-country general equilibrium model of a trade and credit network economy. I start with its benchmark specification, in which cross-country linkages are limited to trade in consumer goods. I then incorporate household heterogeneity by distinguishing between saving Ricardian and hand-to-mouth non-Ricardian households in the first extension of the benchmark model. In every model specification that features two types of households, Ricardian households are the owners of all domestic firms. They are the only household type allowed to invest in financial assets. Non-Ricardian - or hand-to-mouth - households, in turn, consume all their labor income each period and, similarly to Ricardian households, pay taxes.³

In the next part of this chapter, I extend the model by incorporating global supply chains whereby domestically-produced and imported intermediate inputs, combined with labor inputs, are used to produce intermediate goods. First, as indicated earlier, I introduce intermediate inputs in the production function of intermediate goods using a CES function, which combines labor inputs on the one hand and intermediate inputs on the other. I then analyze the effects of a number of standard shocks with a varying elasticity of substitution between labor and intermediate inputs, including the results with intermediate inputs introduced into the model using two special cases of a CES function - with a zero and a unit elasticity of substitution between labor and intermediate inputs - namely, the Leontief and Cobb-Douglas functional forms of a production function.

In the next part of [Chapter 1](#), I introduce long-term bonds in a fashion similar to [Chen et al. \(2012\)](#) or [Bartocci et al. \(2021\)](#). This is done primarily for two reasons. Firstly, as shown by [Kolasa and Wesołowski \(2020\)](#), long-term bonds explain the majority of cross-border trade in financial assets, with international trade in short-term assets being minimal and stable, with the median share in the total cross-border assets trade between 2.2% and 5.2% over the period between 2006 and 2018, according to the Coordinated Portfolio Investment Survey data of the IMF. Secondly, following the

³The classification of the household sector into Ricardian and non-Ricardian allows, for example, to capture the degree of asymmetry in welfare effects of shocks on two distinctively different types of households.

Global Financial Crisis, many central banks, after reaching a zero lower bound on their nominal policy rates, started rapidly expanding their balance sheets by purchasing long-term assets. Therefore, to analyze conventional and unconventional monetary policy measures later in the thesis, an instrument is required in the form of long-term assets to simulate quantitative easing programs or their potential partial reversals.

Having included long-term bonds in the model, in the final step, I allow for the financial linkages between the countries by allowing for cross-border trade in long-term bonds issued by the national governments. In doing so, I follow [Kolasa and Wesołowski \(2020\)](#), who introduce cross-border trade in long-term bonds to analyze the international spillovers of quantitative easing.^{4,5} Cross-border trade in long-term bonds introduces another mechanism of transmission of shocks across borders into the framework in the form of financial flows, which intensifies the global transmission of shocks and evens their welfare effects across countries, as presented in the welfare analysis section.

The model with financial linkages is, therefore, the most extended version of the model built in [Chapter 1](#). On top of the international credit network, it includes other features I develop at the earlier stages: two types of households, supply chains, and long-term bonds. Each version of the model is then calibrated to the US and China. The parameterization of the US economy is based on [Smets and Wouters \(2005\)](#) and the parameterization of the Chinese economy follows both [Zheng and Guo \(2013\)](#) and [Li and Liu \(2017\)](#). The supply chain parameters are as in the 2016 World Input-Output Database (WIOD) and the calibration of the credit network is based on the Quarterly Public Sector Debt Database of the World Bank and the IMF's Coordinated Portfolio Investment Survey (CPIS).

The model with the supply chains featuring a Cobb-Douglas production function with intermediate inputs and two types of households is the basis for the analysis of

⁴The difference between my model specification with international financial linkages and that from [Kolasa and Wesołowski \(2020\)](#) is that non-Ricardian households in my approach have no access to any financial assets. In contrast, the corresponding type of households in [Kolasa and Wesołowski \(2020\)](#) can hold domestic long-term bonds.

⁵The existence of non-Ricardian households with no access to financial markets is supported by the evidence from the emerging markets (see, for example, [Céspedes et al., 2013](#)), in which myopic behavior and an impossibility to smooth out consumption by non-Ricardian households significantly contributes to the aggregate dynamics.

Brexit in [Chapter 2](#). The version of the model with supply chains introduced using a Leontief specification of technology is used as a benchmark in [Chapter 3](#) for the analysis of spillovers of the US-originated monetary policy shocks to Turkey.

1.2 Model

In each version of the model, I consider a world consisting of M countries. In each country there are households, competitive retailers, monopolistically competitive intermediate goods producers, and a government pursuing monetary and fiscal policies. Intermediate goods producers set prices on a staggered basis, introducing nominal rigidities into the model economy in a manner similar to [Calvo \(1983\)](#).

In what follows, I present a model description of a representative country n . I use the index m to identify a foreign economy where necessary. The model blocks of each country are mirror images of that of the representative country n .

In [Chapter 1.3](#), I calibrate each version of the model developed in [Chapter 1.2](#) in a general multi-country environment to a two-country setting featuring the US and China and examine the responses of key variables corresponding to each country to a number of standard shocks under different model configurations in [Chapter 1.4](#). The shocks include: (i) a TFP shock originating in either the US economy or China; (ii) a labor supply shock in either of the two economies; (iii) a trade shock increasing the price of imported goods in either the US or China by 10%; (iv) US-originated and China-originated positive government spending shocks; and (v) 100 basis points hikes of the US and Chinese nominal interest rates specified by the respective Taylor rules.

I explore the differences in the stochastic simulations of these shocks under the different non-linear model configurations outlined in [Chapter 1.2](#) and, specifically, the effects of (i) incorporating household heterogeneity by explicitly considering the distinction between saving Ricardian households and hand-to-mouth non-Ricardian households; (ii) incorporating supply chains in the form of domestic and foreign intermediate inputs using distinct levels of substitutability between labor and intermediate inputs, including a technology given by a CES function and its two special cases: Leontief and Cobb-Douglas specifications; (iii) considering financial assets in the form of long-term bonds; and, finally, (iv) introducing cross-country financial linkages in

the form of long-term government bonds traded across borders. Finally, I present the welfare effects of the shocks for each country and household type under all model configurations and revisit my results under alternative values of some key parameters.

1.2.1 Benchmark model

The benchmark specification of the model takes a simple New Keynesian form, with the linkages between the countries limited to the cross-border trade in consumer goods. There is one household type that supplies labor to intermediate goods producers in exchange for labor income, holds risk-free short-term local government bonds, and receives profits from all domestic firms. Since there are no cross-country financial linkages in this benchmark version, international goods trade must be balanced at all times. Hence, imports of one country must be equal to exports of the country of origin of imported goods, as is common in the models that abstract from international financial linkages (see, for example, [Clarida, 2019](#); [Auray et al., 2020](#); or [Feng and Lin, 2013](#)).

Output is produced by monopolistically competitive intermediate goods producers using labor inputs. International trade in goods is also perfectly competitive, with foreign prices of domestically-produced goods equal to domestic prices when expressed in the same currency. The same applies to the labor market, with the wage rate being perfectly competitive, implying that labor supply is equal to labor demand at all times. Monetary policy is conducted using a standard Taylor rule with interest rate smoothing. Exogenous government spending is financed through lump-sum taxes collected from households and risk-free one-period government bonds, in which only domestic households can invest.

Households

Country n 's households maximize their lifetime utility over consumption C_t , labor inputs supplied to the intermediate goods producers H_t , and optimal holdings of short-term bonds B_t :

$$\max_{C_t, H_t, B_t} \mathbb{E}_t \sum_{k=0}^{\infty} \beta^k \left[\frac{C_{t+k}^{1-\sigma_c}}{1-\sigma_c} - \vartheta \frac{\varepsilon_{l,t+k}}{1+\varphi_h} H_{t+k}^{1+\varphi_h} \right] \quad (1.2.1)$$

where $0 < \beta < 1$ is the discount factor; $\sigma_c > 0$ is the inverse of the elasticity of intertemporal substitution of consumption; $\vartheta > 0$ denotes the disutility from supplying labor to intermediate goods producers; and $\varphi_h > 0$ is the inverse of the Frisch elasticity of labor supply. The labor supply shock $\varepsilon_{l,t}$ in the form of an autoregressive process is common to all domestic households.

The maximization of the households' utility (1.2.1) is subject to a sequence of intertemporal budget constraints of the form:

$$C_t + B_t + T_t = W_t H_t + \frac{R_{t-1}}{\pi_t} B_{t-1} + \Pi_t \quad (1.2.2)$$

where $\pi_t \equiv P_t/P_{t-1}$ denotes inflation, in which P_t is the consumer price index (CPI); R_t is the risk-free interest rate on the short-term bonds fixed by the local monetary authority; T_t denotes lump-sum taxes paid to finance government spending; $W_t H_t$ represents labor income from the households' labor inputs, in which W_t is the real wage rate; and Π_t are real profits from the ownership of all domestic firms.

Households consume domestic and imported goods aggregated in the following way:

$$C_t = \left[\sum_{m=1}^M \gamma_m^{\frac{1}{\varepsilon_c}} (C_{m,t})^{\frac{\varepsilon_c-1}{\varepsilon_c}} \right]^{\frac{\varepsilon_c}{\varepsilon_c-1}} \quad (1.2.3)$$

where $0 < \gamma_m < 1$ represents the shares of domestic goods (when $m = n$) and goods imported from country m ($m \neq n$) in the total consumption of domestic households; and $\varepsilon_c > 0$ is the Armington elasticity of substitution between domestic and imported consumer goods.

The optimization of the consumption basket's composition results in the following demands for domestic goods $C_{n,t}$ and imported goods $C_{m,t}$ (for $m \neq n$) in the representative economy:

$$C_{n,t} = \gamma_n \left[\frac{P_{n,t}}{P_t} \right]^{-\varepsilon_c} C_t \quad (1.2.4)$$

$$C_{m,t} = \gamma_m \left[\frac{\varepsilon_{\tau,t} s_t^{nm} P_{m,t}}{P_t} \right]^{-\varepsilon_c} C_t \quad (1.2.5)$$

where s_t^{nm} is the price of a unit of country m 's currency expressed in the number of units of the domestic currency; $\varepsilon_{\tau,t}$ represents an autoregressive process which introduces a wedge between the foreign price of a good imported from m denominated in the

domestic currency and the domestic price which consumers in the country n pay for goods imported from m ⁶, which I will refer to as a trade shock; while $P_{n,t}$ and $P_{m,t}$ are the price indices of goods produced in n and m and expressed in the currency of the country of their origin.

Retailers

Competitive retailers purchase differentiated output from the domestic intermediate goods producers and combine them into a single good. The aggregate retailers' output XR_t can be represented by the following CES aggregate of differentiated goods purchased from a continuum $v \in (0, 1)$ of intermediate goods producers:

$$XR_t = \left[\int_0^1 XR_t(v)^{\frac{\mu-1}{\mu}} dv \right]^{\frac{\mu}{\mu-1}} \quad (1.2.6)$$

where $\mu > 1$ is the elasticity of substitution between the varieties of intermediate goods, common to all retailers.

Each period, domestic retailers maximize their profits, defined as the difference between the revenues from the sales of domestically-produced final good and the cost of purchases of the varieties of intermediate goods from the domestic intermediate goods producers. Hence, the profit maximization problem of domestic retailers is:

$$\max_{XR_t(v)} \left[P_{n,t} \left[\int_0^1 XR_t(v)^{\frac{\mu-1}{\mu}} dv \right]^{\frac{\mu}{\mu-1}} - \int_0^1 P_{n,t}(v) XR_t(v) dv \right] \quad (1.2.7)$$

where $P_{n,t}(v)$ is the price of a domestically-produced differentiated good produced by a representative local intermediate good producer v . The profit maximization problem described by (1.2.7) results in the following retailers' demand for a typical variety of differentiated goods produced by the intermediate goods producer v :

$$XR_t(v) = \left[\frac{P_{n,t}(v)}{P_{n,t}} \right]^{-\mu} XR_t \quad (1.2.8)$$

Finally, assuming a zero-profit condition, the retail price index of the final good

⁶This can be thought of as, for example, a tariff, a non-tariff barrier to trade, or a transportation cost.

manufactured domestically can be defined as the following combination of the prices of differentiated goods in the domestic economy n :

$$P_{n,t} = \left[\int_0^1 P_{n,t}(v)^{1-\mu} dv \right]^{\frac{1}{1-\mu}} \quad (1.2.9)$$

Intermediate goods producers

Intermediate goods producers combine hours worked $H_t(v)$ supplied by households into a distinctive good according to the technology of producing X_t by a representative firm v as in the following:

$$X_t(v) = \varepsilon_{a,t} H_t(v) \quad (1.2.10)$$

where $\varepsilon_{a,t}$ an autoregressive process in the form of a TFP shock, common to all domestic intermediate goods producers

All intermediate goods producers operate in a monopolistically competitive market structure and only update their prices with a constant probability $0 < (1 - \theta_p) \leq 1$ along the lines of [Calvo \(1983\)](#). This suggests that, on average, prices cannot be updated for $k \equiv \frac{1}{1-\theta_p}$ periods. Firms that cannot reoptimize in a given period keep their price from the previous period $t - 1$.

Therefore, with the probability $(1 - \theta_p)$ a representative firm v updates its price to the optimal level $\tilde{P}_{n,t}$ and with the probability θ_p it maintains its price from the previous period, which yields the following price index:

$$P_{n,t}(v) = \left[\theta_p P_{n,t-1}(v)^{1-\mu} + (1 - \theta_p) \tilde{P}_{n,t}(v)^{1-\mu} \right]^{\frac{1}{1-\mu}} \quad (1.2.11)$$

Producer v , therefore, chooses the optimal nominal price $P_{n,t}(v)$ for which real profits from retail sales are maximized given the number of periods k during which the price is expected to remain unchanged:

$$\max_{P_{n,t}(v)} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta \theta_p)^k q_{t+k} \left[P_{n,t}(v) X R_{t+k}(v) - W_{t+k}(v) H_{t+k}(v) \right] \quad (1.2.12)$$

subject to the demand for varieties of intermediate goods by the retailers [\(1.2.8\)](#), where q_t is the households' marginal utility with respect to consumption.

This optimization by the local intermediate goods producers is subject to the

demand schedules consistent with aggregators' maximization problem outlined above, common to all domestic intermediate goods producers. This results in the retail output XR_t , varying with price dispersion v_t^p :

$$XR_t(v) = X_t / v_t^p \quad (1.2.13)$$

Since $v_t^p \geq 1$, price dispersion results in an output loss – intermediate goods producers produce less output sold to the retailers than they would given aggregate labor inputs if prices are disperse.

Monetary and fiscal authorities

I assume that the monetary policy is conducted according to a standard Taylor rule, which implies that the deviations of the risk-free interest rate R_t from its deterministic steady state R respond to the deviations of inflation π_t from its deterministic steady-state value π , allowing additionally for interest rate smoothing:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_r} \left[\left(\frac{\pi_t}{\pi} \right)^{\varphi_\pi} \right]^{1-\rho_r} \exp(\sigma_{r,t}) \quad (1.2.14)$$

where $0 \leq \rho_r \leq 1$ is the smoothing parameter; $\varphi_\pi > 0$ describes the central bank's weight on the deviations of inflation; and $\sigma_{r,t}$ is the conventional monetary policy shock in the form of a one-off innovation to the risk-free rate with a zero mean.

The domestic government exogenously fixes its spending on the domestic final good G , financed by lump-sum taxes levied on the households sector T_t and net short-term debt. The government's budget constraint is, therefore:

$$G + \frac{R_{t-1}}{\pi_t} B_{t-1} = T_t + B_t \quad (1.2.15)$$

Market clearing

I introduce the following clearing conditions of the retail goods market in the domestic economy:

$$XR_t = \sum_{m=1}^M C_{m,t} + G \quad (1.2.16)$$

which means that total retail output equals the sum of the demands for domestic goods of all the households from the total of M countries, which includes households from the domestic economy n ; and the exogenous domestic government spending. Additionally, following the full segmentation of the bonds markets in each model economy, I maintain that the goods trade between any pair of countries is balanced - a common practice in the literature abstracting from cross-country financial linkages.

1.2.2 Model with Ricardian and non-Ricardian households

In the first extension, I maintain that there are two types of households: Ricardian (R) and non-Ricardian (NR), with the shares $0 < \lambda_R < 1$ and $\lambda_{NR} = (1 - \lambda_R)$, respectively. Patient Ricardian households own all domestic firms and supply labor to the domestic intermediate goods producers. In what follows, Ricardians are the only household type that can invest in financial assets. Non-Ricardian households, in turn, consume all their labor income each period which they earn by supplying labor to domestic intermediate goods producers. Additionally, both household types pay lump-sum taxes to the local government with the shares of fiscal contributions in aggregate taxes collected by the government corresponding to the shares of each household type in the entire population.

The household sector consumes local and imported goods. Aggregate consumption C_t and aggregate hours of labor supplied to intermediate goods producers H_t are given by:

$$C_t = \lambda_R C_{R,t} + (1 - \lambda_R) C_{NR,t} \quad (1.2.17)$$

$$H_t = \lambda_R H_{R,t} + (1 - \lambda_R) H_{NR,t} \quad (1.2.18)$$

where $C_{R,t}$ and $C_{NR,t}$ denote consumption of Ricardian and non-Ricardian households, respectively; while $H_{R,t}$ and $H_{NR,t}$ are labor inputs of Ricardian and non-Ricardian households.

Ricardian households

Country n 's Ricardian households maximize their lifetime utility over consumption $C_{R,t}$, labor inputs to the domestic intermediate goods producers $H_{R,t}$, and optimal

holdings of short-term government bonds B_t :

$$\max_{C_{R,t}, H_{R,t}, B_t} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta_R)^k \left[\frac{C_{R,t+k}^{1-\sigma_c}}{1-\sigma_c} - \vartheta_R \frac{\varepsilon_{l,t+k}}{1+\varphi_h} H_{R,t+k}^{1+\varphi_h} \right] \quad (1.2.19)$$

where $0 < \beta_R < 1$ is the Ricardian households' discount factor and $\vartheta_R > 0$ denotes their disutility from supplying labor to intermediate goods producers.

The maximization of the Ricardian households' utility (1.2.19) is subject to a sequence of intertemporal budget constraints of the form:

$$C_{R,t} + B_t + T_{R,t} = W_t H_{R,t} + \frac{R_{t-1}}{\pi_t} B_{t-1} + \Pi_t \quad (1.2.20)$$

where $T_{R,t}$ is the Ricardian households' share of lump-sum taxes paid to finance government spending and $W_t H_{R,t}$ represents labor income from Ricardian households' labor inputs.

Non-Ricardian households

Non-Ricardian households maximize their lifetime utility over consumption $C_{NR,t}$ and labor $H_{NR,t}$ supplied to intermediate goods producers:

$$\max_{C_{NR,t}, H_{NR,t}} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta_{NR})^k \left[\frac{C_{NR,t+k}^{1-\sigma_c}}{1-\sigma_c} - \vartheta_{NR} \frac{\varepsilon_{l,t+k}}{1+\varphi_h} H_{NR,t+k}^{1+\varphi_h} \right] \quad (1.2.21)$$

where $0 < \beta_{NR} < 1$ is the discount factor⁷ and $\vartheta_{NR} > 0$ denotes non-Ricardian households' disutility from supplying labor.

The maximization of (1.2.21) is subject to a sequence of intertemporal budget constraints of the form:

$$C_{NR,t} + T_{NR,t} = W_t H_{NR,t} \quad (1.2.22)$$

where $T_{NR,t}$ is the non-Ricardian households' share of lump-sum taxes and $W_t H_{NR,t}$ represents labor income from non-Ricardian households' labor inputs.

The remaining equations of the model with two types of households remain un-

⁷Following the assumption of non-Ricardian households being more impatient, the following inequality holds: $\beta_{NR} < \beta_R$.

changed relative to the benchmark specification, except that the discount factor of Ricardian households is now utilized for the optimization problems of firms. This follows from the earlier assumption that only patient Ricardian households own all domestic firms.

1.2.3 Model with supply chains

I add the supply chains in the second extension to the benchmark model to the Ricardian and non-Ricardian households. The supply chains are in the form of domestic and foreign intermediate inputs, which, combined with labor inputs supplied by domestic households, are used to produce the varieties of intermediate goods in the domestic economy. The relevant literature featuring supply chains uses a variety of functional forms for the production function with intermediate inputs. Therefore, in this section, I present the model equations matching a model with a general CES function, a Leontief technology with a zero elasticity of substitution between labor and intermediate inputs, and a Cobb-Douglas technology with a unit elasticity of substitution between the two.

CES technology

Take the following CES production function with labor and intermediate inputs:

$$X_t(v) = \varepsilon_{a,t} \left[(1 - \varphi_s) H_t(v)^{\frac{\eta-1}{\eta}} + \varphi_s X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \quad (1.2.23)$$

where $0 < \varphi_s < 1$ is the share of intermediate goods in technology and $\eta > 0$ is the elasticity of substitution between labor and intermediate inputs.

Intermediate inputs are in the form of both domestic and foreign supplies. Therefore, X_t^s is a composite index of supplies used in domestic production and disaggregated into goods delivered by the domestic retailers $X_{n,t}^s$ (that is for $m = n$) or goods imported from abroad $X_{m,t}^s$ (when $m \neq n$):

$$X_t^s(v) = \left[\sum_{m=1}^M \omega_m^{\frac{1}{\varepsilon_s}} (X_{m,t}^s(v))^{\frac{\varepsilon_s-1}{\varepsilon_s}} \right]^{\frac{\varepsilon_s}{\varepsilon_s-1}} \quad (1.2.24)$$

where $0 \leq \omega_m \leq 1$ denotes the share of supplies delivered from country m in the total

use of supplies and $\varepsilon_s > 0$ is the Armington elasticity of substitution between domestic and imported supplies.

In a fashion similar to consumer goods, the optimal demands for domestically-produced and imported intermediate inputs - $X_{n,t}^s$ and $X_{m,t}^s$, respectively, common to all domestic goods producers:

$$X_{n,t}^s = \omega_n \left[\frac{P_{n,t}}{P_t^s} \right]^{-\varepsilon_s} X_t^s \quad (1.2.25)$$

$$X_{m,t}^s = \omega_m \left[\frac{\varepsilon_{\tau,t} s_t^{nm} P_{m,t}}{P_t^s} \right]^{-\varepsilon_s} X_t^s \quad (1.2.26)$$

Intermediate goods producers face the common wage rate W_t and the price index of supplies P_t^s , which can be associated with the Producer Price Index (PPI). They plan their future production to minimize costs. Their optimization problem can be formalized as follows:

$$\min_{H_t(v), X_t^s(v)} \left[W_t H_t(v) + P_t^s X_t^s(v) \right] \quad (1.2.27)$$

s.t.

$$\varepsilon_{a,t} \left[(1 - \varphi_s) H_t(v)^{\frac{\eta-1}{\eta}} + \varphi_s X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \geq \left[\frac{P_t(v)}{P_t} \right]^{\frac{\mu}{1-\mu}} X_t \quad (1.2.28)$$

Given that all the domestic intermediate goods producers are identical, the first-order conditions of the cost minimization problem in real terms with respect to labor and intermediate inputs are:

$$W_t = mc_t (1 - \varphi_s) \varepsilon_{a,t}^{\frac{\eta-1}{\eta}} \left[\frac{X_t}{H_t} \right]^{\frac{1}{\eta}} \quad (1.2.29)$$

$$P_t^s = mc_t \varphi_s \varepsilon_{a,t}^{\frac{\eta-1}{\eta}} \left[\frac{X_t}{X_t^s} \right]^{\frac{1}{\eta}} \quad (1.2.30)$$

which implies that the ratio of labor to intermediate inputs demanded by the intermediate goods producers depends not only on the implied shares of labor and intermediate inputs in technology and the price ratio of each input but it also depends on the elasticity of substitution η :

$$\frac{H_t}{X_t^s} = \left[\frac{1 - \varphi_s}{\varphi_s} \frac{P_t^s}{W_t} \right]^{\eta} \quad (1.2.31)$$

Intuitively, a unit increase in the unit price of intermediate inputs P_t^s increases the

relative demand for labor when other things are kept unchanged. When η , which measures how easy it is to substitute one input for another, takes a high value, then a unit increase in the price of one input has a more significant effect on the increase of the demand for another input.

Cobb-Douglas technology

The Cobb-Douglas specification implies a unit elasticity of substitution between labor and intermediate inputs, i.e., $\eta = 1$:

$$X_t(v) = \varepsilon_{a,t} H_t(v)^{(1-\varphi_s)} X_t^s(v)^{\varphi_s} \quad (1.2.32)$$

Following the derivation of the first-order-conditions corresponding to a representative intermediate goods producer's cost minimization problem given a more general CES function - equations (1.2.29) and (1.2.30) - the parallel demands for labor and intermediate inputs given the Cobb-Douglas specification are:

$$W_t = mc_t(1 - \varphi_s) \frac{X_t}{H_t} \quad (1.2.33)$$

$$P_t^s = mc_t \varphi_s \frac{X_t}{X_t^s} \quad (1.2.34)$$

This implies, following equation (1.2.31) for $\eta = 1$ that, other things equal, a unit increase in the relative price of intermediate inputs P_t^s / W_t increases the relative demand for labor to intermediate inputs H_t / X_t^s by a constant value of $(1 - \varphi_s) / \varphi_s$.

Leontief technology

In the Leontief specification, intermediate goods producers combine hours worked $H_t(v)$ with the domestic and foreign components $X_t^s(v)$ into a distinctive good with $\eta = 0$. Assuming zero elasticity of substitution between value-added and intermediates as suggested, among others, by [Atalay \(2017\)](#), I formulate the production of X_t by a representative firm v by the following Leontief technology:

$$X_t(v) = \varepsilon_{a,t} \min \left[\frac{H_t(v)}{1 - \varphi_s}, \frac{X_t^s(v)}{\varphi_s} \right] \quad (1.2.35)$$

where $0 < \varphi_s < 1$ remains the share of intermediate goods in technology.

Following the properties of the Leontief technology with a zero elasticity of substitution, cost minimization implies that output is produced using fixed quantities of labor and intermediate inputs, that is:

$$X_t(v) = \frac{\varepsilon_{a,t} X_t^s(v)}{\varphi_s} = \frac{\varepsilon_{a,t} H_t(v)}{1 - \varphi_s} \quad (1.2.36)$$

which suggests the following relationship between the demand for labor and intermediate inputs with zero substitution between both inputs:

$$\frac{H_t(v)}{X_t^s(v)} = \frac{1 - \varphi_s}{\varphi_s} \quad (1.2.37)$$

Equation (1.2.36), therefore, implies that a fixed share of output φ_s is produced with the use of intermediate inputs and the labor component makes up a fixed share $(1 - \varphi_s)$ of the final output:

$$X_t^s(v) = \varphi_s \frac{X_t(v)}{\varepsilon_{a,t}} \quad (1.2.38)$$

$$H_t(v) = (1 - \varphi_s) \frac{X_t(v)}{\varepsilon_{a,t}} \quad (1.2.39)$$

To derive the marginal cost in a way similar to the one based on cost minimization using the CES function earlier, I define the cost function $\mathcal{C}(v)$ of a representative producer as a sum of the products of both inputs and their corresponding unit prices:

$$\mathcal{C}(v) = P_t^s X_t^s(v) + W_t H_t(v) \quad (1.2.40)$$

Using the demand functions of intermediate inputs (equation 1.2.38) and labor (equation 1.2.39), the cost function becomes:

$$\mathcal{C}_t(v) = \frac{X_t(v)}{\varepsilon_{a,t}} \left[\varphi_s P_t^s + (1 - \varphi_s) W_t \right] \quad (1.2.41)$$

The marginal cost $mc_t(v)$ is, therefore, a derivative of the cost function $\mathcal{C}_t(v)$ with respect to output $X_t(v)$:

$$\frac{\partial \mathcal{C}(v)}{\partial X_t(v)} = mc_t(v) = \varphi_s \frac{P_t^s}{\varepsilon_{a,t}} + (1 - \varphi_s) \frac{W_t}{\varepsilon_{a,t}} \quad (1.2.42)$$

which is common to all domestic intermediate goods producers. Equation (1.2.42), therefore, implies that the marginal cost corresponding to Leontief technology is a weighted average of the costs of all the inputs with the weights equal to the corresponding shares of inputs in the production function.

Market clearing

Each of the three functional forms of a production function I just described implies that the following market clearing conditions of the goods market in the domestic economy must hold:

$$XR_t = \sum_{m=1}^M (C_{m,t} + X_{m,t}^s) + G \quad (1.2.43)$$

which means that total retail output equals the sum of the demands of the local and foreign households and the local and foreign intermediate goods producers for goods manufactured in the domestic economy n and exogenous government expenditures.

This completes the outline of the model extension with Ricardian and non-Ricardian households and supply chains. The remaining model equations coincide with those from the extension described in Chapter 1.2.2.

1.2.4 Model with long-term bonds

Introducing long-term bonds in this section is a first step to account for cross-country financial linkages in the form of international trade in long-term bonds in the next stage. International financial linkages significantly increase cross-country co-movement in the model. As shown in Chapter 1.3, accounting for short- versus long-term bonds does not significantly alter the results. Long-term bonds are yet another instrument for smoothing out the consumption of Ricardian households, so they should reduce the consequences of shocks. Although the effect is marginal, for the sake of clarity, I disentangle the effects of introducing an internationally segmented long-term bonds market from the effects of a more comprehensive framework with cross-border trade in long-term bonds.

In this extension, short-term bonds - represented by B_t in the previous model specifications - are now denoted with the S subscript - $B_{S,t}$. Long-term bonds, in turn, are denoted as $B_{L,t}$. Country n 's Ricardian households, therefore, maximize

their lifetime utility over consumption $C_{R,t}$, labor inputs to the intermediate goods producers $H_{R,t}$, and optimal holdings of short-term and long-term bonds - $B_{S,t}$ and $B_{L,t}$, respectively.

I follow [Woodford \(2001\)](#) and [Chen et al. \(2012\)](#) in treating long-term bonds as perpetuities. I further maintain that the bond coupon decays exponentially every period by a constant value $0 < \kappa < 1$. Consequently, the current price of a long-term bond issued k periods ago $P_{b,t-k}$ is related to the price of currently issued bonds $P_{b,t}$ with $P_{b,t-k} = \kappa^k P_{b,t}$. Short-term bonds, in turn, are riskless one-period securities. Both short-term and long-term bonds are issued by the local government.

New investments in long-term bonds are additionally subject to the transaction costs $\zeta_{b,t}$. Following [Chen et al. \(2012\)](#), the transaction costs are the result of the possibility of Ricardian households switching between long-term and short-term assets. This implies a relatively short-term investment horizon of Ricardian households.⁸

The maximization of the Ricardian households' utility is subject to a sequence of intertemporal budget constraints of the form:

$$C_{R,t} + B_{S,t} + (1 + \zeta_{b,t})P_{b,t}B_{L,t} + T_{R,t} = W_t H_{R,t} + \frac{R_{t-1}}{\pi_t} B_{S,t-1} + P_{b,t} \frac{R_{b,t}}{\pi_t} B_{L,t-1} + \Pi_t \quad (1.2.44)$$

where $R_{b,t} \equiv P_{b,t-1}^{-1} + \kappa$ is the gross yield to maturity of the long-term bonds $B_{L,t}$.

The transaction cost $\zeta_{b,t}$ is assumed to change in conjunction with the deviations of the total investment in the long-term bonds from its non-stochastic steady-state value:

$$\frac{1 + \zeta_{b,t}}{1 + \zeta_b} = \left[\frac{P_{b,t} B_{L,t}}{P_b B_L} \right]^{\tilde{\zeta}_b} \quad (1.2.45)$$

where $\tilde{\zeta}_b > 0$ represents the sensitivity of the transaction cost to the deviations of the investment in the long-term bonds from its steady-state.

The domestic government exogenously fixes its spending on the domestic final good G , financed by taxes levied on the two types of households T_t and net short-term and long-term debt. The government's budget constraint is, therefore, composed of

⁸ Absent the transaction cost, long-term and short-term bonds would be perfect substitutes under certainty equivalence except having different maturities.

both short-term and long-term borrowing from the domestic Ricardian households:

$$G + \frac{R_{t-1}}{\pi_t} B_{S,t-1} + P_{b,t} \frac{R_{b,t}}{\pi_t} B_{L,t-1} = T_t + B_{S,t} + P_{b,t} B_{L,t} \quad (1.2.46)$$

Finally, as in [Chen et al. \(2012\)](#) and [Kolasa and Wesołowski \(2020\)](#), the government's long-term debt evolves according to the following rule:

$$\frac{P_{b,t} B_{L,t}}{P_b B_L} = \left[\frac{P_{b,t-1} B_{L,t-1}}{P_b B_L} \right]^{\gamma_b} \quad (1.2.47)$$

where $\gamma_b > 0$ is a smoothing parameter.

1.2.5 Model with credit linkages

I formalize credit networks by introducing foreign bonds in the budget constraint of the domestic Ricardian households in a manner similar to [Kolasa and Wesołowski \(2020\)](#).⁹ The portfolio of the domestic Ricardian households is, therefore, extended by the new investment possibilities, which directly exposes Ricardian households to the changes in foreign financial markets and increases their exposure to the exchange rate risk. As a result, the Ricardian households' budget constraint in the domestic economy n can now be expressed as:

$$\begin{aligned} C_{R,t} + B_{S,t} + (1 + \zeta_{b,t}^n) P_{b,t}^n B_{L,t}^n + \sum_{\substack{m=1 \\ m \neq n}}^M s_t^{nm} (1 + \zeta_{b,t}^m) P_{b,t}^m B_{L,t}^m + T_{R,t} \\ = W_t H_{R,t} + \frac{R_{t-1}}{\pi_t} B_{S,t-1} + P_{b,t}^n \frac{R_{b,t}^n}{\pi_t} B_{L,t-1}^n + \sum_{\substack{m=1 \\ m \neq n}}^M s_t^{nm} P_{b,t}^m \frac{R_{b,t}^m}{\pi_t^m} B_{L,t-1}^m + \Pi_t \end{aligned} \quad (1.2.48)$$

where $B_{L,t}^n$ are domestic long-term bonds and $B_{L,t}^m$ are foreign long-term bonds ($m \neq n$) with $P_{b,t}^n$ and $P_{b,t}^m$ being their corresponding prices denominated in the currencies of the issuing governments.

As indicated earlier, I abstract from the possibility of investing in foreign short-

⁹In the extension with credit linkages, I continue to follow [Chen et al. \(2012\)](#) in their specification of both short-term and long-term bonds, and [Kolasa and Wesołowski \(2020\)](#) in their extension of the model by [Chen et al. \(2012\)](#) which includes foreign bonds. However, unlike [Kolasa and Wesołowski \(2020\)](#), my specification is symmetrical across countries, while theirs features a constant value of long-term bonds in one of the countries.

term bonds given that the data-based evidence suggests small and stable shares of cross-border trade in short-term assets in the total cross-border assets trade.

The domestic government can now finance its expenditures by borrowing both at home and abroad. Hence, in the model with financial linkages, the government's budget constraint also includes domestic long-term bonds held by foreign households, all denominated in the domestic currency:

$$G + \frac{R_{t-1}}{\pi_t} B_{S,t-1} + \frac{R_{b,t}}{\pi_t} P_{b,t}^n \sum_{m=1}^M B_{L,t-1}^{n,m} = T_t + B_{S,t} + P_{b,t}^n \sum_{m=1}^M B_{L,t}^{n,m} \quad (1.2.49)$$

where $B_{L,t}^{n,m}$ represents domestic long-term debt held by the Ricardian households in country m .

The government's long-term debt evolves according to the same rule as in the benchmark version, except that the domestic government can now sell its bonds both to domestic as well as foreign households:

$$\frac{P_{b,t}^n \sum_{m=1}^M B_{L,t}^{n,m}}{P_b^n \sum_{m=1}^M B_L^{n,m}} = \left[\frac{P_{b,t-1}^n \sum_{m=1}^M B_{L,t-1}^{n,m}}{P_b^n \sum_{m=1}^M B_L^{n,m}} \right]^{\gamma_b} \quad (1.2.50)$$

From this point onward, goods trade between any two countries no longer needs to be balanced because a negative (positive) trade balance can accompany a balance of payments deficit (surplus).

Finally, assuming no arbitrage opportunities from investments in the domestic and foreign long-term bonds, from the following Euler equations resulting from the Ricardian households' utility maximization:

$$Q_{R,t}(1 + \zeta_{b,t}^{n,n}) = \beta_R \mathbb{E}_t \left[Q_{R,t+1} P_{L,t+1}^n \frac{R_{b,t+1}^n}{\pi_{t+1}} \right] \quad (1.2.51)$$

$$Q_{R,t}(1 + \zeta_{b,t}^{m,n}) = \beta_R \mathbb{E}_t \left[Q_{R,t+1} s_{t+1}^{nm} P_{L,t+1}^m \frac{R_{b,t+1}^m}{\pi_{t+1}^m} \right] \quad (1.2.52)$$

follows a relation between the domestic and foreign long-term interest rates:

$$\mathbb{E}_t \left[\frac{s_{t+1}^{nm} P_{L,t+1}^m R_{b,t+1}^m}{(1 + \zeta_{b,t}^{m,n}) \pi_{t+1}^m} \right] = \mathbb{E}_t \left[\frac{P_{L,t+1}^n R_{b,t+1}^n}{(1 + \zeta_{b,t}^{n,n}) \pi_{t+1}} \right] \quad (1.2.53)$$

the first-order Taylor approximation of which yields the following linearized long-term uncovered interest rate parity (UIP) between the investments in the domestic and foreign long-term bonds:

$$\begin{aligned} & \mathbb{E}_t (\hat{s}_{t+1}^{nm} - \hat{s}_t^{nm} + \hat{P}_{L,t+1}^m - \hat{P}_{L,t}^m + \hat{R}_{b,t+1}^m - \hat{\pi}_{t+1}^m) \\ &= \mathbb{E}_t (\hat{P}_{L,t+1}^n - \hat{P}_{L,t}^n + \hat{R}_{b,t+1}^n - \hat{\pi}_{t+1}^n) + \zeta_{b,t}^{m,n} - \zeta_{b,t}^{n,n} \end{aligned} \quad (1.2.54)$$

where variables with hats denote log-deviations from the corresponding non-stochastic steady-state values.

For the foreign economy, by symmetry, the following equality must hold:

$$\begin{aligned} & \mathbb{E}_t (\hat{s}_t^{nm} - \hat{s}_{t+1}^{nm} + \hat{P}_{L,t+1}^n - \hat{P}_{L,t}^n + \hat{R}_{b,t+1}^n - \hat{\pi}_{t+1}^n) \\ &= \mathbb{E}_t (\hat{P}_{L,t+1}^m - \hat{P}_{L,t}^m + \hat{R}_{b,t+1}^m - \hat{\pi}_{t+1}^m) + \zeta_{b,t}^{n,m} - \zeta_{b,t}^{m,m} \end{aligned} \quad (1.2.55)$$

Subtracting (1.2.55) from (1.2.54) yields the following equality condition between transaction costs on domestic and foreign long-term bonds:

$$\zeta_{b,t}^{n,m} - \zeta_{b,t}^{m,m} = \zeta_{b,t}^{m,n} - \zeta_{b,t}^{n,n} \quad (1.2.56)$$

That is, the difference between transaction costs associated with country m 's investments in long-term bonds issued in the country n $\zeta_{b,t}^{n,m}$ and long-term bonds issued locally $\zeta_{b,t}^{m,m}$ is equal to the difference between country n 's transaction costs of investment in foreign $\zeta_{b,t}^{m,n}$ and domestic $\zeta_{b,t}^{n,n}$ long-term bonds.

Take now the country n 's Euler equation associated with investments in short-term bonds:

$$\varrho_{R,t} = \beta_R \mathbb{E}_t \left[\varrho_{R,t+1} \frac{R_t^n}{\pi_{t+1}^n} \right] \quad (1.2.57)$$

and equate it with the Euler equation corresponding to the country n 's investment in domestic long-term bonds. This yields:

$$\frac{R_t^n}{\pi_{t+1}^n} = P_{L,t+1}^n \frac{R_{b,t+1}^n}{(1 + \zeta_{b,t}^{n,n}) \pi_{t+1}^n} \quad (1.2.58)$$

which approximated to the first-order gives:

$$\hat{R}_t^n + \zeta_{b,t}^{n,n} = \mathbb{E}_t (\hat{P}_{L,t+1}^n - \hat{P}_{L,t}^n + \hat{R}_{b,t+1}^n) \quad (1.2.59)$$

In the foreign economy, a corresponding condition results in:

$$\hat{R}_t^m + \zeta_{b,t}^{m,m} = \mathbb{E}_t (\hat{P}_{L,t+1}^m - \hat{P}_{L,t}^m + \hat{R}_{b,t+1}^m) \quad (1.2.60)$$

Now use equations 1.2.59 and 1.2.60 to transform the long-run UIP conditions 1.2.54 and 1.2.55 corresponding to country n and m , respectively, into the following short-run UIP conditions:

$$\mathbb{E}_t (\hat{s}_{t+1}^{nm} - \hat{s}_t^{nm} + \hat{R}_t^m + \zeta_{b,t}^{m,m} - \hat{\pi}_{t+1}^m) = \mathbb{E}_t (\hat{R}_t^n + \zeta_{b,t}^{n,n} - \hat{\pi}_{t+1}^n + \zeta_{b,t}^{m,n} - \zeta_{b,t}^{n,n}) \quad (1.2.61)$$

$$\mathbb{E}_t (\hat{R}_t^m + \zeta_{b,t}^{m,m} - \hat{\pi}_{t+1}^m + \zeta_{b,t}^{n,m} - \zeta_{b,t}^{m,m}) = \mathbb{E}_t (\hat{s}_t^{nm} - \hat{s}_{t+1}^{nm} + \hat{R}_t^n + \zeta_{b,t}^{n,n} - \hat{\pi}_{t+1}^n) \quad (1.2.62)$$

Substituting (1.2.62) from (1.2.61) results in the following equality between transaction costs in any pair of countries:

$$\zeta_{b,t}^{n,m} - \zeta_{b,t}^{m,m} = -\zeta_{b,t}^{m,n} + \zeta_{b,t}^{n,n} \quad (1.2.63)$$

By combining (1.2.63) with the previously derived equality between transaction costs (1.2.56) it is straightforward to arrive at the following equality between the two transaction costs in the domestic economy. That is, country n 's transaction costs associated with investments in foreign long-term bonds must be equal to transaction costs associated with investments in domestic long-term bonds:

$$\zeta_{b,t}^{m,n} = \zeta_{b,t}^{n,n} \quad (1.2.64)$$

Using equality from (1.2.64), the implied short-term UIP condition described earlier by (1.2.61) becomes:

$$\mathbb{E}_t [\hat{s}_{t+1}^{nm} - \hat{s}_t^{nm} + \hat{R}_t^m + \zeta_{b,t}^{m,m} - \hat{\pi}_{t+1}^m] = \mathbb{E}_t [\hat{R}_t^n + \zeta_{b,t}^{n,n} - \hat{\pi}_{t+1}^n] \quad (1.2.65)$$

which postulates that the expected real returns on short-term bonds in both countries,

denominated in the currency of the domestic economy, are not equalized. The wedge between the two is in the form of a difference between the transaction costs associated with local long-term bonds in the two economies.

This concludes the outline of the final extension of the model with Ricardian and non-Ricardian households, supply chains, and cross-border financial linkages.

1.3 Calibration

In this section, I outline the parametrization of the benchmark model and each of its six extensions presented in [Chapter 1.2](#). The models are calibrated to the US economy and China. Where it is possible, I base the parameter values on [Smets and Wouters \(2005\)](#) for the US economy and either [Zheng and Guo \(2013\)](#) or [Li and Liu \(2017\)](#) for China. The supply chain parameters are calculated using the 2016 World Input-Output Database (WIOD). In turn, the calibration of the credit network is based on data from the Quarterly Public Sector Debt Database (QPSD) of the World Bank and the Coordinated Portfolio Investment Survey (CPIS) of the IMF. The values of structural parameters corresponding to each model configuration are presented in [Table 1.1](#). The parameters characterizing the five shock processes common to all seven model configurations are outlined in [Table 1.2](#).

Parameters of the benchmark model

I set the discount parameter β at 0.99 in both the US and China, implying a 4% risk-free annualized quarterly steady-state interest rate.

The risk aversion coefficient σ_c is set at 0.576 in the US and 0.466 in China. The Frisch elasticity of labor parameter φ_h is set at 0.513 in the US and 0.347 in China. The labor disutility parameters ϑ in both countries are fixed to match labor demand with the labor supply in the steady state. The implied households' disutility parameter in the US is fixed at 0.876. In China, it equals 0.782.

I follow the 2016 WIOD in determining the shares of domestically produced and imported goods in the consumption basket γ_m . The share of domestically-produced goods in the US is 94.34% versus 96.54% in China. The share of Chinese-produced goods in the US consumption basket is 5.66%, while the share of US-originated goods in

the consumption basket of Chinese households is 3.46%. The elasticity of substitution between domestic and foreign consumption goods ε_c is fixed at 1.5 as in [Monacelli \(2004\)](#).

Based on the Quarterly Public Sector Debt Database (QPSD), I maintain that the steady-state ratio of short-term government debt in GDP is 15.85% in the US and only 4.26% in China. I follow [Chen et al. \(2012\)](#) and assume that the short-term bonds are debt securities issued by the governments of both countries, which are categorized in the QPSD as both short-term debt securities and add to them all the long-term securities which mature in one year or less.

The elasticity of substitution between intermediate goods μ , which measures the degree of retailers' monopoly power in each country, is calculated using firm-level Compustat data as the ratio between profits defined as the difference between the value of sales and the cost of goods sold and the cost of goods sold. The elasticity of substitution parameters μ are then calculated as an inverse of the markups. The μ parameter takes the value of 4.184 in the US and 3.614 in China. This implies an average markup of the US intermediate goods producers of 23.9%. In China, the corresponding markup stands at 27.67%.

I further maintain that the probability of prices being updated θ_p is 0.91 in the US, indicating the average resetting of prices every 2 years and 9 months. On the other hand, the Calvo parameter in China is 0.9237 as in [Li and Liu \(2017\)](#), implying that the Chinese firms update their prices every 3 years and 3 months, on average.

The persistence of the nominal interest rate ρ_r is set at 0.8 in the US and 0.83 in China. The sensitivity of interest rate changes to inflation φ_π is set at 2.03 in the US, and 1.43 in China, as in [Smets and Wouters \(2007\)](#) and [Zheng and Guo \(2013\)](#). Based on the World Bank data, the share of government spending on final goods in GDP is calibrated at 15.6% in the US and 16.2% in China.

Parameters of the model with Ricardian and non-Ricardian households

Following the earlier characterization of the Ricardian and non-Ricardian households, the discount parameters β_R and β_{NR} are set at, respectively, 0.9925 and 0.97; implying a 3% risk-free annualized quarterly steady-state interest rate of Ricardian households and a 12% annualized interest rate of non-Ricardian households as in [Iacoviello and](#)

Neri (2010).

The share of Ricardian households λ_R is set at 0.9 in the US and China, equal to the share of unrestricted households in Kolasa and Wesołowski (2020).¹⁰ The labor disutility parameters of Ricardian and non-Ricardian households - ϑ_R and ϑ_{NR} - are again fixed to match labor demand with the labor supply in the steady state. The Ricardian households' disutility parameter ϑ_R is 0.825 in the US and 0.479 in China. The non-Ricardian households' equivalents are, respectively, 0.901 and 0.527.

The remaining parameters of the model with Ricardian and non-Ricardian households take the values of the parameters from the benchmark specification.

Parameters of the model with supply chains

The share of supplies parameters φ_s are based on the shares of total intermediate consumption in the sum of total intermediate consumption and value-added in basic prices in each country based on the 2016 WIOD as in Timmer et al. (2015). The share of supplies in total output is, therefore, 0.211 in the US and 0.303 in China.

The WIOD data are then used to calibrate the key parameters of the US-China trade network for households and producers. Specifically, data suggests that 96.34% of Chinese consumption is made up of goods produced locally, while the corresponding share for the US stands at 93.74%. The remaining shares, i.e., 3.66% and 6.26%, are consumer goods imported from the US in the case of Chinese households or from China in the case of US households, respectively.

Intermediate goods producers also use domestic and imported supplies to produce intermediate goods. 97.68% of supplies used by Chinese producers are made up of components produced locally, while the corresponding share for the US stands at 93.74%. The remaining shares, i.e., 2.32% and 6.26%, are imported supplies and used by Chinese and US producers.¹¹

The elasticity of substitution between domestic and foreign supplies ε_s is equal to the households' elasticity of substitution between domestic and foreign goods ε_c .

¹⁰I later provide a sensitivity analysis given the shares of Ricardian households in China lower than the benchmark value of 0.9

¹¹The values of the trade network from the WIOD generally result in unrealistically low trade openness. I, therefore, adjust the trade network parameters of the WIOD to match them with the level of trade openness resulting from the UNCTAD.Stat data.

The CES specification of the production functions of the US and Chinese intermediate goods producers implies the elasticity of substitution between value-added and intermediate inputs η different from zero and unity. As the literature suggests, η tends to take a value greater than one, especially in the longer run. Therefore, as a starting point, η is set at 2.¹² In [Chapter 1.4](#), as part of my sensitivity checks, using the model with the CES specification of technology, I re-run my simulations in which η takes different than the benchmark value of 2.

Parametrization of the model with long-term bonds

The critical part of the model with long-term bonds is the calibration of steady-state bond portfolios held by Ricardian households in both countries and their corresponding maturities.

I again maintain that the steady-state ratio of short-term government debt in GDP is 15.85% in the US and 4.26% in China. On the other hand, long-term debt, which matures in one year or more, based on the QPSD data of the World Bank, represents 104.27% of the US GDP and 15.87% of the Chinese GDP.

Following [Chen et al. \(2012\)](#), I define the duration of a long-term bond as $D_L = R_b / (R_b - \kappa)$. The average maturity of the US long-term bonds is 7.5 years according to [Chen et al. \(2012\)](#), which implies $D_L = 30$. This suggests that the US value of κ is 0.974 if the steady-state interest rate on the long-term bonds is $R_L = 1/\beta_R$ given unit inflation π in the steady-state. [Lam and Jingsen \(2019\)](#), in turn, report the average duration of the government long-term bonds issued in China of around 4.5 years, i.e., $D_L = 18$. This corresponds to the value of κ of 0.952.

Following [Kolasa and Wesołowski \(2020\)](#), I assume the sensitivity of the adjustment cost ξ_b of 0.015 and adopt the high persistence of asset purchasing programs by the central banks. The γ_b parameters are set at 0.96 in both countries.

¹²[Saito \(2004\)](#) also find that Armington elasticities tend to be higher when analyzing bilateral rather than multilateral trade.

Table 1.1: Calibrated structural parameters.

Parameter		USA	CHN	Source
<i>Parameters of the benchmark model</i>				
Discount factor	β	0.990	0.990	Smets and Wouters (2005)
Intertemporal substitution	σ_c	0.576	0.466	Assumption
Elasticity of labor supply	φ_h	0.513	0.347	Assumption
Labor disutility	ϑ	0.846	0.782	Target value
Share of US goods	γ_{USA}	0.943	0.035	WIOD 2016
Share of Chinese goods	γ_{CHN}	0.057	0.965	WIOD 2016
e.o.s. domestic and foreign goods	ε_c	1.500	1.500	Monacelli (2004)
e.o.s. intermediate goods	μ	4.184	3.614	Author's calculations
Calvo parameter	θ_p	0.910	0.945	Smets and Wouters (2005); Li and Liu (2017)
Interest rate smoothing	ρ_r	0.800	0.830	Assumption
Taylor rule parameter	φ_π	2.030	1.430	Smets and Wouters (2007); Zheng and Guo (2013)
<i>Parameters of the model with Ricardian and non-Ricardian households</i>				
Discount factor	β_R	0.993	0.993	Iacoviello and Neri (2010)
Discount factor	β_{NR}	0.970	0.970	Iacoviello and Neri (2010)
Share of Ricardian households	λ_R	0.900	0.900	Kolasa and Wesołowski (2020)
Labor disutility	ϑ_R	0.825	0.479	Target value
Labor disutility	ϑ_{NR}	0.901	0.527	Target value
<i>Parameters of the models with supply chains</i>				
Share of intermediate inputs	φ_s	0.211	0.303	WIOD 2016
Share of US goods (households)	γ_{USA}	0.937	0.037	WIOD 2016
Share of Chinese goods (households)	γ_{CHN}	0.063	0.963	WIOD 2016
Share of US goods (producers)	ω_{USA}	0.939	0.023	WIOD 2016
Share of Chinese goods (producers)	ω_{CHN}	0.061	0.977	WIOD 2016
e.o.s. domestic and foreign inputs	ε_s	1.500	1.500	Assumption
e.o.s. intermediate inputs and labor	η	2.000	2.000	Assumption (only applies to CES technology)
<i>Parameters of the model with long-term bonds</i>				
Transaction cost on long-term bond	ξ_b	0.015	0.015	Kolasa and Wesołowski (2020)
Coupon	κ	0.974	0.952	Chen et al. (2012); Lam and Jingsen (2019)
Debt composition smoothing	γ_b	0.960	0.960	Kolasa and Wesołowski (2020)
<i>Parameters of the model with a credit network</i>				
Share of US debt	η_{USA}	0.968	0.013	BIS; CPIS
Share of Chinese debt	η_{CHN}	0.032	0.987	BIS; CPIS

Note: The calibrations across model specifications match the key steady-state ratios of both economies. The alternative calibrations of each model version can have minor effects on the resulting key steady-state ratios. This, however, should have minimal effects on the results.

Parameters of the model with a credit network

The model with a credit network introduces the possibility of Ricardian households investing in foreign long-term bonds. The steady-state ratios of short-term and long-term bonds to GDP are calculated using the QPSD data, resulting in the ratios of short-term and long-term bonds to GDP as indicated in the previous model extension.

The steady-state shares of the domestic versus foreign long-term bonds in the portfolio of Ricardian households, in turn, have been calculated using the Bank of International Settlement's debt securities statistics and the IMF's Coordinated Portfolio Investment Survey (CPIS).

Following [Kolasa and Wesołowski \(2020\)](#), I assume that long-term investments entirely represent cross-border transactions in debt securities. At the same time, the BIS data does not distinguish between short-term and long-term debt. Therefore, using the data from the QPSD, long-term debt is taken to represent 78.84% of the US debt while 86.8% of the Chinese debt is long-term. I, therefore, extract long-term debt from total debt in the BIS data and calculate the shares of investments in foreign long-term bonds in total long-term debt in both countries.

This results in 3.17% of the steady-state US long-term debt being owned by mainland China and 1.34% of the Chinese debt being owned by the US residents. The rest, i.e., 96.83%, of the US debt is owned by the US residents, and 98.66% of long-term debt in China is assumed to be owned by the Chinese residents.

Parameters of the shock processes

Based on [Smets and Wouters \(2007\)](#) and [Zheng and Guo \(2013\)](#), I assume that the TFP shock in the US is more persistent than in China with the autoregressive parameter ρ_a in the former of 0.93 and the latter of 0.91. The size of the TFP shock is 0.55 standard deviation in the US and 0.736 standard deviation in China.

Table 1.2: Shock parameters.

Parameter		USA	CHN	Source
<i>Autoregressive coefficients</i>				
TFP shock	ρ_a	0.930	0.910	Smets and Wouters (2007) ; Zheng and Guo (2013)
Labor supply shock	ρ_l	0.830	0.850	Smets and Wouters (2007) ; Guo et al. (2015)
Trade shock	ρ_τ	0.900	0.900	Assumption
Government spending shock	ρ_g	0.810	0.770	Smets and Wouters (2007) ; Guo et al. (2015)
<i>Standard deviations of stochastic disturbances</i>				
TFP shock	σ_a	0.550	0.736	Smets and Wouters (2007) ; Zheng and Guo (2013)
Labor supply shock	σ_l	0.570	0.960	Smets and Wouters (2007) ; Guo et al. (2015)
Trade shock	σ_τ	10	10	Assumption
Monetary policy shock	σ_r	0.250	0.250	Assumption
Government spending shock	σ_g	3.200	2.800	Smets and Wouters (2007) ; Guo et al. (2015)

Contrary to the TFP shock, the labor supply shock is more persistent in China with ρ_l parameter equal to 0.85, while the corresponding value in the US is 0.83. The size of the labor supply shock in China equals 0.96 standard deviation. The size of the US labor supply shock is 0.57 standard deviation.

In [Chapter 1.4](#), I also present the impulse response functions to the trade shock, which illustrates a 10% increase in the price of goods imported to either the US or China. The persistence ρ_τ of this shock, which I refer to as a trade shock, is relatively high at 0.9 in both countries.

Finally, the government spending shock, which increases the government's demand for local final goods has persistence ρ_g of 0.81 in the US and 0.77 in China. The size of the government spending shocks in terms of standard deviations are 3.2 and 2.8 in the US and China, respectively.

1.4 Comparative statics

In this section, I simulate the effects of five types of shocks: (i) a TFP shock; (ii) a labor supply shock; (iii) a trade shock; (iv) a government spending shock; and (v) a monetary policy shock and compare the responses to each shock type when they originate in the US versus when they originate in China using seven different model configurations developed in [Chapter 1.2](#). Therefore, the models I use are: (i) the benchmark model with international trade in consumer goods and no cross-border financial linkages; (ii) the model with Ricardian and non-Ricardian households; (iii-v) the model with supply chains introduced using three different functional forms of the production function - CES, Cobb-Douglas, and Leontief; (vi) the model with long-term financial assets; and (vii) the model with cross-country financial linkages.

In each model configuration, the properties of the previous versions are preserved. Consequently, the model with financial linkages is the most extended version of the model used in this part of the thesis. On top of cross-border bonds trade, it includes all the features developed in the previous steps, i.e., two types of households, supply chains and long-term bonds. For each stochastic simulation, I analyze the responses of the following four variables characterizing each country: output, CPI, annualized policy rate, and imports.

The figures below display the responses of these key variables in both countries to both US-originated and China-originated shocks over 30 quarters after unexpected shock hits. [Figure 1.1](#) to [Figure 1.10](#) present the responses of four key variables characterizing the US economy (top row) and Chinese economy (bottom row) to the five shocks analyzed in this chapter given all the alternative specifications of the model from [Chapter 1.2](#).

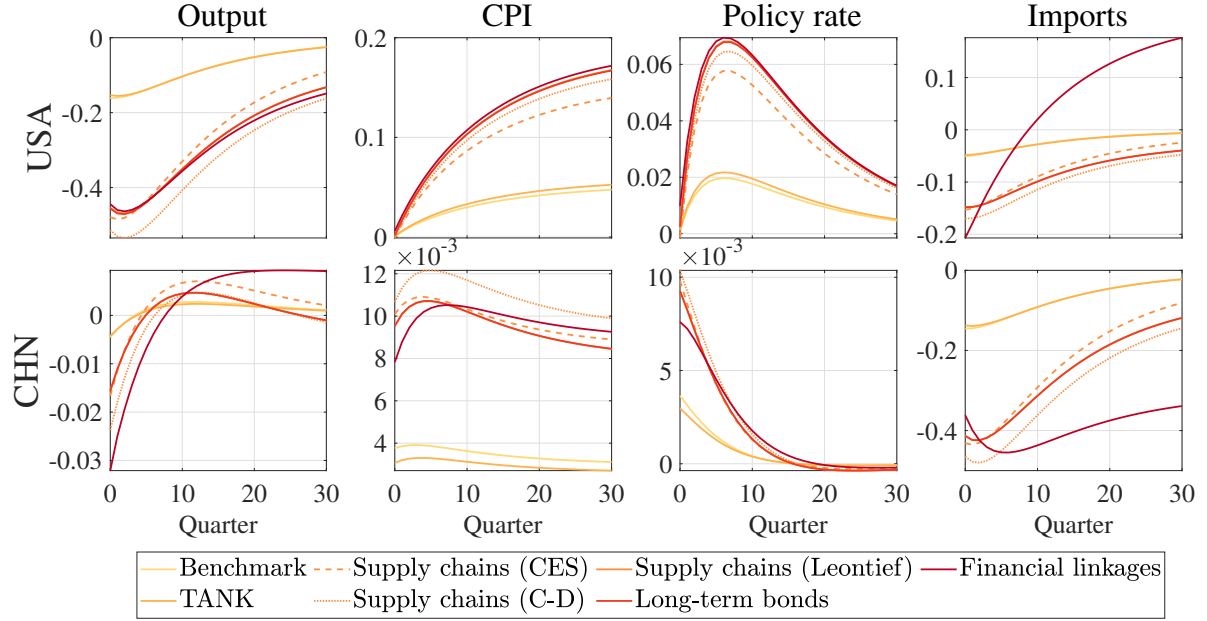
1.4.1 TFP shocks

The responses to the US-originated shocks are displayed [Figure 1.1](#), which in the top row contains the variables characterizing the US economy, and the bottom row displays the responses of the Chinese economy to the same shock. For example, as presented in the top row of [Figure 1.1](#), US output falls by 0.16% in the first quarter after the US-originated TFP shock hits in the benchmark model configuration (yellow line). In the model with two household types, the overall response of the US output is almost identical, with an immediate fall in output of 0.153%. The most significant impact on the response of the US economy comes from supply chains, with the US output falling by 0.456% in the first quarter given the Leontief specification of technology, 0.479% when the CES function is used to describe the technology, and by 0.513% when technology is given by the Cobb-Douglas function.¹³ The responses with Leontief technology are, however, most persistent, while the remaining two specifications of technology converge to the long-run steady-states more quickly.

The impact of a functional form of a production function is clearly visible when looking at the responses of the aggregate price level or the CPI. For example, in the benchmark specification, US CPI increases by 0.047% in the long run, by 0.052% in the Two-Agent New Keynesian (TANK) model, 0.14% given the CES production function with intermediate inputs, 0.158% when the Cobb-Douglas function is used, and 0.167% under the Leontief assumption of technology. This effect of including supply chains in a model and their alternative formulations are then reflected in the responses of the US

¹³The responses are more negative the higher the degree of substitution. When the US economy is hit by the TFP shock, Chinese producers still require US-produced supplies to manufacture goods. As a result, Chinese imports from the US fall by the least given the Leontief specification of technology in both countries.

Figure 1.1: Responses to US-originated TFP shock under alternative model configurations.



Notes: Percentage deviations from the non-stochastic steady-state; the responses of the policy rates are annualized.

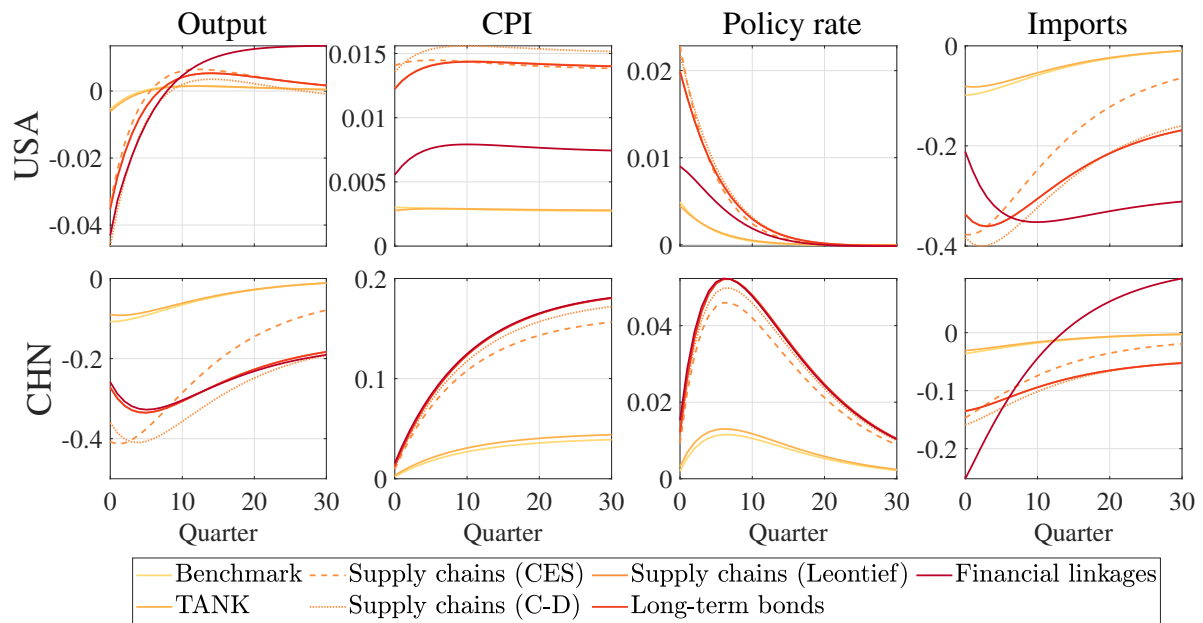
policy rate, which increases between 2 basis points in the benchmark setup to 7 basis points in the model with Leontief technology and financial linkages (dark red color).

Financial linkages imply that trade between the two countries does not need to be balanced. In the long run, the US price level and policy rate, in consequence, converge back to their initial steady-state levels. However, shocks can have long-lasting effects on the price level in each country and, therefore, on the terms of trade. For example, when the price level in the domestic economy increases more than it does in the foreign economy, terms of trade worsen, and a decline in net exports is expected since goods produced domestically are relatively more expensive. This is exactly what happens under each model configuration in Figure 1.1 following the US-originated TFP shock - US imports from China fall, and Chinese imports from the US (US exports to China) fall even more under each model configuration.

With fully segmented financial markets, a worsening of the terms of trade is reflected by an instantaneous increase in the real exchange rate (a depreciation of the dollar). In effect, it makes foreign-produced goods denominated in the domestic currency more expensive than they would have been without the exchange rate adjustment. In the model with financial linkages, the real exchange rate also increases.

However, this increase is no longer governed by the relative prices but rather by log-deviations of the domestic and foreign interest rates and the transaction costs associated with them (as shown in [Chapter 1.2.5](#)). As a result, the adjustments of the long-term bonds are significantly more sluggish than the adjustments of consumption or output, hence the much more persistent effect of the term of trade on net exports in the model with financial linkages.

Figure 1.2: Responses to China-originated TFP shock under alternative model configurations.



Notes: Percentage deviations from the non-stochastic steady-state; the responses of the policy rates are annualized.

In principle, the price level and nominal rate are more responsive in the TANK model compared to the benchmark specification. The key mechanism here is that in the model with two types of households, 10% of households are prevented from smoothing out their consumption. Hence, non-Ricardian households can only increase their labor supply to prevent their consumption from falling, which has positive, yet marginal, short-run effects on the responses of output and imports in the model with non-Ricardian households. Nevertheless, the relatively minor decline in hours worked in the model with non-Ricardian households tends to increase the price level and, therefore, the nominal interest rate relative to the benchmark model.

The responses of the domestic economy are very similar given the China-originated shock as displayed in [Figure 1.2](#). The main difference is that the effect of household

heterogeneity is yet more robust. This, in turn, suggests that Chinese non-Ricardian households increase their labor supply even more than US non-Ricardian households when faced with the domestically-originated TFP shock. Nevertheless, the effects of financial linkages on the price level and policy rates are effectively nonexistent in China. The main transmission channel of the TFP shock in the presence of financial linkages is through the exchange rate adjustment, which has some adverse effects on the Chinese net exports and, in effect, on output.

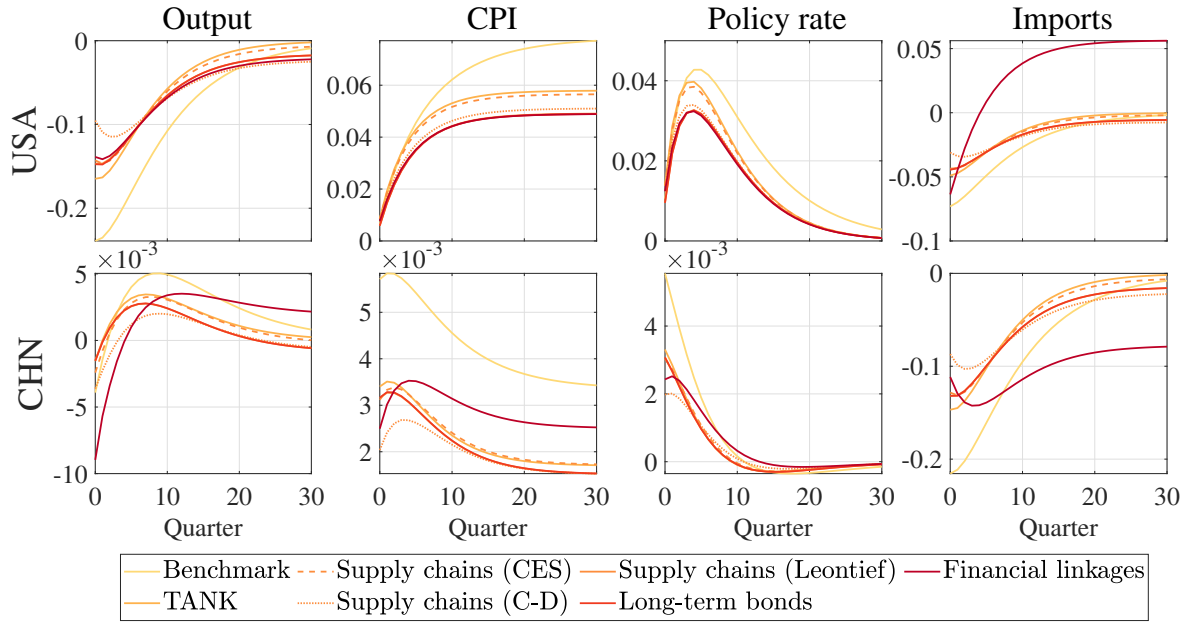
The order of the choice of a functional form of technology and its effect on the CPI and nominal interest rate in China is preserved. The CES function, with the elasticity of substitution between labor inputs and supplies, gives the smallest effect on the responses of the two variables, the Cobb-Douglas technology having a more substantial effect than the CES function and, finally, the Leontief function having the most significant effect out of the three functional forms of technology. Moreover, the responses given the model with the Leontief production function and long-term bonds effectively overlap with the responses when the model with the Leontief technology and short-term bonds only is utilized.

1.4.2 Labor supply shocks

Following a negative labor supply shock in the US, modeled as an increase in the weight of leisure in households' utility function, US labor supply and output decline as displayed in [Figure 1.3](#). Labor inputs play the most significant role in the economy without supply chains (yellow line). Therefore, unsurprisingly, the responses of the model with the output produced with labor only are most negative following the labor supply shock - US output falls by 0.239% in the first period after the shock hits. Once we differentiate households into two types, the response of output is significantly less negative. The effect of non-Ricardian households unable to reduce their hours worked to the same degree as their Ricardian equivalents is rather striking - US output falls by 0.165%.

The effect of intermediate inputs in technology in the presence of the US-originated labor supply shocks is even less negative short-run responses of the US output. Nevertheless, in the long run, driven by a permanent change in terms of trade, the output does not converge back to its original steady state and remains markedly below zero.

Figure 1.3: Responses to US-originated labor supply shock under alternative model configurations.



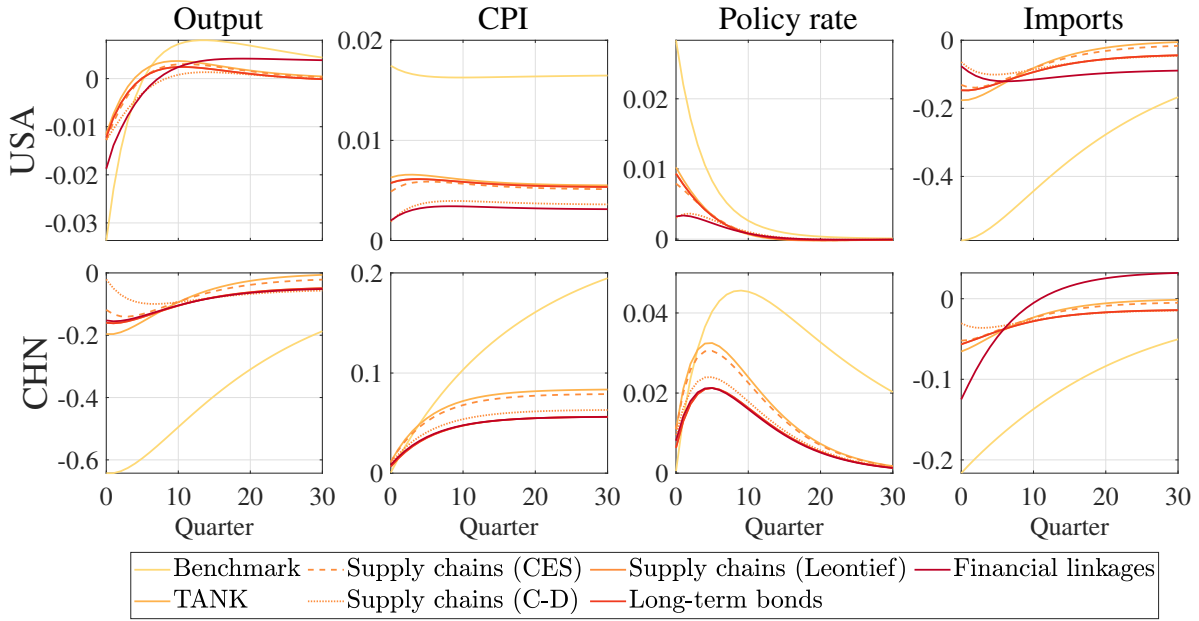
Notes: Percentage deviations from the non-stochastic steady-state; the responses of the policy rates are annualized.

This is the result of a permanent negative change in the US net exports (as displayed in the last column of Figure 1.3), following a permanent increase in the relative US-China price ratio.

The CPI and policy rate responses can be ranked according to the importance of labor inputs on output in each model. Given the most significant importance of hours worked in determining aggregate output, US prices and nominal interest rate both increase by the greatest amount in the benchmark model. The responses given the model with two types of households follow with less positive responses of both variables. Next, there are the responses with intermediate inputs in technology. However, under the highest elasticity of substitution between labor and intermediate inputs, the CPI and policy rate increase by the most out of all three models with supply chains. Intuitively, the more difficult it is to substitute labor for intermediate inputs, the greater the responses of the CPI and policy rate are. Other things unchanged, a fall in hours worked has a relatively more decisive positive effect on the wage rate when technology is given by a CES function with $\eta > 1$ (see equation 1.2.29) than, consecutively, in the Cobb-Douglas function (equation 1.2.33) and in the Leontief function (equation 1.2.42). In the latter, hours worked have no direct effect on the

wage rate. In effect, the wage rate increases by most in the CES model (not reported), driving up prices and the nominal interest rate by the greatest value given the three specifications of supply chains.

Figure 1.4: Responses to China-originated labor supply shock under alternative model configurations.



Notes: Percentage deviations from the non-stochastic steady-state; the responses of the policy rates are annualized.

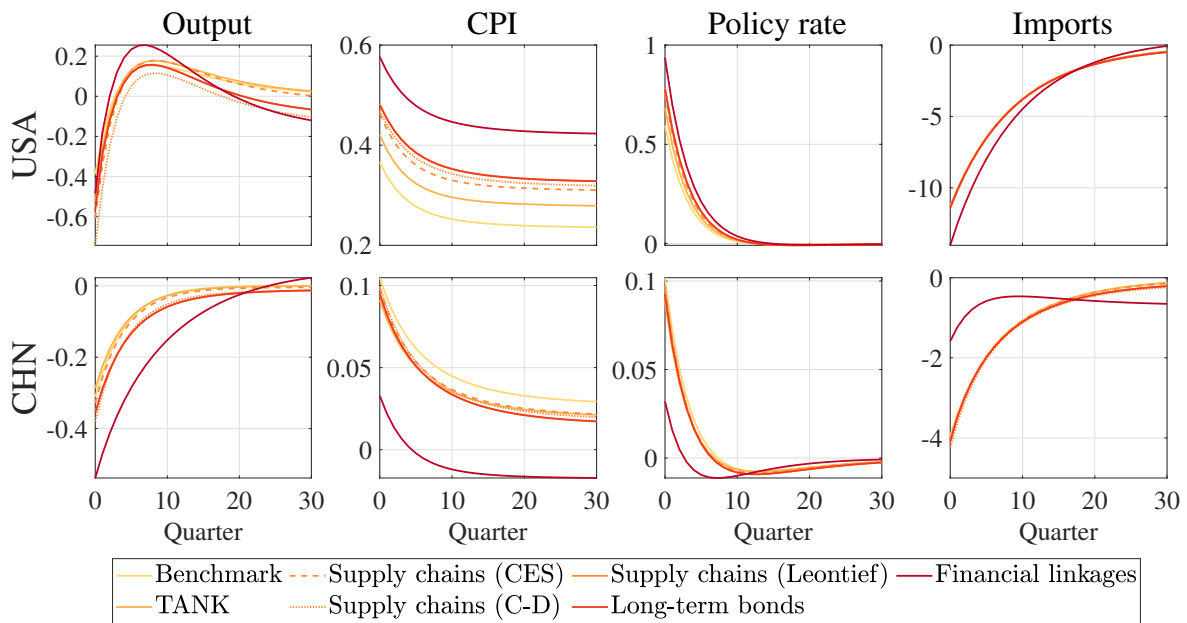
The same effect of supply chains and the specification of technology is visible given the China-originated TFP shock (see [Figure 1.4](#)), in which the order of responses for each displayed variable is preserved from the US responses to the US-originated labor supply shock. The greatest difference in the responses of the Chinese economy comes from a distinction between the responses when the benchmark model is used versus when its version with two types of households is used. This, once more, suggests that the Chinese non-Ricardian households supply relatively more labor inputs than their US equivalents when faced with a shock negatively impacting their consumption.

1.4.3 Trade shocks

Given a 10% increase in import prices in the US, as displayed in [Figure 1.5](#), the response of US imports remains unchanged across different model configurations with balanced trade. US imports fall by around 11.38%, and Chinese imports from the US fall by approximately 4.08%, given a much more substantial increase in prices of US-produced

goods relative to the prices of Chinese-produced goods. In the presence of financial linkages, US imports decline even more in the short-run when trade is balanced - 14.03% - while Chinese imports from the US go down by 1.58%. Importantly, when the trade does not need to be balanced, in every long-run (i.e., after around 80 periods - not reported), US imports from China stabilize at a level which is 0.55% higher than the original steady-state while Chinese imports from the US are lower by 0.69%. This implies that even when a trade shock with 90% persistence effectively disappears after 80 quarters, it permanently affects the terms of trade with continuing adverse effects on the trade balance. In effect, long-run output falls below its initial steady-state because domestically-produced goods are being replaced by its imported equivalents.

Figure 1.5: Responses to 10% increase in US import prices under alternative model configurations.

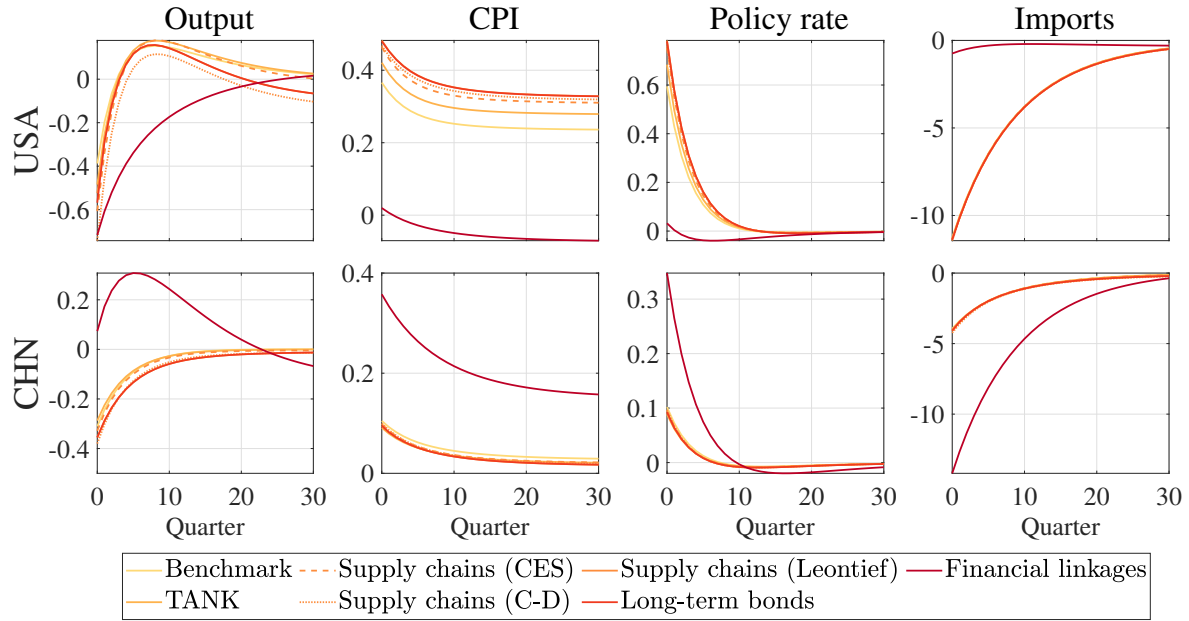


Notes: Percentage deviations from the non-stochastic steady-state; the responses of the policy rates are annualized.

The pass-through of increased import prices to output, CPI, and the policy rate is very strong. In the short-run domestic output falls by up to 0.743% when production is described using the Cobb-Douglas function and 0.388% given the benchmark model specification. In the medium run, it moderately increases above its original steady-state when the immediate effect of the shock on domestic prices and consumption decreases and intermediate goods producers replace more expensive intermediate inputs for cheaper labor, both in relative and absolute terms. Finally, although hours worked,

wages and consumption converge close to their original steady states, permanent changes in terms of trade leave domestic output at a permanently lower than the original level.

Figure 1.6: Responses to 10% increase in Chinese import prices under alternative model configurations.



Notes: Percentage deviations from the non-stochastic steady-state; the responses of the policy rates are annualized.

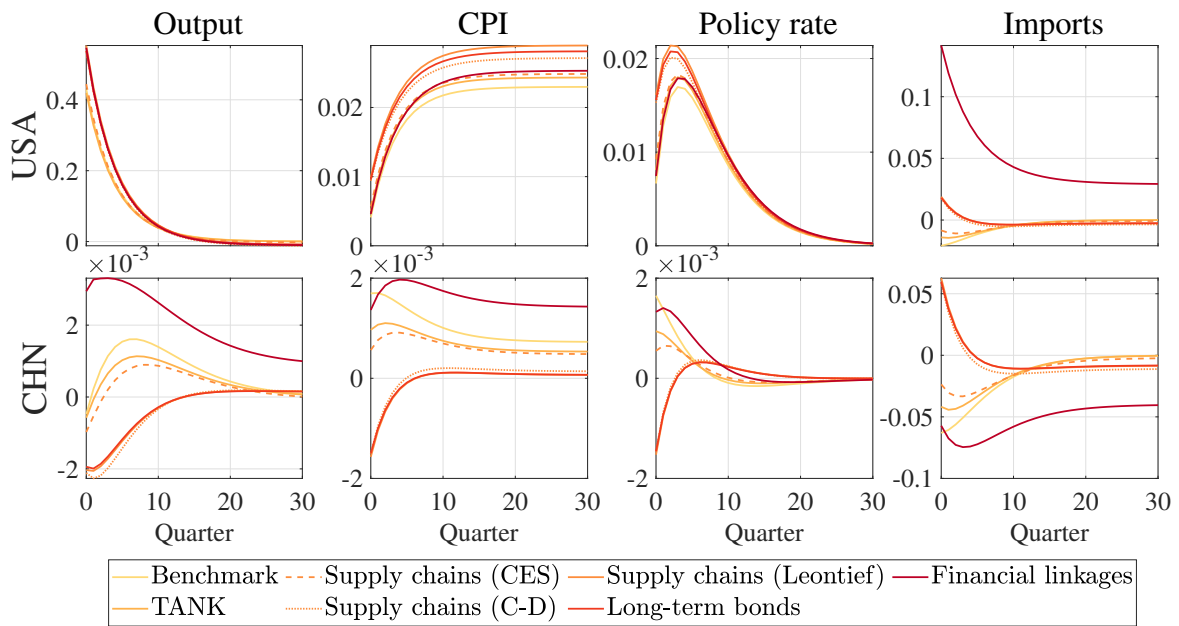
In China, when import prices increase by the same margin, the effect on Chinese CPI and policy rate is significantly lower relative to the symmetrical response of the corresponding variables following the US-originated shock (see Figure 1.6). This is related to significantly lower reliance of Chinese production on imports of supplies from the US. In the model with financial linkages, Chinese imports from the US permanently increase in the very long run by 0.22% which is 2.5 less than the symmetrical effect on the US imports from China following the US-originated shock (US imports from China permanently decrease by 0.33% following the 10% increase in the Chinese import prices).

When faced with the trade shock, Chinese producers reduce production by approximately half as much as the US producers after the US-originated trade shock. Moreover, in the model with financial linkages, in the short and medium term, Chinese output even increases with reduced imports being replaced by increased demand for domestic labor.

1.4.4 Government spending shocks

The transmission channel of increased government spending is through both output and consumption, given the increased demand for final goods and a need to finance increased government consumption through increased taxation. The output responses in the top row of [Figure 1.7](#) can be categorized into two groups. One group is the responses given the production function with labor only or with the supply chains and labor easily replaceable by intermediate inputs (CES function), and the second group is with supply chains and lower substitutability of labor and intermediate inputs. The latter group of models results in more positive short-run responses to the government spending shock.

Figure 1.7: Responses to US-originated government spending shock under alternative model configurations.

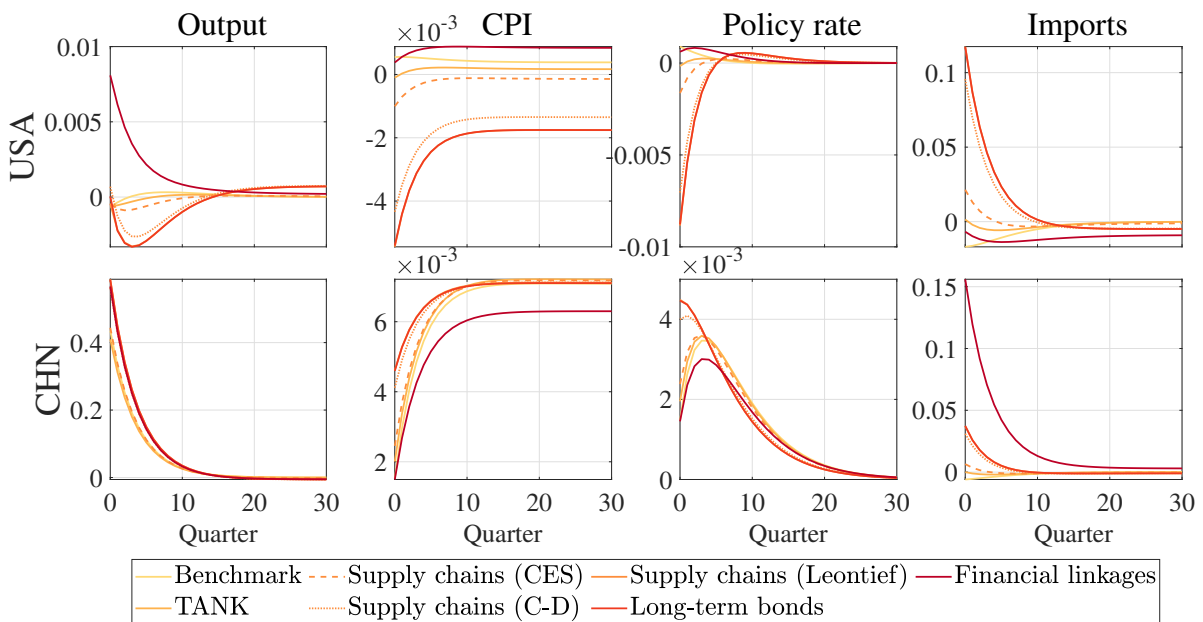


Notes: Percentage deviations from the non-stochastic steady-state; the responses of the policy rates are annualized.

When labor and intermediate inputs are easily substituted, i.e., the elasticity of substitution η takes the value of two as in the CES specification, or when output is produced using labor inputs only, US imports decrease following the shock. On the other hand, under financial linkages or with low elasticity of substitution between labor and intermediate inputs, US imports increase in the short term. It is the latter which

finds more empirical support.¹⁴ This is related to the fact that a local government increases its demand for domestically-produced goods, which in the models with supply chains are produced using an imported component. The result of increased imports is more positive output responses given the models with Leontief and Cobb-Douglas production functions. Consequently, increased output translates into more significant increases in CPI and policy rates. However, when the domestic currency appreciates, in the model with financial linkages, cheap imports result in lower CPI and policy rate increases.

Figure 1.8: Responses to China-originated government spending shock under alternative model configurations.



Notes: Percentage deviations from the non-stochastic steady-state; the responses of the policy rates are annualized.

Supply chain linkages, therefore, tend to drive up prices following a positive government spending shock, even though under sufficiently low elasticity of substitution between value-added and intermediate inputs, they result in positive responses of relatively cheap imports. This is also true for the Chinese-originated government spending shock (see Figure 1.8). The driving force behind more positive output responses in the presence of supply chains can be higher fiscal multipliers because of forward and backward input-output linkages in the models with supply chains, which would require a

¹⁴For example, Blanchard and Perotti (2002) suggest that after an initial increase, it is only in the medium to long term when imports decrease following a positive government spending shock.

more detailed investigation. Following the China-originated shock, however, even the model with the CES production function results in a positive response of imports to China (bottom row). Higher imports in the models with financial linkages, following an appreciation of the yuan, also reduce the effect of increased government spending on the price level. Even though output increases on a comparable scale as the US output following the US-originated shock, this does not translate into equally higher prices and the central bank's interest rate in China. This can be linked to Chinese producers being less likely to update their prices than US producers.

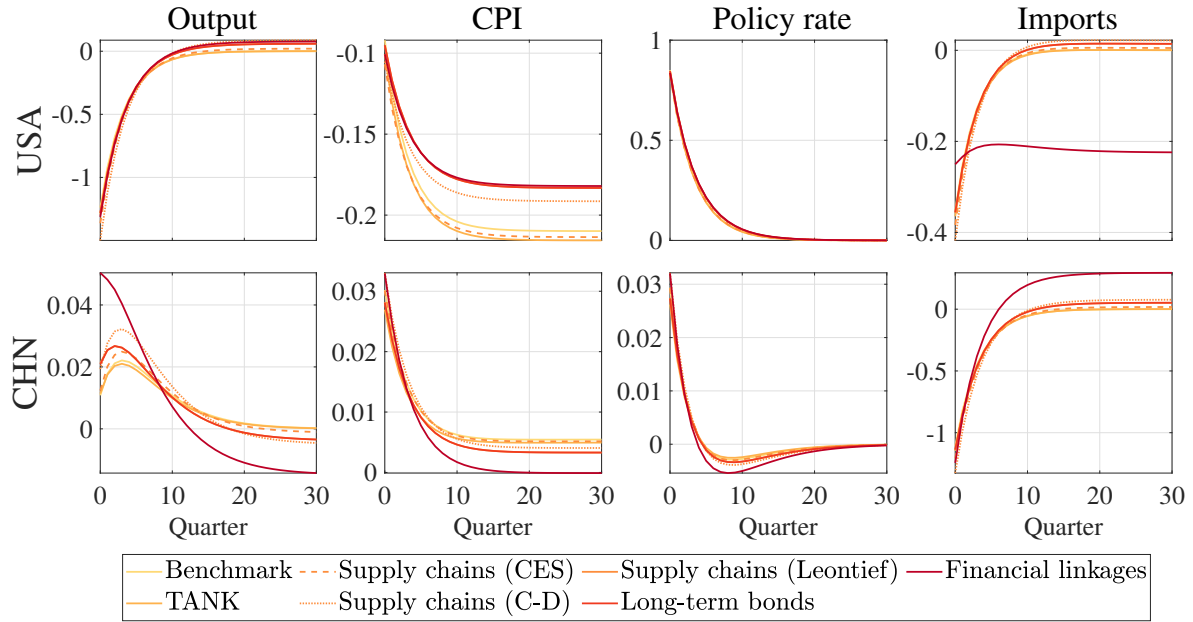
1.4.5 Monetary policy shocks

Supply chains have a much less significant effect on domestic production following an increase in the domestic nominal interest rate. For the US, a one-off 100 basis points increase in the US policy rate results in an immediate decrease in the US output of around 1.35% as displayed in [Figure 1.9](#). The differences in the output responses between each model configuration are minimal, except that the long-run effects of contractionary monetary policy on output are more positive when supply chains are taken into account. This follows from the responses of domestic prices, which decrease, improving the terms of trade of the US economy. Following an appreciation of the dollar, the model with financial linkages results in permanently lower US imports from China and permanently increased exports to the foreign economy.

Finally, under low substitutability of labor and intermediate inputs, contractionary monetary policy has a smaller effect on reducing the domestic aggregate price level. Following an interest rate hike, labor becomes relatively less expensive than intermediate inputs. When it is easy to substitute intermediate inputs for cheaper labor, goods become even less expensive relative to the scenario in which producers are unable or less able to substitute supplies for labor inputs. Therefore, assumptions regarding the formulation of trade linkages have clear and important implications for monetary policy.

The Chinese contractionary monetary policy shock of equal size has an even stronger effect on trade flows (see [Figure 1.10](#)). Chinese imports from the US decline by 0.792%, and Chinese exports to the US fall by over 2%. In the long run, exports to the US increase, especially when supply chains and financial linkages are taken

Figure 1.9: Responses to 100 basis points US interest rate hike.

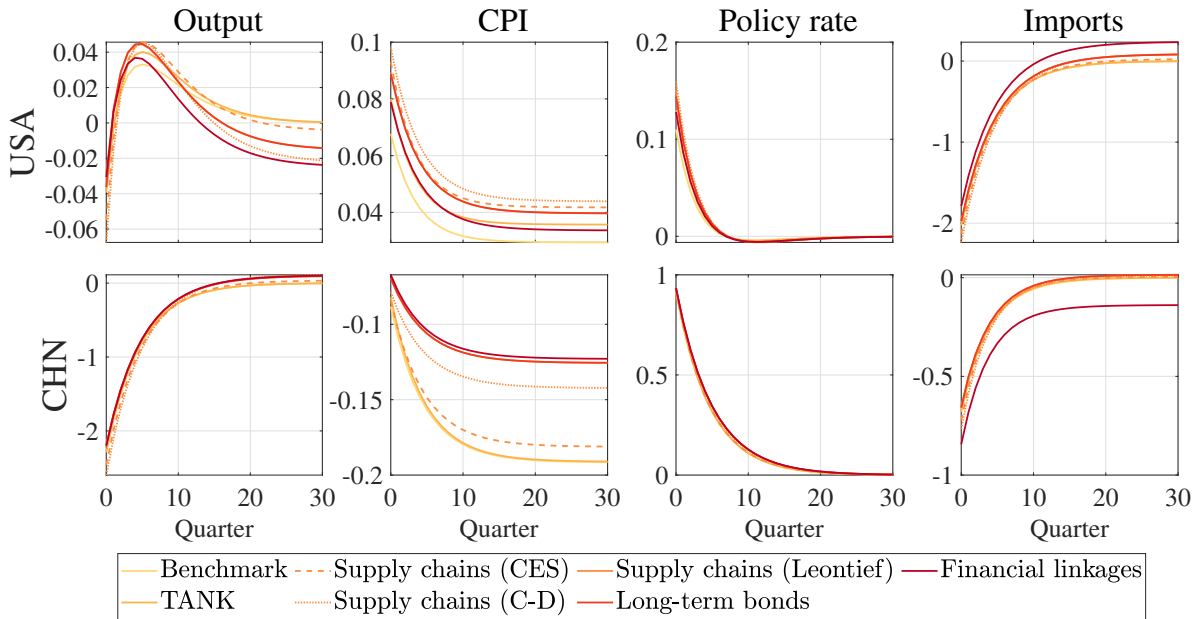


Notes: Percentage deviations from the non-stochastic steady-state; the responses of the policy rates are annualized.

into account. This leaves a long-lasting positive effect on Chinese output and an improvement in Chinese terms of trade. Even though short-run output declines by more than the US output following the US monetary policy shock, monetary policy in China has less significant effects on prices, with CPI falling by 0.189% in the long run, following a 100 basis points interest rate hike.

Accounting for long-term bonds does not significantly alter the results for any shock. The responses resulting from the model with Leontief specification of technology and short-term bonds only and its version with short- and long-term bonds overlap in most cases. A closer look at the responses under the two model specification, however, reveal that long-term bonds, in several instances, reduce the responsiveness to shocks, which is the result of a longer, on average, maturity of bonds in the model with two types of bonds. Although to a marginal extent, this brings about an increased smoothing out the effect of consumption of Ricardian households when long-term bonds are present in a model.

Figure 1.10: Responses to 100 basis points Chinese interest rate hike.



Notes: Percentage deviations from the non-stochastic steady-state; the responses of the policy rates are annualized.

1.4.6 International spillovers

In summary, the responses of domestic variables are more responsive under model configurations with the supply chains relative to any previous model configuration with labor only in a production function. This is supported by [Altinoglu \(2021\)](#) for a closed economy with discrete time, and [Petrella and Santoro \(2011\)](#) in a closed-economy two-sector model. The short-run responses of variables characterizing a domestic economy are up to five times more negative with supply chains in the case of TFP shocks. One exception is the responses to the labor supply shocks, which are more negative in the models that abstract from the supply chain linkages. This is unsurprising given the relatively greater importance of labor in the benchmark model and its extension with two types of households. Supply chains also exert more pronounced long-term effects on the real variables through permanent changes in terms of trade and the importance of imported inputs, especially when producers are unable to substitute imported components for domestically-produced ones. Finally, financial linkages can also result in significant movements in trade balance through the exchange rate channel, given that a financial account deficit can accompany a negative trade balance. Long-term bonds are considerably more persistent than consumption

or output, which can lead to permanent changes in the pattern of trade flows between the two countries.

Domestic shocks, however, result in spillovers to a foreign economy of different scales and patterns, depending on a model version. For example, a drop in the US output following the US-originated TFP shock results in a decline in Chinese production (see [Figure 1.1](#), bottom row). The decline of output in China, depending on the version of a model, is around 5% of the effect of the shock in the US. When financial linkages are considered, both countries' short-run co-movements are most significant. Around 5-7% of the effect of increased CPI and policy rate spills over and is reflected in the responses of the corresponding variables in China.

Up to 14% of the effect of the Chinese-originated shock can be traced by looking at the responses of output in the US (see [Figure 1.2](#), top row). The co-movement between the US and Chinese price levels is weaker at less than 8% of the changes in the Chinese price level spilling over to the US economy. The strongest co-movement can be observed between the two policy rates, with up to 40% of the changes in the Chinese monetary policy spilling over to the US economy following the Chinese-originated TFP shock. The scale of the co-movement is very similar following the labor supply shocks in both countries ([Figure 1.3](#) and [Figure 1.4](#)).

Looking at the responses to the trade shocks in both countries, given a more global character of the trade shocks, it is clear that the foreign effects of domestic trade shocks are more robust than those which follow the TFP or labor supply shocks. When import prices increase by 10% in the US, Chinese output falls by around 19% less than the US output, the Chinese price level declines by around 83% less than the US price level, and the policy rate increases by around 87% less than the US policy rate in the short run (see [Figure 1.5](#)). Supply chains increase the co-movement of both output and prices following the trade shock with financial linkages resulting in increased short-run co-movement of output and a reduction of the co-movement of the price levels and policy rates. After the Chinese trade shock, financial linkages also decrease the co-movement of output in both countries (see [Figure 1.6](#)).

When the effects of the government spending shocks in both countries are taken into account, the international spillovers are negligible given the benchmark specification of the model and its version with Ricardian and non-Ricardian households (see [Figure](#)

1.7 for the US-originated shock and Figure 1.8 for the Chinese-originated shock). In turn, supply chains have an important impact on the cross-border spillovers of government spending shocks, with the foreign effects of domestic shocks becoming negative. That is, when output or CPI in a domestic economy increase, they fall to a small extent in a foreign economy. This is because the domestic currency appreciates in the benchmark model and its first extension with two types of households. Second, it remains roughly unchanged in the model with supply chains specified using a CES function. Third, it depreciates in the models with lower than two elasticity of substitution between labor and intermediate inputs. Finally, the domestic currency appreciates in the model with financial linkages. Because of the domestic currency appreciation, the foreign economy can increase their imports of goods and substitute domestic production by effectively cheaper imports. Recent evidence advocates a domestic currency depreciation following a positive government spending shock¹⁵, once again serving as an argument for the use of input-output linkages in a general equilibrium environment.

The spillovers of monetary policy shocks to the foreign economies support the earlier observed greater co-movement of the US economy to the China-originated shocks than the other way around. Following a 100 basis points interest rate hike in the US, the annualized Chinese interest rate increases by around three basis points (see Figure 1.9). Conversely, following an interest rate hike of equal size in China, the US interest rate increases by up to 15 basis points (see Figure 1.10). Interestingly, production in the US decreases in the short-run following a contractionary monetary policy shock in China to increase in the medium term, while production in China increases immediately following the US interest rate hike. Because of the permanent effect of monetary policy on the terms of trade, the foreign output is permanently reduced after a domestic interest rate hike. The effect is stronger in the models with supply chains - with a lower elasticity of substitution between labor and supplies having a greater effect on the reduction of foreign output - and the model with financial

¹⁵Currency appreciation following a positive government spending shock is in line with a neoclassical paradigm, for example in the standard Hicksian IS-LM model, in which an elevated interest rate attracts foreign capital inflows, leading to an increase the demand for domestic currency and resulting in a nominal appreciation of the exchange rate. More recent evidence, for example, in Ravn et al. (2007) or more modern versions of the Mundell-Fleming IS-LM model suggests a currency depreciation following a positive government spending shock.

linkages having the most significant adverse effect on the long-run response of the foreign level of production.

1.5 Welfare analysis

Another critical element of analyzing the effects of the shocks and their international spillovers is how they translate into welfare losses or gains across the two types of households - Ricardian and non-Ricardian. Except for the benchmark model, which features only one household type, the remaining settings allow for the analysis of how welfare costs or gains arising from the US-originated and China-originated shocks are shared across two countries and two household types in each country.

As in [Schmitt-Grohé and Uribe \(2007\)](#) and [Canova and Ravn \(2000\)](#), I define the welfare function as the present value of households' utility over consumption and hours worked - $W_{R,0}$ and $W_{NR,0}$ - for the Ricardian and non-Ricardian households, respectively.

Let ζ_R and ζ_{NR} denote the welfare cost of shocks expressed in consumption units that households are willing to give up to be as well off after the transition path as in the initial steady-state:

$$\mathcal{W}_{R,0}(\zeta_R) \equiv \mathbb{E}_0 \sum_{t=0}^{\infty} (\beta_R)^t U_R((1 - \zeta_R)C_{NR,t}, H_{R,t}) \quad (1.5.66)$$

$$\mathcal{W}_{NR,0}(\zeta_{NR}) \equiv \mathbb{E}_0 \sum_{t=0}^{\infty} (\beta_{NR})^t U_{NR}((1 - \zeta_{NR})C_{NR,t}, H_{NR,t}) \quad (1.5.67)$$

To calculate the consumption equivalents, ζ_R and ζ_{NR} , discounted welfare which includes the welfare gains or losses from a shock, is set equal to corresponding welfare in the non-stochastic steady state. The consumption equivalents make households indifferent between being affected by the shock and not being affected, which is equivalent to the non-stochastic steady-state level of welfare:

$$\mathcal{W}_{R,0}(\zeta_R) = \mathcal{W}_R \quad (1.5.68)$$

$$\mathcal{W}_{NR,0}(\zeta_{NR}) = \mathcal{W}_{NR} \quad (1.5.69)$$

Table 1.3 to Table 1.6 display welfare outcomes in terms of consumption equivalents of shocks over 1,000 quarters broken down by households type in both countries for each shock type and model configuration, as indicated in each row and column heading. The top panels of each table present the welfare outcomes for Ricardian households, while the bottom panels display the welfare outcomes of non-Ricardian equivalents.

Table 1.3, which displays consumption equivalents of US households corresponding to the US-originated shocks, suggests that a 100 basis points hike of the US nominal interest rate results in the most significant absolute welfare losses which affect the US Ricardian households. Therefore, US Ricardian households would need to be compensated for the interest rate hikes by increasing their consumption. The consumption equivalents are 0.054% to 2.575% of the steady-state consumption level, respectively, in the benchmark model specification and the model with supply chains introduced using a Leontief function. This is in principle supported by Gornemann et al. (2016) who suggest a 0.44% consumption equivalent of a 25 basis points interest rate hike.

Conversely, non-Ricardian households are most negatively affected by trade and TFP shocks. The consumption equivalent of a 10% increase in the US import prices is up to 6.6% in the model with financial linkages. The welfare effects of the domestically-originated TFP shock are the greatest under the Leontief representation of supply chains at 3.05%.¹⁶ Under each model configuration, a contractionary monetary policy results in greater losses for Ricardian households suggesting that interest rate hikes reduce welfare inequalities between per-capita wealthier Ricardian and poorer non-Ricardian households. One exception is consumption equivalents of the US interest rate hike in the model extension with financial linkages, in which welfare losses are more significant for non-Ricardian households. This can be the effect of Ricardian households being able to substitute domestic for foreign bonds in the model with cross-border bond trade.

The corresponding welfare loss resulting from a hike in the Chinese interest rate of

¹⁶Welfare losses from trade shocks for both household types are more significant under the Leontief technology specification than under the Cobb-Douglas assumption. This contrasts with the findings in Steinberg (2019), who find a significant but opposite relationship between the welfare costs. When domestic producers cannot substitute foreign supplies with an increased domestic supply of equivalent inputs, the result is a permanent worsening of the terms of trade. Intuitively, the worsening of terms of trade is more severe relative to a scenario in which, at least to some degree, domestic producers can increase their supply of intermediate inputs to make up for decreased imports.

100 basis points decreases the welfare of Chinese Ricardian households by 0.17% to 5.25% as displayed in the bottom row of the top panel in [Table 1.4](#). Interestingly, while supply chains increase the welfare costs for Ricardian households, the most significant welfare losses from a contractionary monetary policy in both the US and China for non-Ricardian households are the result of an interest rate hike in the model with two types of households. Accounting for supply chains - models (3) to (7) - lowers the welfare losses for non-Ricardian households in China from 2.42% to between 1.19% in the model with the Cobb-Douglas specification of technology and 1.83% in the model with CES technology. The effect of adding supply chains on the welfare losses in the US is smaller: consumption equivalent decreases from 1.8% to between 4.87% and 6.92% in the models with Cobb-Douglas and Leontief technologies, respectively.

Table 1.3: US-originated shocks: consumption equivalents of US households.

RICARDIAN HOUSEHOLDS	(1)	(2)	(3)	(4)	(5)	(6)	(7)
TFP	-0.558	-0.816	-1.063	-1.428	-1.803	-1.793	-1.038
Labor supply	-0.201	-0.285	-0.255	-0.3	-0.34	-0.339	-0.143
Trade	-0.176	-1.108	-1.154	-1.62	-1.899	-1.896	-0.735
Government spending	-0.124	-0.174	-0.157	-0.202	-0.26	-0.252	-0.166
Monetary policy	-0.054	-1.982	-1.882	-2.449	-2.575	-2.57	-0.237
NON-RICARDIAN HOUSEHOLDS	(1)	(2)	(3)	(4)	(5)	(6)	(7)
TFP	-	-1.339	-2.639	-2.371	-3.053	-3.044	-2.649
Labor supply	-	-1.283	-1.024	-0.732	-0.86	-0.854	-0.723
Trade	-	-6.333	-5.759	-4.708	-5.919	-5.924	-6.601
Government spending	-	-0.574	-0.48	-0.421	-0.554	-0.536	-0.415
Monetary policy	-	-1.803	-1.467	-1.076	-1.282	-1.276	-1.106

Notes: (1): benchmark model; (2): model with Ricardian and non-Ricardian households; (3): supply chains (CES technology); (4): supply chains (Cobb-Douglas technology); (5): supply chains (Leontief technology); (6): model with long-term bonds; (7): model with a credit network.

Accounting for long-term bonds generally decreases welfare losses in both the US and China, but the effect is marginal. Importantly, accounting for financial linkages between the two countries makes the welfare losses for domestic households less harmful following domestically-originated shocks. In turn, welfare losses from foreign-originated shocks increase significantly in the model with financial linkages, as displayed in [Table 1.5](#) with consumption equivalents of Chinese households resulting from the US-originated shocks. In turn, [Table 1.6](#) displays consumption equivalents

of US households resulting from the China-originated shocks. The effect is greater in the US, which holds relatively more Chinese bonds as part of its financial portfolio. Relatively less diversified financial assets held by the Chinese Ricardian households result in relatively more welfare costs of Chinese-originated shocks not spilling over to the US.

Table 1.4: China-originated shocks: consumption equivalents of Chinese households.

RICARDIAN HOUSEHOLDS	(1)	(2)	(3)	(4)	(5)	(6)	(7)
TFP	-0.475	-0.919	-1.533	-2.621	-4.027	-4.026	-3.199
Labor supply	-1.393	-0.673	-0.643	-0.844	-1.139	-1.139	-0.899
Trade	-0.168	-0.23	-0.211	-0.241	-0.343	-0.343	-1.608
Government spending	-0.081	-0.125	-0.108	-0.132	-0.199	-0.198	-0.157
Monetary policy	-0.173	-2.304	-2.556	-4.082	-5.248	-5.249	-3.487
NON-RICARDIAN HOUSEHOLDS	(1)	(2)	(3)	(4)	(5)	(6)	(7)
TFP	-	-1.501	-3.809	-3.109	-3.846	-3.843	-3.136
Labor supply	-	-2.55	-1.893	-1.131	-1.21	-1.209	-0.991
Trade	-	-0.634	-0.526	-0.436	-0.575	-0.577	-2.806
Government spending	-	-0.248	-0.196	-0.153	-0.194	-0.193	-0.144
Monetary policy	-	-2.422	-1.834	-1.186	-1.385	-1.384	-1.117

Notes: (1): benchmark model; (2): model with Ricardian and non-Ricardian households; (3): supply chains (CES technology); (4): supply chains (Cobb-Douglas technology); (5): supply chains (Leontief technology); (6): model with long-term bonds; (7): model with a credit network.

Although the monetary policy contraction is a single shock that generally results in the greatest losses for the Ricardian households in both countries, non-Ricardian households suffer the most significant losses from all other shock types in most model configurations. Moreover, the differences between the welfare losses for Ricardian versus non-Ricardian households from all real shocks, as opposed to a monetary policy shock, are greater in the US than in China, where the welfare effects of the real shocks are more equalized between the two household types.

Because of the relatively greater trade openness of the US economy, the welfare losses from trade shocks are significantly more damaging in the US for both Ricardian and non-Ricardian households, with consumption equivalents of up to 6.6% for the US non-Ricardian households and 1.9% for Ricardian households. In China, an increase in import prices results in a welfare loss of up to 2.81% for Chinese non-Ricardian households and 1.61% for Chinese Ricardian households.

Another shock that affects non-Ricardian households more is the labor supply shock. Consumption of non-Ricardian households depends on labor income in a much more significant proportion than consumption of Ricardian households. Therefore, the labor supply shock decreases the welfare of the US non-Ricardian households by 0.723% in the model with financial linkages and 0.128% in the model with two types of households, in which production depends on labor inputs relatively more than it does in the further model extensions. In China, the welfare of non-Ricardian households decreases by 0.99% in the model with financial linkages and 2.55% in the model with two household types.

Table 1.5: US-originated shocks: consumption equivalents of Chinese households.

RICARDIAN HOUSEHOLDS	(1)	(2)	(3)	(4)	(5)	(6)	(7)
TFP	−0.003	−0.016	−0.06	−0.136	−0.166	−0.166	−0.728
Labor supply	−0.002	−0.008	−0.012	−0.025	−0.032	−0.032	−0.191
Trade	−0.168	−0.23	−0.211	−0.241	−0.343	−0.343	−1.04
Government spending	0	−0.003	−0.004	−0.007	−0.007	−0.007	−0.102
Monetary policy	−0.002	−0.022	−0.018	−0.006	−0.013	−0.013	−1.779
NON-RICARDIAN HOUSEHOLDS	(1)	(2)	(3)	(4)	(5)	(6)	(7)
TFP	-	−0.081	−0.209	−0.172	−0.178	−0.178	−0.616
Labor supply	-	−0.055	−0.043	−0.028	−0.035	−0.035	−0.166
Trade	-	−0.634	−0.526	−0.436	−0.575	−0.577	−1.159
Government spending	-	−0.017	−0.012	−0.002	−0.002	−0.002	−0.091
Monetary policy	-	−0.162	−0.135	−0.085	−0.084	−0.084	−0.14

Notes: (1): benchmark model; (2): model with Ricardian and non-Ricardian households; (3): supply chains (CES technology); (4): supply chains (Cobb-Douglas technology); (5): supply chains (Leontief technology); (6): model with long-term bonds; (7): model with a credit network.

Positive government spending shocks are welfare decreasing. Increased government spending is financed through higher taxes, which negatively affect the consumption of both types of households. However, increased government expenditures increase output and prices and profit Ricardian households through increased production and prices. This positive effect of government spending is not sufficient to offset the negative consequences of higher taxes in any model configuration. This can be due to the model's simplistic treatment of fiscal policy. A more careful configuration of fiscal policy might result in different welfare outcomes.

Finally, consumption equivalents in [Table 1.5](#) and [Table 1.6](#) display welfare losses

from foreign shocks. Specifically, [Table 1.6](#) displays welfare outcomes for US households from shocks originated in China. [Table 1.5](#), in turn, presents welfare outcomes for Chinese households from the US-originated shocks.

Table 1.6: China-originated shocks: consumption equivalents of US households.

RICARDIAN HOUSEHOLDS	(1)	(2)	(3)	(4)	(5)	(6)	(7)
TFP	-0.003	-0.013	-0.075	-0.177	-0.239	-0.239	-0.725
Labor supply	-0.036	-0.022	-0.028	-0.052	-0.075	-0.075	-0.217
Trade	-0.176	-1.108	-1.154	-1.62	-1.899	-1.896	-0.991
Government spending	0	-0.001	0	-0.007	-0.009	-0.009	-0.026
Monetary policy	-0.013	-0.124	-0.118	-0.129	-0.107	-0.107	-1.317
NON-RICARDIAN HOUSEHOLDS	(1)	(2)	(3)	(4)	(5)	(6)	(7)
TFP	-	-0.063	-0.252	-0.211	-0.234	-0.234	-0.444
Labor supply	-	-0.125	-0.094	-0.049	-0.092	-0.092	-0.147
Trade	-	-6.333	-5.759	-4.708	-5.919	-5.924	-1.032
Government spending	-	-0.004	-0.001	-0.008	-0.013	-0.013	-0.026
Monetary policy	-	-0.825	-0.791	-0.669	-0.743	-0.746	-0.309

Notes: (1): benchmark model; (2): model with Ricardian and non-Ricardian households; (3): supply chains (CES technology); (4): supply chains (Cobb-Douglas technology); (5): supply chains (Leontief technology); (6): model with long-term bonds; (7): model with a credit network.

Unsurprisingly, trade shocks result in the greatest cross-country spillovers of welfare effects. However, notably, the US welfare losses from China-originated trade shocks are significantly reduced for both household types in the model with financial linkages. Conversely, the welfare effects of all other foreign-originated shocks increase in the final model extension. The effect of reduced welfare losses from the foreign-originated trade shock is robust, with welfare losses of the US Ricardian households falling from 5.92% in the model with long-term bonds and Leontief technology to 1.03% in the model with financial linkages (see [Table 1.6](#)). The welfare losses of the US Ricardian households fall from 1.9% to 0.99%.

In China, the effect is reversed, with the consumption equivalent of Ricardian households increasing in absolute terms from 0.34% to 1.04% and the consumption equivalent of the Chinese non-Ricardian households increasing from 0.58% to 1.16% when financial linkages are present. Therefore, financial openness helps reduce welfare losses for US households from Chinese-originated trade shocks. However, the welfare effects from all other China-originated shocks are more negative in the presence of

cross-border financial linkages.

Chinese-originated shocks generally have a more significant effect on US households than the other way around because of the relatively greater openness of the US economy, both trade and financial. Non-Ricardian US households are again generally more affected by the China-originated shocks than their Ricardian equivalents, except for the aforementioned trade shock in the model with financial linkages. The Chinese shocks most negatively affecting the US non-Ricardian households after the trade shock are the TFP shock and the monetary policy shock of 100 basis points (see [Table 1.6](#)). Except for the trade shock, financial linkages increase the effects of Chinese-originated shocks on US Ricardian households, especially those of the Chinese-originated monetary policy shock, which results in a decrease in the welfare of 1.32% for US Ricardian households - a jump from 0.11% in the model with segmented financial markets.

1.6 Sensitivity checks

The analysis in this chapter strongly emphasizes cross-country linkages, and the dynamics are inevitably driven by assumptions about how the cross-country dependencies are formalized. Therefore, the results described earlier can be sensitive to the parameters governing international goods trade and investments in domestic and foreign long-term bonds. Specifically, I verify my results under a varying elasticity of domestic and foreign consumer goods and intermediate inputs - ε_c and ε_s .¹⁷ Additionally, I allow for the elasticity of substitution between intermediate inputs and labor in the model with CES technology η to take different values than the benchmark value of 2.

Higher values of the Armington elasticities ε_c and ε_s help to achieve greater cross-country co-movement through more aggressive responses of trade flows. However, the evidence in the relevant literature suggests that a lower value of the Armington elasticity helps achieve a better fit to the international business cycle (see [Bodenstein, 2010](#)). Therefore, in all my simulations, I fix both ε_c and ε_s at a conservative level of 1.5 as in [Monacelli \(2004\)](#).

¹⁷I assume equal values of both ε_c and ε_s .

The higher the values of ε_c and ε_s , the more responsive domestic imports under all the domestically-originated shocks analyzed in this chapter with significant consequences for the terms of trade and policy rate adjustments. This is clear from [Figure A.1](#) (see [Appendix A](#)), which displays the responses to the US-originated TFP shock in a model with CES technology and short-term bonds. There, US imports respond more negatively to the shock when the Armington elasticities ε_c and ε_s take values higher than 1.5. This results in more significant domestic aggregate price and policy rate increases. In turn, higher nominal interest rate hikes under a high degree of substitutability of domestic and imported consumer goods and supplies lead to a relative decrease in output, especially in the short term. The same applies to the labor supply shock and government spending shock as presented in [Figure A.2](#) and [Figure A.4](#) for US-originated labor supply and government spending shocks.

Higher Armington elasticity implies that it is easier for domestic producers to substitute imported supplies and domestically produced equivalents. The higher the values of ε_c and ε_s the less negative are the effects of a contractionary monetary policy on the domestic price level as displayed in [Figure A.5](#). In the models with supply chains, intermediate goods producers substitute imported supplies for domestic inputs when it is easy to do, which become relatively cheaper after an interest rate hike. In relative terms, increased demand for domestic goods tends to increase domestic prices. Hence, the easier it is to replace imported supplies through increased relative demand for domestic inputs, the smaller the effects of a contractionary monetary policy on the domestic price level.

The reason behind the value of both ε_c and ε_s of 1.5 in the model simulations are the responses of imports to a 10% increase in the import price in the US and China as displayed in [Figure A.3](#). When ε_c and ε_s take higher values, the short-term responses of US imports to a 10% increase of the US import prices are in the range of 22%-28%. This is highly unrealistic given that the estimates of short-run import demand elasticities are between -1.09 for the US and -0.44 for China, as suggested by [Tokarick \(2014\)](#). The short-run responses of imports to trade shocks in [Figure A.3](#) support the choice of the benchmark value of ε_c and ε_s equal to 1.5.

Additionally, when both elasticities take high values, except for the trade shocks, the spillovers abroad of the domestically-originated shocks are smaller. This is clear

from the responses of foreign imports, which are less responsive when the elasticities take high values. When, regardless of the price, foreign producers and consumers must purchase a fixed proportion of imported goods, they are more affected by changes in the domestic price level than when they can easily substitute imported goods for local ones.

The literature differs on the approach to supply chains in a general equilibrium framework. Further to the elasticities of substitution between domestic and imported goods, I find some interesting differences between the results under varying elasticities of substitution between labor and intermediate inputs η . As indicated earlier, welfare outcomes under domestically-originated shocks tend to be most negative under the assumption of Leontief technology with a zero elasticity between labor and intermediate inputs and least negative when technology is given by a CES function with η equal to two.

Regarding the impulse response functions given the Leontief specification of technology, its Cobb-Douglas specification with unit elasticity between labor and intermediate inputs, and the CES specification with η equal to 1.5, 2, or 3, the former two leave a more pronounced long-run footprint on production as indicated by [Figure A.6](#) - [Figure A.10](#). Hours worked strongly depend on the supply of intermediate inputs when η is low. Therefore, if terms of trade change and so does domestic production of intermediate inputs, not only the latter is permanently affected by the change in terms of trade but also the former.

When η is high, and it is easier to substitute one input for another, reduced imports of intermediate inputs can then be substituted by increased demand for labor. This is reflected in the long-run responses of output following the US-originated shocks under low values of η .

Lower values of η tend to lead to more robust responses of the domestic aggregate price level and nominal interest rate following a TFP shock, a government spending, and a trade shock as displayed in [Figure A.6](#), [Figure A.8](#) and [Figure A.9](#), respectively. The CPI and policy rate are, however, less responsive when η is low, as compared to when it takes a higher value, following labor supply and monetary policy shocks (see [Figure A.7](#) and [Figure A.10](#)). The former three shocks make intermediate inputs relatively more expensive than labor. The latter two, in turn, result in the lower relative

cost of intermediate inputs. Following the derivation of relative demand for labor in a CES production function (see equation 1.2.31), the higher the value of η , the stronger is the increase in the demand for one input following an increase in the relative price of another input. When the relative price of intermediate inputs goes up, CPI responds stronger when η takes a low value because the relative demand for labor does not increase significantly. Conversely, when the relative price of labor increases, a more significant increase in the demand for intermediate inputs tends to reduce the adverse effects of shocks on production resulting in less negative consequences of shocks on inflation.

Low values of the elasticity of substitution η also result in more significant spillovers of domestic shocks to the foreign economy through the trade channel. When foreign producers require domestic components in their technology, the foreign output is directly affected by changes in the domestic supply of goods. On the other hand, when it is easy for foreign producers to switch from importing components to producing them locally under higher values of η , changes in real domestic activity are less relevant from the perspective of the foreign economy.

An argument behind adopting lower values of η in a general equilibrium model could be the responses of imports to the government spending shocks as indicated by Figure A.9. Evidence strongly suggests that imports increase after a positive government spending shock. For example, Blanchard and Perotti (2002) suggest that after an initial increase, imports start declining in response to a government spending shock and reach a negative peak after less than ten quarters. An increase in domestic imports in response to positive government spending shocks is also supported for low-income countries, among many others, by Shen et al. (2018). However, this effect of increased imports in the short run can only be achieved when η takes either 0 or 1, which points to Leontief and Cobb-Douglas technology specifications as more appropriate, at least in the short run.

One could argue that the share of non-Ricardian households in an emerging economy, including China, should be lower than the corresponding value in an advanced economy, which is the US in my exercise. The posterior median of the share of constrained households in the US takes the value of 0.05 in Chen et al. (2012), which implies the share of unconstrained households of 95%. Kolasa and Wesołowski (2020) adopt

the share of unconstrained households in an advanced economy of 90%. Therefore, there is no doubt that when the US economy is considered, the share of unconstrained households should be high and in the magnitude of values greater than 90%. For the Chinese economy, however, the share of Ricardian households can be lower than the US share. For example, [Guo and Jiang \(2021\)](#) estimate the share of patient households in China equal to 57%.

[Figure A.11](#) to [Figure A.15](#) in [Appendix A](#) display the responses of the US and Chinese economies to China-originated shocks when the share of Ricardian households λ_R in China varies from 0.7 to 0.9. Differences between the responses are most pronounced in the case of China-originated TFP, labor supply, and government spending shocks. The responses to trade and monetary policy shocks are largely unchanged regardless of the value of λ_R . A common feature of the responses to the TFP, labor supply, and government spending shocks - as displayed in, respectively, [Figure A.11](#), [Figure A.12](#), and [Figure A.14](#), is a more robust response of the aggregate price level, both at home and abroad, when the share of non-Ricardian households is higher. This is unsurprising given the impossibility of non-Ricardian households to smooth out consumption and greater exposure of their consumption to shocks. As a consequence of more significant increases in the price level in China, when the share of non-Ricardian households is high, Chinese net exports respond more negatively relative to the scenario when the share of non-Ricardian households is 10%.

Finally, I verify how the transaction cost parameter on long-term debt ξ_b , the debt smoothing parameter γ_b , and the composition of long-term debt with respect to the country of origin affect the results in the model with financial linkages (not reported). In the range of values where these parameters take reasonable values, they do not significantly affect my results. This is, in principle, confirmed by [Kolasa and Wesołowski \(2020\)](#), who also do not find any significant changes in their results when the values of parameters related to the investment portfolio change.

1.7 Discussion

The analysis of shocks and their cross-country spillovers in this chapter is based on the New-Keynesian models with trade and financial linkages. Standard DSGE models, as

shown among others by [Alpanda and Aysun \(2014\)](#) and [Georgiadis and Jančoková \(2020\)](#), fail to replicate the large scale of cross-country business cycle co-movement found in the data. Even the final extension of the benchmark model developed in this chapter, while resulting in the greatest cross-country co-movement out of all versions, fails to replicate the global effects of shocks fully. However, once financial linkages are considered, the welfare analysis presented in this chapter results in a much more satisfactory size of the transmission of domestic shocks to the foreign economy.

Nonetheless, it is clear that other and more powerful linkages between the countries, trade and financial, should be accounted for to increase the degree of cross-country business cycle co-movement. The models used in this chapter lack physical capital and a banking sector, which are introduced in the following chapters of this thesis.¹⁸

Each of my model specifications assumes a flexible exchange rate of the US dollar to the Chinese yuan. However, the exchange rate between the two currencies, although not fully fixed, is strongly controlled by the Chinese monetary authority. Flexible exchange rates generally help to insulate countries against foreign-originated shocks, acting as a shock absorber.¹⁹ From a theoretical perspective, therefore, the co-movement of both countries should be greater under the assumption of a fixed exchange rate.

Furthermore, my analysis considers trade and financial linkages between the US economy and mainland China. For simplicity, it ignores trade and financial flows through important trade and financial hubs in Asia, including Hong Kong, Singapore, Taiwan, and Macao. Serving as important channels through which goods and money flow into mainland China, taking these countries into account in the calibration of linkages between the US economy and mainland China should also affect the results in the direction of more significant spillovers of shocks in both directions.

¹⁸As suggested by [Atalay \(2017\)](#), financial frictions still do not result in a satisfactory cross-country co-movement. To solve the problem of inadequate spillovers of domestic shocks, they suggest either using ad hoc cross-country shock correlations or introducing global banks in a model - financial intermediaries operating globally.

¹⁹Although it is not always true as shown in [Corsetti et al. \(2021\)](#).

1.8 Conclusions

In this chapter, I have built a number of model configurations to analyze the responses to a number of standard shocks and their international spillovers. The models included: (i) the benchmark model with international trade in consumer goods and no cross-border financial linkages; (ii) the model with Ricardian and non-Ricardian households; (iii-v) the model with supply chains introduced using three different functional forms of the production function - CES, Cobb-Douglas, and Leontief; (vi) the model with long-term financial assets; and (vii) the model with cross-country financial linkages.

The analysis presented in this part of the thesis summarizes the effects of standard shocks in a two-country general equilibrium setting. Its purpose is to shed some light on the quantitative effects of assuming households heterogeneity, supply chain linkages, and international financial networks or a lack thereof in a general equilibrium framework. Considering supply chain linkages, it further gives an intuition behind the quantitative effects of assuming different forms of cross-country trade linkages with different levels of substitutability between value-added and intermediate inputs.

The analysis in this chapter yields a number of interesting findings. I find that: (i) supply chain linkages are the key most important element behind the responsiveness of the domestic and foreign economies to shocks; (ii) input-output linkages leave the most significant long-run footprint on real variables, including output; (iii) the next important element affecting the results are financial linkages in the form of cross-border trade in long term-bonds, thanks to which the responses of the exchange rate are more slack and result in more significant permanent changes of the terms-of-trade and balance of trade; (iv) government spending shocks and trade shocks result, respectively, in the smallest and greatest foreign spillovers; (v) thanks to financial linkages, welfare effects of shocks are more equalized between the two countries; (vi) the assumptions regarding the division of the household sector into Ricardian and non-Ricardian have significant consequences for the responses of the price level, affecting the trade balance (also in the long run) in the presence of supply chains; and (vii) assumptions regarding a functional form of technology with intermediate inputs affect the responses to shocks, their welfare effects for households and, very importantly, result in significantly different responses of prices and inflation with

important consequences for monetary policy.

Although my analysis produces several interesting findings, it fails to replicate the cross-country business cycle co-movement realistically. For this reason, in what follows I add physical capital, financial frictions in the form of a banking sector, and the possibility of investing in foreign financial assets to better match the scale of international spillovers in the face of domestic, foreign, and global shocks.

CHAPTER 2

SUPPLY CHAIN NETWORKS, TRADE AND THE BREXIT DEAL: A GENERAL EQUILIBRIUM ANALYSIS

2.1 Introduction

Disintegration of economic ties in the form of withdrawal from a major economic block has no historical precedence. The UK's exit from the EU, therefore, constitutes a rare economic experiment. By ending the UK's membership of the EU single market - with free movement of goods, services, people, and capital across borders - Brexit has reintroduced frictions to trade and migration flows between the UK and the EU from the 1st of January, 2021, following the completion of the long-awaited Brexit-deal - formally known as the Trade and Cooperation Agreement (TCA) - between the two sides.

It is commonly acknowledged that the appeal of the UK's ability, as a non-EU country, to control the EU-UK immigration flows played a major role in the outcome of the Brexit referendum (see, for example, [Portes, 2016](#)). It was therefore widely expected that any post-Brexit arrangement would feature at least some restrictions on the free movement of workers across the UK-EU border. Indeed, the new UK immigration system that also came into effect on the 1st of January 2021, entails such restrictions in the form of a points-based structure and a salary threshold. As such, the new system is widely expected to bring about a fall in net immigration of low-skilled labour from the EU countries (see, for example, [Rolfe et al., 2019](#)).

Another key aspect of the post-Brexit arrangements is undoubtedly the nature of trade between the UK and the EU with the former now outside the EU's single market. Although the risk of tariffs is averted by the provisions of the TCA, the UK-EU trade is now subject to non-tariff barriers (NTBs). NTBs derive from border controls; rules-of-origin checks; divergence in regulations about product standards and safety, workers' rights and environmental protection and are seen as an important source of losses for the UK economy beyond Brexit (see, for example, [Ottaviano et al., 2014](#); [Van Reenen, 2016](#); [Sampson, 2017](#)). Conversely, as is consistently argued by the proponents of the UK's withdrawal from the EU, Brexit allows the UK to forge its own trade agreements with the third countries, which she was unable to do while operating in a customs union with the EU.

While the resumption of tariff and quota-free trade in goods across the UK-EU border, as secured by the TCA, has been hailed as a major achievement for both sides,

the omission of the services sector from the agreement is noted as a significant risk factor. This is particularly the case for the UK economy 80 percent of which is made up of the services sector, a vast proportion of which are financial services (see, for example, [Hall, 2021](#)). As the UK has left the single market with no provision for the services, the British financial sector runs the risk of losing the so-called ‘passporting rights’ that has allowed British financial entities to provide financial services in the European Economic Area (EEA) (see, for example, [Armour, 2017](#); [Ramiah et al., 2017](#); [Erken et al., 2018](#)). The resulting frictions to bilateral financial services trade is likely to increase the cost of providing financial services across the UK-EU border. TCA also changes the structure of the UK-EU trade in non-financial services due to the absence of mutual recognition of qualifications, for example, in engineering, architecture and legal services, with important implications for the cost of their cross-border provision.

Naturally, Brexit has led to an explosion of interest in its potential consequences, generating a burgeoning new literature on how withdrawal from the EU would impact the UK economy.²⁰ There is now a substantial body of work on the economic consequences of alternative forms of Brexit. Evaluation of potential post-Brexit scenarios has been carried out by using dynamic trade models ([Dhingra et al., 2016](#); [Van Reenen, 2016](#); [Dhingra et al., 2017](#); [Sampson, 2017](#)); macroeconometric models ([Kierzenkowski et al., 2016](#); [Erken et al., 2018](#); [Hantzsche et al., 2019](#); [Berthou et al., 2020](#)); and dynamic general equilibrium models ([Pisani and Vergara-Caffarelli, 2018](#); [Broadbent et al., 2019](#); [Steinberg, 2019](#); [McGrattan and Waddle, 2020](#)). A separate and large body of work has explored the effects of Brexit utilising empirical methods including expectations augmented vector-autoregressions ([Born et al., 2019](#)); structural VAR ([Driffield and Karoglou, 2019](#)); gravity models ([Campos and Timini, 2019](#)); and event studies ([Oehler et al., 2017](#)). Findings from both the simulation exercises based on general equilibrium models and empirical studies suggest that Brexit is likely to exert a significant impact, particularly on the UK economy, and the size of that impact varies with the scale of frictions in the UK-EU economic arrangements.

²⁰Given that Brexit is the first example of a member leaving a major economic group, it is not surprising that much of the previous work on economic unions focuses almost exclusively on the dynamics and effects of economic integration (see, for example, [Anderson and Reichert, 1995](#); [Brenton et al., 1999](#); [Guiso et al., 2004](#)). Among the rare exceptions to this are [Eichengreen and Irwin \(1993\)](#) that examines trade disintegration during the Great Depression; and [Fidrmuc and Fidrmuc \(2003\)](#) investigating economic disintegration of the Soviet Union, Yugoslavia, and Czechoslovakia.

The completion of the Brexit-deal, TCA, on the 24th of December, 2020 allows us to move beyond alternative scenarios and carry out a comprehensive analysis of the agreed form of the future UK-EU economic relationship. We argue that, in addition to the need to fully address the effects of the new arrangements for the services sector and of NTBs in trading of goods, as set out earlier, any proper analysis of the Brexit deal will need to explicitly consider substantial supply chain networks between the UK and the EU. Indeed, global value chains (GVC) - production being broken into stages that are completed in different countries - now make up a significant share of international trade (70% in 2020) (see, for example, [Cattaneo et al., 2010](#); [Miroudot et al., 2013](#)). When countries are interconnected in production to such an extent, any frictions to cross-border trade has the potential to disrupt supply chains, and hence production processes in multiple countries. Therefore, even in the absence of tariffs and quotas, new frictions underlying the NTBs on the UK-EU trade are likely to have significant consequences for both the UK and the EU as well as their major trading partners, working through the substantial supply chains in place.²¹

Following from the arguments presented above, this paper develops a multi-country dynamic general equilibrium model incorporating (i) migration flows across borders; (ii) explicit supply chains between sectors and across countries; (iii) explicit consideration of services sector; and (iv) a separate banking sector enabling exploration of financial transmission channel through which the new frictions impact the economy.

In doing so, we build upon [Gali and Monacelli \(2005\)](#) by incorporating supply chains along the lines of [Altinoglu \(2021\)](#), [Imura \(2019\)](#) and [Steinberg \(2020\)](#); by including labour flows similar to [Canova and Ravn \(2000\)](#); and by integrating a banking sector along the lines of [Gertler and Kiyotaki \(2010\)](#) and [Gertler and Karadi \(2011\)](#) to carry out a comprehensive analysis of the economic disintegration between the UK and the EU. To the best of our knowledge, our paper is the first to utilise a dynamic multi-country framework combining network effects in trade in both goods and services; migration between countries; and a separate banking sector in studying Brexit. As such, our model also provides a suitable setting for analysis of other recent

²¹Although the global supply chains have been at the heart of the international economic architecture for some time, the role of trade networks in macroeconomic outcomes has only recently been incorporated formally (see, for example, [Acemoglu et al., 2012](#); [Carvalho and Gabaix, 2013](#); [Johnson, 2014](#); [Caliendo et al., 2019](#); [Bigio and La'o, 2020](#); [Steinberg, 2020](#)).

events, such as the rewriting of NAFTA; tariffs on the US-China trade flows; and the slowdown in trade integration since the global financial crisis in 2009.

We derive our quantitative results by calibrating our multi-country model economy to the UK, the EU, and the third countries - with explicit configuration of the UK's trade links with advanced and emerging economies, separately. We consider permanent NTBs in cross-border trade in both goods and services between the UK and the EU; potential permanent reduction in tariff barriers in trade between UK and third countries that move the model economy to a new steady-state; and stochastic migration shocks.

We have a set of interesting findings that are of significant policy relevance. First, we find that the existence of supply chain networks plays a significant role in determining the size of fluctuations even in the absence of tariffs, raising the cost of Brexit significantly. For example, the contraction in the UK's output in the face of NTBs to trade in goods and services is nearly three times as large when supply chains are present, irrespective of the size of the shock. More specifically, we find that the contraction in the UK's output varies between 0.75% and 0.24% with and without supply chains, respectively.

Second, incorporating the significant share of services in the UK's trade, using input-output data, we find that frictions to trade in services reduce the UK's output by 0.23%, smaller than in the goods sector due to the latter's greater reliance on inputs from other countries.

Third, the reduction in immigration from the EU is a source of further fluctuations for the UK, although the size of this effect is considerably smaller than that from trade frictions. Moreover, we find that while it is possible to replace reduced inflow of workers from the EU with those from non-EU countries, quantitatively the benefit from the latter falls short of the loss from the former.

Our multi-country setting also enables us to quantify the implications of potential trade liberalisation between the UK and the non-EU countries, pointing to favourable effects. It is clear, however, that the size of this favourable effect is significantly smaller than the losses from frictions to the UK-EU trade, even in the limiting case of lifting all trade barriers against the third countries. We also show that the scope of gains from trade liberalisation with emerging economies is greater given the already low trade barriers against the advanced economies.

Our characterisation of the labour market featuring heterogeneous households enables us to also provide a welfare analysis, with important insights into the distributional implications of Brexit. Importantly, we find that losses from Brexit are not shared equally and fall disproportionately on low-skilled households. This is due to the greater drop in the output of the goods sector which employs a greater share of low-skilled labour.

The remainder of this chapter is organised as follows. [Chapter 2.2](#) presents a detailed description of a benchmark multi-country model featuring homogeneous households and its calibration. [Chapter 2.3](#) introduces three extensions to the baseline model: heterogeneous households, supply chain networks, and banks; and presents the calibration of the extended model. Our policy experiments are presented in [Chapter 2.4](#), covering frictions in migration and trade in goods and services between the UK and the EU; and trade agreements between the UK and its non-EU trading partners, with a comprehensive examination of impacts for all four sets of countries. In [Chapter 2.5](#) we discuss the features of our model and provide a welfare analysis. We also present a rich set of robustness and sensitivity checks in [Chapter 2.6](#) and show that our main findings prevail across a wide range of features and parameter values. Finally, [Chapter 2.7](#) concludes.

2.2 Benchmark model

Our baseline model builds on the framework in [Gali and Monacelli \(2005\)](#). Given our interest in both the goods and services sectors separately, we generalise the model into a multi-country setting with three sectors; a sector producing goods that are consumed both at home and abroad; a services sector producing two types of services: tradable and nontradable. Tradable services which include, among others, financial services, legal services, telecommunications, and other business and trade-related activities are directly exposed to trade shocks. Nontradable services, for the most part, are consumed locally and their exposure to trade shocks is mostly indirect. Our classification of the services sector is motivated by the UK's comparative advantage in providing tradable services - tradable services explain 50.4% of all EU's imports from the UK.

Our model also features monopolistically competitive firms producing goods and providing services; perfectly competitive retailers, importers, capital goods producers and both a fiscal and a monetary authority.

In each sector - and in each country - producers combine labour supplied by local households and capital to produce intermediate goods and services. Retailers sell goods and services to local households, local government, and to foreign importers.

In what follows, we present the key features of our model economy in four parts - a baseline model and the three stages of extensions. In the first extension, we introduce migration across countries as well as differentiate between two types of labour; high-skilled and low-skilled. In the second extension, we add supply chains with input-output linkages both across the local goods and services sectors, similar to [Altinoglu \(2021\)](#), and also across countries as in [Steinberg \(2020\)](#). Finally, our complete model features a banking sector along the lines of [Gertler and Kiyotaki \(2010\)](#), allowing us to examine the role of financial sector in the transmission of shocks to trade in goods, services and flow of labour across countries.

In order to isolate the contribution of each feature to the outcomes, we present our model in stages. We first build a baseline model with fairly standard features and then develop our complete version sequentially.

In the benchmark specification, all households save by holding one-period risk-free bonds. Household decision-making is formulated in terms of an optimal rule to select savings in each period taking account of the uncertainty arising from stochastic migration shocks and permanent trade frictions. When we introduce heterogeneous households in the first extension of the benchmark model, high-skilled households' optimization entails consumption smoothing, while hand-to-mouth low-skilled households are more exposed to migration and trade shocks.

The fiscal and monetary authorities both play a role in reducing the negative effects of shocks through adjustments in nominal interest rate and redistribution of government's income from tariffs and taxes to both low-skilled and high-skilled households, where relevant, each according to their share in total labour.

In the benchmark configuration, firms' output is fully dependent on domestic and foreign households' demand for local goods and services. In the extended version with inflow of labour across borders and supply chains in production, producers'

uncertainty is also linked to migration shocks and trade frictions. Migration affects labour supply, labour demand and wage rates, while the producers' demand for foreign intermediate inputs depends on import prices - directly affected by tariffs and non-tariff barriers.

The inclusion of banks in the final extension of the benchmark model aggravates the unfavourable consequences of migration and trade shocks on households. Since assets in the financial sector are backed by real capital, any shocks negatively impacting the level of real capital in the economy will accelerate the negative effects of shocks on households' income through changes in domestic interest rates.

2.2.1 The benchmark specification

Consider a world with M countries and three sectors, where countries are identified by the index m and sectors are represented by $i = \{1, 2, 3\}$. In what follows, we present the key features of a representative - domestic - economy, denoted by index $m = h$. The full model description and the derivations of the optimisation conditions are presented in [Appendix B](#).

Households

The model economy is populated by infinitely-lived, identical households whose aggregate consumption C_t is a composite index consisting of domestically produced and imported goods and services, as given by:

$$C_t = \frac{\prod_{i=1}^3 C_{i,t}^{\gamma_i}}{\prod_{i=1}^3 \gamma_i^{\gamma_i}} \quad (2.2.1)$$

where $0 < \gamma_i < 1$ represents the consumption of commodities produced by sector i as a share of the household's aggregate consumption; $C_{i,t}$ is the total consumption of i - both locally produced and imported - represented by the following:

$$C_{i,t} = \left[\sum_{m=1}^M \gamma_i^{m \frac{1}{\eta}} (C_{i,t}^m)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \quad (2.2.2)$$

where $\eta > 1$ is the elasticity of substitution between locally-produced and imported goods or services; and $0 < \gamma_i^m < 1$ is the share of imports from country m in the total consumption of i .

The Consumer Price Index (CPI) is therefore a composite index of $P_{i,t}$ weighted by the corresponding shares of i in the households' consumption basket:

$$P_t = \prod_{i=1}^3 P_{i,t}^{\gamma_i} \quad (2.2.3)$$

Households supply labour to the local goods sector (sector $i = 1$), the tradable services sector (sector $i = 2$), and the nontradable services sector (sector $i = 3$), and consume locally produced and imported goods and services. In each period, households maximise the discounted utility over consumption, C_t , labour supplied to the three sectors, $L_{i,t}$, and the new acquisitions of risk-free bonds B_{t+1} :

$$\max_{C_t, L_{i,t}, B_{t+1}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma_c}}{1-\sigma_c} - \sum_{i=1}^3 \frac{\vartheta_i}{1+\varphi_h} L_{i,t}^{1+\varphi_h} \right] \quad (2.2.4)$$

where $0 < \beta < 1$ is the discount factor; $\sigma_c > 0$ is the inverse of the elasticity of intertemporal substitution of consumption; $\vartheta_i > 0$ denotes disutility from supplying high-skilled labour to sector i ; and $\varphi_h > 0$ is the inverse of the Frisch elasticity of labour supply.

Households own domestic firms and save in the form of one-period risk-free bonds, and face the following sequence of intertemporal budget constraints in maximising utility (2.2.4):

$$\begin{aligned} (1 - \tau_c)C_t + B_{t+1} + K_{i,t} = & (1 - \tau_w) \sum_{i=1}^3 W_{i,t} L_{i,t} + \sum_{i=1}^3 R_{i,t}^k K_{i,t-1} \\ & + \sum_{i=1}^3 \Pi_{i,t} + R_t B_t + TR_t \end{aligned} \quad (2.2.5)$$

where B_{t+1} denotes bond holdings from t to $t + 1$, $W_{i,t}$ is the real wage rate in sector i ; $0 \leq \tau_w < 1$ is the labour income tax rate; $R_{i,t}^k$ is the return on capital $K_{i,t-1}$ in sector i ; $\Pi_{i,t}$ are real profits arising from the ownership of firms in sector i ; R_t denotes the risk-free interest rate paid for holding bonds B_t from $t - 1$ to t ; and TR_t are government

transfers. The full derivations of the optimisation conditions are presented in [Appendix B](#).

Retailers

There are three types of retailers; those in the goods sector (sector $i = 1$); those in the tradable services sector (sector $i = 2$); and those in the nontradable services sector (sector $i = 3$). Competitive retailers in each sector purchase differentiated commodities across producers and combine them into a single good or service. Aggregate output of each sector's retailers, $X_{i,t}$, is given by the following CES aggregate of differentiated intermediate goods or services purchased from a continuum $z \in [0, 1]$ of sector i 's firms:

$$X_{i,t} = \left[\int_0^1 X_{i,t}(z)^{\frac{\varepsilon_i-1}{\varepsilon_i}} dz \right]^{\frac{\varepsilon_i}{\varepsilon_i-1}} \quad (2.2.6)$$

where $\varepsilon_i > 0$ is the elasticity of substitution between differentiated varieties of sector i 's output.

The profit maximisation problem of the sector i 's retailer can be stated as:

$$\max_{X_{i,t}(z)} \left[P_{i,t}^h \left[\int_0^1 X_{i,t}(z)^{\frac{\varepsilon_i-1}{\varepsilon_i}} dz \right]^{\frac{\varepsilon_i}{\varepsilon_i-1}} - \int_0^1 P_{i,t}^h(z) X_{i,t}(z) dz \right] \quad (2.2.7)$$

where $P_{i,t}^h$ is the price of a unit of sector i 's final good produced locally and $P_{i,t}^h(z)$ is the price of sector i 's differentiated variety of a good or service.

Retailers' demand for a typical variety of sector i 's differentiated good or service produced by a representative firm z can therefore be given by:

$$X_{i,t}(z) = \left[\frac{P_{i,t}^h(z)}{P_{i,t}^h} \right]^{-\varepsilon_i} X_{i,t} \quad (2.2.8)$$

Finally, given the zero-profit condition, the price index of the final good or service in sector i is given by:

$$P_{i,t}^h = \left[\int_0^1 P_{i,t}^h(z)^{1-\varepsilon_i} dz \right]^{\frac{1}{1-\varepsilon_i}} \quad (2.2.9)$$

Producers

Producers in each sector combine domestic labour inputs, $L_{i,t}$, and capital, $K_{i,t-1}$, both specific to sector i ; and turn them into a distinctive good or service. The technology of producing $X_{i,t}$ by a representative producer z is summarised by the following:

$$X_{i,t}(z) = A_{i,t} L_{i,t}(z)^{\alpha_i} K_{i,t-1}(z)^{1-\alpha_i} \quad (2.2.10)$$

where $A_{i,t}$ Hicks-neutral and sector-specific productivity and $0 < \alpha_i < 1$ is the labour share in production.

All producers operate in a monopolistically competitive market structure and only update their prices with a constant probability $0 < (1 - \theta_i) \leq 1$ along the lines of [Calvo \(1983\)](#). This suggests that, on average, prices remain constant for $k_i \equiv \frac{1}{1-\theta_i}$ periods.

In sector i , producer z chooses the optimal nominal price $P_{i,t}^h(z)$ for which real profits are maximised given the number of periods k_i during which the price is expected to remain unchanged:

$$\max_{P_{i,t}^h(z)} \mathbb{E}_t \sum_{k_i=0}^{\infty} (\beta \theta_i)^{k_i} q_{t+k_i} \frac{1}{P_{i,t+k_i}^h} \left[P_{i,t}^h(z) X_{i,t+k_i}(z) - mc_{i,t+k_i}(z) X_{i,t+k_i}(z) \right] \quad (2.2.11)$$

subject to the technology in producing aggregate output as given by equation (2.2.8). In equation (2.2.11), q_t is the marginal utility of consumption and $X_{i,t}(z)$ is the retailers' demand for sector i 's output. Profit maximisation in sector i yields the following price index:

$$P_{i,t}^h = \left[\theta_i \left(P_{i,t-1}^h \right)^{1-\varepsilon_i} + (1 - \theta_i) \left(\tilde{P}_{i,t}^h \right)^{1-\varepsilon_i} \right]^{\frac{1}{1-\varepsilon_i}} \quad (2.2.12)$$

where $\tilde{P}_{i,t}^h$ is the price set by producers in sector i when they are able to adjust prices.

The production of capital input is part of the capital goods producers' activity. These producers operate in a perfectly competitive market, purchasing investment goods and transforming them into new capital. Capital goods producers also refurbish obsolete stocks of capital from the three sectors at the end of each period. The new and repaired capital specific to sector i is then sold to producers at the optimal price $Q_{i,t}$. The aggregate capital stock in period t is given by the following law of motion for

sector i 's capital:

$$K_{i,t} = I_{i,t} \left[1 - f \left(\frac{I_{i,t}}{I_{i,t-1}} \right) \right] + (1 - \delta) K_{i,t-1} \quad (2.2.13)$$

where $0 < \delta < 1$ is the depreciation rate of capital. The full derivations of the capital producers' optimality conditions are presented in [Appendix B](#).

Importers

There are competitive importers who purchase goods and services from foreign retailers and sell them at home to households as consumption goods. The price of i , imported from country m , expressed in domestic currency is given by:

$$P_{i,t}^{h,m} = (1 + \tau_i^m) v_i^m s_t^m P_{i,t}^m \quad (2.2.14)$$

where $0 < \tau_i^m < 1$, represents the local tariff rate charged on imported goods ($i = 1$) from country m ; v_i^m denotes non-tariff barriers to trade in goods (for $i = 1$), tradable services (for $i = 2$) or nontradable services (for $i = 3$) with country m ; s_t^m is the bilateral exchange rate between the domestic country and country m , defined as the price of country m 's currency in terms of the domestic currency; and $P_{i,t}^m$ is the foreign price of i denominated in the currency of country m .

Fiscal and monetary policy

Government raises revenues through taxation on consumption and labour income, and through tariffs on imported goods, when in place, and makes transfers to households TR_t , as in [Steinberg \(2020\)](#):

$$TR_t = \tau_c C_t + \tau_w \sum_{i=1}^3 W_{i,t} L_{i,t} + \sum_{m=1}^M \tau_{i=1}^m s_t^m P_{i=1,t}^m C_{i=1,t}^m \quad (2.2.15)$$

Following [Schmitt-Grohé and Uribe \(2007\)](#) and [Gali and Monacelli \(2005\)](#), we formulate monetary policy using an implementable Taylor rule, where the central bank sets the short-run nominal interest rate in response to observable variables. As such, local monetary policy is set by a feedback rule, where the nominal interest rate r_t depends on its value in the previous period and the deviation of inflation $\pi_t \equiv P_t / P_{t-1}$

from its steady-state value π :

$$r_t = r_{t-1}^{\rho_r} \left[r \left(\frac{\pi_t}{\pi} \right)^{\varphi_\pi} \right]^{1-\rho_r} \quad (2.2.16)$$

where $\varphi_\pi \geq 1$ is the central bank's weight on the deviation of inflation from its steady-state level and $0 \leq \rho_r < 1$ is the degree of smoothing in the setting of the policy interest rate.

The link between the nominal interest rate, r_t , and the real interest rate, R_t , is given by the following Fisher relation:

$$r_t = R_t \mathbb{E}_t \pi_{t+1} \quad (2.2.17)$$

Market clearing conditions

The market clearing conditions in sector i in the domestic economy are given by:

$$X_{i,t} = \sum_{m=1}^M C_{i,t}^{m,h} + G_{i,t} + \left[1 + f \left(\frac{I_{i,t}}{I_{i,t-1}} \right) \right] I_{i,t} \quad (2.2.18)$$

that is, total output in sector i equals the sum of the domestic and foreign households' consumption demand for sector i 's output; the demand by the local government represented by the fixed share $0 \leq \chi_i < 1$ of sector i 's final output; and investment expenditures.

2.2.2 Benchmark model simulations

We start by calibrating the benchmark model for the UK, the EU, and the rest of the world made up of two distinct group of countries: advanced economies (AE) and emerging economies (EE).²² We use data from the *World Input-Output Database* (WIOD) as in [Timmer et al. \(2015\)](#) and OECD to calibrate the key parameters of the model. Where this is not possible, we use standard values from the existing literature as presented in [Table 2.1](#).

²²In calibration of the AE parameters, we use data from Australia, Canada, Switzerland, Japan, South Korea, Taiwan, and the US. Similarly, calibrating the EE economy is based on data from Brazil, China, Indonesia, India, Mexico, Russia, and Turkey.

Parameters in the benchmark model

We set the discount factor of households β at 0.99, implying a risk-free annualised quarterly steady-state interest rate of around 4%. The inverse of the risk aversion coefficient σ_c is set at 0.66 in the UK following [Harrison and Oomen \(2010\)](#), at 0.72 in the EU as in [Smets and Wouters \(2003\)](#), at 0.74 in the AE as in [Smets and Wouters \(2007\)](#), and at 0.44 in the EE following [Zheng and Guo \(2013\)](#). We calibrate the disutility parameter of labour, ϑ_i , such that labour demand matches with the labour supply in the steady-state. The inverse Frisch elasticity of labour parameter φ_h is set at 0.342 for the UK as in [Millard \(2011\)](#). The corresponding value for the EU is set at 0.281 as in [Villa \(2016\)](#), at 0.276 for the AE as in [Banerjee et al. \(2016\)](#), and at 0.2 for the EE as in [Li and Liu \(2017\)](#).

Table 2.1: Calibrated parameters of the benchmark model.

Parameter		UK	EU	AE	EE	Source
<i>Households</i>						
Discount factor	β	0.990	0.990	0.990	0.990	I05
CRRA	σ_c	0.660	0.720	0.740	0.440	HO10; SW07; SW03; ZG13
Frisch labour elasticity	φ_h	0.342	0.281	0.276	0.200	M11; V13; BDL16; LL17
e.o.s. domestic and imported output	η	1.770	1.770	1.770	1.770	HO10
Labour disutility	$\vartheta_{i=1}$	1.819	0.296	0.226	0.232	Target value
Labour disutility	$\vartheta_{i=2}$	0.852	0.131	0.142	0.197	Target value
Labour disutility	$\vartheta_{i=3}$	0.893	0.171	0.125	0.194	Target value
Share of goods in consumption	$\gamma_{i=1}$	0.228	0.313	0.307	0.594	WIOD
Share of tradable services in consumption	$\gamma_{i=2}$	0.337	0.324	0.303	0.177	WIOD
Share of nontradable services in consumption	$\gamma_{i=3}$	0.434	0.363	0.390	0.229	WIOD
<i>Production</i>						
Labour share	$\alpha_{i=1}$	0.653	0.615	0.603	0.695	WIOD
Labour share	$\alpha_{i=2}$	0.694	0.715	0.720	0.641	WIOD
Labour share	$\alpha_{i=3}$	0.648	0.620	0.611	0.682	WIOD
Calvo parameter	θ_p	0.760	0.740	0.660	0.622	FMZ11; SW07; SW03; R16
e.o.s. among varieties	$\varepsilon_{i=1}$	6.000	6.000	6.000	6.000	CV12
e.o.s. among varieties	$\varepsilon_{i=2}$	4.000	4.000	4.000	4.000	CV12
e.o.s. among varieties	$\varepsilon_{i=3}$	3.000	3.000	3.000	3.000	CV12
Depreciation rate	δ	0.025	0.025	0.025	0.025	HO10; DN07
Adjustment cost	Φ	6.000	6.000	6.000	6.000	BT17
<i>Fiscal and monetary policy</i>						
Labour income tax rate	τ_w	0.233	0.289	0.215	0.199	OECD
Consumption tax rate	τ_c	0.200	0.221	0.064	0.170	OECD
Interest rate persistence	ρ_r	0.881	0.870	0.810	0.980	HO10; ALL07; SW07; R16
Taylor Rule parameter	φ_π	1.113	1.680	2.030	1.744	HO10; SW07; SW03; R16
Government spending to output ratio	G/X	0.300	0.316	0.152	0.245	Target value

Note: Abbreviations used in the table are as follows: ALL07: [Adolfson et al. \(2007\)](#); BDL16: [Banerjee et al. \(2016\)](#); BT17: [Bhattarai and Trzeciakiewicz \(2017\)](#); CV12: [Christopoulou and Vermeulen \(2012\)](#); DN07: [DiCecio and Nelson \(2007\)](#); FMZ11: [Faccini et al. \(2011\)](#); HO10: [Harrison and Oomen \(2010\)](#); I05: [Iacoviello \(2005\)](#); LL17: [Li and Liu \(2017\)](#); M11: [Millard \(2011\)](#); R16: [Razafindrabe \(2016\)](#); SW03: [Smets and Wouters \(2003\)](#); SW07: [Smets and Wouters \(2007\)](#); V16: [Villa \(2016\)](#); ZG13: [Zheng and Guo \(2013\)](#).

The shares of local and imported goods and services in households' consump-

tion baskets, γ_i and γ_i^m , respectively, are calculated on the basis of the 2014 *World Input-Output Tables* (WIOT) from the WIOD treating household consumption as the only source of demand for all goods and services, as is the basis of our benchmark specification. The resulting share of goods in the UK households' consumption basket, $\gamma_{i=1}$ is 22.8%. The corresponding shares for the EU, AE, and EE are, respectively, 31.3%, 30.7%, and 59.4%. Similarly, the corresponding share of tradable services in the representative household's consumption basket, $\gamma_{i=2}$, equals 33.7% in the UK, 32.4% in the EU, 30.3% in the AE, and 17.7% in the EE. Finally, the corresponding shares of nontradable services, $\gamma_{i=3}$, are: 43.4%, 36.3%, 39.0%, and 22.9%.

Table 2.2 displays the shares of imports broken down by the country of origin in the final consumption in each country. They represent the values of γ_i^m parameters in the model to describe the compositions of consumption baskets in each country. Entries in each cell represent the shares of imports from the country-sector pair denoted in that row in the total consumption of the country specified in that column. For example, the cell corresponding to the first column and the second row indicates that 6.36% of the UK households' consumption is made up of goods imported from the EU. The darker the shade in a cell, the greater the consumption shares. Darker shades in the lower part of the table demonstrate the well-documented home bias in the consumption of services, and especially that of nontradable services, in all four countries (see, for example, [Mika, 2017](#)).

Table 2.2: Summary of consumption baskets of the four countries.

Supplier	UK	EU	AE	EE
$i = 1, m = UK$	7.484	0.381	0.097	0.132
$i = 1, m = EU$	6.355	21.096	0.891	1.173
$i = 1, m = AE$	0.816	0.826	14.065	1.175
$i = 1, m = EE$	2.125	1.9	2.053	38.461
$i = 2, m = UK$	18.961	0.331	0.1	0.062
$i = 2, m = EU$	1.205	19.551	0.253	0.211
$i = 2, m = AE$	0.395	0.509	19.941	0.135
$i = 2, m = EE$	0.044	0.11	0.058	17.455
$i = 3, m = UK$	61.451	0.067	0.021	0.018
$i = 3, m = EU$	0.715	55.017	0.063	0.095
$i = 3, m = AA$	0.235	0.146	62.42	0.094
$i = 3, m = EE$	0.214	0.066	0.038	40.989

The labour income shares α_i are calculated using the WIOD *Social Economic Accounts* data. The shares of labour in the goods sector, $\alpha_{i=1}$, are set at 0.653, 0.615, 0.603, and 0.695 respectively, for the UK, EU the AE and the EE. The corresponding shares in the

tradable services sector, $\alpha_{i=2}$, are 0.694, 0.715, 0.72 and 0.641 for the UK, the EU, the AE, and the EE, respectively. Finally, the labour shares in the nontradable sector $\alpha_{i=3}$ are equivalent to 0.648, 0.62, 0.611 and 0.682 for the for the UK, the EU, AE and the EE, respectively.

We maintain that the probability of prices being updated, θ_p , is the same in all three sectors. For the UK, θ_p is set at 0.76, following [Faccini et al. \(2011\)](#). This suggests that on average UK prices remain unchanged for 12.5 months. In calibrating the degree of price stickiness for the EU, we follow [Smets and Wouters \(2003\)](#) and adopt a Calvo parameter of 0.74, implying that firms update prices every 11.5 months on average. We follow [Smets and Wouters \(2007\)](#) in setting a Calvo parameter of 0.66 for the AE, indicating the resetting of prices every 8.8 months, on average. Finally, the Calvo parameter in EE is 0.662 as in [Razafindrabe \(2016\)](#), implying that firms in the emerging economies update their prices every 8.9 months, on average.

Following [Harrison and Oomen \(2010\)](#), the elasticity of substitution between foreign and domestic goods and services η is set at 1.77 in all the four countries, while we follow [Christopoulou and Vermeulen \(2012\)](#) in setting the elasticities of substitution between varieties of goods, $\varepsilon_{i=1}$, at 6, implying around 20% markup in the steady-state. In the tradable services sector, the corresponding parameter, $\varepsilon_{i=2}$, is 4; implying a 33% markup in the steady-state. Finally, in the nontradable services sector, the elasticity of substitution $\varepsilon_{i=3}$ is set equal to 3, implying a 50% markup in the steady-state. The classification of the three sectors is presented in [Appendix B](#).

Following [DiCecio and Nelson \(2007\)](#) and [Harrison and Oomen \(2010\)](#), the depreciation rate of capital, δ , is set at 0.025 in each of the four countries, implying an annual capital depreciation of 10 percent. The adjustment cost parameter Φ is set at 6 in each economy, close to the value in [Bhattarai and Trzeciakiewicz \(2017\)](#).

Regarding policy parameters, the labour income tax rates τ_w are calculated using OECD data on taxation of personal gross labour income, implying tax rates of 23.3%, 28.9%, 21.46%, and 19.95%, respectively. Based on the data from the [OECD \(2020a\)](#) report on *the Consumption Tax Trends 2020 VAT/GST and Exercise Rates, Trends and Policy Issues*, we set the consumption tax rates, τ_c , at 20% in the UK, 22.1%, 6.4% and 17% for the EU, AE and EE, respectively. These are close to values in [Carey and Tchilinguirian \(2000\)](#), also calculated using the OECD data.

Calibration of the Taylor rule parameters are based on [Harrison and Oomen \(2010\)](#) for the UK, [Smets and Wouters \(2003\)](#) for the EU, and [Smets and Wouters \(2007\)](#) for the AE and EE, and are set at 1.113, 1.68 and 2.03 and 1.744, respectively. The persistence of the nominal interest rate coefficients, ρ_r , are set at 0.881 in the UK, 0.87 in the EU, 0.81 in the AE and 0.074 in the EE.

Impact of Brexit in the benchmark model

We now turn to examining how Brexit is likely to impact the UK and the EU, using our benchmark specification. Having calibrated our benchmark model, the key next step in this exercise is the characterisation of the source and the size of the shock the UK's withdrawal from the EU represents for the two countries. We base this assessment on the terms of the separation, as set out by the TCA.

Whilst the agreement to resume tariff and quota-free trade between the UK and the EU has been a major achievement for both sides, trade between the two is now subject to NTBs, introducing a clear source of frictions into the bilateral trade flows (see, for example, [Tetlow and Stojanovic, 2018](#)). Indeed, due to the secular reductions in tariff rates in global trade through rounds of multilateral trade negotiations since the 1950s, it is the NTBs that are the main sources of trade restrictions today.²³ Given that the EU Single Market eliminated much of the NTBs between its members, the UK's withdrawal from the Single Market has reinstated a range of barriers back into the UK-EU bilateral trade, in both directions.

We therefore use the rise in NTBs as the main friction representing Brexit, and use our baseline model to explore its implications for both the UK and the EU.²⁴ Differences in product standards, consumer and environmental protection, health and safety, competition rules and state aid as well as rule of origin requirements and

²³See [WTO \(2012\)](#) report.

²⁴Press release from the European Commission following the TCA agreement on the 24th of December, 2020 spells out the new frictions as follows: "Trading under 'FTA' (free trade agreement) terms – even one as ambitious as this one, with zero tariffs or quotas – will inevitably be very different compared to the frictionless trade enabled by the EU's Customs Union and Single Market. In particular: rules of origin will apply to goods in order to qualify for preferential trade terms under the agreement; all imports will be subject to customs formalities and will need to comply with the rules of the importing party; and all imports into the EU must meet all EU standards and will be subject to regulatory checks and controls for safety, health and other public policy purposes, available at <https://ec.europa.eu/commission/presscorner/detail>.

custom checks are the sources of new frictions to trade between the UK and the EU.²⁵ In effect, rises in NTBs amount to hikes in import prices paid by households and firms in the EU for the commodities produced in the UK and *vice versa*.²⁶

Our analysis of Brexit therefore entails simulating our benchmark model against a range of increases in the NTBs to the UK-EU trade in goods, which, in turn, are reflected in rises of import prices in both countries. In this section, we consider a range of increases in NTBs, while we examine specific calibrations of trade frictions in our analysis of policy experiments with the extended model in [Chapter 2.4](#). The responses of a set of outcomes to increases in NTBs, expressed as percentage deviations from the initial steady-state values for both the UK and the EU are displayed in [Figure 2.1](#).

Each panel in [Figure 2.1](#) combines three dimensions of dynamics; the size of the shock to NTBs (varying between 1 and 10 per cent); the time period over which the impact is observed (across 40 quarters); and the size of the impact on the relevant variable.

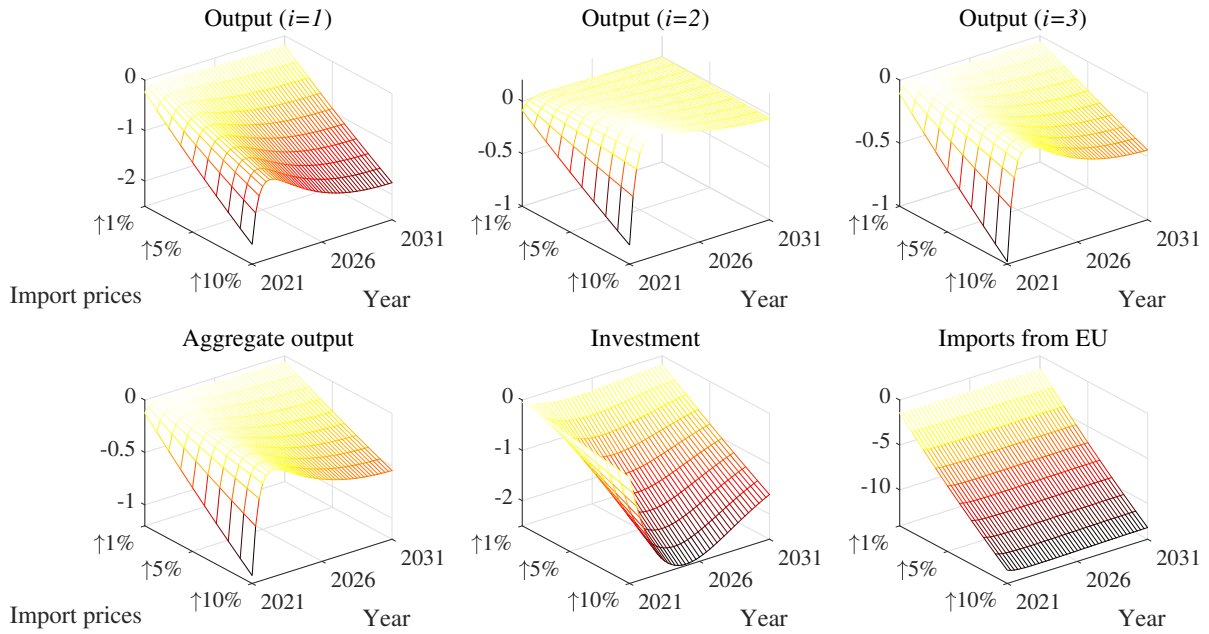
A number of observations can be made from the findings presented in [Figure 2.1](#). Clearly, through raising the prices of imported goods, NTBs reduce the volume of trade between the two countries, where the scale of the reduction rises with the size of NTBs, as is seen in the second and the fourth rows of [Figure 2.1](#). This is particularly the case for the UK's imports from the EU, given that the latter's share in the former's imports, as is evident from the entries in [Table 2.2](#). The resulting fall in net exports in the two countries leads to contraction in both economies, originating in the goods sector, as displayed in the first (third) row for the UK (EU). The reduction in trade leads to a fall in aggregate output and three sectoral outputs, with the subsequent reduction in consumption and output reducing the demand for labour, with unfavourable consequences for wages as well as capital accumulation.

In sum, the introduction of NTBs to the UK-EU trade has unfavourable implications for almost all UK variables, although the greatest declines are in the UK's consumption

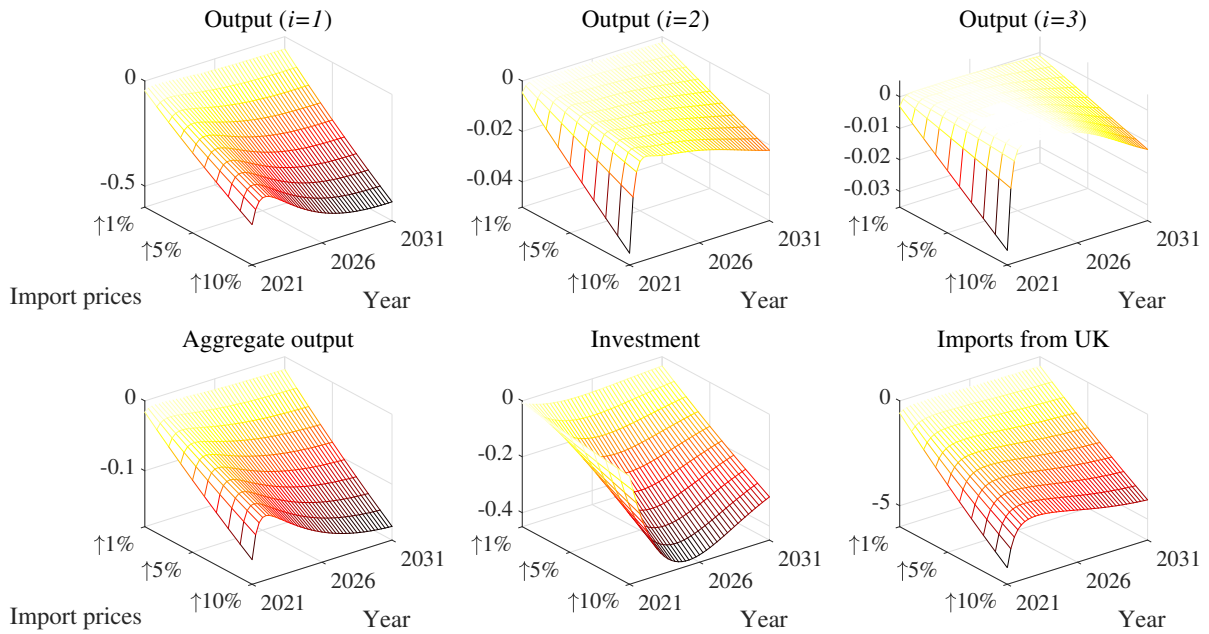
²⁵Harmonisation of such rules and standards is seen as the route to creating 'level playing field' and, as such, is a key part of all trade negotiations. Similarly, disagreements on how to establish a level playing field between the post-Brexit UK and the EU have been a major stumbling block throughout the Brexit negotiations.

²⁶[Hummels \(2007\)](#) and [Hummels and Schaur \(2013\)](#) show that NTBs may be more costly than tariffs, and document that existing frictions arising from NTBs are, on average, equivalent to those arising from 12 percent of tariffs).

Figure 2.1: Responses to bilateral non-tariff barriers to trade in goods across the UK-EU border in the benchmark model.



(a) UK



(b) EU

Note: % deviations from the initial steady-state.

of goods and services imported from the EU. Overall, aggregate outputs are lower in both countries although the scale of the contraction is significantly greater in the UK given the greater home bias exhibited by the EU.

2.3 Migration, supply chains and the banking sector

As is set out earlier, our focus in this paper is to explore the role of (i) migration flows across borders; (ii) explicit supply chain networks; (iii) services sector with a significant role in both production and trade; (iv) a separate banking sector in the consequences of the the UK's withdrawal from the EU.

In order to examine the role of each component, we build our final model in stages, by incorporating each feature separately, by gradually extending the baseline model with three features, one at a time: (i) flows of high- and low-skilled labour across borders; (ii) supply chain networks in intermediate inputs; and (iii) a banking sector.

While our final model includes all three extensions, we also present outcomes under the four separate cases - baseline and the three extensions - to isolate the contribution of each component.

2.3.1 Migration flows and heterogeneous labour

In order to account for dynamics of migration flows between the UK and the EU, in what follows we distinguish between two types of households $j = \{hs, ls\}$: high-skilled, denoted by hs , and low-skilled, ls . High-skilled households own domestic firms, receive profits from those, and hold bonds; they also receive labour income and pay consumption and labour income taxes. Low-skilled households consume all their income every period, acting as hand-to-mouth agents, following the characterization of the low-income household behaviour in the existing work on household heterogeneity in consumption (Galí et al., 2007; Iacoviello and Neri, 2010; McManus et al., 2020).²⁷

²⁷The empirical basis for this distinction comes from the significant cross-country evidence on hand-to-mouth behaviour. Using extensive survey data on household portfolios, Kaplan et al. (2014) point to a substantial share of 'wealthy hand to mouth' households in advanced economies - households who hold sizeable amounts of wealth in illiquid assets such as housing or retirement accounts, but very little or no liquid wealth. As a result, a major share of households spend all their disposable income every period. The share of hand-to-mouth - including both poor and wealthy hand-to-mouth- is estimated to be above 30 percent of the population in the UK.

Such an explicit distinction between the two types of agents allows us to explore the effects of post-Brexit trade shocks for both types of households, with important distributional implications.

The aggregate consumption is the sum of the high-skilled and low-skilled's consumption:

$$C_t = \lambda_{hs} C_t^{hs} + (1 - \lambda_{hs}) C_t^{ls} \quad (2.3.19)$$

where λ_{hs} is the share of high-skilled households in the economy, and C_t is expressed as a composite index of consumption of all goods and services, as specified in equation (2.2.1).

Native high- and low-skilled households maximise the following utility over consumption, C_t^j , labour supplied to the three sectors, $L_{i,t}^{j,n}$, and new bond acquisitions B_{t+1} (applies to high-skilled households only):

$$U_t^j = \frac{C_t^{j1-\sigma_j}}{1-\sigma_j} - \sum_{i=1}^3 \frac{\vartheta_i^j}{1+\varphi_h} L_{i,t}^{j,n1+\varphi_h} \quad (2.3.20)$$

where $j = ls, hs$; $\vartheta_i^j > 0$ denotes disutility from supplying labour to sector i ; and $\sigma_j > 0$ is the inverse of the elasticity of intertemporal substitution of consumption.

In maximising discounted utility given by (2.3.20), high-skilled households face a sequence of intertemporal budget constraints given by:

$$(1 - \tau_c) C_t^{hs} + B_{t+1} + \sum_{i=1}^3 K_{i,t} = (1 - \tau_w) \sum_{i=1}^3 W_{i,t}^{hs} L_{i,t}^{hs,n} + \sum_{i=1}^3 R_{i,t}^k K_{i,t-1} + \sum_{i=1}^3 \Pi_{i,t} + R_{t-1} B_t + TR_t^{hs} \quad (2.3.21)$$

where $W_{i,t}^{hs}$ is the real wage rate for high-skilled labour in sector i ; $R_{i,t}^k$ is the gross return on capital $K_{i,t-1}$ in sector i , $\Pi_{i,t}$ are real profits arising from the ownership of sector i 's firms, and TR_t^{hs} are government transfers to high-skilled households.

Likewise, the low-skilled maximise (2.3.20) subject to a sequence of intertemporal budget constraints in the form:

$$C_t^{ls} = \sum_{i=1}^3 W_{i,t}^{ls} L_{i,t}^{ls,n} + TR_t^{ls} \quad (2.3.22)$$

where $W_{i,t}^{ls}$ is the real wage rate for supplying low-skilled labour to sector i and TR_t^{ls} are government transfers to low-skilled households.

Following Canova and Ravn (2000), we maintain that at the beginning of each period, all workers face a probability of death $0 < v < 1$, which is independent of age or skill type. The surviving share of workers $(1 - v)$ is joined by the new-born cohort which replaces the population of workers who died at the beginning of the period.

A new-born worker becomes high-skilled at birth with probability $0 < \rho_i^{hs} < 1$ and joins the workforce immediately after birth. Total high-skilled and low-skilled labour in each sector i evolve as in the following manner:

$$L_{i,t+1}^{hs} = (1 - v)L_{i,t}^{hs,n} + v\rho_i^{hs}L_{i,t}^n \quad (2.3.23)$$

$$L_{i,t+1}^{ls} = (1 - v)L_{i,t}^{ls,n} + v(1 - \rho_i^{hs})L_{i,t}^n + \gamma_i^{m,ls}\varepsilon_t^{m,ls} \quad (2.3.24)$$

where $L_{i,t}^n \equiv L_{i,t}^{hs,n} + L_{i,t}^{ls,n}$ represents total native workforce in sector i ; $\varepsilon_t^{m,ls}$ denotes the inflow of low-skilled labour from country m , which joins the local low-skilled workforce; and $0 \leq \gamma_i^{m,ls} \leq 1$ is the parameter governing the inflow of migrants into specific sectors.

The evolution of low-skilled newcomers follows the form:²⁸

$$\varepsilon_t^{m,ls} = \rho^m \varepsilon_{t-1}^{m,ls} + \sigma_t^{m,ls}; \quad \sigma_t^{m,ls} \sim (0, \sigma^{m,ls}) \quad (2.3.25)$$

where $0 \leq \rho^m < 1$ captures persistence of immigration from m and $\sigma_t^{m,ls}$ is the zero-mean, uncorrelated innovation with standard deviation $\sigma^{m,ls}$.

Finally, high-skilled and low-skilled labour inputs are aggregated into total hours $L_{i,t}$ employed by sector i in the following manner:

$$L_{i,t} = \left[\omega_i^{hs} \left(L_{i,t}^{hs} \right)^{1-\rho_l} + \left(L_{i,t}^{ls} \right)^{1-\rho_l} \right]^{\frac{1}{1-\rho_l}} \quad (2.3.26)$$

where $\omega_i^{hs} > 1$ represents productivity of high-skilled relative to low-skilled workers and $0 < \rho_l < 1$ is the elasticity of substitution between the two. To focus on the flows

²⁸The migration shock enters in both countries' low-skilled labour law of motion equations with an opposite sign. That is, a negative shock to the low-skilled immigration into the domestic economy has a counterpart in an equal-sized positive shock to the total supply of low-skilled labour in country m .

of workers across borders and for tractability, we maintain that workers cannot migrate between the three sectors.^{29,30}

2.3.2 Supply chain networks

One of our key arguments in this paper is related to how the substantial supply chain networks between the UK and the EU shape the implications of Brexit for the two countries. To examine the role of supply chains in Brexit dynamics, we now extend our benchmark model by allowing intermediate inputs both across the three sectors and across m countries.

Producers in each sector combine native and migrant labour inputs, $L_{i,t}$, capital $K_{i,t-1}$ specific to sector i , and supplies in the form of goods $X_{i,t}^{s=1}$, tradable services $X_{i,t}^{s=2}$, and nontradable services $X_{i,t}^{s=3}$ supplied by both domestic retailers and importers, and turn them into a distinctive good or service. As in [Altinoglu \(2021\)](#), [Imura \(2019\)](#) or [Steinberg \(2020\)](#), the technology of producing $X_{i,t}$ by a representative producer z is summarised by the following:

$$X_{i,t}(z) = A_{i,t} \left[\prod_{s=1}^3 X_{i,t}^s(z)^{\omega_i^s} \right]^{\zeta_i} \left[L_{i,t}(z)^{\alpha_i} K_{i,t-1}(z)^{1-\alpha_i} \right]^{1-\zeta_i} \quad (2.3.27)$$

where $0 < \zeta_i < 1$ is the share of all intermediate inputs and $0 < \omega_i^s < 1$ is the share of intermediate inputs of type s in the total use of supplies.

Each type of supplies can be either domestic, purchased from local retailers, or foreign, purchased from importers. Therefore, $X_{i,t}^s$ is a composite index of supplies s originally produced in country $m \in M$:

$$X_{i,t}^s(z) = \left[\sum_{m=1}^M \omega_{i,m}^s \frac{1}{\eta_s} X_{i,t}^{s,m}(z)^{\frac{\eta_s-1}{\eta_s}} \right]^{\frac{\eta_s}{\eta_s-1}} \quad (2.3.28)$$

where $0 \leq \omega_{i,m}^s \leq 1$ denotes the share of supplies of type s delivered from country m in the total use of supplies of type s and $\eta_s > 0$ is the Armington elasticity of substitution between domestic and imported supplies.

²⁹One possible justification for this assumption is the importance of sector-specific skills.

³⁰It is straightforward to extend our model to allow for job transitions across sectors.

2.3.3 Banks

Our final extension to the benchmark model entails incorporating financial intermediation, as in [Gertler and Kiyotaki \(2010\)](#). Goods and services producers optimally choose the demand for capital and finance their investment plans by borrowing from domestic banks purchasing new capital at a price $Q_{i,t}$, and issuing a claim for each unit. Consequently, assets in the banking sector are backed by the amount of real capital³¹ - a key channel of transmission between the financial and the real side of the economy and the core of the financial accelerator mechanism ([Bernanke et al., 1999](#)).

Banks operate in a competitive market and live a finite horizon with $0 < \theta_b < 1$ denoting the survival rate of a bank in the next period, which is independent of its history. At the end of a bank's lifetime, earnings are transferred to high-skilled households - the owners of domestic banks. Exiting banks are replaced with new banks every period who receive starting funds denoted by $0 < \kappa < 1$, expressed as the ratio of total assets.

On observing demand for its lending, an individual bank chooses the value of loans to the three sectors of the domestic economy $S_t(z)$; hold liabilities equal to net worth $N_t(z)$ and deposits owned by high-skilled households $D_t(z)$. The net worth accumulation of a representative bank is equal to the payoff from assets net of payments for liabilities:³²

$$N_t(z) = R_{k,t}S_{t-1}(z) - R_tD_{t-1}(z) \quad (2.3.29)$$

At the end of each period, an individual bank maximises the discounted value of its future dividends:

$$V_t = \max_{S_t(z), D_t(z)} \mathbb{E}_t \left[\sum_{k=0}^{\infty} (1 - \theta_b) \theta_b^{k-1} \beta_{hs} \frac{q_{t+1}^{hs}}{q_t^{hs}} N_{t+k}(z) \right] \quad (2.3.30)$$

where $0 < \beta_{hs} < 1$ is the discount factor of high-skilled workers.

The relationship between the bank and households is subject to a moral hazard problem. The bank may transfer a fraction, $0 < \lambda < 1$, of assets for its own benefits.

³¹Total assets issued correspond to aggregate capital that is subject to the following capital accumulation equation: $K_{i,t} = I_{i,t} \left[1 - f \left(\frac{I_{i,t}}{I_{i,t-1}} \right) \right] + (1 - \delta)K_{i,t-1}$ and assets correspond to the value of capital, equivalent to the claims issued by firms to finance new investments $S_t(z) = \sum_{i=1}^3 Q_{i,t}K_{i,t}(z)$.

³²The return on capital $R_{k,t}$ is equal across all three sectors, as detailed in [Appendix B](#).

High-skilled households, thus, are willing to deposit in the bank only if the bank's present value of future profits $V_t(\cdot)$ is at least as large as the earnings from diverting funds. Thus, the maximisation problem of a representative bank z is subject to the following incentive constraint:

$$V_t(S_t(z), D_t(z)) \geq \lambda S_t(z) \quad (2.3.31)$$

Banks are homogeneous, hence the aggregate banks' balance sheet and the aggregate net worth are expressed as follows:

$$S_t = \phi_t N_t \quad (2.3.32)$$

$$N_t = (\theta_b + \kappa) R_{k,t} S_{t-1} - \theta_b R_t D_{t-1} \quad (2.3.33)$$

where ϕ_t denotes the leverage ratio and κ stands for the fraction of assets provided as 'starting funds' to the newly created banks. The full derivations of the bank's optimisation problem are presented in [Appendix B](#).

Introducing the banking sector explicitly allows for an additional channel through which shocks are transmitted to the economy. Any change in output and hence households' income will now trigger additional dynamics by impacting the deposits, D_t , through which the high-skilled households can now save in addition to via purchasing government bonds.

2.3.4 Calibration of the extended model

As earlier, we calibrate the key parameters of the extended model using data from the *World Input-Output Database* (WIOD), OECD and values from the existing literature, as is outlined in [Table 2.3](#).

Parameters related to labour and employment

Following [Iacoviello \(2005\)](#), we set the discount factor of high and low-skilled households β_{hs} and β_{ls} at 0.99 and 0.97 respectively, implying a risk-free annualised quarterly steady-state interest rate of 4% and 12%. Based on the empirical evidence by [Dohmen et al. \(2010\)](#), we differentiate between the relative risk aversion coefficients of high-

skilled households, σ_{hs} , and the low-skilled households, σ_{ls} , to match the average values for the population of the UK, EU, AE, and EE, as presented in [Table 2.1](#). The disutility parameters of high-skilled, ϑ_i^{hs} , and low-skilled labour, ϑ_i^{ls} , are calibrated such that labour demand matches with the labour supply in the steady-state.

Following [Canova and Ravn \(2000\)](#), the death rate v is set at 0.025 in each country, implying that 2.5% of the labour force is replaced every quarter. In turn, the elasticity of substitution between high-skilled and low-skilled labour inputs falls inside the $0 < \rho_l < 1$ interval, indicating that the two types of workers are gross substitutes. We use the value of 0.40 for each country, following [Autor et al. \(1998\)](#).

We set the shares of high-skilled workers $\rho_{i=1}^{hs}$ for $i = 1$ at 42% for the UK, 54.1% for the EU, 69.2% for the AE and 13.8% for the EE based on the *Database on Immigrants in OECD Countries* (DIOC). The corresponding values for tradable services, $\rho_{i=2}^{hs}$, are, respectively, 50%, 62.5%, 78.0% and 36.6%. The shares of high-skilled workers in the nontradable services $\rho_{i=3}^{hs}$ are set at 59.6% for the UK, 72.6% for the EU, 77.5% for the AE, and 50.5% for the EE.

We calculate the wage premium of high-skilled labour inputs ω_i^{hs} , as in [Canova and Ravn \(2000\)](#) and [Dolado et al. \(2018\)](#). In the UK, high-skilled workers are 1.96 times more productive than the low-skilled based on *Education and Earnings* dataset from the OECD for 2018 and [OECD \(2020b\)](#). The corresponding figures are 1.92 for the EU, 2.12 for the AE and 2.78 for the EE. The wage premia, ω_i^{hs} are set equal across the three sectors.

Supply chain parameters

The shares of local and imported goods and services in households' consumption baskets, γ_i and γ_i^m , respectively, are calculated using the 2014 *World Input-Output Tables* (WIOT) from the WIOD mimicking the total share of imported goods in the economy.

The shares of intermediate inputs in each sector, ζ_i , are calculated using data from 2014 WIOT on the ratios of total intermediate consumption to output. The resulting shares of intermediate inputs in the goods sector, $\zeta_{i=1}$, in the UK, EU, AE and EE are, respectively, given by 0.579, 0.634, 0.598 and 0.679. The corresponding shares of the tradable services sector, $\zeta_{i=2}$, are 0.447, 0.465, 0.405 and 0.41, and for the nontradable service sector, $\zeta_{i=3}$, are as follows: 0.379, 0.373, 0.39 and 0.501.

Table 2.3: Calibrated parameters of extensions and shocks.

Parameter		UK	EU	AE	EE	Source
<i>Heterogeneous households</i>						
Discount factor	β_{hs}	0.990	0.990	0.990	0.990	I05
Discount factor	β_{ls}	0.970	0.970	0.970	0.970	I05
CRRA	σ_{hs}	0.839	0.860	0.811	0.935	HO10; SW03; SW07; ZG13
CRRA	σ_{ls}	0.495	0.540	0.555	0.330	HO10; SW03; SW07; ZG13
Productivity premium	ω^{hs}	1.963	1.918	2.116	2.776	OECD
e.o.s. high- vs low-skilled labour	ρ_l	0.400	0.400	0.400	0.400	AKK98
Death rate	v	0.025	0.025	0.025	0.025	CR00
Share of high-skilled workers	λ_{hs}	0.495	0.572	0.727	0.189	OECD
Share of high-skilled workers	$\rho_{i=1}^{hs}$	0.420	0.541	0.692	0.138	OECD
Share of high-skilled workers	$\rho_{i=2}^{hs}$	0.501	0.625	0.780	0.366	OECD
Share of high-skilled workers	$\rho_{i=3}^{hs}$	0.596	0.726	0.775	0.505	OECD
Labour disutility	$\theta_{i=1}^{hs}$	0.097	0.003	0.06	0.008	Target value
Labour disutility	$\theta_{i=2}^{hs}$	0.452	0.039	0.051	0.117	Target value
Labour disutility	$\theta_{i=3}^{hs}$	0.388	0.048	0.028	0.021	Target value
Labour disutility	$\theta_{i=1}^{ls}$	0.054	0.004	0.024	0.002	Target value
Labour disutility	$\theta_{i=2}^{ls}$	0.317	0.080	0.277	0.075	Target value
Labour disutility	$\theta_{i=3}^{ls}$	0.363	0.136	0.150	0.019	Target value
Share of migrants in $i = 1$	$\gamma_{i=1}^{m,ls}$	0.512	-	-	-	Target value
Share of migrants in $i = 2$	$\gamma_{i=2}^{m,ls}$	0.238	-	-	-	Target value
Share of migrants in $i = 3$	$\gamma_{i=3}^{m,ls}$	0.250	-	-	-	Target value
<i>Supply chain networks</i>						
Share of goods in consumption	$\gamma_{i=1}$	0.168	0.242	0.171	0.409	WIOD
Share of tradable services in consumption	$\gamma_{i=2}$	0.206	0.205	0.204	0.179	WIOD
Share of nontradable services in consumption	$\gamma_{i=3}$	0.626	0.553	0.625	0.412	WIOD
Share of supplies in production	$\zeta_{i=1}$	0.579	0.634	0.598	0.679	WIOD
Share of supplies in production	$\zeta_{i=2}$	0.447	0.465	0.405	0.410	WIOD
Share of supplies in production	$\zeta_{i=3}$	0.379	0.373	0.390	0.501	WIOD
e.o.s. domestic and imported supplies	η_s	1.770	1.770	1.770	1.770	HO10
<i>Banks</i>						
Survival rate	θ_b	0.968	0.972	0.969	0.965	Target value
Fraction of diverted funds	λ	0.248	0.366	0.183	0.338	Target value
Fraction of starting funds	ω	0.002	0.002	0.002	0.002	GK10; GK11
<i>Fiscal policy</i>						
Government spending to output ratio	G/X	0.493	0.448	0.280	0.424	Target value
<i>Shocks</i>						
Persistence: migration	ρ_{ω}^m	0.965	0.965	-	-	ONS
Migration	$\sigma^{m,ls}$	-0.067	0.067	-	-	Authors' calculation
Tariffs	$\tau_{i=1}$	-1.49%;-2.94%	-	-1.49%	-2.94%	GJMP12
Non-tariff barriers	$v_{i=1}$	3.69%	3.69%	-	-	FBT09; DHO17
Non-tariff barriers	$v_{i=2}$	1.63%	1.63%	-	-	FBT09; DHO17
Non-tariff barriers	$v_{i=3}$	1.63%	1.63%	-	-	FBT09; DHO17

Note: Abbreviations used in the table are as follows: AKK98: Autor et al. (1998); CR00: Canova and Ravn (2000); DHO17: Dhingra et al. (2017); FBT09: Francois et al. (2013); GJMP12: Guimbard et al. (2012); GK10: Gertler and Kiyotaki (2010); GK11: Gertler and Karadi (2011); HO10: Harrison and Oomen (2010); I05: Iacoviello (2005); SW03: Smets and Wouters (2003); SW07: Smets and Wouters (2007); ZG13: Zheng and Guo (2013).

The elasticity of substitution between domestic and imported supplies, η_s , is set equal to 1.77 - the value of the elasticity of substitution between domestic and imported consumer goods and services η in our baseline calibration. We consider other values of η_s corresponding to fully inelastic and very elastic cases as part of our robustness checks in [Chapter 2.6](#).

Table 2.4: Summary of the supply chain parameters.

Supplier	$i = 1$ (UK)	$i = 2$ (UK)	$i = 3$ (UK)
$s = 1, m = UK$	38.723	6.301	14.759
$s = 2, m = UK$	21.079	62.786	30.815
$s = 3, m = UK$	13.943	20.208	42.614
$s = 1, m = EU$	13.749	2.317	4.462
$s = 2, m = EU$	2.071	4.176	2.229
$s = 3, m = EU$	0.97	0.748	1.181
$s = 1, m = AE$	4.938	0.676	1.455
$s = 2, m = AE$	0.353	1.537	0.613
$s = 3, m = AE$	0.171	0.274	0.343
$s = 1, m = EE$	3.758	0.657	1.302
$s = 2, m = EE$	0.133	0.245	0.13
$s = 3, m = EE$	0.113	0.074	0.097

Supplier	$i = 1$ (EU)	$i = 2$ (EU)	$i = 3$ (EU)
$s = 1, m = UK$	1.052	0.198	0.383
$s = 2, m = UK$	0.422	1.521	0.565
$s = 3, m = UK$	0.08	0.093	0.121
$s = 1, m = EU$	52.973	10.37	20.789
$s = 2, m = EU$	21.658	60.652	32.71
$s = 3, m = EU$	14.946	21.899	40.948
$s = 1, m = AE$	2.887	0.643	1.122
$s = 2, m = AE$	0.946	2.84	0.916
$s = 3, m = AE$	0.299	0.3	0.446
$s = 1, m = EE$	4.086	0.712	1.478
$s = 2, m = EE$	0.406	0.697	0.358
$s = 3, m = EE$	0.245	0.075	0.162

Our supply chain parameters $\omega_i^{s,m}$ are based on the 2014 WIOT, and are summarised in [Table 2.4](#) for the UK and the EU (parameter values for the AE and EE are presented in [Appendix B](#)). Parallel to [Table 2.2](#), an entry in each cell in [Table 2.4](#) represents the share of inputs purchased by the sector identified in that column from the sector-country pair identified in that row. These are presented for the UK (EU) in the upper (lower) part of the table. For example, the entry in the first row of the second column suggests that 38.72 % of all intermediate inputs in the UK's good sector comes from the sector's own output. Similar to the case with [Table 2.2](#), the darker the shade in a cell, the greater the resource intensity of the input in the relevant row in the use of the sector and in the country, as specified in that column.

The values presented in Table 2.4 reveal insights into the extent of the supply chains across the four countries. First, the share of imported inputs is significantly greater in the goods sector relative to the services sector, with clear implications for sectoral exposures to frictions in cross-border trade. Second and relatedly, the reliance of the goods sector on imported inputs is considerably greater in the UK (26.25%) than in the EU (10.42%). Put differently, the UK's backward linkages in supply chains (its reliance on inputs from the EU) is significantly stronger than its forward linkages (the UK's provision of inputs to the EU). Third, the highest intensities are observed in the tradable services sector's use of its own output as inputs for both the UK and the EU. For example, 62.79% (60.66%) of inputs in the tradable services sector in the UK (EU) comes from the sector's own outputs. The corresponding value for the goods sector is 38.72% (52.97%).

Banking sector parameters

We set the survival rate of banks θ_b at 0.968 for the UK, 0.972 for the EU, 0.969 for the AE and 0.965 for the EE to match a UK leverage ratio of around 5, as reported in the 2020 *Financial Stability Report*. For the EU, AE, and EE, the survival rate matches a leverage ratio of around 4, following the benchmark figures calculated by Villa (2016) and Gertler and Kiyotaki (2010), respectively. This suggests a lifetime equivalent of 7.9, 8.8, 8.1, and 7.1 years on average for the UK and the EU, AE, and EE, respectively.

We set the proportion of diverted funds λ in the UK, EU, AE, and EE at 0.248, 0.366, 0.183, and 0.338 to match the average yearly credit spread at 180 basis points for the UK, 250 for the EU, 110 for the AE and 300 for the EE. The fraction of starting funds as a ratio of assets is set at 0.2% as in Gertler and Kiyotaki (2010) and Gertler and Karadi (2011).

2.4 Policy experiments: frictions in migration and trade of goods and services

Having calibrated our extended model, we are now in a position to examine the effects of three sets of frictions that the UK-EU economic relationship has been subject to

following the UK's formal exit from the EU on the 31st of December, 2020: (i) reduced immigration of low-skilled workers from the EU (resulting from the new migration policy); (ii) NTBs to the UK-EU trade in goods; and (iii) NTBs to the UK-EU trade in services, creating higher cost of cross-border services provision.³³

A key first step in this exercise is to quantify the size of each friction triggered by Brexit. Although the TCA specifies the types of frictions facing the UK-EU bilateral trade, the exact scale of these impediments will evolve with implementation and hence will only be known in time. We therefore approximate the most likely scope of the frictions by utilising (i) data from the post-Brexit referendum period; and (ii) data on the existing frictions between the EU and the non-EU countries. With respect to immigration flows, our experiments are also guided by the parameters of the new points-based immigration system that also came into effect on the 1st of January, 2021 and had already proven to reduce net migration from the EU, primarily of low-skilled labour. More specifically, the fall in net migration from the EU between the pre-Brexit referendum period and the year 2020 has been at 124,200, which take as our benchmark migration scenario. This, in turn, corresponds to a negative migration shock of 0.067 standard deviations. Using the ONS time series of migration, we estimate the quarterly persistence of migration between the UK and the EU at 96.48%.

Regarding, trade frictions, we match the size of NTBs arising from the TCA with the scale of the existing NTBs in the EU-US trade at present. As stated earlier, NTBs arise from differences in product standards, health and safety requirements, consumer and environmental protection as well as costs of trade across countries. Naturally, trade agreements can eliminate some of these barriers but not others such as trade costs. In our analysis, we set the level of new NTBs to trade in goods between the UK and the EU as the 3.69% tariff-equivalent which corresponds to one-third of the reducible share of NTBs between EU and the US, as calculated in [Francois et al. \(2013\)](#), close to the value of one-fourth of the reducible share in [Dhingra et al. \(2017\)](#). The NTBs to trade in services are set at 1.63%, which amounts to the full reducible share of NTBs between EU and the US as the TCA do not cover trade in services.

We base the range of potential trade liberalisation between the UK and the rest of

³³Using deterministic simulations, we explore the transition path to a new equilibrium following a set of permanent shocks.

the world on the Market Access Map (MAcMap) database as in [Guimbard et al. \(2012\)](#). The existing scale of trade frictions between the UK and the AE (EE) reveals that full trade liberalisation will require elimination of tariffs by 1.49% (2.94%) between the UK and the AE (EE).

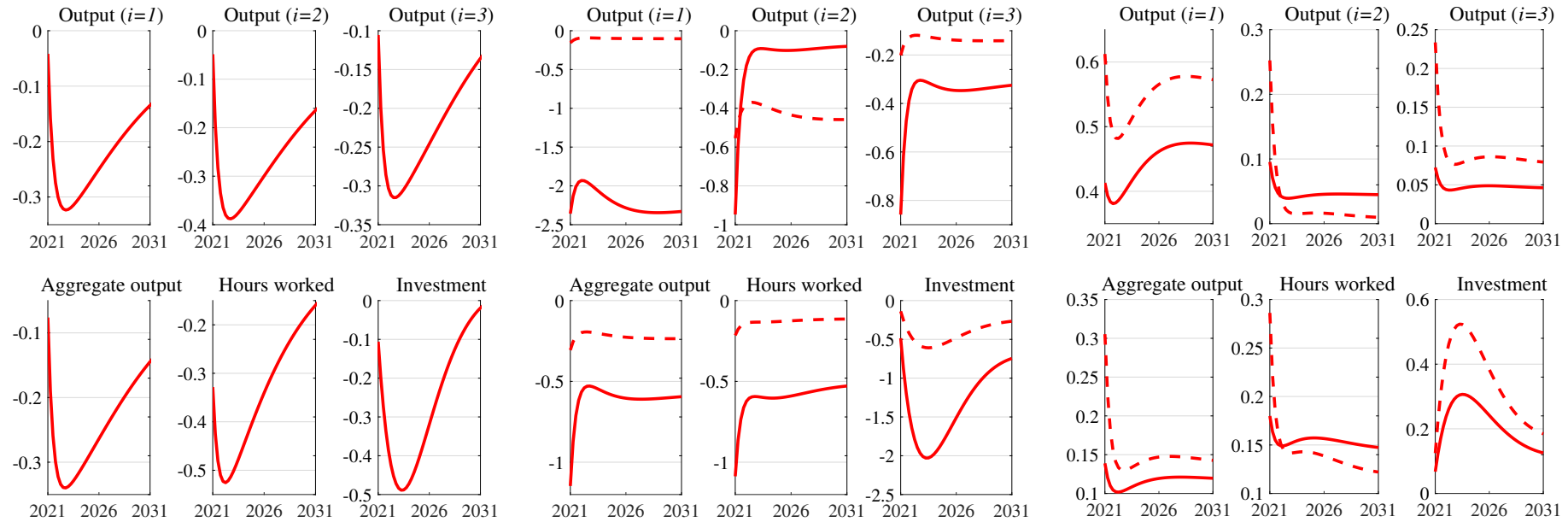
In what follows, using our complete model we organise our results in a way to isolate the contribution of each set of frictions by separately presenting the outcomes in response of shocks in (i) migration flows; (ii) NTBs to the trade in goods; and (iii) NTBs to the trade in services.

Furthermore, we also subsequently present our results for the baseline model and its three extensions separately to isolate the role of each component in our extended framework to the dynamics arising from the UK's exit from the EU for all four countries.

2.4.1 Migration

The UK's new migration policy entails a points-based system with a threshold salary of £26,500 annual gross payment, with significant implications for the flow of low-skilled workers. We therefore configure migration shocks in our benchmark experiments as reductions in the flows of low-skilled labour - by 124,200 corresponding to a negative shock of 0.067 standard deviation, as set out above. Changes in high-skilled immigration are taken up as part of our robustness checks, presented in [Chapter 2.6](#).

The direct effect of the migration shock is a decrease in hours worked in the UK and a symmetrical increase in the hours worked in the EU, adjusted by the higher relative population in the EU. [Panel \(a\) in Figure 2.2](#) displays a series of panels tracing how the UK economy responds to the fall in low-skilled immigration over a period of 40 quarters, hence featuring both the immediate response and the adjustment in the aftermath of the migration shock as the UK monetary policy responds to the resulting fall in economic activity.



(a) Fall in net EU low-skilled migration by 124,200. (b) Non-tariff barriers in goods trade (solid line) and services trade (dashed line). (c) Liberalisation of trade with AE (solid line) and EE (dashed line).

Figure 2.2: UK economy responses to migration and trade shocks.

Notes: % deviations from the initial steady-state; the migration shock corresponds to a decline in net migration of 124,200 low-skilled EU workers into the UK, the size of the shock is equal to 0.067 std; the size of bilateral NTBs to trade in goods is 3.692% which corresponds to the one-third of the reducible share of NTBs between EU and the US; NTBs to trade in services of 1.628% which corresponds to the full reducible share of NTBs between EU and the US; lifting tariffs between the UK and the AE (1.493%), and between the UK and the EE (2.938%).

What happens to the four economies in the long-term following the migration shock is clearly also of great interest as the economies reach a new post-Brexit steady-state, presented by Table 2.5. Entries in Table 2.5 display the change in outcomes between the pre-TCA steady-state and a ten-year average during transition to the post-Brexit steady-state.³⁴

As is clear from Figure 2.2 and Table 2.5, a fall in the flow of low-skilled EU labour reduces UK output in all three sectors, leading to a contraction in the UK economy, with the tradable services sector sustaining the largest fall in output (0.28 %), due to its greater use of labour than the other two sectors. The fall in output is also accompanied by a fall in the UK's consumption of goods and services produced by all four countries, with the sharpest fall in consumption and input demand for domestically produced goods and services, by 0.21% and 0.31%, respectively. Investment also falls in the UK (0.27%), reducing the value of assets and deposits in the financial sector, contributing to a further contraction in economic activity, reducing the size of the UK economy by 0.25%.

As is also reported in Table 2.5, the reduction in low-skilled labour inflows from the EU and hence the supply of low-skilled labour in the UK put upward pressure on their wage, raising it by 0.51% in the goods sector and by 0.49% in the services sectors. In contrast, wages of high-skilled workers fall by 0.01% in the goods sector and by 0.03% in both services sectors on account of the contraction in the UK's output.

As expected, an opposite chain of events is put in motion in the EU, given that the reduction in migration of low-skilled labour to the UK is equivalent to a positive labour supply shock for the EU. However, the size of the favourable effect on the EU (0.04%) is much smaller relative to the responses of the UK due to a respectively larger EU population, and hence the smaller relative size of the labour supply shock for the EU. As a result, both the high- and the low-skilled in the EU experience a 0.01% rise in their wages over the same period.

³⁴It must be noted that while most of the fall in immigration from the EU has been in the low-skilled labour inflows, not all of the fall has been in this category. We therefore take up the case of shocks to the flow of high-skilled labour as part of our robustness checks in Chapter 2.6.

Table 2.5: Responses to shocks - final model.

	Fall in net EU low-skilled migration by 124,200				Non-tariff barriers to trade in goods				Non-tariff barriers to trade in services				Elimination of UK-AE tariffs on goods				Elimination of UK-EE tariffs on goods			
	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE
Aggregate output	-0.25	0.04	0.00	0.00	-0.61	-0.18	0.00	-0.01	-0.23	-0.05	0.00	0.00	0.12	0.01	0.01	0.00	0.15	0.01	0.00	0.03
Output ($i = 1$)	-0.23	0.01	0.00	0.00	-2.22	-0.44	-0.02	-0.02	-0.10	-0.03	0.00	0.00	0.45	0.01	0.03	0.00	0.55	0.02	0.01	0.05
Output ($i = 2$)	-0.28	0.04	0.00	0.00	-0.14	-0.09	0.00	-0.01	-0.43	-0.09	0.00	0.00	0.05	0.00	0.01	0.00	0.03	0.01	0.00	0.02
Output ($i = 3$)	-0.23	0.05	0.00	0.00	-0.36	-0.05	0.00	-0.01	-0.14	-0.03	0.00	0.00	0.05	0.00	0.00	0.00	0.09	0.00	0.00	0.02
Consumption	-0.14	0.02	0.00	0.00	-0.74	0.00	0.01	0.00	-0.08	-0.02	0.00	0.00	0.04	0.00	0.00	0.00	0.20	-0.01	-0.01	0.01
Investment	-0.27	0.04	0.00	0.00	-1.35	-0.30	-0.01	-0.02	-0.43	-0.08	0.00	0.00	0.21	0.01	0.02	0.00	0.34	0.01	0.00	0.06
Deposits	-0.13	0.02	0.00	0.00	-0.54	-0.12	0.00	-0.01	-0.17	-0.03	0.00	0.00	0.09	0.00	0.01	0.00	0.14	0.00	0.00	0.02
Assets	-0.16	0.02	0.00	0.00	-0.73	-0.15	0.00	-0.01	-0.22	-0.04	0.00	0.00	0.11	0.00	0.01	0.00	0.19	0.00	0.00	0.03
Hours worked	-0.35	0.02	0.00	0.00	-0.60	-0.30	-0.01	-0.02	-0.13	-0.02	0.00	0.00	0.15	0.01	0.02	0.00	0.14	0.02	0.01	0.03
CPI	0.03	-0.01	0.00	0.00	0.04	-0.01	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00
Consumption of UK goods and services	-0.21	-0.14	-0.16	-0.16	-0.32	-2.45	0.69	0.62	-0.01	-1.35	0.13	0.08	0.02	-0.07	1.13	-0.08	0.09	-0.19	-0.19	3.22
Consumption of EU goods and services	-0.05	0.04	0.01	0.01	-5.66	0.04	0.14	0.09	-0.76	0.00	0.03	-0.01	0.08	0.00	0.00	-0.01	0.28	-0.01	-0.02	0.02
Consumption of AE goods and services	-0.05	0.02	0.00	0.00	-1.06	-0.06	0.01	-0.03	-0.13	-0.03	0.00	-0.03	1.60	-0.01	0.00	-0.01	0.29	0.00	0.00	0.03
Consumption of EE goods and services	-0.06	0.02	0.00	0.00	-1.02	-0.03	0.05	0.00	-0.11	-0.01	0.03	0.00	0.08	0.00	0.01	0.00	5.11	-0.03	-0.04	0.00
Purchases of UK supplies	-0.31	-0.14	-0.16	-0.16	-0.56	-2.27	0.67	0.59	-0.22	-1.58	0.13	0.07	0.14	-0.07	1.24	-0.08	0.13	-0.18	-0.19	3.74
Purchases of EU supplies	-0.12	0.04	0.01	0.01	-5.67	-0.20	0.13	0.08	-1.34	-0.04	0.03	-0.01	0.34	0.00	0.02	0.00	0.51	0.01	-0.01	0.05
Purchases of AE supplies	-0.13	0.02	0.00	0.00	-2.07	-0.35	0.00	-0.04	-0.30	-0.07	0.00	-0.03	2.11	0.00	0.02	-0.01	0.53	0.01	0.00	0.06
Purchases of EE supplies	-0.12	0.02	0.00	0.00	-2.40	-0.39	0.04	-0.01	-0.23	-0.03	0.03	0.00	0.41	0.01	0.04	0.00	5.33	-0.01	-0.03	0.03

Notes: Values are defined in relation to the initial steady-state and are expressed as average percentage deviations over the decade 2021-2031; size of the migration shock: 0.046 std; bilateral NTBs to trade in goods of 3.692% which corresponds to the one-third of the reducible share of NTBs between EU and the US; NTBs to trade in services of 1.628% which corresponds to the full reducible share of NTBs between EU and the US as in [Dhingra et al. \(2017\)](#); reducible tariffs between the UK and both the AE (1.493%) and EE (2.938%) are calculated based on the Market Access Map (MAcMap) as in [Guimbard et al. \(2012\)](#).

2.4.2 Frictions to trade in goods

As is stated above, NTBs to the UK-EU trade in goods are widely viewed as the key source of frictions arising from Brexit. In our benchmark simulations in [Chapter 2.2.2](#) above we considered NTB shocks over a range corresponding to import price rises between 1% and 10%. In this section, we specify the likely size of the NTB shocks using data on the existing NTBs between the EU and the US. Following [Francois et al. \(2013\)](#), [Dhingra et al. \(2016\)](#) and [Dhingra et al. \(2017\)](#), we approximate UK-EU NTBs to trade in goods in post-Brexit arrangements as corresponding to 3.69% rise in import prices, as specified above.

The resulting dynamics are displayed by [Panel \(b\)](#) in [Figure 2.2](#) and [Table 2.5](#). Clearly, NTBs raise the prices of imported goods, reducing the volume of UK's imports from the EU, both for inputs (5.67%) and consumption goods (5.66%), as is seen in the fifth column in [Table 2.5](#). This reduction in trade leads to a fall in aggregate output and output of the three sectors, as is clear from both [Figure 2.2](#) and the entries in the first four rows of [Table 2.5](#). The goods sector in the UK exhibits the sharpest fall (2.22%), due to its greatest reliance on imported inputs, as is displayed in [Table 2.4](#) above.

The reduction in consumption and output in the UK by, respectively, 0.68% and 0.62% reduces the demand for labour, with unfavourable consequences for the wages of both low and high-skilled workers. Consequently, the fall in labour income brings about a fall in deposits from high-skilled households, leading to lower capital and hence lower investment (1.35%). As is also clear, the imposition of NTBs to the UK-EU trade has unfavourable implications for all UK variables depicted in [Figure 2.2](#) and [Table 2.5](#) although the greatest slide is in the UK's consumption of goods and services imported from the EU (5.66%). Overall, the UK economy sustains a contraction of 0.61% and a rise in prices.

In the UK's goods sector, wages of both the low and the high-skilled workers fall, by 0.95% and 1.04%, respectively (not reported in [Table 2.5](#)). The corresponding figures are 0.53% and 0.44% for the tradable, and 0.59% and 0.5% for the non-tradable services sectors, and are smaller as expected, given the greater contraction in the goods sector.

A key question regarding the imposition of NTBs on the UK-EU goods trade is to what extent the UK and the EU reallocate their trade to other trading partners as a result. To answer this question, we consider an amended version of the UK's

input-output table (Table 2.4), incorporating NTBs to the goods trade between the UK and the EU. This is presented in Table B.9 in Appendix B in the form of changes from the benchmark values relative to the pre-Brexit trade linkages in Table 2.4.³⁵ The pattern of changes in Table B.9 indicates that there is a fall in the UK goods sector's use of goods as inputs from all sources including its own (0.12%), although the sharpest fall is in imports of goods from the EU (0.895%). Evidently, UK firms substitute their use of goods by the use of services as inputs that are not subject to the new barriers; use of imported services from the EU, AE and the EE go up by 0.1%, 0.002% and 0.001%, respectively.

2.4.3 Frictions to trade in services

The omission of the services trade from the TCA is widely noted as a major risk factor for the UK, particularly given that UK is a services based economy about 80% of which is produced by the services sector.^{36,37}

The absence of provisions for the services sector in the TCA has introduced NTBs to trade in services between the UK and EU, implying a hike in export prices across the UK-EU border by 1.63% - a fully reducible share of NTBs in services trade between the EU and the US, as reported by Dhingra et al. (2017). Similar to the case of NTBs to trade in goods above, the resulting dynamics are displayed in Panel (b) in Figure 2.2 and Table 2.5.

As is clear from Figure 2.2 and from Table 2.5, the rise in import prices leads to a contraction of 0.43% in the tradable services sector and 0.14% in the nontradable services sector, resulting in 0.23% drop in total UK output. As expected, the UK's (EU's) demand for imports from the EU (UK) for consumption also falls by 0.76% (1.36%) given that the frictions raise export prices in both countries. Following the fall in total output in the UK, UK's imports of supplies from both the EU and non-EU countries

³⁵To calculate post-Brexit input-output linkages in intermediate goods and services trade, we use the steady-state values of trade flows under a new increased level of NTBs and compare them with the pre-Brexit input-output linkages (Table 2.4).

³⁶See ONS data <https://www.ons.gov.uk/economy/economicoutputandproductivity/output/articles/servicessectoruk/2008to2018>.

³⁷Given the UK's comparative advantage in the financial services sector - and hence the size of the sector's trade surplus with the EU - the risk of British banks' losing their ability to export financial services to the EU has featured significantly in the Brexit debate.

also fall, although the latter to a lesser degree, given that price rises only apply to trade between the UK and the EU. The fall in output also prompts lower investment and a decline in the activity of the financial sector as suggested by the reported fall in deposits and assets, by 0.12% and 0.15%, respectively.

Similar to the case with NTBs on goods, NTBs on services also forces a reallocation, as portrayed in [Table B.10](#) in [Appendix B](#), this time in the opposite direction. The new NTBs in services trade force producers in all three sectors to use more of goods as inputs, at the expense of services, reducing the UK's tradable services sector's use of EU services the most, by 0.12%, while raising the use of goods from the UK and the EU, respectively, by 0.005%, 0.002% and from the AE and the EE by 0.001%.

Clearly, the emergence of frictions in the bilateral trade in goods and services between the UK and the EU has consequences for both economies. The response to NTBs to trade in both goods and services, as reported in [Table 2.5](#), points to a 0.84% drop in the UK's total output (0.62 % due to NTBs in goods and 0.23% due to NTBs in services), while the fall in the EU's output is approximately one-fourth of that at 0.22%. Due to the contraction in output, both employment and investment are lower in both countries, by 1.78% and 0.73%, respectively. The financial sectors of both countries also contract, with a fall in total assets by 0.95% (0.19%) in the UK (EU).

Following the fall in employment, wages of high-skilled workers fall by 0.06% in the UK's goods sector, the source of new frictions, while in the tradable and nontradable services sectors the declines are 0.17% and 0.08%, respectively. Wages of low-skilled workers in the UK fall more sharply - by 0.09%, 0.2%, and 0.11% in the corresponding sectors.

2.4.4 Trade deals with non-EU countries

In principle, leaving the EU and its customs union can also be beneficial as it allows the UK to forge its own trade agreements with the third countries, as is consistently put forward by the proponents of Brexit. Our multi-country framework enables us to quantify the effects of such arrangements directly. We do this by exploring two further scenarios, in which the UK lowers its external tariffs on goods imported from the non-EU countries, which is reciprocated by the recipient countries through lowering their own tariffs on imports from the UK.

Our calibration of non-EU countries distinguishing between the AE and EE countries facilitates a consideration of potential trade liberalisation between the UK and the two sets of countries separately, providing us with a set of findings with clear policy implications. We calculate the current tariff rates between the UK and both the AE and EE based on the the Market Access Map (MAcMap) database as in [Guimbard et al. \(2012\)](#).³⁸ The responses to the elimination of tariffs between the UK and the third countries (1.49% for AE and 2.94% for EE) are displayed in the last eight columns of [Table 2.5](#) and in [Panel \(c\)](#) in [Figure 2.2](#).

Unsurprisingly, trade liberalisation between the UK and both the AE and EE leads to an increase in imports from the AE for consumption (for inputs) by 1.6% (2.11%) while the corresponding increases following trade liberalisation with the EE are 5.11% (5.33%). Lifting tariffs on the third countries also prompts a relocation from the services to the goods sector as source of inputs; all three sectors in the UK make a greater use of goods as inputs, primarily those imported from the AE and EE. The relocation effect is the strongest in the UK's goods sector that has the greatest reliance on goods as intermediate inputs, where the favourable impact of trade liberalisation is also greatest, featuring expansion in output, by 0.45% and 0.55%, after lifting tariffs against the AE and the EE, respectively.

The source of the greater impact from the elimination of tariffs on the UK-EE goods trade relative to that on the UK-AE is the significantly higher tariffs that are currently imposed on trade between the UK and the former (2.94%) relative to that with the latter (1.49%). In sum, purchases of supplies from both the EU and non-EU countries increase, due to an increase in output in the UK (0.27%), fed by cheaper imports from the third countries.

The UK economy benefits from trade liberalisation with non-EU countries, with higher output, higher investment, higher employment, lower prices at home, and expansion of the financial sector. Similarly, AE (EE) countries also benefit from the removal of tariffs with the UK, raising their consumption of UK goods and services by 1.13% (3.22%) and imports of supplies from the UK by 1.24% (3.74%).

It is important to note, however, that the gain from trade liberalisation with the

³⁸Except for Taiwan, for which tariff data are not available.

non-EU countries does not offset the losses from higher NTBs even in the scenario with full trade liberalisation between the UK and non-EU countries. For example, the total contraction in UK's output arising from NTBs to trade with the EU is 0.83% (see [Table 2.5](#)) - consisting of 0.61% from frictions in trade in goods and 0.23% in trade in services - while the output gain from lifting tariffs on the AE (EE) amounts to 0.12% (0.15%).

Under trade liberalisation, wages of both high-skilled and low-skilled workers in the UK increase. Wages of high-skilled workers rise by 0.43% in the goods sector, by 0.2% in the tradable services sector, and by 0.21% in the nontradable goods sector. Wages of low-skilled workers increase to a lesser degree - by 0.36%, 0.12%, and 0.15%, respectively.

2.4.5 Comparative statics

A major policy question regarding the different sources of frictions is the relative importance of each source in contributing to the overall impact of Brexit. For example, are migration shocks more costly in terms of outcomes? Are there frictions that dominate others in terms of fluctuations in macroeconomic variables? Is it possible to rank different frictions regarding their contribution to losses from Brexit?

It is important to make such comparisons on the relative cost of each friction independently of the likely size of those frictions. To that end, in this section we present a comparative statics analysis, displaying the magnitude of changes between the pre- and post-Brexit steady-states in response to a normalised variation in each friction, specified as a 1% change in steady-state values, as presented in [Table 2.6](#).

In [Table 2.6](#), changes are calculated for four separate cases, depicting the shape of Brexit transition in each case. Consistent with our earlier findings, NTBs to trade in goods emerge as the key source of fluctuations, followed by migration shocks, which is closely followed by NTBs to trade in services. More specifically, a one per cent rise in NTBs to trade in goods prompts more than one-to-one impact on imports, leading to reductions in output in all three sectors, consumption, employment, capital and investment with an overall fall of 0.29% in output. A rise in NTBs to services trade also leads to a contraction in the UK economy albeit by a smaller size (0.06%). The main reason for the NTBs on goods having more than three times the impact of the NTBs on services is the much greater reliance of the UK's goods sector on inputs from the EU

Table 2.6: Steady-state values of the UK economy.

Variable	Single Market	Non-tariff barriers to trade in goods	Non-tariff barriers to trade in services	UK-AE trade liberalisation	UK-EE trade liberalisation
Aggregate output	0.952	-0.287	-0.064	+0.105	+0.080
Output ($i = 1$)	0.165	-0.287	-0.064	+0.105	+0.080
Output ($i = 2$)	0.304	-0.287	-0.064	+0.105	+0.080
Output ($i = 3$)	0.483	-0.287	-0.064	+0.105	+0.080
Consumption HS	0.427	-0.290	-0.064	+0.096	+0.068
Consumption LS	0.124	-0.278	-0.062	+0.066	+0.031
Hours worked	6.797	-0.145	-0.013	+0.054	+0.040
Capital	3.430	-0.287	-0.064	+0.105	+0.080
Deposits	2.870	-0.287	-0.064	+0.105	+0.080
Assets	3.430	-0.287	-0.064	+0.105	+0.080
Government spending	0.300	-0.138	+0.102	+0.043	+0.051
Transfers	0.170	-0.287	-0.064	+0.043	0.000
Imports	0.079	-1.166	-0.446	+0.324	+0.347
Exports	0.068	-0.735	-0.632	+0.361	+0.220

Notes: Entries are values in the initial pre-Brexit steady-state, and the percentage changes to those when the economy arrives at the post-Brexit steady state in response to the rise in NTBs (1% tariff equivalents) and trade liberalisation (lifting of 1% tariffs).

relative to the services sector; the EU goods sector provides 13.75% of inputs for the goods sector, as opposed to 2.32% of those for the tradable services sector in the UK.

Interestingly, lifting tariffs against the AE by 1% raises the UK output slightly more than lifting tariffs against the EE. When combined with our earlier findings that full trade liberalisation with the EE raises the UK output significantly more than that with the AE suggests that although the lifting of tariffs on trade with AE is more effective per unit of tariff reduction, the scope of doing so on trade with the EE is much greater.

2.5 Discussion

2.5.1 Model choice

Our analysis of the TCA in this paper is based on the general equilibrium model we have developed, featuring a number of dimensions. We now turn to examining how individual components of our framework contribute to the dynamics following Brexit. In so doing, we present our results under four separate model specifications: (i) the baseline model; (ii) extension with flows of high and low-skilled labour across borders; (iii) extension with supply chains in intermediate inputs; and (iv) extension with banks. In what follows, we pick NTBs to trade in goods and services as the basis of this exercise and present outcomes in response to shocks in NTBs, as calibrated earlier. We

derive our model solutions by adding each component sequentially, arriving at the complete model framework after the three sets of extensions. This strategy enables us to gauge the contribution of each component, as can be deduced from the differences in each two consecutive sets of outcomes.

Table 2.7 displays responses to NTBs in goods and services under four alternative model specifications starting with the baseline results in the first four columns of the table. Cross comparison of the four sets of outcomes in **Table 2.7** indicates that while the response of the four economies to the post-Brexit distortions in both the goods and the services trade are qualitatively similar, the quantitative responses vary, significantly in some cases.

More specifically, the fall in output in response to the NTBs in the model with intermediate inputs is more than double the fall in models excluding supply chains, 0.76% as compared with 0.24% in the benchmark and 0.29% with labour flows across borders. This suggests that the existence of supply chain networks significantly aggravates the cost of trade restrictions. As expected, the difference between the two cases is larger for the goods sector, which exhibits greater reliance on imported inputs from the EU. Such importance of supply chains for Brexit outcomes - a key motivation of our modelling strategy - is corroborated by the early evidence on the impact of Brexit on the stock market. It was shown that firms with global supply chains across the UK and the EU and those reliant on imported inputs sustained the sharpest falls in their stock prices following the Brexit referendum (see **Davies and Studnicka, 2018**).

Similarly, incorporating the role of financial intermediation in the transmission of shocks to frictions in trade, through an explicit banking sector, also accounts for additional aggravation in outcomes, as can be read from the fourth set of results - the complete model - in the final block of columns in **Table 2.7**. When our model specification contains financial intermediation through the banking sector, a fall in output and hence in household incomes also lower deposits, further reducing assets in the UK, intensifying the fall in investment and output.

It is also clear from **Table 2.7** that labour market structure regarding inflows of labour across borders and skills distribution, while playing an important role in matching the realistic features of the model economy, is not essential in driving the responses to the emergence of frictions in the UK-EU trade.

Table 2.7: Responses to non-tariff barriers to trade in goods and services under four model specifications.

	Baseline model				Heterogeneous households				Supply chains				Banks			
	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE
Aggregate output	-0.24	-0.07	0.00	0.00	-0.29	-0.06	0.00	-0.01	-0.75	-0.21	0.00	-0.01	-0.84	-0.22	0.00	-0.01
Output ($i = 1$)	-0.58	-0.18	0.00	0.00	-0.70	-0.17	0.00	-0.01	-2.24	-0.45	-0.02	-0.02	-2.32	-0.47	-0.02	-0.02
Output ($i = 2$)	-0.17	-0.03	0.00	0.00	-0.19	-0.03	0.00	0.00	-0.49	-0.16	-0.01	-0.01	-0.57	-0.18	-0.01	-0.01
Output ($i = 3$)	-0.17	-0.01	0.00	0.00	-0.20	-0.01	0.00	0.00	-0.41	-0.07	0.01	-0.01	-0.49	-0.08	0.01	-0.01
Consumption	-0.61	-0.02	0.01	0.01	-0.54	-0.01	0.01	0.01	-0.80	-0.02	0.02	0.00	-0.82	-0.02	0.02	0.00
Investment	-0.98	-0.18	0.00	0.01	-1.02	-0.16	0.01	0.00	-1.56	-0.35	0.00	-0.02	-1.78	-0.39	-0.01	-0.03
Deposits	-	-	-	-	-	-	-	-	-	-	-	-	-0.71	-0.16	0.00	-0.01
Assets	-	-	-	-	-	-	-	-	-	-	-	-	-0.95	-0.19	0.00	-0.01
Hours worked	-0.18	-0.06	0.00	0.00	-0.23	-0.06	0.00	-0.01	-0.69	-0.31	-0.02	-0.02	-0.73	-0.32	-0.02	-0.02
CPI	0.00	-0.01	0.00	0.00	-0.01	-0.01	0.00	0.00	0.02	-0.01	0.00	0.00	0.03	-0.01	0.00	0.00
Consumption of UK goods and services	0.03	-2.92	1.53	1.66	0.13	-2.82	1.64	1.80	-0.29	-3.78	0.86	0.73	-0.33	-3.81	0.83	0.70
Consumption of EU goods and services	-6.21	0.05	0.21	0.28	-6.20	0.05	0.21	0.30	-6.40	0.04	0.18	0.10	-6.41	0.03	0.17	0.09
Consumption of AE goods and services	-1.39	-0.11	0.00	0.07	-1.38	-0.11	0.00	0.08	-1.18	-0.10	0.01	-0.06	-1.19	-0.10	0.01	-0.06
Consumption of EE goods and services	-1.45	-0.18	-0.06	0.01	-1.46	-0.19	-0.08	0.00	-1.12	-0.03	0.08	0.00	-1.13	-0.03	0.09	0.00
Purchases of UK supplies	-	-	-	-	-	-	-	-	-0.68	-3.81	0.83	0.70	-0.78	-3.86	0.80	0.66
Purchases of EU supplies	-	-	-	-	-	-	-	-	-6.92	-0.23	0.16	0.08	-6.99	-0.25	0.15	0.08
Purchases of AE supplies	-	-	-	-	-	-	-	-	-2.31	-0.41	0.00	-0.07	-2.37	-0.43	0.00	-0.07
Purchases of EE supplies	-	-	-	-	-	-	-	-	-2.57	-0.40	0.07	-0.01	-2.63	-0.42	0.07	-0.01

Notes: Values are defined in relation to the initial steady-state and represent aggregate responses to NTBs to trade in goods and services as in Table 2.5. Each model component is added sequentially. For example, the third column incorporates both heterogeneous households and supply chains as additions to the benchmark model.

Finally, it is important consider the economic significance of the overall size of the contraction in the UK economy arising from Brexit in our analysis. In our calibrations, the drop in the UK output amounts to 1.09%: 0.25% from the fall in inflow of low-skilled workers; 0.61% from NTBs in goods; and 0.23% from NTBs in services. In a related line of work, it is found that the global financial crisis - widely viewed as the greatest economic crisis since the Great Depression in the 1930s - has led to long-term output losses of 0.94% (see, for example, [Schmitz, 2021](#)). This suggests that even when leaving out other important consequences of Brexit such as the loss of passporting rights for the financial sector, falls in FDI and the long-run productivity implications, all of which are excluded in our work, in the long-run Brexit is likely reduce the UK output by more than the global financial crisis.

2.5.2 Welfare analysis

Another major policy question related to Brexit is how the losses or gains are likely to be shared across different groups in the society. Our framework featuring heterogeneous households allows us to conduct a welfare analysis measuring the losses and gains over the adjustment path for both types of households in each country, allowing us to answer this question comprehensively.

As in [Schmitt-Grohé and Uribe \(2007\)](#) and [Canova and Ravn \(2000\)](#), we define the welfare function as the present value of households' utility over consumption and hours worked, W_0^{hs} and W_0^{ls} , for the high and low-skilled, respectively.

Let ζ_{hs} and ζ_{ls} denote the welfare cost of NTBs, ν_i^m , and tariffs, τ_i^m , expressed in consumption units that households are willing to give up to be as well off after the transition path as in the initial steady-state:

$$\mathcal{W}_0^{hs}(\zeta_{hs}, \nu_i^m, \tau_i^m) \equiv \mathbb{E}_0 \sum_{t=0}^{\infty} (\beta_{hs})^t U_{hs} \left((1 - \zeta_{hs}) C_t^{hs}, L_t^{hs} \right) \quad (2.5.34)$$

$$\mathcal{W}_0^{ls}(\zeta_{ls}, \nu_i^m, \tau_i^m) \equiv \mathbb{E}_0 \sum_{t=0}^{\infty} (\beta_{ls})^t U_{ls} \left((1 - \zeta_{ls}) C_t^{ls}, L_t^{ls} \right) \quad (2.5.35)$$

To calculate the consumption equivalents, ζ_{hs} and ζ_{ls} , we equate utility in the new

Table 2.8: Welfare analysis.

Consumption equivalent (%)	Households	Non-trade barriers				
		Goods	Services	Goods and services	Goods and services (incl. UK-AE trade liberalisation)	Goods and services (incl. UK-EE trade liberalisation)
UK	HS	-0.43	-0.02	-0.44	-0.42	-0.28
UK	LS	-1.27	-0.29	-1.56	-1.52	-1.45
UK	weighted average	-0.84	-0.15	-0.99	-0.96	-0.85
EU	HS	+0.02	-0.01	+0.01	+0.01	+0.00
EU	LS	-0.12	-0.06	-0.17	-0.17	-0.18
EU	weighted average	-0.03	-0.03	-0.06	-0.06	-0.06
AE	HS	+0.01	+0.00	+0.01	+0.02	+0.01
AE	LS	+0.00	+0.00	+0.01	+0.01	+0.00
AE	weighted average	+0.01	+0.00	+0.01	+0.01	+0.01
EE	HS	+0.00	-0.00	+0.00	+0.00	+0.00
EE	LS	-0.02	-0.00	-0.02	-0.02	+0.00
EE	weighted average	-0.01	-0.00	-0.01	-0.01	+0.00

Notes: The size of bilateral NTBs to trade in goods is 3.6923% which corresponds to the one-third of the reducible share of NTBs between EU and the US; NTBs to trade in services of 1.628% which corresponds to the full reducible share of NTBs between EU and the US; lifting tariffs between the UK and the AE (1.493%), and between the UK and the EE (2.938%).

steady-state compared to that in the pre-Brexit steady-state:

$$\mathcal{W}^{hs}(\zeta_{hs}, 0, 0) = \mathcal{W}_0^{hs}(0, v_i^m, \tau_i^m) \quad (2.5.36)$$

$$\mathcal{W}^{ls}(\zeta_{ls}, 0, 0) = \mathcal{W}_0^{ls}(0, v_i^m, \tau_i^m) \quad (2.5.37)$$

where the left and right-hand side expressions represent the pre- and post-Brexit outcomes, respectively. Following Canova and Ravn (2000), we calculate country level welfare, $\mathcal{W}_0$, as the weighted average of high and low-skilled households, where λ_{hs} represents the share of high-skilled consumption in total consumption.

$$\mathcal{W}_0 = \lambda_{hs} \mathcal{W}_0^{hs} + (1 - \lambda_{hs}) \mathcal{W}_0^{ls} \quad (2.5.38)$$

Table 2.8 displays welfare outcomes in consumption equivalent terms by households type for each country as well as the corresponding weighted averages in the face of trade and migration shocks and trade liberalisation with both the AE and EE, as indicated in each column heading.

Entries in Table 2.8 provide some additional insights into the consequences of the UK's exit from the EU, with important implications. First, welfare losses from Brexit is shared unequally, with a disproportionate burden falling on the low-skilled households. This is due to the significantly greater contraction in the goods sector featuring a greater

share of low-skilled employment.³⁹ More specifically, low-skilled households suffer 1.56% reduction in welfare, as compared with 0.44% for the high-skilled. Second, households in both the UK and the EU lose out following Brexit although the size of those losses are much greater in the UK. Third, although lifting tariffs on the non-EU countries clearly improves UK welfare, even full trade liberalisation with both the AE and the EE only compensates a fraction of the losses from Brexit. In contrast, liberalisation of trade with the UK improves welfare for both the AE and the EE although the welfare gains from lifting tariffs only just offsets losses from the unfavourable effects of Brexit for the latter, resulting in no net gains.

2.6 Robustness checks

In addition to scrutinising our findings across various model specifications in the previous section, we now extend our results to three additional cases.

2.6.1 A fall in high-skilled labour inflows

Our analysis of migration shocks so far only considered reductions in the inflow of low-skilled labour. We now take up the case of migration shocks to the inflow of high-skilled labour from the EU into the UK, as displayed in [Table B.13](#) (see [Appendix B](#)). This case has been made particularly relevant following the absence of any provisions for mutual recognition of professional qualifications in the TCA.

As is seen in [Table B.13](#), the reduction in the inflow of high-skilled labour intensifies the contraction in the UK economy; total output falls by at least twice as much as the drop following the drop in low-skilled immigration. The fall in the two services sectors output is greater than that in the goods sector due to the former's greater reliance on

³⁹This is closely in line with the emerging evidence on the distributional consequences of Brexit. Recent evidence suggests that (i) blue-collar workers with fewer formal qualifications are more exposed to the new trade barriers in the post-Brexit period ([Griffith et al., 2021](#)); (ii) the percentage of the low-educated is greater in the most exposed sectors, for both men and women ([Levell, 2018](#)); and (iii) regions mostly inhabited by low-skilled workers display lower levels of technology, lower global connectivity and tend to be more reliant on EU funding streams and less resilient to economic shocks, particularly those introducing frictions between the UK and the EU ([Billing et al., 2019](#)).

Such evidence on the greater exposure of the low-skilled add to previous findings from other countries pointing to the difficulty faced by low-skilled workers in responding to economic shocks (see, for example, [Utar, 2018](#); [Autor, 2014](#))

the high-skilled labour. Overall, the UK's total output falls by 0.56% with the tradable services sector contracting by 0.62% and nontradable services sector contracting by 0.55%.

What if this reduction in high-skilled labour inflows from the EU is replaced by an inflow of high-skilled labour from the non-EU countries? As can be seen from [Table B.13](#), while an increase in high-skilled labour from third countries raises the UK's output, it falls short of compensating for the unfavourable impact of restrictions on EU immigration. This is primarily due to immigration flows from the EU being more persistent than those from outside the EU, indicating that a given cohort of workers from the former remain in the UK labour force longer than those from the latter.⁴⁰

2.6.2 Elasticity of substitution between domestic and foreign goods

In our calibration of the model with supply chain networks we maintained that the elasticity of substitution between domestic and foreign inputs, η_s , is the same as the elasticity of substitution between the consumption of domestic and foreign goods. To assess the sensitivity of our findings to this assumption, we produce additional sets of results corresponding to a range of elasticities including fully inelastic and very elastic cases.

The new sets of results as presented in [Table B.14](#) indicate that although the model outcomes vary quantitatively with elasticity of substitution, our main findings on the relative size and the direction of responses are unaffected.

2.6.3 Composition of consumption baskets for low versus high-skilled households

Our model specifications also maintain that both low and high-skilled households bundle their consumption baskets in the same way using the same weights for the three types of output in their consumption baskets. Yet, existing evidence from micro data reveals that the share of services in consumption rises with income, suggesting high-skilled households are likely to spend a greater share of their income on services

⁴⁰While the 31% of EU migrants stay in the UK for longer than 10 years, only 17% of non-EU immigrants do ([Kone et al., 2020](#)).

than the low-skilled households (Boppart, 2014). We therefore extend our main results incorporating this variation in consumption shares.

As can be seen from the new results in Table B.15, our main findings remain robust in the presence of different weights in consumption across the two types of households.

2.6.4 Further sensitivity checks

We also carry out a number of other robustness and sensitivity checks by repeating our earlier experiments across variations in (i) the Calvo parameter; (ii) the survival rate of banks; (iii) inflation coefficient in the Taylor rule; and (iv) persistence of nominal interest rates; (v) the investment adjustment cost; and (vi) the share of low skilled workers as hand-to-mouth consumers, as presented in the rest of Appendix B. Our results are robust to different configurations and prevail across a wide range of parameter values.

2.7 Conclusions

In this paper, we develop a multi-country general equilibrium model with four key features: (i) migration flows across borders; (ii) incorporation of network effects arising from supply chains across sectors and countries; (iii) explicit consideration of services sector; and (iv) a separate banking sector incorporating the role of financial intermediation in the transmission of Brexit shocks. Moreover, our multi-country setting also allows a comprehensive analysis of international linkages and implications for the third countries.

By utilising this model, we present a carefully calibrated and comprehensive examination of the new frictions to migration and trade in goods and services between the UK and the EU, producing a set of important findings. First, we show that the existence of national and international supply networks significantly increases the unfavourable consequences of the frictions, with the greatest losses arising from barriers to the UK-EU trade in goods - featuring the strongest supply chains of the three sectors, aggravating the losses arising from trade disintegration.

Second, incorporating the important role of the services sector in UK's output and trade in our calibrations reveals that frictions to the services trade also worsen

outcomes for the UK. We also find that the deterioration in the UK outcomes is greater, the greater the supply chains in the services sector.

Third, the reduction in immigration from the EU is a source of further fluctuations for the UK, although the size of this effect is smaller than that of trade frictions. We also show that while the fall in immigration from the EU can be replaced by a rise in immigration from other countries in principle, the benefit from the latter is considerably smaller than the loss from the former due to the greater persistence of immigration flows from the EU relative to those from the non-EU countries.

Our multi-country setting also allows us to quantify the effects of potential trade agreements between the UK and the non-EU countries, revealing favourable effects. Yet, we find that the gains from trade liberalisation with the third countries fall well short of the losses from Brexit even under full trade liberalisation. Also importantly, our findings reveal that losses from Brexit are not shared equally and fall disproportionately on low-skilled households. Finally, we establish that our results are robust to a number of different configurations and across a wide range of parameter values.

CHAPTER 3

SUPPLY CHAINS, FINANCIAL LINKAGES AND INTERNATIONAL SPILLOVERS OF MONETARY POLICY

3.1 Introduction

The emergence of global value chains and growing financial cross-country linkages over recent decades have significantly impacted the functioning of the global economy. Spillovers of shocks originating in the advanced economies have become driving forces underlying domestic dynamics in the emerging world, given the global financial cycle and trade networks.

The unprecedented interconnectedness of global trade and finance provides fertile ground for analyzing the effects of monetary policy in an advanced economy that spills over to an emerging economy through the trade and credit channels. For emerging markets, liquidity fluctuations in developed countries are an important source of spillovers through changes in capital inflows and exports of goods and services. For example, after a large liquidity squeeze following the Global Financial Crisis (GFC), emerging markets witnessed substantial devaluations of their currencies. They were, however, far from able to eliminate all the consequences of financial shocks originating in the developed world (see [Ozkan and Unsal, 2017](#)).

In this paper, I propose a two-country Dynamic Stochastic General Equilibrium (DSGE) model featuring the interconnectedness between the advanced and emerging market economies and derive the quantitative effects of the monetary policy shocks originating in an advanced economy - its conventional monetary policy and asset purchasing programs.

My model explicitly incorporates network effects in both trade and finance for a comprehensive analysis of the sources of fluctuations in an emerging economy followed by monetary policy adjustments in an advanced economy. My model specification of an emerging economy differs from an advanced economy in two ways. First, I assume that a larger proportion of long-term debt held by an emerging economy is denominated in a currency of the advanced economy. Second, the adverse attitude of policymakers in emerging economies towards large exchange rate fluctuations is explicitly taken into account in the model by utilizing a modified Taylor rule that responds to changes in the nominal exchange rate, as suggested by, for example, [Ghosh et al. \(2016\)](#).

I start my analysis with a benchmark specification of the model, in which cross-

country linkages are limited to trade in consumer goods. I then extend the model by incorporating global supply chains that feature domestically-produced and imported intermediate inputs, which are used to produce intermediate goods combined with labor inputs and physical capital.

Sizable literature argues that the standard New-Keynesian models perform poorly in replicating the international business cycles (see, for example, [Justiniano and Preston, 2010](#), [Gornemann et al., 2016](#), [Alpanda and Aysun, 2014](#), or [Kollmann et al., 2016](#)). Motivated by these findings, I introduce explicit cross-border flows of financial assets between banks with financial frictions similar to [Karadi and Nakov \(2021\)](#). Allowing for cross-border capital flows - domestic banks lending to both domestic and foreign intermediate goods producers - introduces a strong degree of financial interconnectedness between the two countries, significantly increasing the cross-country co-movement.

I calibrate the model to the US economy and Turkey to consider the spillovers of the US monetary policy to Turkey and the policy response in Turkey to the US monetary policy. Calibrating my framework with data from the US and Turkey yields several interesting findings on the pattern of international transmission of monetary policy shocks originating in the US and spilling over to an emerging economy such as Turkey.

To simulate the effects of the US monetary policy, I use a conditional forecast - a method of simulating the responses of model variables for a given constrained path of an endogenous variable or variables of choice. This is done by finding a shock or structural shocks of choice needed to match the restricted paths. For the purpose of the conditional forecast exercises presented in [Chapter 3.7](#), I use stochastic simulations of US monetary policy between the years 2003 and 2023 - the Fed's risk-free interest rate and the share of long-term bonds held by the Fed relative to the US GDP. Using the conditional forecasts, I study the effects of the US conventional monetary policy and asset purchases by the US Fed and their spillovers to Turkey.

There exists important empirical evidence on the spillovers of the US conventional monetary policy to emerging markets (see, for example, [Albagli et al., 2019](#), [Ozkan and Unsal, 2012](#), [Georgiadis, 2016](#), [Walerych and Wesołowski, 2021](#)). However, not until the recent years, many of the world's central banks, mainly in the advanced world, have built up significant balance sheets to lessen the macroeconomic disturbances following

the GFC or the European sovereign debt crisis. The literature on the spillovers of the Fed asset purchases to emerging markets is still very limited (see, for example, [Kolasa and Wesolowski, 2020](#) or [Chen et al., 2016](#)).

Recently announced by the Federal Open Market Committee partial reversal of the asset purchasing program of the Fed has important implications outside the US. The decision to cease re-investments of maturing securities is projected to significantly reduce the Federal Reserve's balance sheet. However, the scale of the balance sheet tapering is still uncertain.⁴¹ Although limited from the perspective of the real economy (see [Chen et al., 2012](#)), asset purchases by the US Fed have important consequences on financial markets - a vital transmission channel of shocks to emerging markets.

I build three versions of the model: (i) in which cross-country linkages are limited to trade in consumer goods; (ii) with local and imported intermediate inputs used in the production of local intermediate goods; (iii) with both the supply chains and financial linkages in the form of a share of domestic physical capital backed by foreign loans.

My framework employs conditional forecasts to simulate the effects of the US conventional monetary policy over the years 2003-23 and those of asset purchases by the Fed over the same period and result in several significant findings. First, I find that the financial channel is critical in driving the aggregate fluctuations in Turkey following the adjustments of the US monetary policy. Second, although some degree of sensitivity to the exchange rate fluctuations in the emerging markets is desirable following the adjustments of the US interest rate, my results suggest that it generally disadvantageous to attach a high weight on the nominal exchange rate following balance sheet adjustments by the Fed. Finally, financial frictions are important in driving the dynamics following the US. The calibration of the banking sector is crucial in driving the effects of the Fed's asset purchases, in particular, and their spillovers to the emerging economy.

The remainder of this paper is organized as follows: [Chapter 3.2](#) first presents the model of a two-country world without financial or supply chain linkages. Then [Chapter 3.3](#) outlines two extensions of the benchmark model: supply chains and

⁴¹While the duration of the tapering program is unknown, the reduction of the balance sheet has been announced to be at the speed of \$95 billion a month.

financial linkages. The detailed parameterization of the final model is outlined in [Chapter 3.4](#). [Chapter 3.5](#) describes the conditional forecast used to simulate the effects of the US monetary policy. [Chapter 3.6](#) presents the key results from examining the transmission of monetary policy shocks originating in the US and propagating through trade and credit channels to the Turkish economy. [Chapter 3.7](#) analyzes the results under alternative parameter values. I discuss my findings in [Chapter 3.8](#). Finally, [Chapter 3.9](#) concludes.

3.2 Two-country model with financial frictions

I consider a world consisting of two countries - domestic and foreign. Each country has households, competitive retailers, monopolistically competitive intermediate goods producers, financial intermediaries, and a government pursuing monetary and fiscal policies. Intermediate goods producers set prices on a staggered basis, introducing nominal rigidities into the model economy in a manner similar to [Calvo \(1983\)](#).

In what follows, I present a model description of the domestic economy. I use the asterisk (*) to identify variables associated with the foreign economy where necessary. The model blocks of both countries are mirror images of each other.

3.2.1 Households

I assume a unit continuum of identical households that have ‘external’ habits. That is, their utility in period t depends on aggregate consumption from the previous period $\bar{C}_{t-1}$. Households maximize their utility with respect to consumption C_t , hours worked H_t , short-term assets B_t ⁴², and long-term bonds $B_{h,t}$:

$$\max_{C_t, H_t, B_t, B_{h,t}} \mathbb{E}_t \sum_{k=0}^{\infty} \beta^k \left[\frac{(C_{t+k} - h\bar{C}_{t+k-1})^{1-\sigma_c}}{1-\sigma_c} - \vartheta \frac{H_{t+k}^{1+\varphi_h}}{1+\varphi_h} \right] \quad (3.2.1)$$

where $0 < \beta < 1$ is the discount factor; $\sigma_c > 0$ is the inverse of the elasticity of intertemporal substitution of consumption; $\vartheta > 0$ denotes the disutility from supplying

⁴²Short-term bonds issued by the government and bank deposits both fall under the category of short-term assets. They are both risk-free and, therefore, perfect substitutes.

labor to intermediate goods producers; and $\varphi_h > 0$ is the inverse of the Frisch elasticity of labor supply.

The maximization of the households' utility (3.2.1) is subject to a sequence of intertemporal budget constraints of the form:

$$C_t + B_t + B_{h,t} = W_t H_t + R_{b,t} B_{h,t-1} - \frac{1}{2} \kappa (B_{h,t} - \bar{B}_h)^2 + R_t B_{t-1} + \Pi_t \quad (3.2.2)$$

where W_t is the real wage; $R_{b,t}$ and R_t are returns on long-term and short-term bonds, respectively, where the latter is the risk-free rate; $\bar{B}_h$ is the steady-state value of long-term bonds held by households while $\kappa \geq 0$ governs the sensitivity of the quadratic transaction cost associated with purchases or sales of long-term bonds; and Π_t are real profits from the ownership of domestic firms.

The households' optimization problem results in the following marginal utility with respect to consumption (equation 3.2.3), optimal supply of labor (equation 3.2.4), Euler equation associated with the optimal holdings of short-term assets (equation 3.2.5), and optimal holdings of long-term bonds (equation 3.2.6):

$$q_t = (C_t - hC_{t-1})^{-\sigma_c} - \beta h \mathbb{E}_t (C_{t+1} - hC_t)^{-\sigma_c} \quad (3.2.3)$$

$$\chi H_t^\varphi = q_t W_t \quad (3.2.4)$$

$$1 = \mathbb{E}_t [\Lambda_{t,t+1} R_{t+1}] \quad (3.2.5)$$

$$B_{h,t} = \bar{B}_h + \kappa^{-1} \mathbb{E}_t [\Lambda_{t,t+1} (R_{b,t+1} - R_{t+1})] \quad (3.2.6)$$

where $\Lambda_{t,t+1} \equiv \beta \frac{q_{t+1}}{q_t}$ is the discount factor.

Households consume domestic and foreign goods. The purchases of domestic and imported consumer goods are, respectively:

$$C_{h,t} = \gamma_h \left[\frac{P_{h,t}}{P_t} \right]^{-\varepsilon_c} C_t \quad (3.2.7)$$

$$C_{f,t} = (1 - \gamma_h) \left[\frac{P_{f,t}}{P_t} \right]^{-\varepsilon_c} C_t \quad (3.2.8)$$

where $0 < \gamma_h < 1$ is the share of domestically-produced goods in total consumption; $P_{h,t}$ is the price of a domestically-produced final good; $P_{f,t} = s_t P_{h,t}^*$ is the domestic

price of the foreign-produced final good, in which s_t is the price of a unit of a foreign currency expressed in the number of units of the domestic currency; P_t is the domestic Consumer Price Index (CPI); and $\varepsilon_c > 1$ is the elasticity of substitution between domestic and imported consumer goods.

3.2.2 Firms

Retailers

Competitive retailers purchase differentiated goods from intermediate goods producers and combine them into a homogeneous final good. The following CES aggregate of a continuum of differentiated intermediate goods gives the aggregate output of retailers XR_t :

$$XR_t = \left[\int_0^1 XR_t(v)^{\frac{\mu-1}{\mu}} dv \right]^{\frac{\mu}{\mu-1}} \quad (3.2.9)$$

where $\mu > 1$ is the elasticity of substitution between the varieties of intermediate goods common to all retailers.

Each period, domestic retailers maximize their profits, defined as the difference between the revenues from the sales of goods and the cost of purchases of the varieties of intermediate goods from the domestic intermediate goods producers. Hence, the profit maximization problem of domestic retailers is:

$$\max_{XR_t(v)} \left[P_{h,t} XR_t - \int_0^1 P_{h,t}(v) XR_t(v) dv \right] \quad (3.2.10)$$

where $P_{h,t}(v)$ is the price of a domestically-produced differentiated good produced by a representative local intermediate good producer v . The first-order condition of the retailers' profit maximization problem yields the following retailers' demand for a typical variety of the intermediate good produced by the representative firm v :

$$XR_t(v) = \left[\frac{P_{h,t}(v)}{P_{h,t}} \right]^{-\mu} XR_t \quad (3.2.11)$$

Finally, following the zero-profit condition, the price of the final good can be defined by:

$$P_{h,t} = \left[\int_0^1 P_{h,t}(v)^{1-\mu} dv \right]^{\frac{1}{1-\mu}} \quad (3.2.12)$$

Intermediate goods producers

Intermediate goods producers combine physical capital K_t with labor inputs H_t and transform them into a distinctive good:

$$X_t(v) = K_t(v)^\alpha H_t(v)^{1-\alpha} \quad (3.2.13)$$

where α is the share of capital in technology.

Intermediate goods producers face the common wage rate W_t and the rental price of capital $Z_{k,t}$ and plan their future production with the goal of minimizing cost. Given that all intermediate goods producers are identical, the first-order conditions in real terms are given by:

$$Z_{k,t} = mc_t \alpha \frac{X_t}{K_t} \quad (3.2.14)$$

$$W_t = mc_t (1 - \alpha) \frac{X_t}{H_t} \quad (3.2.15)$$

All intermediate goods producers operate in a monopolistically competitive market structure and only update their prices with a constant probability $0 < (1 - \theta_p) \leq 1$ along the lines of [Calvo \(1983\)](#). This suggests that, on average, prices cannot be updated for $k \equiv \frac{1}{1-\theta_p}$ periods. Firms that cannot reoptimize in a given period keep their price from the previous period $t - 1$.

Price dispersion between the prices of individual intermediate goods producers and the aggregate price index results in the following relation between retail output XR_t and technology-based production X_t :

$$XR_t = X_t / v_{p,t} \quad (3.2.16)$$

Since v_t^p - the measure of price dispersion - is greater or equal to zero, price dispersion results in an output loss – intermediate goods producers produce less output sold to the retailers than they would given aggregate inputs of labor and physical capital if prices are dispersed.

With the probability $(1 - \theta_p)$ a representative firm v updates its price to the optimal level $\tilde{P}_t$ and with the probability θ_p it maintains its price from the previous period,

which yields the following price index:

$$P_t = \left[\theta_p P_{t-1}^{1-\mu} + (1 - \theta_p) \tilde{P}_t^{1-\mu} \right]^{\frac{1}{1-\mu}} \quad (3.2.17)$$

This optimization by the local intermediate goods producers is subject to the demand schedules consistent with aggregators' maximization problem outlined above, common to all domestic intermediate goods producers. When they can update their prices, intermediate goods producers choose the price $\tilde{P}_t$ for which real profits from retail sales are maximized given the number of periods k when the price is expected to remain unchanged.

Capital goods producers

Capital goods producers incur a quadratic investment adjustment cost per unit of investment defined as:

$$f\left(\frac{I_t}{I_{t-1}}\right) \equiv \frac{\eta_i}{2} \left[\frac{I_t}{I_{t-1}} - 1 \right]^2 \quad (3.2.18)$$

where $\eta_i > 0$ is the adjustment cost parameter.

Capital goods producers maximize their present discounted profits by choosing the optimal quantity of investment by solving the following profit maximization problem:

$$\max_{I_t} \mathbb{E}_t \sum_{t=0}^{\infty} \Lambda_{t,t+1} \left[Q_t I_t - \left[1 + f\left(\frac{I_t}{I_{t-1}}\right) \right] I_t \right] \quad (3.2.19)$$

where Q_t is the price of a security that finances the purchase of a unit of physical capital.

The optimality condition yields the following Q -investment relation for capital goods:

$$Q_t = 1 + f\left(\frac{I_t}{I_{t-1}}\right) + \frac{I_t}{I_{t-1}} f'\left(\frac{I_t}{I_{t-1}}\right) - \mathbb{E}_t \left[\Lambda_{t,t+1} \left(\frac{I_{t+1}}{I_t}\right)^2 f'\left(\frac{I_{t+1}}{I_t}\right) \right] \quad (3.2.20)$$

The following law of motion equation gives the aggregate capital stock in period t :

$$K_t = I_t \left[1 - f\left(\frac{I_t}{I_{t-1}}\right) \right] + (1 - \delta) K_{t-1} \quad (3.2.21)$$

where $0 < \delta < 1$ is the depreciation rate of capital.

Intermediate producers finance their investment plans by borrowing from banks to purchase physical capital from capital goods producers. At the end of t , firms purchase new capital at a price Q_t issuing a claim for each unit. Consequently, the assets in the banking sector are backed by the amount of physical capital and $S_t = K_t$.

The return on physical capital resulting from the intermediate goods producers' optimal demand for physical capital backed by financial assets is:

$$R_{k,t+1} = \frac{[Z_{k,t+1} + (1 - \delta)Q_{t+1}]}{Q_t} \quad (3.2.22)$$

3.2.3 Banks

As part of their asset portfolio, financial intermediaries keep capital-backed financial assets and hold long-term government bonds $B_{b,t}$. The liabilities part of their balance sheet is composed of households' deposits D_t and the net worth N_t :

$$Q_t S_t + q_t B_{b,t} = N_t + D_t \quad (3.2.23)$$

where q_t is the unit price of the government long-term bonds with coupon payments Ξ and rate of decay $0 < \varrho < 1$, which can be linked to the return on long-term bonds using the following formula:

$$R_{b,t+1} = \frac{\Xi + \varrho q_{t+1}}{q_t} \quad (3.2.24)$$

The net worth evolves according to the following rule:

$$N_t = R_{k,t} Q_{t-1} S_{t-1} + R_{b,t} q_{t-1} B_{b,t-1} - R_t D_{t-1} + J_{t-1} \quad (3.2.25)$$

where J_t represents the issuance of new equity.

From equation (3.2.23) deposits are given by:

$$D_t = Q_t S_t + q_t B_{b,t} - N_t \quad (3.2.26)$$

So, by substituting the definition of deposits from (3.2.26) in $t - 1$ into (3.2.25), the net

worth becomes:

$$N_t = (R_{k,t} - R_t)Q_{t-1}S_{t-1} + (R_{b,t} - R_t)q_{t-1}B_{b,t-1} + R_tN_{t-1} + J_t \quad (3.2.27)$$

The end-of-period value function with the issuance of new equity J_t conditional on the survival of the bank is:

$$\mathcal{V}_t(N_t) = \max_{S_t, J_t, D_t} \mathbb{E}_t \left[\Lambda_{t,t+1} \left[\begin{array}{c} (1 - \sigma)N_{t+1} \\ + \sigma(\mathcal{W}_{t+1}(N_{t+1}) - J_t - C(J_t, N_t)) \end{array} \right] \right] \quad (3.2.28)$$

where the cost of equity issuance $C(J_t, N_t) \equiv \frac{\zeta}{2} \xi_t^2 N_t$ is linear in the banks' net worth N_t , quadratic in the share of new equity issuance relative to outstanding equity $\xi \equiv J_t/N_t$ and its level is governed by a parameter $\zeta > 0$. The cost disincentivizes the bank from large equity issuance.

The bank's ability to obtain deposits is limited by the risk faced by the depositors and linked to the possibility of the bank diverting a share $0 < \theta < 1$ of funds from the assets it holds to the household that owns the bank. The risk to the intermediary of diverting funds is that the depositors can force the bank into bankruptcy and recover the remaining fraction of assets. Therefore, I assume it is easier for the bank to divert funds from its holdings of private bonds than from its holding of government bonds. In particular, it can divert the fraction θ of its private bond portfolio and the fraction $\Gamma\theta$ with $0 \leq \Gamma \leq 1$, from its government bond portfolio. The bankers' maximization problem is to choose their portfolio of S_t and $B_{b,t}$ to maximize $\mathcal{V}_t(N_t)$ subject to the following incentive constraint⁴³:

$$\mathcal{V}_t(N_t) \geq \theta Q_t S_t + \Gamma \theta q_t B_{b,t} \quad (3.2.29)$$

and to choose their equity issuance J_t to maximize $\mathcal{W}_{t+1}(N_{t+1})$ subject to the definition of net worth given by (3.2.27); assuming at the same time the existence of a linear solution of the form $\mathcal{V}_t = \mu_{s,t} Q_t S_t + \mu_{b,t} q_t B_{b,t} + v_t N_t$ and $\mathcal{W}_t = \eta_t N_t$.

Let v_t be the Lagrange multiplier associated with the incentive constraint (3.2.29),

⁴³The left side is of (3.2.29) is the value of what the banker would lose by diverting a fraction of assets. The right side is the gain from doing so.

$\lambda_t = v_t / (1 + v_t)$ and Ω_{t+1} the term that augments the banks' discount factor relative to the household's discount factor. Then, the bank's optimization problem is solved by guessing a linear value function on assets and deposits:

$$\mathcal{V}_t(S_t, B_{b,t}, N_t) = \mu_{s,t} Q_t S_t + \mu_{b,t} q_t B_{b,t} + v_t N_t \quad (3.2.30)$$

The first-order conditions with respect to S_t , $B_{b,t}$, v_t and are expressed as follows:

$$\mu_{s,t} = \theta \frac{v_t}{1 + v_t} \quad (3.2.31)$$

$$\mu_{b,t} = \Gamma \frac{v_t}{1 + v_t} \quad (3.2.32)$$

$$\theta Q_t S_t + \Gamma \theta q_t B_{b,t} - \mu_{s,t} Q_t S_t - \mu_{b,t} q_t B_{b,t} - v_t N_t = 0 \quad (3.2.33)$$

where v_t is the value of banks' net worth (see equation 3.2.41).

Then the solution can be characterized as follows: at the end of each period, an individual bank maximizes the present value of its future dividends given the quadratic cost of equity issuance:

$$\begin{aligned} \mathcal{V}_t(N_t) = \max_{S_t, J_t, D_t} \mathbb{E}_t \left[\Lambda_{t,t+1} \left[(1 - \theta_b) N_{t+1} + \theta_b \left(\mathcal{W}_{t+1}(N_{t+1}) - J_t - \frac{\zeta}{2} \frac{J_t^2}{N_t} \right) \right] \right] \\ \text{s.t. } \mathcal{V}_t(S_t, B_{b,t}, N_t) \geq \theta Q_t S_t + \Gamma \theta q_t B_{b,t} \end{aligned} \quad (3.2.34)$$

$$\text{for } N_{t+1} = (R_{k,t+1} - R_{t+1}) Q_t S_t + (R_{b,t+1} - R_{t+1}) q_t B_{b,t} + R_{t+1} N_t + J_t$$

Definitions:

$$\eta_t \equiv \frac{\partial \mathcal{V}_t}{\partial N_t}, \quad \zeta_t \equiv \frac{J_t}{N_t}, \quad \lambda_t \equiv \eta_t (1 - \lambda_t), \quad \Omega_t \equiv (1 - \theta_b) + \theta_b \eta_t \quad (3.2.35)$$

The first-order condition of the optimization problem of banks with respect to assets S_t is:

$$\mathbb{E}_t [\Lambda_{t,t+1} \Omega_{t+1} (R_{k,t+1} - R_{t+1})] = \theta \lambda_t \quad (3.2.36)$$

The first-order condition with respect to long-term bonds held by banks $B_{b,t}$ is:

$$\mathbb{E}_t [\Lambda_{t,t+1} \Omega_{t+1} (R_{b,t+1} - R_{t+1})] = \theta \Gamma \lambda_t \quad (3.2.37)$$

The objective of the banker is also to issue equity J_t in order to maximize $\mathcal{W}_{t+1}(N_{t+1})$ subject to the definition of net worth given by equation (3.2.26):

$$\max_{J_t} \mathbb{E}_t \left[\Lambda_{t,t+1} \left[\Omega_{t+1} \left[\begin{array}{l} (R_{k,t+1} - R_{t+1})Q_t S_t \\ + (R_{b,t+1} - R_{t+1})q_t B_{b,t} \\ + R_{t+1}N_t + J_t \end{array} \right] - J_t - \frac{\zeta}{2} \frac{J_t^2}{N_t} \right] \right] \quad (3.2.38)$$

It is, therefore, assumed that the equity is issued and the cost of equity is paid only by the surviving banks. So, conditional the bank has survived to $t + 1$, the amount of equity it issues in t is such that the bank maximizes $\mathcal{W}_{t+1}(N_{t+1}) = \eta_{t+1}N_{t+1}$ subject to the cost of equity issuance.

The first-order condition with respect to the cost of equity issuance J_t is:

$$\tilde{\zeta}_t = \frac{\mathbb{E}_t \Lambda_{t,t+1} (\Omega_{t+1} - 1)}{\zeta} \quad (3.2.39)$$

Since the shadow value of net worth η_t is defined as a derivative of the value function $\mathcal{V}_t$ with respect to net worth, it follows that:

$$\eta_t \equiv \frac{\partial \mathcal{V}_t}{\partial N_t} \Rightarrow \eta_t = \mathbb{E}_t [\Lambda_{t,t+1} \Omega_{t+1} R_{t+1}] + \frac{\zeta}{2} \tilde{\zeta}_t^2 + \lambda_t \eta_t \quad (3.2.40)$$

The marginal value of the intermediaries' net worth v_t is given by:

$$v_t = \mathbb{E}_t [\Lambda_{t,t+1} \Omega_{t+1} R_{t+1}] + \frac{\mathbb{E}_t [\Lambda_{t,t+1} \Omega_{t+1} - 1]^2}{2\zeta} \quad (3.2.41)$$

Finally, since $\mathcal{V}_t = \eta_t N_t$ and (3.2.29) holds with equality, it follows that $\eta_t = \theta \phi_t$, where ϕ_t is the measure of banks' leverage defined as:

$$\phi_t \equiv \frac{Q_t S_t + \Gamma q_t B_{b,t}}{N_t} \quad (3.2.42)$$

From equation (3.2.40) I get that $\eta_t(1 - \lambda_t) = v_t$. After substituting $v_t/(1 - \lambda_t)$ for η_t in $\eta_t = \theta \phi_t$, I get the following expression for the multiplier λ_t :

$$\lambda_t = 1 - \frac{v_t}{\theta \phi_t} \quad (3.2.43)$$

3.2.4 Monetary and fiscal authorities

I assume that the monetary policy is conducted according to a standard Taylor rule, which implies that the deviations of the risk-free interest rate R_t from its deterministic steady state R respond to the deviations of inflation π_t from its deterministic steady-state value π , allowing additionally for interest rate smoothing:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_r} \left[\left(\frac{\pi_t}{\pi} \right)^{\varphi_\pi} \right]^{1-\rho_r} \exp(\sigma_{r,t}) \quad (3.2.44)$$

where $0 \leq \rho_r \leq 1$ is the smoothing parameter; $\varphi_\pi > 0$ describes the central bank's weight on the deviations of inflation; and $\sigma_{r,t}$ is the conventional monetary policy shock in the form of a one-off innovation to the risk-free rate with a zero mean.

The domestic government exogenously fixes its spending on the domestic final good G by spending a fixed share τ on retail goods:

$$G_t = \tau X R_t \quad (3.2.45)$$

3.2.5 Clearing conditions

The government issues short-term and long-term bonds. Aggregate long-term bonds are at the fixed quantity at all times B . Government-held bonds B_g are fixed endogenously. A greater share of government-held bonds in aggregate long-term bonds implies less debt held by banks and households. The clearing condition of long-term bonds held by government, households, and banks is:

$$B = B_{g,t} + B_{h,t} + B_{b,t} \quad (3.2.46)$$

I introduce the following clearing conditions of the retail goods market in the domestic economy:

$$X R_t = C_{h,t} + C_{h,t}^* + G_t + I_t \left[1 + f \left(\frac{I_t}{I_{t-1}} \right) \right] + \frac{\zeta}{2} \tilde{\zeta}_t^2 N_t \quad (3.2.47)$$

which means that total retail output equals the sum of the demands for domestic goods of all the households from both countries, domestic government spending, investment

in physical capital, and the cost of new equity issuance.

Additionally, because of a full segmentation of the bonds markets in each model economy, I maintain that the goods trade between any pair of countries is balanced - a common practice in the literature abstracting from cross-country financial linkages as is common in the models that abstract from international financial linkages (see, for example, [Clarida, 2019](#); [Auray et al., 2020](#); or [Feng and Lin, 2013](#)).

3.3 Extensions

3.3.1 Supply chains

Take the Leontief technology with capital K_t , labor H_t , and intermediate inputs X_t^s combined as follows:

$$X_t(v) = \left[\frac{K_t(v)^\alpha H_t(v)^{1-\alpha}}{1 - \varphi_i}, \frac{X_t^s(v)}{\varphi_i} \right] \quad (3.3.48)$$

where $0 < \varphi_i < 1$ is the share of intermediate inputs in technology.

Intermediate inputs are in the form of both domestic and foreign supplies. Therefore, X_t^s is a composite index of supplies used in domestic production and disaggregated into goods delivered by the domestic retailers $X_{h,t}^s$ or goods imported from abroad $X_{f,t}^s$:

$$X_t^s(v) = \left[\omega_h^{\frac{1}{\varepsilon_s}} (X_{h,t}^s(v))^{\frac{\varepsilon_s-1}{\varepsilon_s}} + (1 - \omega_h)^{\frac{1}{\varepsilon_s}} (X_{f,t}^s(v))^{\frac{\varepsilon_s-1}{\varepsilon_s}} \right]^{\frac{\varepsilon_s}{\varepsilon_s-1}} \quad (3.3.49)$$

where $0 \leq \omega_h \leq 1$ denotes the share of local supplies in the total use of supplies and $\varepsilon_s > 0$ is the Armington elasticity of substitution between domestic and imported supplies.

In a fashion similar to consumer goods, the optimal demands for domestically-produced and imported intermediate inputs - $X_{h,t}^s$ and $X_{f,t}^s$, respectively, common to all domestic goods producers are:

$$X_{h,t}^s = \omega_h \left[\frac{P_{h,t}}{P_t} \right]^{-\varepsilon_s} X_t^s \quad (3.3.50)$$

$$X_{f,t}^s = (1 - \omega_h) \left[\frac{s_t P_{f,t}}{P_t} \right]^{-\varepsilon_s} X_t^s \quad (3.3.51)$$

Given the properties of the Leontief specification, cost minimization requires that output is produced using equal shares of each input at all times. It, therefore, implies that the value added explains a fixed share $(1 - \varphi_i)$ of output:

$$K_t(v)^\alpha H_t(v)^{1-\alpha} = (1 - \varphi_i) X_t(v) \quad (3.3.52)$$

and the share of intermediate inputs in output equals φ_i at all times:

$$X_t^s(v) = \varphi_i X_t(v) \quad (3.3.53)$$

The cost function is the sum of inputs multiplied by their corresponding unit prices:

$$C_t(v) = Z_{k,t} K_t(v) + W_t H_t(v) + P_t^s X_t^s(v) \quad (3.3.54)$$

where P_t^s is the price index of intermediate inputs, which can be associated with a Producer Price Index (PPI).

Solving the first-order condition (3.3.52) for capital $K_t(v)$ yields:

$$K_t(v) = \left[(1 - \varphi_i) \frac{X_t(v)}{H_t(v)^{1-\alpha}} \right]^{\frac{1}{\alpha}} \quad (3.3.55)$$

so that the cost function becomes:

$$C_t(v) = Z_{k,t} \left[(1 - \varphi_i) \frac{X_t(v)}{H_t(v)^{1-\alpha}} \right]^{\frac{1}{\alpha}} + W_t H_t(v) + P_t^s X_t^s(v) \quad (3.3.56)$$

The first-order condition of the cost-minimization problem with respect to labor is:

$$W_t = Z_{k,t} \frac{1-\alpha}{\alpha} \left[(1 - \varphi_i) \frac{X_t(v)}{H_t(v)^{1-\alpha}} \right]^{\frac{1}{\alpha}} \quad (3.3.57)$$

So, the optimal use of labor in technology $\tilde{H}_t(v)$ by a representative producer is given by:

$$\tilde{H}_t(v) = (1 - \varphi_i) \left[\frac{1-\alpha}{\alpha} \frac{Z_{k,t}}{W_t} \right]^\alpha X_t(v) \quad (3.3.58)$$

Substituting for $H_t(v)$ in equation (3.3.57) the optimal demand for labor $\tilde{H}_t(v)$ yields the optimal use of capital $\tilde{K}_t(v)$ in technology:

$$\tilde{K}_t(v) = (1 - \varphi_i) \left[\frac{\alpha}{1 - \alpha} \frac{W_t}{Z_{k,t}} \right]^{1-\alpha} X_t(v) \quad (3.3.59)$$

Substituting for $H_t(v)$ and $K_t(v)$ in the cost function their optimal quantities - $\tilde{H}_t(v)$ and $\tilde{K}_t(v)$ - and using condition (3.3.53) yields:

$$\begin{aligned} C_t(v) = & Z_{k,t} (1 - \varphi_i) \left[\frac{W_t}{Z_{k,t}} \frac{\alpha}{1 - \alpha} \right]^{1-\alpha} X_t(v) \\ & + W_t (1 - \varphi_i) \left[\frac{Z_{k,t}}{W_t} \frac{1 - \alpha}{\alpha} \right]^\alpha X_t(v) + P_t^s \varphi_i X_t(v) \end{aligned} \quad (3.3.60)$$

The marginal cost is the derivative of the cost function with respect to output $X_t(v)$, which can be simplified into the following formula with the weighted unit cost of value-added and intermediate inputs:

$$mc_t(v) = (1 - \varphi_i) \frac{Z_{k,t}^\alpha W_t^{1-\alpha}}{\alpha^\alpha (1 - \alpha)^{1-\alpha}} + \varphi_i P_t^s \quad (3.3.61)$$

3.3.2 Financial linkages

Assume that physical capital K_t is divided into local and export capital - $K_{h,t}$ and $K_{f,t}$, respectively - according to the following rule:

$$K_t(v) = \left[\varphi_k K_{h,t-1}(v)^{\frac{\eta_k-1}{\eta_k}} + (1 - \varphi_k) K_{f,t-1}(v)^{\frac{\eta_k-1}{\eta_k}} \right]^{\frac{\eta_k}{\eta_k-1}} \quad (3.3.62)$$

where $0 < \varphi_k < 1$ is the share of local capital and $\eta_k \geq 1$ is the elasticity of substitution between local and export capital.

Under the assumption of a CES function, which aggregates local and export capital into $K_t(v)$, I get the following optimal demands for local and export capital:

$$K_{h,t}(v) = \varphi_k \left[\frac{Z_{h,t}}{Z_{k,t}} \right]^{-\eta_k} K_t(v) \quad (3.3.63)$$

$$K_{f,t}(v) = (1 - \varphi_k) \left[\frac{Z_{f,t}}{Z_{k,t}} \right]^{-\eta_k} K_t(v) \quad (3.3.64)$$

where $Z_{h,t}$ is the price of local capital, $Z_{f,t}$ is the price of export capital, and $Z_{k,t}$ is the price index of physical capital

The cost function is the sum of inputs multiplied by their corresponding unit prices:

$$C_t(v) = Z_{k,t}K_{h,t}(v) + Z_{k,t}K_{f,t}(v) + W_tH_t(v) + P_t^s X_t^s(v) \quad (3.3.65)$$

Substituting for $K_{h,t}$ and $K_{f,t}$ the optimal demands for local and export capital (equations 3.3.63 and 3.3.64) and assuming $Z_{h,t} = Z_{f,t}$ results in the following cost function:

$$C_t(v) = Z_{k,t}^{1-\eta_k} K_t(v) + W_tH_t(v) + P_t^s X_t^s(v) \quad (3.3.66)$$

Solving the first-order condition of the cost minimization problem for capital $K_t(v)$ yields:

$$K_t(v) = \left[(1 - \varphi_i) \frac{X_t(v)}{H_t(v)^{1-\alpha}} \right]^{\frac{1}{\alpha}} \quad (3.3.67)$$

The first-order condition of the cost-minimization problem with respect to labor $H_t(v)$ gives the following optimal use of labor in technology $\tilde{H}_t(v)$ by a representative producer:

$$\tilde{H}_t(v) = (1 - \varphi_i) \left[\frac{1 - \alpha}{\alpha} \frac{Z_{k,t}}{W_t} \right]^{\alpha} X_t(v) \quad (3.3.68)$$

Substituting for $H_t(v)$ in equation (3.3.67) the optimal demand for labor $\tilde{H}_t(v)$ yields the optimal use of capital $\tilde{K}_t(v)$ in technology:

$$\tilde{K}_t(v) = (1 - \varphi_i) \left[\frac{\alpha}{1 - \alpha} \frac{W_t}{Z_{k,t}} \right]^{1-\alpha} X_t(v) \quad (3.3.69)$$

Substituting for $H_t(v)$ and $K_t(v)$ in the cost function their optimal quantities - $\tilde{H}_t(v)$ and $\tilde{K}_t(v)$ - and using $X_t^s = \varphi_i X_t$ yields:

$$\begin{aligned} C_t(v) = & Z_{k,t}^{1-\eta_k} (1 - \varphi_i) \left[\frac{W_t}{Z_t} \frac{\alpha}{1 - \alpha} \right]^{1-\alpha} X_t(v) \\ & + W_t (1 - \varphi_i) \left[\frac{Z_{k,t}}{W_t} \frac{1 - \alpha}{\alpha} \right]^{\alpha} X_t(v) + P_t^s \varphi_i X_t(v) \end{aligned} \quad (3.3.70)$$

The marginal cost is the derivative of the cost function with respect to output $X_t(v)$:

$$\begin{aligned} \frac{\partial \mathcal{C}_t(v)}{\partial X_t(v)} = mc_t(v) = & Z_{k,t}^{1-\eta_k} (1 - \varphi_i) \left[\frac{W_t}{Z_t} \frac{\alpha}{1 - \alpha} \right]^{1-\alpha} \\ & + W_t (1 - \varphi_i) \left[\frac{Z_t}{W_t} \frac{1 - \alpha}{\alpha} \right]^\alpha + \varphi_i P_t^s \end{aligned} \quad (3.3.71)$$

which can be simplified into the following formula with the weighted unit cost of value-added and intermediate inputs:

$$mc_t(v) = (1 - \varphi_i) \frac{Z_{k,t}^\alpha W_t^{1-\alpha} (1 - \alpha + \alpha Z_{k,t}^{-\eta_k})}{\alpha^\alpha (1 - \alpha)^{1-\alpha}} + \varphi_i P_t^s \quad (3.3.72)$$

In the extension with two types of capital, domestic banks extend their lending to both domestic and foreign intermediate goods producers. They now hold two types of financial assets as part of their portfolio: (i) assets backed by local domestic capital and (ii) assets backed by foreign export capital:

$$S_{h,t-1} = K_{h,t} \quad (3.3.73)$$

$$S_{f,t-1} = K_{h,t}^* \quad (3.3.74)$$

As part of their asset portfolio on top of long-term bonds, financial intermediaries keep financial assets backed by local physical capital and foreign export capital. The liabilities part of their balance sheet is composed of deposits collected from households in both countries and the net worth N_t :

$$Q_t S_{h,t} + s_t Q_t^* S_{f,t} + q_t B_{b,t} = N_t + D_t \quad (3.3.75)$$

where the net worth evolves according to the following rule:

$$N_t = R_{k,t} Q_{t-1} S_{h,t-1} + R_{k,t}^* s_t Q_{t-1}^* S_{f,t-1} + R_{b,t} q_{t-1} B_{b,t-1} - R_t D_{t-1} + J_{t-1} \quad (3.3.76)$$

From (3.3.75) deposits are given by:

$$D_t = Q_t S_{h,t} + s_t Q_t^* S_{f,t} + q_t B_{b,t} - N_t \quad (3.3.77)$$

So, by substituting the definition of deposits from (3.3.74) in $t - 1$ into (3.3.73), the net worth becomes:

$$N_t = (R_{k,t} - R_t)Q_{t-1}S_{h,t-1} + (R_{k,t}^* - R_t)s_tQ_{t-1}^*S_{f,t-1} + (R_{b,t} - R_t)q_{t-1}B_{b,t-1} + R_tN_{t-1} + J_{t-1} \quad (3.3.78)$$

The end-of-period value function with the issuance of new equity J_t conditional on the survival of the bank is:

$$\mathcal{V}_t(N_t) = \max_{S_{h,t}, S_{f,t}, J_t, D_t} \mathbb{E}_t \left[\Lambda_{t,t+1} \left[\begin{array}{c} (1 - \sigma)N_{t+1} \\ + \sigma(\mathcal{W}_{t+1}(N_{t+1}) - J_t - C(J_t, N_t)) \end{array} \right] \right] \quad (3.3.79)$$

The bankers' maximization problem is to choose their portfolio of $S_{h,t}$, $S_{f,t}$, and $B_{b,t}$ to maximize $\mathcal{V}_t(N_t)$ subject to the following incentive constraint:

$$\mathcal{V}_t(N_t) \geq \theta(Q_tS_{h,t} + s_tQ_t^*S_{f,t}) + \Gamma\theta q_tB_{b,t} \quad (3.3.80)$$

and to choose their equity issuance J_t to maximize $\mathcal{W}_{t+1}(N_{t+1})$ subject to the definition of net worth given by (3.3.78); assuming at the same time the existence of a linear solution of the form $\mathcal{V}_t = \mu_{s,t}(Q_tS_{h,t} + s_tQ_t^*S_{f,t}) + \mu_{b,t}q_tB_{b,t} + v_tN_t$ and $\mathcal{W}_t = \eta_tN_t$.

The bank's optimization problem is solved by guessing a linear value function on assets and deposits:

$$\mathcal{V}_t(S_{h,t}, S_{f,t}, B_{b,t}, N_t) = \mu_{s,t}(Q_tS_{h,t} + s_tQ_t^*S_{f,t}) + \mu_{b,t}q_tB_{b,t} + v_tN_t \quad (3.3.81)$$

The first-order conditions with respect to $S_{h,t}$, $S_{f,t}$, $B_{b,t}$, v_t and are expressed as follows:

$$\mu_{s,t} = \theta \frac{v_t}{1 + v_t} \quad (3.3.82)$$

$$\mu_{b,t} = \Gamma \frac{v_t}{1 + v_t} \quad (3.3.83)$$

$$\theta(Q_tS_{h,t} + s_tQ_t^*S_{f,t}) + \Gamma\theta q_tB_{b,t} - \mu_{s,t}(Q_tS_{h,t} + s_tQ_t^*S_{f,t}) - \mu_{b,t}q_tB_{b,t} - v_tN_t = 0 \quad (3.3.84)$$

At the end of each period, an individual bank maximizes the present value of its

future dividends given the quadratic cost of equity issuance:

$$\begin{aligned}
 \mathcal{V}_t(N_t) = \max_{S_{h,t}, S_{f,t}, J_t, D_t} \mathbb{E}_t \left[\Lambda_{t,t+1} \left[\begin{array}{c} (1 - \theta_b) N_{t+1} \\ + \theta_b \left(\mathcal{W}_{t+1}(N_{t+1}) - J_t - \frac{\zeta}{2} \frac{J_t^2}{N_t} \right) \end{array} \right] \right] \\
 \text{s.t. } \mathcal{V}_t(S_{h,t}, S_{f,t}, B_{b,t}, N_t) \geq \theta(Q_t S_{h,t} + s_t Q_t^* S_{f,t}) + \Gamma \theta q_t B_{b,t} \quad (3.3.85) \\
 \text{for } N_{t+1} = (R_{k,t+1} - R_{t+1}) Q_t S_{h,t} + (R_{k,t+1}^* - R_{t+1}) s_t Q_t^* S_{f,t} \\
 + (R_{b,t+1} - R_{t+1}) q_t B_{b,t} + R_{t+1} N_t + J_t
 \end{aligned}$$

The first-order condition of the optimization problem of banks with respect to $S_{h,t}$ is:

$$\mathbb{E}_t [\Lambda_{t,t+1} \Omega_{t+1} (R_{k,t+1} - R_{t+1})] = \theta \lambda_t \quad (3.3.86)$$

The first-order condition of the optimization problem of banks with respect to $S_{f,t}$ is:

$$\mathbb{E}_t [\Lambda_{t,t+1} \Omega_{t+1} s_t (R_{k,t+1}^* - R_{t+1})] = \theta \lambda_t \quad (3.3.87)$$

The first-order condition with respect to $B_{b,t}$ is:

$$\mathbb{E}_t [\Lambda_{t,t+1} \Omega_{t+1} (R_{b,t+1} - R_{t+1})] = \theta \Gamma \lambda_t \quad (3.3.88)$$

The conditions given by equations (3.3.86) and (3.3.87) result in the following interest rate parity between investment in local and foreign assets:

$$\mathbb{E}_t [\hat{s}_t + \hat{R}_{k,t+1}^*] = \mathbb{E}_t \hat{R}_{k,t+1} \quad (3.3.89)$$

where variables in hats denote log deviations from non-stochastic steady-state.

The objective of the banker is to issue equity to maximize $\mathcal{W}_{t+1}(N_{t+1})$ subject to (3.3.78):

$$\max_{J_t} \mathbb{E}_t \left[\Lambda_{t,t+1} \left[\Omega_{t+1} \left[\begin{array}{c} (R_{k,t+1} - R_{t+1}) Q_t S_t \\ + (R_{k,t+1}^* - R_{t+1}) s_t Q_t^* S_t^* \\ + (R_{b,t+1} - R_{t+1}) q_t B_{b,t} \\ + R_{t+1} N_t + J_t \end{array} \right] - J_t - \frac{\zeta}{2} \frac{J_t^2}{N_t} \right] \right] \quad (3.3.90)$$

The first-order conditions of which remain unchanged relative to the version of the model without lending to the foreign economy with the exception that now the banks' leverage ϕ_t is defined as:

$$\phi_t \equiv \frac{Q_t S_{h,t} + s_t Q_t^* S_{f,t} + \Gamma q_t B_{b,t}}{N_t} \quad (3.3.91)$$

3.4 Calibration

In this section, I outline the parametrization of the benchmark two-country model and its two extensions: (i) with supply chains and (ii) with both supply chains and financial linkages. The models are calibrated to the US economy and Turkey. I follow the standard practice of setting the parameters to match a number of key steady-state ratios observed in the data. Where it is possible, I base the parameter values on [Smets and Wouters \(2007\)](#) for the US economy, and [Elekdag and Alp \(2011\)](#) or [Çebi \(2012\)](#) for Turkey. The supply chain parameters are calculated using the 2016 World Input-Output Database (WIOD). In turn, the calibration of the credit network is based on data from the Quarterly Public Sector Debt Database (QPSD) of the World Bank and the Coordinated Portfolio Investment Survey (CPIS) of the IMF. The values of structural parameters corresponding to each model configuration are presented in [Table 3.1](#).

In [Chapter 3.5](#), I investigate the transmission of the US monetary policy shocks to the Turkish economy and highlight how trade and credit networks affect the cross-country spillovers. In effect, I run policy experiments using three versions of the model: (i) the benchmark model; (ii) the model with the trade network only; and (iii) the model with both the trade and financial networks. I use projections of a set of variables corresponding to the US and Turkish economies on the paths of the US policy rates and the ratio of the Fed's balance sheet to the US GDP (see [Bańbura et al., 2015](#)).

3.4.1 Parameters of households

I set the discount parameter β at 0.99, implying a 4% risk-free annualized quarterly steady-state interest rate. The inverse of the risk aversion coefficient σ_c is set to 1.38 in the US as in [Smets and Wouters \(2007\)](#), while in Turkey, the corresponding parameter is set equal to 3.35 as in [Çebi \(2012\)](#). The habit persistence parameter h is fixed at 0.71

in the US as in [Smets and Wouters \(2007\)](#) and 0.904 in Turkey as in [Elekdag and Alp \(2011\)](#). The inverse of the Frisch elasticity of labor supply φ_h in the US is set equal to 1.83, following [Smets and Wouters \(2007\)](#), while in Turkey, the same parameter takes the value of 1.530 as in [Çebi \(2012\)](#). The labor disutility parameters ϑ are fixed to match labor demand with the labor supply in the steady state.

The parameters of the home bias in consumption γ_h are calculated to match the shares of imports to GDP in both countries. The shares of domestic goods in the consumption basket are 99.1% and 94.8% in the US and Turkey, respectively. The remaining shares, i.e., 0.9% and 5.2%, are goods produced in Turkey and the US in the consumption baskets of the US and Turkish households, respectively. The elasticity of substitution between domestic and foreign consumer goods ε_c is fixed at 1.5 as in [Monacelli \(2004\)](#).

Assuming steady-state inflation π equal to unity, I maintain that coupons of long-term bonds held by households decay exponentially each period at the rate of ϱ equal 0.974 in the US. This implies the duration of long-term bonds in the US of 7.5 years as in [Chen et al. \(2012\)](#). Following [Dvorkin et al. \(2021\)](#), the average maturity of long-term bonds in emerging markets is 3.43 years. Therefore, I set ϱ associated with long-term Turkish bonds at 0.936. Finally, coupon payments of long-term bonds Ξ are 0.0359.

The model introduces the possibility of households investing in long-term bonds. Short-term bonds are in zero supply in the non-stochastic steady state, whereas the quantities of long-term bonds are calibrated to match the shares of long-term bonds to GDP based on the Quarterly Public Sector Debt (QPSD) data of the World Bank. I maintain that the steady-state ratio of long-term debt, which matures in one year or more, represents 104.27% of the US GDP and 25.97% of the Turkish GDP.

3.4.2 Parameters of producers

Labor shares α are based on the shares of the compensation of employees in total output and adjusted to match the steady-state investment to GDP ratios in each country based on the *2010 Regional Input-Output Data for Europe* as described in [Thissen et al. \(2018\)](#). In the US, the share of labor in output is 0.342. In Turkey, α is assumed to be 0.359.

The elasticity of substitution between domestic and foreign supplies ε_s is set equal to the households' elasticity of substitution between domestic and foreign goods ε_c .

The elasticity of substitution between intermediate goods η measures the degree of retailers' monopoly power in each country, where the markups in each region are calculated as the ratio between profits - the difference between the value of sales and the cost of goods sold. The elasticity of substitution parameters μ are then calculated as an inverse of the markups. In the US and Turkey, μ is 4.184 and 4.67, respectively. This comes from the calculation of markups of 23.9% and 21.4%, respectively.

The Calvo parameters are the equivalents of the probabilities of not receiving the price signal. For the US, the Calvo parameter is set equal to 0.92 as in [Karadi and Nakov \(2021\)](#), indicating the average resetting of prices every 37.5 months. In Turkey, the same probability takes the value of 0.88, implying that Turkish firms update prices every 25 months. The Calvo parameters are higher than the estimates from [Smets and Wouters \(2007\)](#) and [Çebi \(2012\)](#) of 0.66 in the US and 0.59 in Turkey. My model specifications assume perfectly competitive labor markets and no price indexation. Hence, higher values of the Calvo parameters.

The depreciation rate δ is set to the standard value of 0.025, as in [Faia and Monacelli \(2007\)](#), which implies annual capital depreciation of 10 percent. The investment adjustment cost parameter η_i is identical across countries and equal to 10 - the value similar to the estimates from [Smets and Wouters \(2005\)](#), or [Sala \(2015\)](#).

3.4.3 Parameters of banks

The calibration of banks is generally identical in both countries except for the duration of long-term bonds and the different values of financial assets in the US and Turkey. The parameters of financial intermediaries are based on [Karadi and Nakov \(2021\)](#).

I assume households hold three-quarters of long-term bonds in the steady state, and financial intermediaries hold the remaining quarter. Following [Karadi and Nakov \(2021\)](#), I further maintain that the banks' balance sheet constraints are loose in the non-stochastic steady state and, therefore, banks' equity is greater than the demand for credit. This implies that the governments have no incentive to hold long-term bonds in the steady state and that the lending spread equals zero.

The survival rate of banks σ is 0.972 in both countries, which implies the expected longevity of banks of 10 years, on average. The fraction of divertable funds θ is 1/6, which indicates the banks' leverage of 6. The transfers to entering bankers ω are

such that the interest rate premia are 0 in both countries. The relative absconding rate of government debt relative to private assets Γ is 0.83. The household portfolio adjustment costs κ are 0.009%. The equity issuance cost ζ is 28 in both countries as in [Akinci and Queralto \(2022\)](#).

3.4.4 Parameters of government

Calibration of the Taylor rule parameters is based on [Smets and Wouters \(2005\)](#) for the US and [Elekdag and Alp \(2011\)](#) for Turkey. The persistence of the nominal interest rate, ρ_r , is set at 0.91 in the US and 0.724 in Turkey. The sensitivity of interest rate changes to inflation, φ_π , is set at 2.04 in the US and 1.537 in Turkey.

Governments exogenously purchase a fixed proportion of output, contributing to aggregate demand for the domestic final good. The share of government spending of the retail production τ is calculated as the share of general government final consumption expenditure in GDP based on World Bank data. In the US, the share of government spending is 0.15. In Turkey, the corresponding percentage is 0.116.

Long-term bonds held by the governments B_g in both countries are assumed to be zero in the steady state. $B_{g,t}$, in turn, follows an autoregressive process with high persistence of asset purchase programs ρ_b of 0.99 as in [Kolasa and Wesołowski \(2020\)](#).

3.4.5 Parameters of the trade and credit network

I use data from the *EUREGIO* input-output database as in [Thissen et al. \(2018\)](#) to calibrate the key parameters of the global trade network for households and producers. The shares of intermediate inputs in output φ_i corresponding to the economies of the US and Turkey are, respectively, 0.241 and 0.350. I then break intermediate inputs down by the countries of their origin. In the US, domestic supplies represent 99.2% of total intermediate inputs. At the same time, in Turkey, the same parameter ω_h is 93.6%, indicating a relatively greater reliance of the Turkish economy on US-produced supplies. Consequently, I maintain that 0.8% of US supplies originally come from Turkey, while 6.4% of Turkish supplies are US-made.

The model with financial linkages offers the possibility of banks holding assets backed by foreign capital. Following [Kolasa and Wesołowski \(2020\)](#), I maintain that

Table 3.1: Calibrated parameters.

Parameter		USA	TUR	Source
<i>Benchmark model</i>				
Discount factor	β	0.990	0.990	Assumption
CRRA	σ_c	1.380	3.350	Smets and Wouters (2007); Çebi (2012)
Inverse Frisch elasticity	φ_h	1.830	1.530	Smets and Wouters (2007); Çebi (2012)
Labor disutility	ϑ	0.967	1.277	Target value
Habit persistence	h	0.710	0.904	Smets and Wouters (2007); Elekdag and Alp (2011)
e.o.s. domestic and foreign goods	ε_c	1.500	1.500	Monacelli (2004)
Share of domestic consumer goods	γ_h	0.991	0.948	Author's calculations
Coupon	ϱ	0.974	0.936	Author's calculation
Portfolio adjustment cost	κ	0.009	0.009	Karadi and Nakov (2021)
Coupon	Ξ	0.036	0.036	Karadi and Nakov (2021)
Cost of equity issuance parameter	ζ	28	28	Akinci and Queralto (2022)
Advantage in absconding rate	Γ	0.830	0.830	Karadi and Nakov (2021)
Labor share	α	0.392	0.439	Target value
e.o.s. intermediate inputs	μ	4.110	4.670	Author's calculations
Calvo parameter	θ_p	0.920	0.880	Assumption
Depreciation rate	δ	0.025	0.025	Faia and Monacelli (2007)
Investment adjustment cost	Ψ	10	10	Assumption
Government spending	τ	0.150	0.116	Author's calculations
Survival rate of banks	σ	0.972	0.972	Karadi and Nakov (2021)
Fraction of divertable funds	θ	0.167	0.167	Karadi and Nakov (2021)
Transfer to entering banks	ω	0.067	0.067	Karadi and Nakov (2021)
Interest rate smoothing	ρ_r	0.910	0.724	Smets and Wouters (2007); Çebi (2012)
Taylor rule parameter	φ_π	2.040	1.537	Smets and Wouters (2007); Elekdag and Alp (2011)
Persistence of asset purchases	ρ_b	0.990	-	Kolasa and Wesołowski (2020)
Steady-state inflation	π	1.000	1.000	Assumption
<i>Supply chains</i>				
Share of supplies	φ_i	0.241	0.350	Author's calculations
Share of domestic supplies supplies	ω_h	0.992	0.936	Author's calculations
e.o.s. domestic and foreign supplies	ε_s	1.500	1.500	Monacelli (2004)
<i>Financial linkages</i>				
Share of local capital	φ_k	0.991	0.908	Author's calculations
e.o.s. between local and export capital	η_k	1.100	1.100	Assumption

Note: The calibrations across the three model specifications match the key steady-state ratios of both economies. The alternative calibrations of each model version can have minor effects on the resulting key steady-state ratios. This, however, should have minimal or no effects on the results.

long-term investments entirely represent cross-border transactions in debt securities. At the same time, the BIS data does not distinguish between short-term and long-term debt. Therefore, using the data from the QPSD, I assume that long-term debt represents 78.84% of the US debt while 81.11% of the Turkish debt is long-term. I, therefore, extract long-term debt from total debt in the BIS data and calculate the shares of investments in foreign long-term bonds in total long-term debt in both countries.

The steady-state shares of the domestic versus foreign long-term bonds in the portfolio of households, in turn, have been calculated using the Bank of International Settlement's debt securities statistics and the IMF's Coordinated Portfolio Investment Survey (CPIS). This results in 0.9% of the steady-state Turkish long-term debt being owned by US households and 9.2% of the US debt being owned by Turkish residents. The rest, i.e., 99.1%, of the US debt is owned by the US residents, and 90.8% of the Turkish long-term debt is assumed to be owned by the Turkish residents.

I follow [Leblebicioğlu and Weinberger \(2021\)](#) in determining the elasticity of substitution between domestic and export capital and find that domestic and foreign capital are slightly substitutable. The elasticity of substitution η_k I adopt is 1.1, while [Leblebicioğlu and Weinberger \(2021\)](#) assume the value of 1.85. I provide a sensitivity analysis to varying values of η_k .

3.5 Conditional forecast

The conditional forecast is used for an exogenously given constrained path of an endogenous variable or variables of choice. This is done by finding a structural shock or shocks of choice that are needed to match the restricted paths. For the purpose of the conditional forecast exercises presented in [Chapter 3.6](#) I use stochastic simulations of US monetary policy.

I, therefore, provide the paths of percentage point deviations of the US (foreign) policy rate from its non-stochastic steady state. In order to generate the responses to a path of percentage points deviations of a nominal interest rate, I create a new variable $R_{cd,t}^*$ which represents deviations of the nominal interest from its steady-state value $R^* = 1/\beta^*$:

$$R_{cd,t}^* = \log(R_t^*) - \log(R^*) \quad (3.5.92)$$

and provide a path for $R_{cd,t}^*$ using data from the Board of Governors of the Federal Reserve System on discount window primary credit rate as a proxy for the risk-free policy rate. I assume that the annualized steady-state policy rate is 4% and provide a path for the deviations of the discount window primary credit rate from its steady-state value of 4%.

In the second exercise, I simulate the effects of the US asset purchases. In my second conditional forecast exercise, I provide a path of the ratio of long-term bonds held by the US monetary authority in annualized US GDP:

$$AP_{cd,t}^* = \frac{B_{g,t}^*}{4 \times GDP^*} \quad (3.5.93)$$

$B_{g,t}^*$ follows an autoregressive process with an autocorrelation parameter $0 < \rho_b^* < 1$ and a shock size $\sigma_{b,t}^*$:

$$B_{g,t}^* = \rho_b B_{g,t-1}^* + \sigma_{b,t}^* \quad (3.5.94)$$

I determine the path of $AP_{cd,t}^*$ using data on total assets of the Federal Reserve System less eliminations from consolidation (Wednesday level) and divide them by the annual US GDP. The conditional forecast provides the shock sizes $\sigma_{r,t}^*$ and $\sigma_{b,t}^*$ which generate data-based paths of $R_{cd,t}^*$ and $AP_{cd,t}^*$. The lengths of the two paths of the controlled variables and shock sizes match. In my simulations, the two paths include 81 periods, i.e., quarters, and correspond to the period which starts in the first quarter of 2003 and ends in the first quarter of 2023. For the technical summary of a conditional forecast, see [Bańbura et al. \(2015\)](#).

3.6 Network contagion

In what follows, I consider the effects on the economies of the US and Turkey of (i) the US conventional monetary policy and (ii) the asset purchases by the Fed over the years 2003-23. For this purpose I use stochastic simulations and provide conditional forecasts of the deviations of the US policy rate from its non-stochastic steady state and the ratio of total assets held by the Fed relative to the US GDP over the 20 years.

In simulating the effects of the US monetary policy, I assume an endogenous response of the Turkish monetary authority in the benchmark scenario. As a coun-

terfactual, I maintain that the Turkish monetary authority does not respond to the changes in the US monetary policy and keeps its policy rate at the steady-state level.⁴⁴

Following the literature on monetary policy in emerging markets, I also introduce deviations of the nominal exchange rate into the Taylor rule associated with the Turkish economy. Ilzetzi et al. (2019) and Garcia et al. (2011) maintain that monetary authorities in emerging markets put considerable weight on the exchange rate fluctuations in determining their monetary policy. The adverse sentiment towards the exchange rate volatility is often known as the ‘fear of floating’ (see Calvo and Reinhart, 2002). As a last set of conditional forecast simulations, I provide the responses to the US monetary policy under the assumption that the Turkish monetary authority responds with its monetary policy to the nominal exchange rate between the US dollar and the Turkish lira.

3.6.1 Spillovers of conventional monetary policy

I set the stage by analyzing the effects of the US conventional monetary policy and its spillovers to Turkey. I first postulate the conditional forecast of the US policy rate and its path over the years 2003-23, defined by the percentage deviations of the US policy rate from its non-stochastic steady state. This serves as a benchmark for the conditional forecast of the asset purchases by the US Fed that follows. I summarize the conditional forecasts with the following variables corresponding to both countries: interest rate, output, inflation, imports, asset price, lending spread, and leverage. I also provide the responses of the USD/TRY real exchange rate and the inflows of capital to Turkey from the US.

The resulting effects of the US conventional monetary policy over 2003-23 are reported in the panels of Figure 3.1. The exogenously provided path of the deviations of the US policy rate from its steady-state value of 4% is displayed in the first panel of the top row of Figure 3.1.

Before the 2007-2008 Global Financial Crisis (GFC), the US interest rates stood at

⁴⁴To keep the Turkish policy rate at the steady-state level of 4%, I define the percentage deviations of Turkish policy rate from its non-stochastic steady state $R_{cd,t}$ and provide a path for $R_{cd,t}$ such that R_t associated with the Turkish policy rate does not deviate from its annualized level of 4%. The conditional forecast generates a path of $\sigma_{r,t}$ - the shock sizes associated with the Turkish Taylor rule such that R_t is kept constant over the entire time span of the forecast.

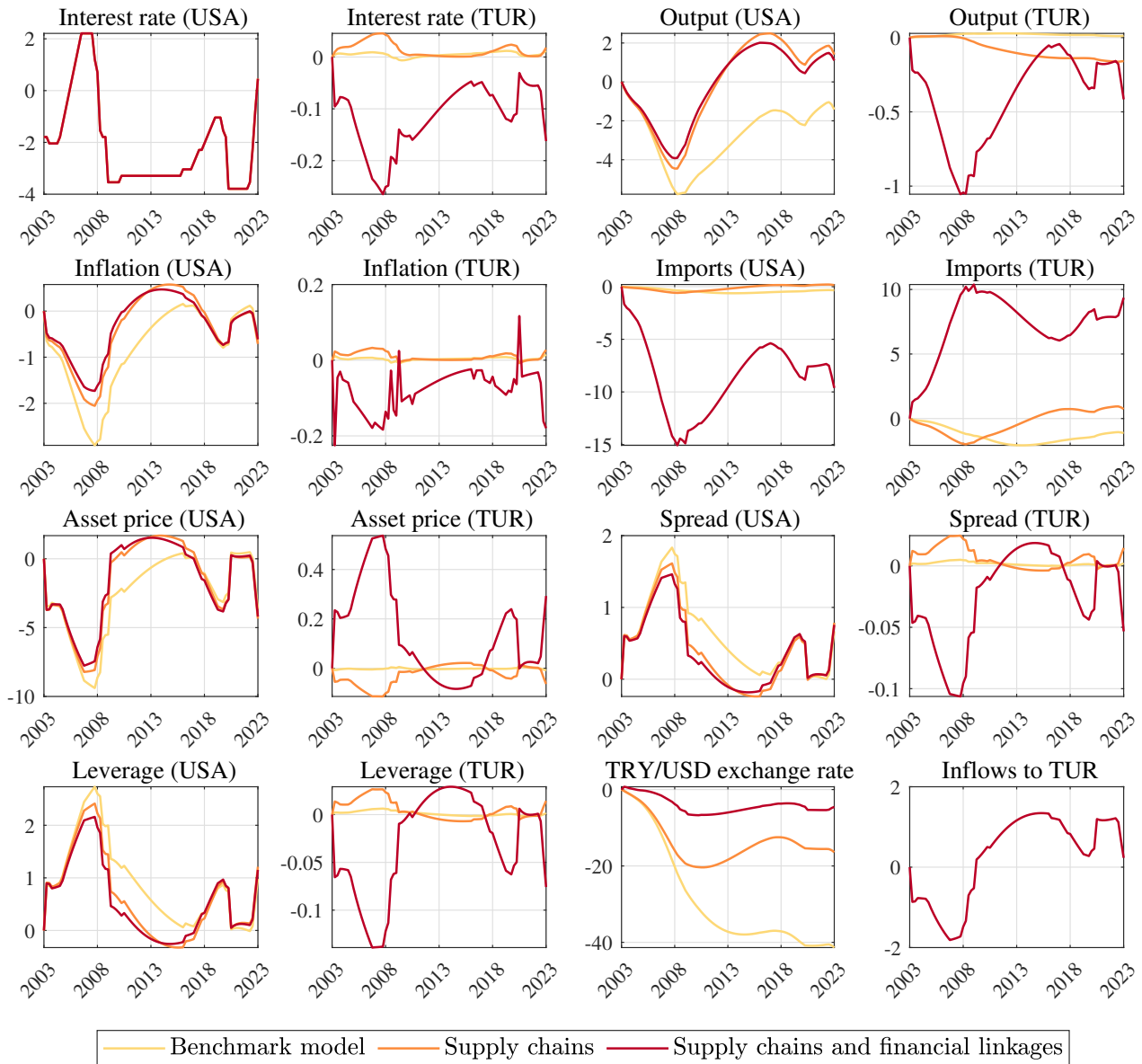
6.25% - around two percentage points above their steady-state value. During the GFC, the interest rates decreased considerably and reached 0.5% in 2009. They remained stable at 0.75% until 2016 to increase to 3% in 2019 after the economic conditions improved. With the outbreak of the COVID-19 pandemic, the US Fed again started cutting its benchmark interest rate at the beginning of 2020. Soon after, it lowered the benchmark rate to 0.25%. Following the increases of inflation significantly above inflation targets related to supply chain disruptions and global increases in energy prices following the Russian invasion of Ukraine in 2022, central banks again started raising interest rates to curb rising inflation.

Following the US monetary policy tightening in the years 2004-2007, output falls in both the US and Turkey. However, the largest impact of the spillovers of the US monetary policy on output in Turkey comes from financial linkages since the difference between the responses from the model which assumes no credit networks (financial autarky) and the extended model with both supply chains and financial linkages are the greatest.

Supply chains, on the other hand, help reduce the negative consequences of monetary policy tightening on domestic output. In the model with supply chains, physical capital explains a smaller proportion of aggregate output since the output is produced using three instead of two inputs - labor, physical capital, and intermediate inputs. In addition, in the model with supply chains, the financial accelerator mechanism which links the banking sector with the real sector is weaker. Hence, the less negative effect of monetary policy tightening on local output when supply chains are taken into account.

The differences in the impulse response functions between the model with trade networks but no credit networks (financial autarky) and the extended model with both trade and credit networks are less significant in the responses of the US economy. On the other hand, the credit channel plays a crucial role in driving the cross-country spillovers of the US-originated monetary shock in Turkey. Therefore, compared with the responses given the two model versions with no financial linkages, the model with both trade and credit networks (dark red lines) suggests significant fluctuations in the emerging economy following the US monetary policy shocks.

Figure 3.1: Conditional forecast of the US conventional monetary policy path.



Notes: Values in percent deviations from the non-stochastic steady state. The responses of interest rates, lending spreads, and inflation are annualized. The responses of leverages are expressed in percentage points.

In the model with supply chains but no financial linkages, a decline in US output reduces the demand for Turkish-made goods in the US. Turkish producers must, therefore, replace US-made supplies with local substitutes. This causes Turkish output not to respond as negatively to monetary policy tightening in the US as output responds in the model with financial linkages, in which the financial channel plays a more important role than the trade channel.

When the US interest rate is two percentage points above its steady-state, domestic

inflation is 1.6 percentage points below its steady-state level in the model with financial linkages and 2.85 percentage points in the benchmark model specification. US imports fall considerably in the model with financial linkages, which reduces the effects of monetary policy on local inflation.

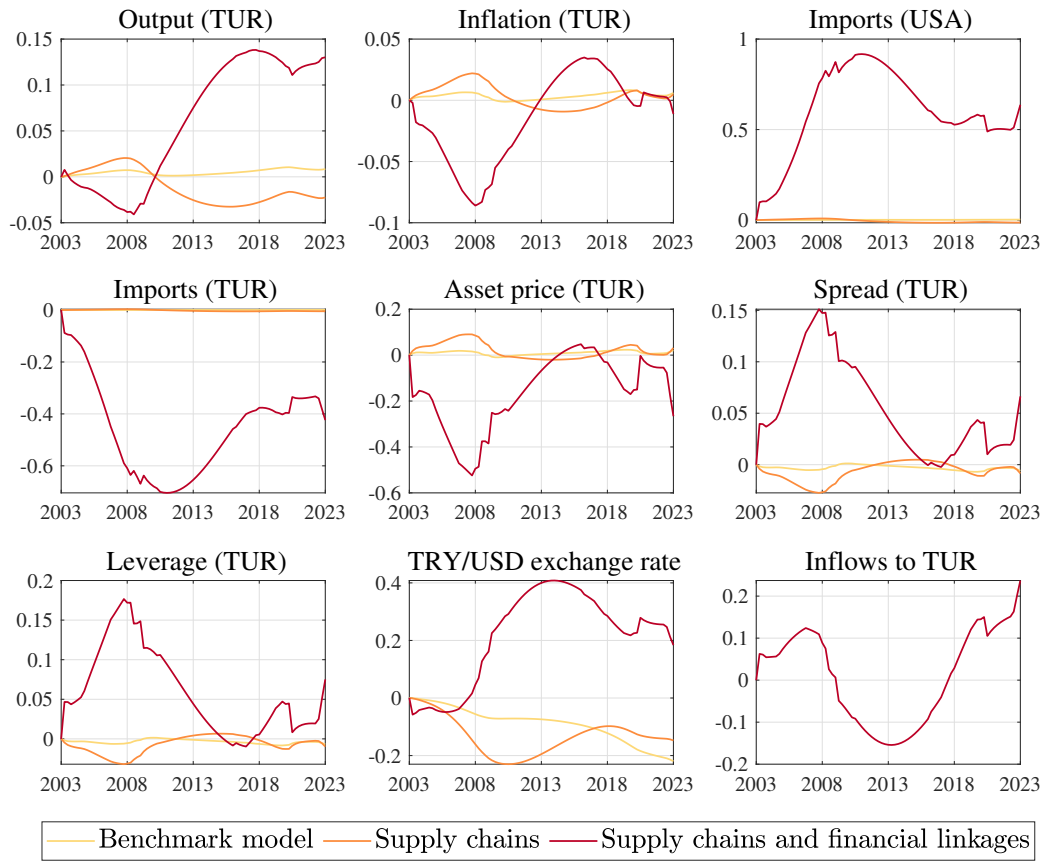
The Turkish lira is very sensitive to the US monetary policy and depreciates in real terms by as much as 40% in the benchmark model and 8% in the model with financial linkages. The persistent scale of its depreciation relative to the US dollar is well supported by the data. The sensitivity of the value of the lira translates into significant fluctuations in trade between the US and Turkey. A depreciating lira results in nearly twice the negative response of Turkish exports to the US. The trade effect, however, is this significant only in the model with financial linkages, even though the lira depreciates more in the models which assume financial autarky.⁴⁵

Due to the increased lending spread in the US, the demand for long-term bonds increases when the US policy rate increases. This translates to increased prices of assets in the US and higher leverage. In Turkey, under the assumption of financial autarky, inflation rises when the US interest rate increases. The opposite happens in the model with financial linkages, following fluctuations of capital inflows to Turkey linked to the Turkish lending spread.

The financial channel is critical in driving aggregate fluctuations in Turkey. When the US increases its interest rate, the US lending spread increases, leading to an outflow of capital from Turkey and a decline in the Turkish lending spread. Asset prices and leverage are also closely linked to lending spreads. When the spreads in both countries increase by one basis point, asset prices fall by approximately five basis points, and the leverage responds almost one-to-one to changes in the spreads.

⁴⁵The decline in Turkish output and exports and the resulting fall in inflation in the model with financial linkages help to partly cushion the real depreciation of the lira relative to the models with no financial linkages, in which Turkish inflation responds positively to interest rate hikes in the US.

Figure 3.2: Differences between the responses to the US conventional monetary policy with and without the endogenous responses of Turkish monetary policy.



Notes: Values in percent deviations from the non-stochastic steady state. The responses of interest rates, lending spreads, and inflation are annualized. The responses of leverages are expressed in percentage points.

Furthermore, I provide the responses of the variables corresponding to the Turkish economy under the assumption that the monetary policy authority in Turkey does not respond to the US interest rate changes by adjusting its policy rate. The results are reported in the panels of [Figure 3.2](#).

To simulate the effects of the same path of the US interest rate as shown in [Figure 3.1](#) under the assumption that the Turkish monetary authority keeps the Turkish policy rate at the steady-state level of 4%, I define the percentage deviations of the Turkish policy rate from its non-stochastic steady state $R_{cd,t}$ and provide a path for $R_{cd,t}$ such that R_t associated with the Turkish policy rate does not deviate from its annualized level of 4%. Since I assume no deviations of the annualized Turkish policy rate from 4%, the path of $R_{cd,t}$ consists of values equal to zero in each period over the years 2003-23. The conditional forecast generates a path of $\sigma_{r,t}$ - the shock sizes associated

with the Turkish Taylor rule such that R_t is kept constant over the entire time span of the forecast.

For example, if the optimal response of the monetary policy authority in Turkey was to decrease its interest rate following the US monetary policy shock as presented in [Figure 3.1](#), the conditional forecast generates a positive monetary policy shock in Turkey such that the Turkish policy rate defined as a deviation from its steady state is zero in this and every other quarter.

As is clear from [Figure 3.1](#), given the model with supply chains and financial linkages, the Turkish policy rate was below its steady-state level throughout the 2003-23 period. On the other hand, given the two specifications of the model with no financial linkages, the policy rate associated with the Turkish economy was almost always slightly above its steady-state level. In the model with financial linkages, the conditional forecast generates a path illustrating monetary policy tightening and its expansion in the two model specification with no financial linkages.

Given the two model specifications with no financial linkages, further monetary expansion in Turkey generally leads to a positive response of output, inflation, asset prices, a depreciation of the lira linked to lower lending spread and leverage, and an improvement in the trade balance.

When financial linkages are taken into account, a further tightening of monetary policy in Turkey to keep the interest rate unchanged relative to the steady state generally results in a higher lending spread, inflows of capital, an appreciation of the lira, and lower inflation. It, however, has a positive impact on Turkish leverage and a negative effect on asset prices. Despite the appreciation of the lira, the trade balance improves thanks to the inflow of capital with positive consequences on output.

3.6.2 Spillovers of asset purchases

In the next part of my analysis, I study the effects of asset purchases by the US Fed and their spillovers to Turkey. Many of the world's central banks, mainly in the advanced world, have built up significant balance sheets to lessen the macroeconomic disturbances following the GFC or the European sovereign debt crisis.

Recently announced by the Federal Open Market Committee, partial reversal of the asset purchasing program of the Fed has important implications outside the US.

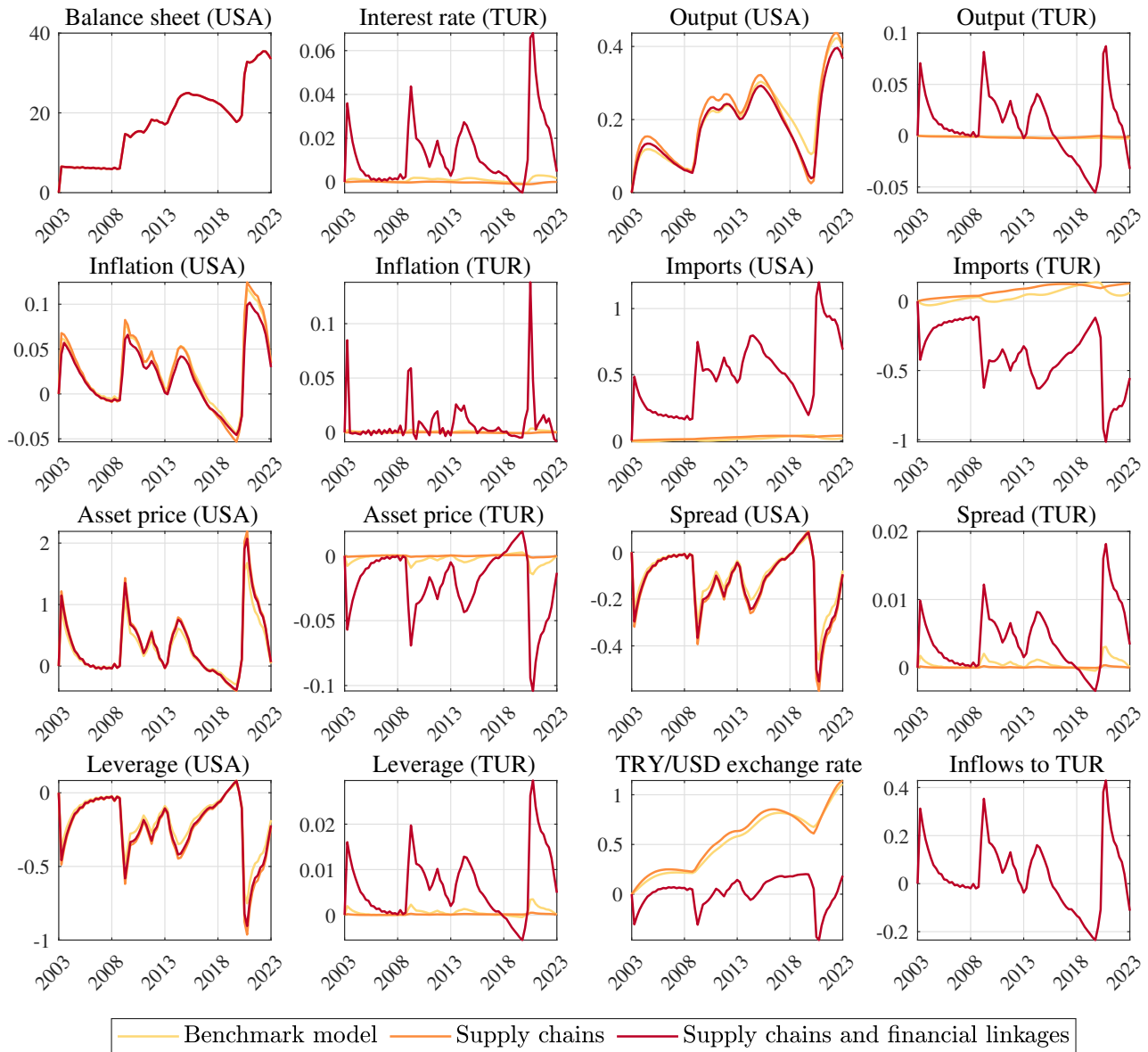
The decision to cease re-investments of maturing securities is projected to significantly reduce the Federal Reserve's balance sheet, although the scale of the tapering is still uncertain.⁴⁶ Although limited from the perspective of the real economy (see [Chen et al., 2012](#)), asset purchases by the US Fed have important consequences on financial markets - a vital transmission channel of shocks to emerging markets.

The results of the partial reversal of the quantitative easing program in the US are reported in the panels of [Figure 3.3](#). The exogenous path of the value of the Fed's balance sheet relative to the US GDP is displayed in the first panel in the top row. The share of assets has increased to 15% of the US GDP after the GFC. Asset purchase programs were also an important instrument in the post-GFC recovery. Their value relative to GDP increased to 25% in 2014 and then dropped to 20% in late 2018. Again, QE programs were an essential tool in financing the measures to fight the effects of the COVID-19 pandemic and the economic consequences that followed. As a result, the share of assets held by the Fed increased once more to 37%. Recently, faced with the rise in inflation, central banks worldwide, including the US Fed, decided in 2022 to begin tapering their balance sheets to reduce inflation pressures.

Long-term and short-term bonds are imperfect substitutes in the model setting. Therefore, asset purchases are not neutral for other macro variables. More specifically, long-term asset purchases by the monetary authority have a negative impact on the lending spread in the domestic economy. Balance sheet expansion in 2008-2009 by around 10% of GDP decreases the US lending spread by 40 basis points on impact. The spread recovers partially under no drastic changes in the balance sheet, except for the year 2014, and then falls drastically by almost 60 basis points in 2021, following the most recent COVID-related expansion of the balance sheet. The magnitude of the responses to asset purchases is consistent with the findings in [Chen et al. \(2012\)](#) for a closed economy, and [Kolasa and Wesołowski \(2020\)](#) for the spillovers of the US QE programs to Poland.

⁴⁶While the duration of the tapering program is unknown, the balance sheet reduction has been announced to be at the speed of \$95 billion a month.

Figure 3.3: Conditional forecast of asset purchases by the US Fed.



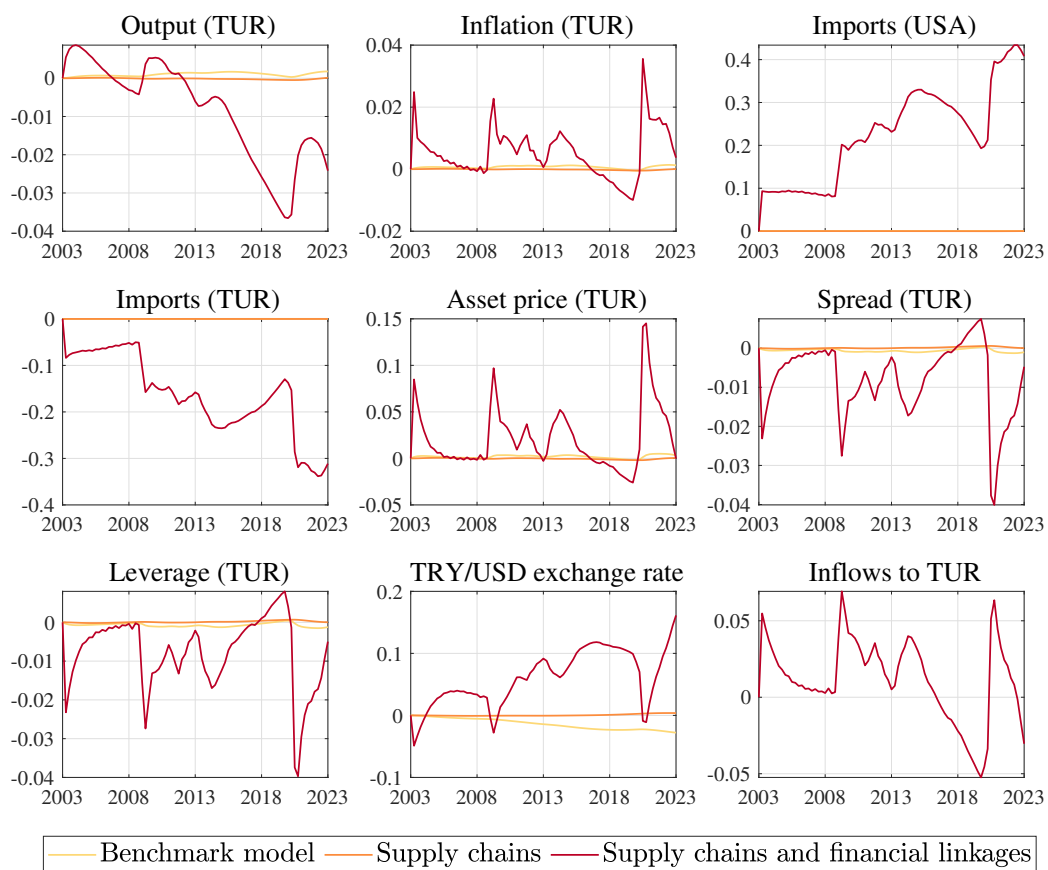
Notes: Values in percent deviations from the non-stochastic steady state. The responses of interest rates, lending spreads, and inflation are annualized. The responses of leverages are expressed in percentage points.

I now turn to the responses of the Turkish economy to changes in the Fed's balance sheet. Turkish economy attracts US investors who are faced with the lower lending spread and start looking for alternative investment opportunities abroad. In effect, a lower spread in the US increases capital inflows to Turkey which, in turn, positively affects the Turkish lending spread. Moreover, improvement in domestic demand in the US economy supports Turkish exports. At the same time, however, the inflow of US capital to Turkey leads to some appreciation of the Turkish lira with negative

consequences on the trade balance in Turkey. Therefore, currency appreciation from the viewpoint of the Turkish economy is not enough to overturn an improvement in the trade balance followed by an expansion of aggregate demand in the US economy.

The financial channel is key in driving the cross-country spillovers of the US asset purchases to Turkey. Capital flows are critical in driving aggregate fluctuations in Turkey, with output responses given the two model specifications that assume financial autarky being insignificant.

Figure 3.4: Differences between the responses to asset purchases by the US Fed with and without the endogenous responses of Turkish monetary policy.



Notes: Values in percent deviations from the non-stochastic steady state. The responses of interest rates, lending spreads, and inflation are annualized. The responses of leverages are expressed in percentage points.

Clearly, the trade channel is much less significant in driving the spillovers of US asset purchases than in driving the spillovers of the US conventional monetary policy. The variables associated with the Turkish economy barely move, given the two model specifications with no financial linkages. The exceptions are the real exchange rate and trade volume, both positively affected by the expansion of the Fed's balance

sheet. This is because Turkish producers and consumers, to some degree, are able to substitute more expensive imported goods by increasing local production of their close equivalents.

I now turn to analyze the responses of the variables corresponding to the Turkish economy under the assumption that the monetary policy authority in Turkey does not respond to the US asset purchases. The results are reported in the panels of [Figure 3.4](#).

In the case of asset purchases, the optimal response over the years 2003-23 of the monetary policy authority in Turkey, given all three model specifications, was to increase its interest rate following the expansion of the Fed's balance sheet as presented in [Figure 3.4](#). The conditional forecast, therefore, generates a negative monetary policy shock in Turkey when the optimal Turkish rate is above its steady-state level, such that the Turkish policy rate defined as a deviation from its steady state is zero.

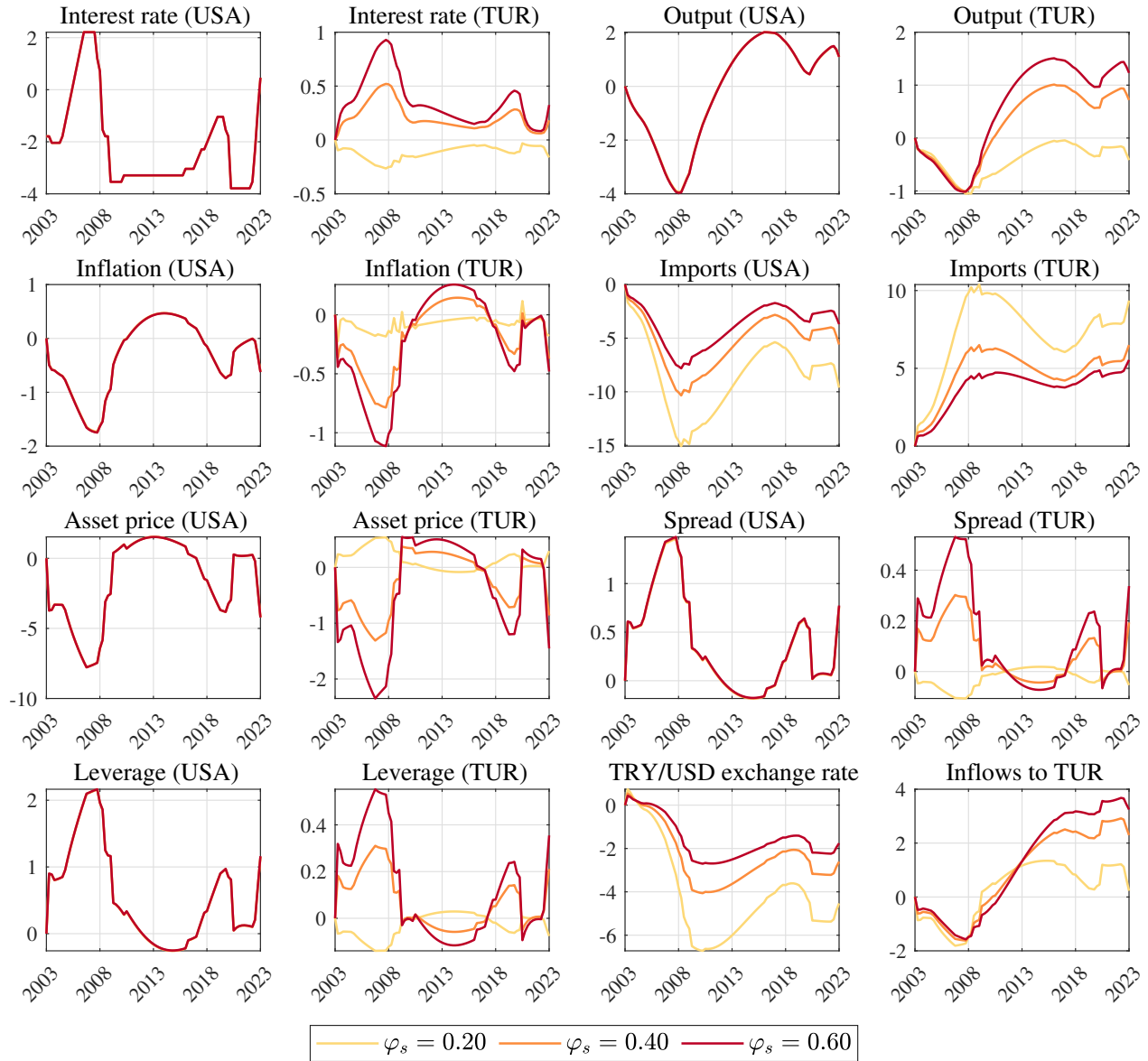
Given all model specifications, monetary expansion in Turkey generally leads to positive responses of output, inflation, asset prices, lira depreciation linked to lower lending spread and leverage, and an improvement in the trade balance.

Given the model with financial linkages, however, capital inflows to Turkey are essential in driving the responses of Turkish output. When the Turkish monetary authority keeps its interest rate unchanged when the US Fed expands its balance sheet, inflation in Turkey is higher relative to the scenario when the Turkish interest rate increases. This has important implications on the Turkish lending spread, the real exchange rate, and capital inflows to Turkey, with unfavorable consequences on Turkish output.

3.6.3 Fear of floating

[Ilzetzki et al. \(2019\)](#) argue that despite the abandonment of the Bretton Woods system, many countries, emerging markets in particular, still put considerable weight on variations of the exchange rates. The term associated with the unwillingness to commit a value of a national currency to become determined entirely by the demand-supply market mechanism is called the 'fear of floating' (see [Calvo and Reinhart, 2002](#)). [Garcia et al. \(2011\)](#) find that emerging and financially-vulnerable economies, being more prone to risk premium shocks, tend to considerably benefit from exchange rate smoothing due to the exchange rate volatility they experience when hit by shocks.

Figure 3.5: Conditional forecast of the US conventional monetary policy path with the fear of floating.



Notes: Values in percent deviations from the non-stochastic steady state. The responses of interest rates, lending spreads, and inflation are annualized. The responses of leverages are expressed in percentage points.

I assume that the monetary policy in Turkey is conducted according to a Taylor rule augmented by the deviations of the nominal exchange rate, which implies that the deviations of the risk-free interest rate R_t from its deterministic steady state R respond to the deviations of inflation π_t from its deterministic steady-state value π and the deviations of the nominal exchange rate s_t from its non-stochastic steady-state

s , allowing additionally for interest rate smoothing:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_r} \left[\left(\frac{\pi_t}{\pi} \right)^{\varphi_\pi} \left(\frac{s_t}{s} \right)^{\varphi_s} \right]^{1-\rho_r} \exp(\sigma_{r,t}) \quad (3.6.95)$$

where $\varphi_s > 0$ describes the central bank's weight on the deviations of the nominal exchange rate.

Ozkan and Unsal (2017) in their analysis of the spillovers of the US monetary policy to South Korea, maintain that φ_s takes the value of 0.5. In my calibration, I assume that φ_s can take a range of values from 0.2 to 0.6.

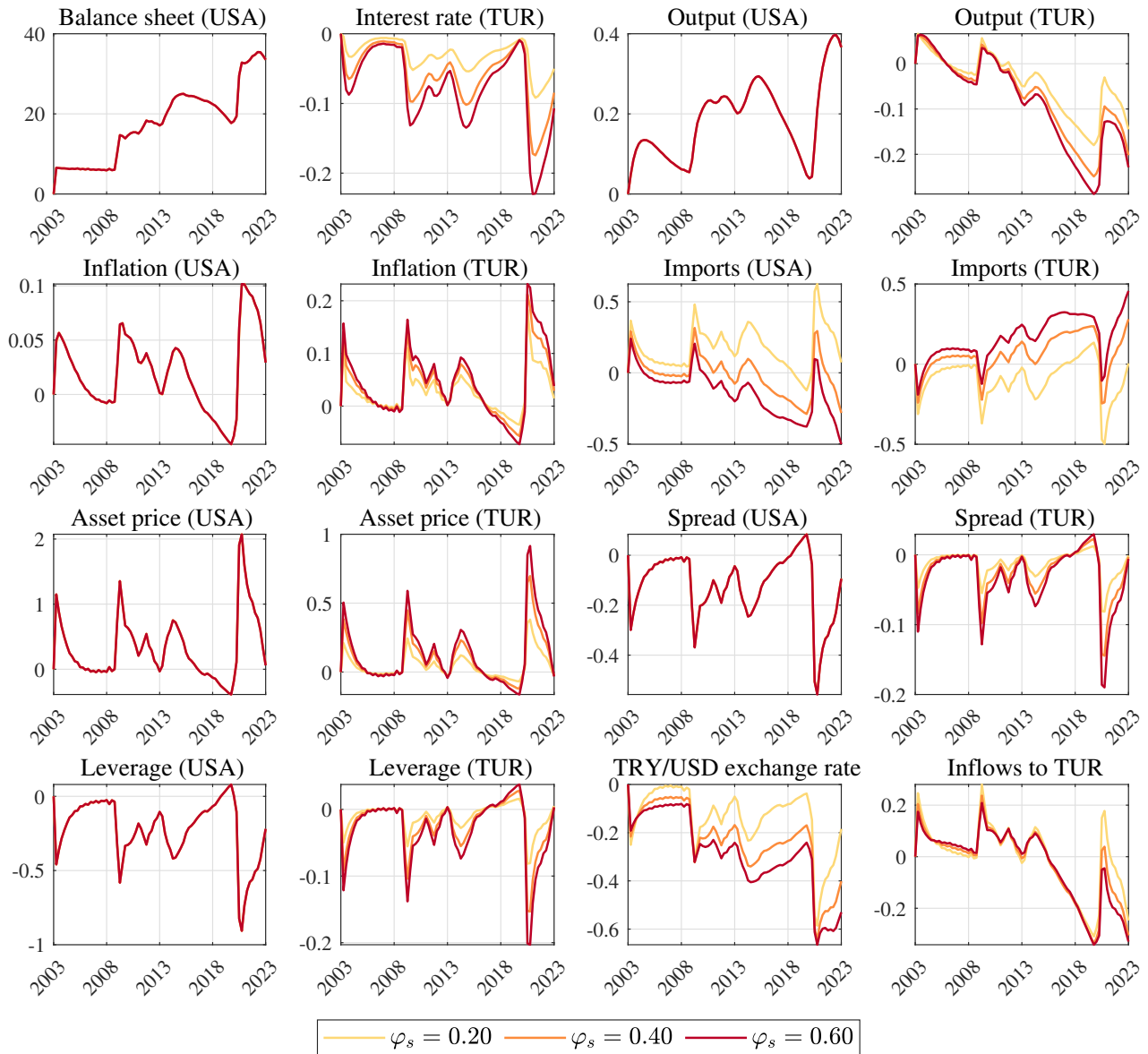
Figure 3.5 presents the responses which correspond to the effects of the US conventional monetary policy over the years 2003-23 from **Figure 3.1** with the only difference now being that the Turkish monetary authority responds to the deviations of the nominal TRY/USD exchange rate from its steady-state value given the sensitivity of that deviation φ_s equal to 0.20, 0.40, or 0.60.

In turn, **Figure 3.6** outlines the responses matching the effects of asset purchases by the Fed over the years 2003-23 from **Figure 3.2** under the assumption that the Turkish monetary authority acts to reduce changes in the nominal exchange rate between the US dollar and the Turkish lira.

The fear of floating has important implications for Turkish monetary policy. When the lira depreciates, the Turkish central bank increases its interest rate relative to the fully flexible exchange rate assumption. The higher the weight of the monetary authority on deviations of the nominal exchange rate from the steady state, the more forcefully the central bank acts with its monetary policy adjustments to reduce the deviations of the nominal exchange from its steady-state value.

Relative to the scenario in which Turkey decreases its interest rate following monetary policy tightening in Turkey in **Figure 3.1**, the Turkish interest rate now increases when the US lending spread increases. This implies a higher spread in Turkey and an inflow of capital compared to the earlier scenario when capital flowed out of Turkey following monetary policy tightening in the US. As a result, the Turkish lira depreciates less with higher sensitivity of the central bank to deviations of the nominal exchange rate, leading to smaller trade flow fluctuations.

Figure 3.6: Conditional forecast of asset purchases by the US Fed with the fear of floating.



Notes: Values in percent deviations from the non-stochastic steady state. The responses of interest rates, lending spreads, and inflation are annualized. The responses of leverages are expressed in percentage points.

Following asset purchases by the Fed, as presented in Figure 3.6, the higher weight of the emerging market's central bank's weight on the nominal exchange rate, the more expansionary the monetary policy in the emerging market economy should be. This implies higher inflation relative to the scenario with zero weight on the nominal exchange rate, a loss of price competitiveness, and a depreciation of the currency in real terms. Therefore, results from Figure 3.6 suggest that it is not desirable to attach a

high weight on the nominal exchange rate in an emerging economy following balance sheet expansions by the Fed.

The higher the central bank's weight on the nominal exchange rate in the emerging market economy, the more deflationary consumer and asset prices pressures and the higher the leverage. Following conventional monetary policy shocks in the advanced economy, output in the emerging market economy is generally higher the higher the central bank's weight on the nominal exchange rate.

3.7 Sensitivity analysis

I also carry out a number of sensitivity checks by repeating my earlier experiments across variations in (i) the investment adjustment cost; (ii) the survival rate of banks; (iii) the proportional advantage in absconding rate; (iv) the persistence of nominal interest rates; (v) the fraction of divertable funds; and (vi) the elasticity of substitution between local and export capital, as presented in [Appendix C.4](#). The results of the conditional forecasts presented in [Chapter 3](#) prevail across a wide range of parameter values. The sensitivity analysis is carried out using the version of the model with both supply chains and financial linkages.

Investment adjustment cost (η_i)

[Figure C.1](#) and [Figure C.2](#) present the conditional forecasts of the conventional monetary policy in the US and the Fed's asset purchases, respectively, over the years 2003-23 under three alternative values of the investment adjustment cost η_i .

Higher η_i reduces the effects of the US monetary policy on local inflation and the effects thereof on the real economy. When the adjustment cost of investment in physical capital is low, investment in physical capital adjusts more robustly to the monetary policy shock, which is closely interlinked with the cost of physical capital. As a result, changes in the spillovers to the Turkish economy are less sensitive to the changes in the investment adjustment cost than the responses of the macro variables characterizing the US economy.

Survival rate of banks (σ)

Because of the nature of monetary policy shocks, the planning horizon of banks has important implications for the effects of monetary policy shocks and their spillovers. [Figure C.3](#) and [Figure C.4](#) outlines the responses of variables corresponding to the economies of the US and Turkey to the US monetary policy shocks under three different values of σ .

The higher the survival rate of banks, the more responsive spreads, asset prices, and leverage rates are to the conventional monetary policy in the US. However, the survival rate of banks has much more critical implications on the effects of the asset purchases as shown in [Figure C.4](#). The longer the planning horizon of banks is, the lower the effects of asset purchases on both the US economy and its spillovers to Turkey. The empirical evidence, however, points to a high survival rate of banks which is the reason behind the relatively small effects of asset purchases on the real economy regardless of the large share of assets held by the Fed relative to the GDP.

Proportional advantage in absconding rate (Γ)

[Figure C.5](#) and [Figure C.6](#) show the responses to the US-originated monetary policy shocks under different values of the proportional advantage in absconding rate Γ , which measures how easy it is for banks to divert government bonds. The higher the value of Γ , the easier it is to divert government bonds.

The easier it is to divert government bonds, the greater the effects of asset purchases on output. Significantly, higher Γ reduces the responses of the spread, asset prices, and leverage, especially in the emerging market economy, for both conventional and unconventional monetary policy shocks.

Fraction of divertable funds (θ)

The results under three alternative values of the fraction of funds that can be diverted θ are presented in [Figure C.7](#) and [Figure C.8](#).

Similarly to the survival rate of banks, higher θ implies more significant positive effects from the balance sheet expansion on the real economy and greater positive spillovers to Turkey. In addition, a higher value of θ implies less fluctuations in the

Turkish spread and capital flows following the conventional monetary policy shocks.

Elasticity of substitution between local and export capital (η_k)

The elasticity of substitution between local and export capital η_k measures how easy it is for firms to substitute local capital with that share of capital backed by foreign loans.

Figure C.9 and Figure C.10 present the responses under alternative values of η_k . Generally, the easier it is to substitute local with export capital, the greater the effects of the US monetary policy on the local real economy with important implications on domestic inflation.

Under high values of η_k , capital inflows are less sensitive to the US monetary policy shocks with a smaller impact on the exchange rate fluctuations.

3.8 Discussion

My analysis of the effects of the US monetary policy and its spillovers to Turkey is based on the non-linear DSGE model and stochastic simulations. The stochastic simulations imply that both conventional monetary policy and asset purchases are unanticipated every period. As a result, agents have no information about the future paths of the US interest rate and the Fed's asset purchases. My framework, therefore, abstracts from the effects of forward guidance or expectations in shaping the effects of monetary policy on current variables.

Moreover, I abstract from a number of non-linearities in the model, common in the most recent literature on monetary policy, including the zero-lower bound on interest rates, and assume that the financial constraint is always binding. As shown by Karadi and Nakov (2021), non-linearities have significant effects on aggregate fluctuations.

Finally, the scale of cross-border spillovers of US-originated monetary policy shocks is much greater than the corresponding spillovers in the absence of financial linkages or with financial linkages limited to international trade in long-term bonds, as in Chapter 1. However, the magnitude of cross-country linkages can be calibrated more accurately, so that the responses using the methods from Chapter 3 match with, for example, a corresponding vector autoregression (VAR) model.

Nevertheless, with this paper I contribute to a still relatively small literature on

the spillovers of unconventional monetary policies to emerging markets which still require further research.

3.9 Conclusions

This paper proposes a two-country DSGE model with financial frictions for the analysis of the effects of the US monetary policy shocks and their spillovers to an emerging economy, which in this chapter is calibrated to Turkey.

I build three versions of the model: (i) in which cross-country linkages are limited to trade in consumer goods; (ii) with local and imported intermediate inputs used in the production of local intermediate goods; (iii) with both the supply chains and financial linkages in the form of a share of domestic capital backed by foreign loans.

My framework employs conditional forecasts to simulate the effects of the US conventional monetary policy over the years 2003-23 and those of asset purchases by the Fed over the same period.

I find that (i) the financial channel is critical in driving the aggregate fluctuations in Turkey following the adjustments of the US monetary policy; (ii) although some degree of sensitivity to the exchange rate fluctuations in the emerging markets is desirable following the adjustments of the US interest rate, my results suggest that it generally disadvantageous to attach a high weight on the nominal exchange rate following balance sheet adjustments by the Fed; (iii) financial frictions have an important impact in driving the dynamics following the US asset purchases with the survival rate of banks, the rate of divertable funds, the proportional advantage in absconding rate, and the elasticity of substitution between local and export capital being key in driving the effects of the Fed's asset purchases in particular.

Although my analysis my results are important and contributes to a small literature on the spillovers of the US monetary policy to emerging markets, which is particularly scarce when it comes to the spillovers of asset purchases to emerging markets. The next steps of my research on the spillovers of the US monetary policy will involve incorporating non-linearities into the model, including the zero-lower bound and occasionally binding constraints and a perfect foresight simulations aimed at incorporating the effects of expected future paths of interest rates and asset purchases.

Concluding remarks

This thesis investigates how the trade and financial interactions between countries affect the propagation of shocks. Across the thesis, I have developed a number of multi-country general equilibrium models with different features directly or indirectly impacting the transmission channels of shocks originating in one country and spilling over to a foreign economy. In addition, I employed three alternative solution methods for the simulation of shocks: stochastic simulations, perfect foresight solutions, and conditional forecasts.

Each of the chapters is unique in its way. However, they all tell a similar story of cross-country spillovers of different types of shocks under alternative model configurations, originating and affecting different types of countries.

I set the stage in [Chapter 1](#) by developing several standard configurations of a two-country DSGE model with New Keynesian features: (i) the model with international trade limited to trade in consumer goods and no cross-border financial linkages; (ii) the model with Ricardian and non-Ricardian households; (iii-v) the models with supply chains introduced using three different functional forms of the production function - CES, Cobb-Douglas, and Leontief; (vi) the model with long-term financial assets; and (vii) the model with cross-country financial linkages. I calibrate each model to the US and China and provide the analysis of the effects of TFP, labor supply, trade, government spending, and monetary policy shocks originating in the US and China and spilling over abroad.

Findings in [Chapter 1](#) offer a number of interesting observations. Among others, I maintain that (i) supply chain linkages are the key element behind the responsiveness of the domestic and foreign economies to shocks; (ii) thanks to financial linkages, welfare effects of shocks are spread more evenly between the two countries; and (iii) assumptions regarding a functional form of technology with intermediate inputs result

in significantly different responses of prices and inflation with important consequences for monetary policy. I conclude, however, that the scale of international spillovers given standard formulations of a two-country DSGE models with New Keynesian features in [Chapter 1](#) fail to mimic the actual size of spillovers found in the data.

There are at least two solutions to increase the responsiveness of a domestic economy to foreign-originated shocks. [Alpanda and Aysun \(2014\)](#) suggest an ad-hoc cross-country correlation of shock processes or incorporating global banks - financial entities lending to more than one country.

The Brexit-related shocks in [Chapter 2](#) are global in nature. Therefore, even in the absence of explicit financial linkages, Brexit-related trade and migration shocks affect more than just the UK economy. Trade shocks affect import prices in both the UK and the EU economies, and the size of their effects in each country depends on the scale of reliance on a given market on goods imported from abroad. The effects of the migration shocks, in turn, depend on the share of the population leaving a given country in the population of that country and the share of the population immigrating to another country to the population of that country. By definition, trade and migration shocks and the formulation of trade and migration shock processes must affect both countries directly affected by the shocks.

[Chapter 2](#) establishes that the existence of national and international supply networks significantly increases the unfavorable consequences of frictions to trade and migration flows. Furthermore, regarding migration frictions, the reduction in immigration from the EU is a source of further fluctuations for the UK, although this effect is smaller than that of trade frictions. Finally, the results from [Chapter 2](#) suggest that gains from trade liberalization with the third countries fall well short of the losses from Brexit even under full trade liberalization. Also importantly, the findings reveal that losses from Brexit fall disproportionately on low-skilled households.

In [Chapter 3](#), I postulate the possibility of dividing physical capital used to produce intermediate inputs into local capital backed by domestic loans and export capital backed by foreign loans. This assumption yields an interest rate parity condition which drives the international co-movement with its scale much greater relative to comparable models built in [Chapter 1](#). I calibrate the two-country model in [Chapter 3](#) to the US and Turkey and find that the financial linkages are key in driving aggregate

fluctuations in Turkey following the US-originated monetary policy shocks. Moreover, I maintain that some degree of sensitivity to the exchange rate fluctuations in emerging markets is desirable following the adjustments of the US interest rate. However, the results from [Chapter 3](#) suggest that it is generally disadvantageous to attach a high weight on the nominal exchange rate following balance sheet adjustments by the Fed. Finally, I conclude that financial frictions have an important impact on driving the dynamics following the US asset purchases. Therefore, the calibration of the banking sector is vital in driving the effects of monetary policy shocks, particularly of the Fed's asset purchases.

My findings may serve to stimulate further research. Thus, for example, the model developed in [Chapter 2](#) can serve as a tool to study other trade arrangements like NAFTA, TTIP; the trade war between the US and China; or the effects of cross-border migration flows. Likewise, the model built in [Chapter 3](#) has various possible uses for analyzing the global effects of monetary and financial shocks and their spillovers to advanced and emerging market economies.

It is my hope that this thesis will encourage further theoretical and empirical studies on the role of supply chains and financial linkages in aggregate fluctuations.

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Appendix A

The derivations presented in [Appendix A.1-Appendix A.5](#) correspond to the model versions outlined in their more condensed forms in [Chapter 1.2](#) of this thesis. In each model version I consider a world consisting of M countries. In each country there are households, competitive retailers, monopolistically competitive intermediate goods producers, and a government pursuing monetary and fiscal policies. Variables associated with the domestic economy, where necessary, are represented using the index n . Variables associated with a representative foreign economy are denoted with the index m .

The optimization problems included in [Appendix A.1](#) correspond to the benchmark model; [Appendix A.2](#) presents the optimization problems characteristic to the model with Ricardian and non-Ricardian households; [Appendix A.3](#) introduces derivations given the three functional forms of technology: a CES function, a Cobb-Douglas function, and a Leontief function; [Appendix A.4](#) introduces optimization problems in the presence of long-term bonds; and, finally, [Appendix A.5](#) corresponds to the final model extension with financial linkages and cross-border trade in long-term bonds. Provided that the derivations in each model extension are unchanged relative to the benchmark specification or any previous extension, they are not repeated in each section of this appendix and take their previous form.

Additionally, [Appendix A.6](#) displays the responses to shocks analyzed in [Chapter 1.4](#) under alternative values of three key parameters: the elasticity of substitution between domestically-produced and imported goods - ε_c and ε_s ; the elasticity of substitution between labor and intermediate inputs η ; and the share of Ricardian households in China λ_R .

A.1 Optimization problems of the benchmark model

A.1.1 The households' problem

Country n 's households maximize their lifetime utility over consumption C_t , labor inputs supplied to the intermediate goods producers H_t , and optimal holdings of short-term bonds B_t to maximize their discounted lifetime utility:

$$\max_{C_t, H_t, B_t} \mathbb{E}_t \sum_{k=0}^{\infty} \beta^k U_{t+k} \quad (\text{A.1})$$

where the utility function is assumed to be the same for each individual household and takes the form:

$$\max_{C_t, H_t, B_t} \mathbb{E}_t \sum_{k=0}^{\infty} \beta^k \left[\frac{C_{t+k}^{1-\sigma_c}}{1-\sigma_c} - \vartheta \frac{\varepsilon_{l,t}}{1+\varphi_h} H_{t+k}^{1+\varphi_h} \right] \quad (\text{A.2})$$

subject to a sequence of intertemporal budget constraints of the form:

$$C_t + B_t + T_t = W_t H_t + \frac{R_{t-1}}{\pi_t} B_{t-1} + \Pi_t \quad (\text{A.3})$$

The Lagrangian for the household's optimization problem is given by:

$$\mathcal{L}(C_t, H_t, B_t) = \mathbb{E}_t \sum_{k=0}^{\infty} \beta^k \left[\begin{aligned} & \frac{C_{t+k}^{1-\sigma_c}}{1-\sigma_c} - \vartheta \frac{H_{t+k}^{1+\varphi_h}}{1+\varphi_h} \\ & - q_{t+k} \left(C_{t+k} + B_{t+k} + T_{t+k} - W_{t+k} H_{t+k} \right. \\ & \quad \left. - \frac{R_{t+k-1}}{\pi_{t+k}} B_{t+k-1} - \Pi_{t+k} \right) \end{aligned} \right] \quad (\text{A.4})$$

The first-order conditions with respect to C_t , H_t , and B_t are:

$$\frac{\partial \mathcal{L}(C_t, H_t, B_t)}{\partial C_t} = C_t^{-\sigma_c} - q_t = 0 \quad (\text{A.5})$$

$$\frac{\partial \mathcal{L}(C_t, H_t, B_t)}{\partial H_t} = \vartheta \varepsilon_{l,t} H_t^{\varphi_h} + q_t W_t = 0 \quad (\text{A.6})$$

$$\frac{\partial \mathcal{L}(C_t, H_t, B_t)}{\partial B_t} = -q_t + \beta q_{t+1} \frac{R_t}{\pi_{t+1}} = 0 \quad (\text{A.7})$$

The first-order conditions result in the following marginal utility of consumption

condition, the optimal labor supply, and the conventional Euler equation:

$$q_t = C_t^{-\sigma_c} \quad (\text{A.8})$$

$$q_t W_t = \vartheta \varepsilon_{l,t} H_t^{\varphi_h} \quad (\text{A.9})$$

$$1 = \mathbb{E}_t \left[\beta \frac{q_{t+1}}{q_t} \frac{R_t}{\pi_{t+1}} \right] \quad (\text{A.10})$$

The aggregate consumption of households C_t consists of consumption of domestic and imported goods aggregated in the following manner:

$$C_t = \left[\sum_{m=1}^M \gamma_m^{\frac{1}{\varepsilon_c}} (C_{m,t})^{\frac{\varepsilon_c-1}{\varepsilon_c}} \right]^{\frac{\varepsilon_c}{\varepsilon_c-1}} \quad (\text{A.11})$$

Households optimize their consumption basket of domestic and imported goods subject to the following aggregate expenditure on consumer goods:

$$P_t C_t = P_{n,t} C_{n,t} + \sum_{\substack{m=1 \\ m \neq n}}^M (1 + \varepsilon_{\tau,t}) s_t^{nm} P_{m,t} C_{m,t} \quad (\text{A.12})$$

where P_t is the consumer price index composed of the prices of goods consumed by the local households and weighted by their corresponding shares in the aggregate consumption basket:

$$P_t = \left[\sum_{m=1}^M \gamma_m (P_{m,t})^{1-\varepsilon_c} \right]^{\frac{1}{1-\varepsilon_c}} \quad (\text{A.13})$$

The Lagrangian associated with household's optimization of expenditures on domestically-produced versus imported goods is given by:

$$\begin{aligned} \mathcal{L}(C_{n,t}, C_{m,t}) = & \left[\sum_{m=1}^M \gamma_m^{\frac{1}{\varepsilon_c}} (C_{m,t})^{\frac{\varepsilon_c-1}{\varepsilon_c}} \right]^{\frac{\varepsilon_c}{\varepsilon_c-1}} \\ & - q_t^c \left(P_{n,t} C_{n,t} + \sum_{\substack{m=1 \\ m \neq n}}^M (1 + \varepsilon_{\tau,t}) s_t^{nm} P_{m,t} C_{m,t} - P_t C_t \right) \end{aligned} \quad (\text{A.14})$$

The first-order conditions of the optimization problem w.r.t. $C_{n,t}$ and $C_{m,t}$ (for

$m \neq n$) are as follows:

$$\frac{\partial \mathcal{L}(C_{n,t}, C_{m,t})}{\partial C_{n,t}} = \gamma_n^{\frac{1}{\varepsilon_c}} (C_{n,t})^{-\frac{1}{\varepsilon_c}} \left[\sum_{m=1}^M \gamma_m^{\frac{1}{\varepsilon_c}} (C_{m,t})^{\frac{\varepsilon_c-1}{\varepsilon_c}} \right]^{\frac{1}{\varepsilon_c-1}} - q_t^c P_{n,t} = 0 \quad (\text{A.15})$$

$$\frac{\partial \mathcal{L}(C_{n,t}, C_{m,t})}{\partial C_{m,t}} = \gamma_m^{\frac{1}{\varepsilon_c}} (C_{m,t})^{-\frac{1}{\varepsilon_c}} \left[\sum_{m=1}^M \gamma_m^{\frac{1}{\varepsilon_c}} (C_{m,t})^{\frac{\varepsilon_c-1}{\varepsilon_c}} \right]^{\frac{1}{\varepsilon_c-1}} - q_t^c (1 + \varepsilon_{\tau,t}) s_t^{nm} P_{m,t} = 0 \quad (\text{A.16})$$

Combining and simplifying the first-order conditions - (A.15) and (A.16) - yields:

$$C_{m,t} = \frac{\gamma_m}{\gamma_n} \left[\frac{(1 + \varepsilon_{\tau,t}) s_t^{nm} P_{m,t}}{P_{n,t}} \right]^{-\varepsilon_c} C_{n,t} \quad (\text{A.17})$$

I substitute (A.17) into (A.13), which results in:

$$P_t C_t = P_{n,t} C_{n,t} + \sum_{\substack{m=1 \\ m \neq n}}^M (1 + \varepsilon_{\tau,t}) s_t^{nm} P_{m,t} \frac{\gamma_m}{\gamma_n} \left[\frac{(1 + \varepsilon_{\tau,t}) s_t^{nm} P_{m,t}}{P_{n,t}} \right]^{-\varepsilon_c} C_{n,t} \quad (\text{A.18})$$

Assuming the definition of the price index given by equation (A.13), equation (A.18) simplifies into the following optimal allocation of the households' budget to locally produced goods:

$$C_{n,t} = \gamma_n \left[\frac{P_{n,t}}{P_t} \right]^{-\varepsilon_c} C_t \quad (\text{A.19})$$

Equation (A.19) is substituted back into (A.17) to obtain the optimal demand conditions for imported goods:

$$C_{m,t} = \frac{\gamma_m}{\gamma_n} \left[\frac{(1 + \varepsilon_{\tau,t}) s_t^{nm} P_{m,t}}{P_{n,t}} \right]^{-\varepsilon_c} \gamma_n \left[\frac{P_{n,t}}{P_t} \right]^{-\varepsilon_c} C_t \quad (\text{A.20})$$

Simplifying further yields the following optimal demand condition for imported consumer goods:

$$C_{m,t} = \gamma_m \left[\frac{(1 + \varepsilon_{\tau,t}) s_t^{nm} P_{m,t}}{P_t} \right]^{-\varepsilon_c} C_t \quad (\text{A.21})$$

A.1.2 The firms' problem

Retailers

Competitive retailers purchase differentiated goods from intermediate goods producers and combine them into a homogeneous final good. Aggregate output of retailers XR_t is given by the following CES aggregate of a continuum differentiated intermediate goods:

$$XR_t = \left[\int_0^1 XR_t(v)^{\frac{\mu-1}{\mu}} dv \right]^{\frac{\mu}{\mu-1}} \quad (\text{A.22})$$

The profit maximization problem of the representative retailer v is given by the difference between the revenues from the sales of the final good and the expenditures on intermediate goods:

$$\max_{XR_t(v)} \left[P_{n,t} XR_t - \int_0^1 P_{n,t}(v) XR_t(v) dv \right] \quad (\text{A.23})$$

which given the definition of the final good from (A.22) yields:

$$\max_{XR_t(v)} \left[P_{n,t} \left[\int_0^1 XR_t(v)^{\frac{\mu-1}{\mu}} dv \right]^{\frac{\mu}{\mu-1}} - \int_0^1 P_{n,t}(v) XR_t(v) dv \right] \quad (\text{A.24})$$

The first-order condition of the retailers' profit maximization problem is:

$$P_{n,t} \left[\int_0^1 XR_t(v)^{\frac{\mu-1}{\mu}} dv \right]^{\frac{1}{\mu-1}} XR_t(v)^{-\frac{1}{\mu}} - P_{n,t}(v) = 0 \quad (\text{A.25})$$

which can be simplified into the following retailers' demand for a typical variety of the intermediate good produced by the representative firm v :

$$XR_t(v) = \left[\frac{P_{n,t}(v)}{P_{n,t}} \right]^{-\mu} XR_t \quad (\text{A.26})$$

Using the production function for each intermediate good, (A.26) becomes:

$$\int_0^1 H_t(v) dv = \left[\frac{P_{n,t}(v)}{P_{n,t}} \right]^{-\mu} XR_t \quad (\text{A.27})$$

Now define a measure of price dispersion v_t^p :

$$v_t^p = \int_0^1 \left[\frac{P_{n,t}(v)}{P_{n,t}} \right]^{-\mu} dv \quad (\text{A.28})$$

Using the definition of aggregate labor input, we can define retail output XR_t as:

$$XR_t = \frac{X_t}{v_t^p} \quad (\text{A.29})$$

Finally, following the zero-profit condition, the price of the final good can be defined by:

$$P_{n,t} = \left[\int_0^1 P_{n,t}(v)^{1-\mu} dv \right]^{\frac{1}{1-\mu}} \quad (\text{A.30})$$

Intermediate goods producers

Intermediate goods producers combine labor inputs and transform labor into a distinctive good:

$$X_t(v) = \varepsilon_{a,t} H_t(v) \quad (\text{A.31})$$

Intermediate goods producers face the common wage rate W_t and plan their future production with a goal to minimize cost. Their optimization problem can be formalized as:

$$\min_{H_t(v)} W_t H_t(v) \quad (\text{A.32})$$

s.t.

$$\varepsilon_{a,t} H_t(v) \geq \left[\frac{P_{n,t}(v)}{P_{n,t}} \right]^{-\mu} X R_t \quad (\text{A.33})$$

The corresponding Lagrangian is given by:

$$\mathcal{L}(H_t(v)) = W_t H_t(v) - mc_t(v) \left[\varepsilon_{a,t} H_t(v) - \left[\frac{P_{n,t}(v)}{P_{n,t}} \right]^{\frac{\mu}{1-\mu}} X R_t \right] \quad (\text{A.34})$$

The first-order condition of the cost minimization problem w.r.t. $H_t(v)$ is:

$$\frac{\partial \mathcal{L}(H_t(v))}{\partial H_t(v)} = W_t - \varepsilon_{a,t} mc_t(v) = 0 \quad (\text{A.35})$$

Given that all intermediate goods producers are identical, the first-order condition in real terms is given by:

$$W_t = \varepsilon_{a,t} mc_t \quad (\text{A.36})$$

Real (flow) profit of the representative producer is given by:

$$\Pi_t(v) = P_{n,t}(v) X R_t(v) - W_t H_t(v) \quad (\text{A.37})$$

which given that $W_t(v) = \varepsilon_{a,t} mc_t(v)$ takes the form:

$$\Pi_t(v) = P_{n,t}(v) X R_t(v) - mc_t(v) X R_t(v) \quad (\text{A.38})$$

The profit maximization problem of a firm that is able to reset its price can be written as:

$$\max_{P_{n,t}(v)} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta\theta_p)^k q_{t+k} \frac{1}{P_{n,t+k}} \left[P_{n,t}(v) X R_{t+k}(v) - m c_{t+k}(v) X R_{t+k}(v) \right] \quad (\text{A.39})$$

$$\max_{P_{n,t}(v)} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta\theta_p)^k q_{t+k} \frac{1}{P_{n,t+k}} \left[P_{n,t}(v) \left[\frac{P_{n,t+k}(v)}{P_{n,t+k}} \right]^{-\mu} X_{t+k} - m c_{t+k}(v) \left[\frac{P_{n,t}(v)}{P_{n,t+k}} \right]^{-\mu} X_{t+k} \right] \quad (\text{A.40})$$

The first-order condition can be written as:

$$(1 - \mu) P_{n,t}(v)^{-\mu} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta\theta_p)^k q_{t+k} P_{n,t+k}^{\mu-1} X R_{t+k} + \mu P_{n,t}(v)^{-\mu-1} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta\theta_p)^k q_{t+k} m c_{i,t+k} P_{n,t+k}^{\mu} X R_{t+k} = 0 \quad (\text{A.41})$$

$$\tilde{P}_{n,t}(v) = \mu \frac{\mathbb{E}_t \sum_{k=0}^{\infty} (\beta\theta_p)^k q_{t+k} m c_{i,t+k} P_{n,t+k}^{\frac{1}{1-\mu}} X R_{t+k}}{\mathbb{E}_t \sum_{k=0}^{\infty} (\beta\theta_p)^k q_{t+k} P_{n,t+k}^{\frac{1}{1-\mu}} X R_{t+k}} \quad (\text{A.42})$$

which can be written as:

$$\tilde{P}_{n,t}(v) = \frac{\mu}{\mu - 1} \frac{e_t}{f_t} \quad (\text{A.43})$$

where

$$e_t = q_t m c_t P_{n,t}^{\mu} X R_t + \theta_p \beta \mathbb{E}_t e_{t+1} \quad (\text{A.44})$$

$$f_t = q_t P_{n,t}^{\mu-1} X R_t + \theta_p \beta \mathbb{E}_t f_{t+1} \quad (\text{A.45})$$

A.2 Optimization problems of Ricardian and non-Ricardian households

A.2.1 Ricardian households

Country n 's Ricardian households maximize their lifetime utility over consumption $C_{R,t}$, labor inputs to the intermediate goods producers $H_{R,t}$, and optimal holdings of short-term bonds B_t :

$$\max_{C_{R,t}, H_{R,t}, B_t} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta_R)^k U_{R,t+k} \quad (\text{A.46})$$

where the utility function is assumed to be the same for each individual Ricardian household and takes the form:

$$\max_{C_{R,t}, H_{R,t}, B_t} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta_R)^k \left[\frac{C_{R,t+k}^{1-\sigma_c}}{1-\sigma_c} - \vartheta_R \frac{H_{R,t+k}^{1+\varphi_h}}{1+\varphi_h} \right] \quad (\text{A.47})$$

subject to a sequence of intertemporal budget constraints of the form:

$$C_{R,t} + B_t + T_{R,t} = W_t H_{R,t} + \frac{R_{t-1}}{\pi_t} B_{t-1} + \Pi_t \quad (\text{A.48})$$

The Lagrangian for the Ricardian household's optimization problem is given by:

$$\mathcal{L}(C_{R,t}, H_{R,t}, B_t) = \mathbb{E}_t \sum_{k=0}^{\infty} (\beta_R)^k \left[\begin{array}{c} \frac{C_{R,t+k}^{1-\sigma_c}}{1-\sigma_c} - \vartheta_R \frac{H_{R,t+k}^{1+\varphi_h}}{1+\varphi_h} \\ - \varrho_{R,t+k} \left(\begin{array}{c} C_{R,t+k} + B_{t+k} + T_{R,t+k} \\ - W_{t+k} H_{R,t+k} - \frac{R_{t-1+k}}{\pi_{t+k}} B_{t-1+k} \\ - \Pi_{t+k} \end{array} \right) \end{array} \right] \quad (\text{A.49})$$

The first-order conditions with respect to $C_{R,t}$, $H_{R,t}$, and B_t are:

$$\frac{\partial \mathcal{L}(C_{R,t}, H_{R,t}, B_t)}{\partial C_{R,t}} = C_{R,t}^{-\sigma_c} - \varrho_{R,t} = 0 \quad (\text{A.50})$$

$$\frac{\partial \mathcal{L}(C_{R,t}, H_{R,t}, B_t)}{\partial H_{R,t}} = \vartheta_R H_{R,t}^{\varphi_h} + \varrho_{R,t} W_t = 0 \quad (\text{A.51})$$

$$\frac{\partial \mathcal{L}(C_{R,t}, H_{R,t}, B_t)}{\partial B_t} = -\varrho_{R,t} - \beta_R \varrho_{R,t+1} \frac{R_t}{\pi_{t+1}} = 0 \quad (\text{A.52})$$

The first-order conditions result in the following marginal utility of consumption condition, the optimal labor supply, and the conventional Euler equation:

$$\varrho_{R,t} = C_{R,t}^{-\sigma_c} \quad (\text{A.53})$$

$$\varrho_{R,t} W_t = \vartheta_R H_{R,t}^{\varphi_h} \quad (\text{A.54})$$

$$1 = \mathbb{E}_t \left[\beta_R \frac{\varrho_{R,t+1}}{\varrho_{R,t}} \frac{R_t}{\pi_{t+1}} \right] \quad (\text{A.55})$$

A.2.2 Non-Ricardian households

Non-Ricardian households maximize their lifetime utility over consumption $C_{NR,t}$ and labor $H_{NR,t}$ supplied to intermediate goods producers:

$$\max_{C_{NR,t}, H_{NR,t}} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta_{NR})^k U_{NR,t+k} \quad (\text{A.56})$$

where the utility function is assumed to be the same for each individual non-Ricardian household and takes the form:

$$\max_{C_{NR,t}, H_{NR,t}} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta_{NR})^k \left[\frac{C_{NR,t+k}^{1-\sigma_c}}{1-\sigma_c} - \vartheta_{NR} \frac{H_{NR,t+k}^{1+\varphi_h}}{1+\varphi_h} \right] \quad (\text{A.57})$$

subject to a sequence of intertemporal budget constraints of the form:

$$C_{NR,t} + T_{NR,t} = W_t H_{NR,t} \quad (\text{A.58})$$

The Lagrangian for the non-Ricardian household's optimization problem is given by:

$$\mathcal{L}(C_{NR,t}, H_{NR,t}) = \mathbb{E}_t \sum_{k=0}^{\infty} (\beta_{NR})^k \left[\frac{C_{NR,t+k}^{1-\sigma_c}}{1-\sigma_c} - \vartheta_{NR} \frac{H_{NR,t+k}^{1+\varphi_h}}{1+\varphi_h} - \varrho_{NR,t+k} \begin{pmatrix} C_{NR,t+k} + T_{NR,t+k} \\ -W_{t+k} H_{NR,t+k} \end{pmatrix} \right] \quad (\text{A.59})$$

The first-order conditions with respect to $C_{NR,t}$ and $H_{NR,t}$ are:

$$\frac{\partial \mathcal{L}(C_{NR,t}, H_{NR,t})}{\partial C_{NR,t}} = C_{NR,t}^{-\sigma_c} - \varrho_{NR,t} = 0 \quad (\text{A.60})$$

$$\frac{\partial \mathcal{L}(C_{NR,t}, H_{NR,t})}{\partial H_{NR,t}} = \vartheta_{NR} H_{NR,t}^{\varphi_h} + \varrho_{NR,t} W_t = 0 \quad (\text{A.61})$$

The first-order conditions result in the following marginal utility of consumption condition and the optimal labor supply:

$$\varrho_{NR,t} = C_{NR,t}^{-\sigma_c} \quad (\text{A.62})$$

$$\varrho_{NR,t} W_t = \vartheta_{NR} H_{NR,t}^{\varphi_h} \quad (\text{A.63})$$

A.3 Optimization problems with supply chains

A.3.1 CES technology

Take the following CES production function with labor and intermediate inputs:

$$X_t(v) = \varepsilon_{a,t} \left[(1 - \varphi_s) H_t(v)^{\frac{\eta-1}{\eta}} + \varphi_s X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \quad (\text{A.64})$$

where X_t^s is defined as:

$$X_t^s(v) = \left[\sum_{m=1}^M (\omega_m)^{\frac{1}{\varepsilon_s}} X_{m,t}^s(v)^{\frac{\varepsilon_s-1}{\varepsilon_s}} \right]^{\frac{\varepsilon_s}{\varepsilon_s-1}} \quad (\text{A.65})$$

The optimization problem of a representative intermediate goods producer can be formalized as:

$$\min_{H_t(v), X_t^s(v)} \left[W_t H_t(v) + P_t^s X_t^s(v) \right] \quad (\text{A.66})$$

s.t.

$$\varepsilon_{a,t} \left[(1 - \varphi_s) H_t(v)^{\frac{\eta-1}{\eta}} + \varphi_s X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \geq \left[\frac{P_t(v)}{P_t} \right]^{-\mu} X R_t \quad (\text{A.67})$$

The corresponding Lagrangian is given by:

$$\begin{aligned} \mathcal{L}(H_t(v), X_{m,t}^s(v)) &= W_t H_t(v) + P_t^s X_t^s(v) \\ &- mc_t(v) \left(\varepsilon_{a,t} \left[(1 - \varphi_s) H_t(v)^{\frac{\eta-1}{\eta}} + \varphi_s X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} - \left[\frac{P_t(v)}{P_t} \right]^{-\mu} X R_t \right) \end{aligned} \quad (\text{A.68})$$

The first-order conditions of the cost minimization problem with respect to $H_t(v)$ and $X_{m,t}^s(v)$ are:

$$\begin{aligned} \frac{\partial \mathcal{L}(H_t(v), X_{m,t}^s(v))}{\partial H_t(v)} &= W_t - mc_t(v) \varepsilon_{a,t} \left[(1 - \varphi_s) H_t(v)^{\frac{\eta-1}{\eta}} + \varphi_s X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{1}{\eta-1}} \\ &\times (1 - \varphi_s) H_t(v)^{-\frac{1}{\eta}} = mc_t(v) (1 - \varphi_s) \varepsilon_{a,t}^{\frac{\eta-1}{\eta}} \left[\frac{X_t(v)}{H_t(v)} \right]^{\frac{1}{\eta}} = 0 \end{aligned} \quad (\text{A.69})$$

$$\begin{aligned} \frac{\partial \mathcal{L}(H_t(v), X_t^s(v))}{\partial X_t^s(v)} &= P_t^s - mc_t(v) \left[(1 - \varphi_s) (\varepsilon_{a,t} H_t(v))^{\frac{\eta-1}{\eta}} + \varphi_s X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{1}{\eta-1}} \\ &\times \varphi_s X_t^s(v)^{-\frac{1}{\eta}} = mc_t(v) \varphi_s \left[\frac{X_t(v)}{X_t^s(v)} \right]^{\frac{1}{\eta}} = 0 \end{aligned} \quad (\text{A.70})$$

Given that all the domestic intermediate goods producers are identical, the first-order conditions of the cost minimization problem in real terms with respect to labor and intermediate

inputs are:

$$W_t = mc_t(1 - \varphi_s)\varepsilon_{a,t}^{\frac{\eta-1}{\eta}} \left[\frac{X_t}{L_t} \right]^{\frac{1}{\eta}} \quad (\text{A.71})$$

$$P_t^s = mc_t\varphi_s \left[\frac{X_t}{X_t^s} \right]^{\frac{1}{\eta}} \quad (\text{A.72})$$

Now take the following CES technology with labor, capital, and intermediate inputs:

$$X_t(v) = \left[(1 - \varphi_s) \left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{\frac{\eta-1}{\eta}} + \varphi_s X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \quad (\text{A.73})$$

A Lagrangian corresponding the cost minimization problem is given by:

$$\begin{aligned} \mathcal{L}(H_t(v), K_t(v), X_t^s(v)) &= W_t H_t(v) + Z_t K_t(v) + P_t^s X_t^s(v) \\ -mc_t(v) &\left(\left[(1 - \varphi_s) \left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{\frac{\eta-1}{\eta}} + \varphi_s X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} - \left[\frac{P_t(v)}{P_t} \right]^{-\mu} X R_t \right) \end{aligned} \quad (\text{A.74})$$

The first-order conditions with respect to $H_t(v)$, $K_t(v)$, and $X_t^s(v)$ are:

$$\begin{aligned} \frac{\partial \mathcal{L}(H_t(v), K_t(v), X_t^s(v))}{\partial H_t(v)} &= W_t - mc_t(v) \\ &\times \left[(1 - \varphi_s) \left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{\frac{\eta-1}{\eta}} + \varphi_s X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{1}{\eta-1}} \\ &\times (1 - \varphi_s) \left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{-\frac{1}{\eta}} (1 - \alpha) \varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{-\alpha} \\ &= W_t - mc_t(v)(1 - \varphi_s)(1 - \alpha) X_t(v)^{\frac{1}{\eta}} \frac{\left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{\frac{\eta-1}{\eta}}}{H_t(v)} = 0 \end{aligned} \quad (\text{A.75})$$

$$\begin{aligned} \frac{\partial \mathcal{L}(H_t(v), K_t(v), X_t^s(v))}{\partial K_t(v)} &= Z_t - mc_t(v) \\ &\times \left[(1 - \varphi_s) \left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{\frac{\eta-1}{\eta}} + \varphi_s X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{1}{\eta-1}} \\ &\times (1 - \varphi_s) \left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{-\frac{1}{\eta}} \alpha \varepsilon_{a,t} K_t(v)^{\alpha-1} H_t(v)^{1-\alpha} \\ &= Z_t - mc_t(v)(1 - \varphi_s) \alpha X_t(v)^{\frac{1}{\eta}} \frac{\left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{\frac{\eta-1}{\eta}}}{K_t(v)} = 0 \end{aligned} \quad (\text{A.76})$$

$$\begin{aligned}
\frac{\partial \mathcal{L}(H_t(v), K_t(v), X_t^s(v))}{\partial X_t^s(v)} &= P_t^s - mc_t(v) \\
&\times \left[(1 - \varphi_s) \left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{\frac{\eta-1}{\eta}} + \varphi_s X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{1}{\eta-1}} \varphi_s X_t^s(v)^{-\frac{1}{\eta}} \\
&= P_t^s - mc_t(v) \varphi_s \left[\frac{X_t(v)}{X_t^s(v)} \right]^{\frac{1}{\eta}} = 0
\end{aligned} \tag{A.77}$$

All intermediate goods producers are identical. Therefore, the first-order conditions of the cost-minimization problem of all intermediate goods producers with respect to labor, capital, and intermediate inputs given the CES specification of technology are, respectively:

$$W_t = mc_t(1 - \varphi_s)(1 - \alpha) X_t^{\frac{1}{\eta}} \frac{\left[\varepsilon_{a,t} K_t^\alpha H_t^{1-\alpha} \right]^{\frac{\eta-1}{\eta}}}{H_t} \tag{A.78}$$

$$Z_t = mc_t(1 - \varphi_s)\alpha X_t^{\frac{1}{\eta}} \frac{\left[\varepsilon_{a,t} K_t^\alpha H_t^{1-\alpha} \right]^{\frac{\eta-1}{\eta}}}{K_t} \tag{A.79}$$

$$P_t^s = mc_t \varphi_s \left[\frac{X_t}{X_t^s} \right]^{\frac{1}{\eta}} \tag{A.80}$$

A.3.2 Leontief technology

In the Leontief specification, intermediate goods producers combine hours worked $H_t(v)$ with the domestic and foreign components $X_t^s(v)$ into a distinctive good:

$$X_t(v) = \min \left[\frac{\varepsilon_{a,t} H_t(v)}{1 - \varphi_s}, \frac{X_t^s(v)}{\varphi_s} \right] \tag{A.81}$$

Cost minimization implies that output is produced using fixed quantities of labor and intermediate inputs, that is:

$$X_t(v) = \varepsilon_{a,t} \frac{X_t^s(v)}{\varphi_s} = \frac{H_t(v)}{1 - \varphi_s} \tag{A.82}$$

which implies that a fixed share of output φ_s is produced with the use of intermediate inputs and the labor component makes up a fixed share $(1 - \varphi_s)$ of the final output:

$$\varepsilon_{a,t} X_t^s(v) = \varphi_s X_t(v) \tag{A.83}$$

$$\varepsilon_{a,t} H_t(v) = (1 - \varphi_s) X_t(v) \tag{A.84}$$

I define the cost function of a representative producer $\mathcal{C}(v)$, which is the sum of the products

of both inputs and their corresponding unit prices:

$$\mathcal{C}(v) = P_t^s X_t^s(v) + W_t H_t(v) \quad (\text{A.85})$$

Using the demand functions of intermediate inputs (equation A.83) and labor (equation A.84), the cost function becomes:

$$\mathcal{C}_t(v) = P_t^s \frac{\varphi_s X_t(v)}{\varepsilon_{a,t}} + W_t \frac{(1 - \varphi_s) X_t(v)}{\varepsilon_{a,t}} = X_t(v) \left[\varphi_s \frac{P_t^s}{\varepsilon_{a,t}} + (1 - \varphi_s) \frac{W_t}{\varepsilon_{a,t}} \right] \quad (\text{A.86})$$

The marginal cost $mc_t(v)$ is, therefore, the derivative of the cost function $\mathcal{C}_t(v)$ with respect to output $X_t(v)$:

$$\frac{\partial \mathcal{C}(v)}{\partial X_t(v)} = mc_t(v) = \varphi_s \frac{P_t^s}{\varepsilon_{a,t}} + (1 - \varphi_s) \frac{W_t}{\varepsilon_{a,t}} \quad (\text{A.87})$$

Now take the Leontief technology with capital, labor, and intermediate inputs combined as follows:

$$X_t(v) = \varepsilon_{a,t} \left[\frac{K_t(v)^\alpha H_t(v)^{1-\alpha}}{1 - \varphi_s}, \frac{X_t^s(v)}{\varphi_s} \right] \quad (\text{A.88})$$

Given the properties of the Leontief specification, cost minimization requires that output is produced using equal shares of each input at all times. That is:

$$X_t(v) = \frac{\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha}}{1 - \varphi_s} = \frac{\varepsilon_{a,t} X_t^s(v)}{\varphi_s} \quad (\text{A.89})$$

It, therefore, implies that the value added explains a fixed share $(1 - \varphi_s)$ of output:

$$\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} = (1 - \varphi_s) X_t(v) \quad (\text{A.90})$$

and the share of intermediate inputs in output equals φ_s at all times:

$$\varepsilon_{a,t} X_t^s(v) = \varphi_s X_t(v) \quad (\text{A.91})$$

The cost function is the sum of inputs multiplied by their corresponding unit prices:

$$\mathcal{C}_t(v) = Z_t K_t(v) + W_t H_t(v) + P_t^s X_t^s(v) \quad (\text{A.92})$$

Solving the first-order condition (A.90) for capital $K_t(v)$ yields:

$$K_t(v) = \left[(1 - \varphi_s) \frac{X_t(v)}{\varepsilon_{a,t} H_t(v)^{1-\alpha}} \right]^{\frac{1}{\alpha}} \quad (\text{A.93})$$

so that the cost function becomes:

$$C_t(v) = Z_t \left[(1 - \varphi_s) \frac{X_t(v)}{\varepsilon_{a,t} H_t(v)^{1-\alpha}} \right]^{\frac{1}{\alpha}} + W_t H_t(v) + P_t^s X_t^s(v) \quad (\text{A.94})$$

The first-order condition of the cost-minimization problem with respect to labor is:

$$W_t = Z_t \frac{1-\alpha}{\alpha} \left[(1 - \varphi_s) \frac{X_t(v)}{\varepsilon_{a,t} H_t(v)^{1-\alpha}} \right]^{\frac{1}{\alpha}} \quad (\text{A.95})$$

So, the optimal use of labor in technology $\tilde{H}_t(v)$ by a representative producer is given by:

$$\tilde{H}_t(v) = (1 - \varphi_s) \left[\frac{1-\alpha}{\alpha} \frac{Z_t}{W_t} \right]^{\alpha} \frac{X_t(v)}{\varepsilon_{a,t}} \quad (\text{A.96})$$

Substituting for $H_t(v)$ in equation (A.93) the optimal demand for labor $\tilde{H}_t(v)$ yields the optimal use of capital $\tilde{K}_t(v)$ in technology:

$$\tilde{K}_t(v) = (1 - \varphi_s) \left[\frac{\alpha}{1-\alpha} \frac{W_t}{Z_t} \right]^{1-\alpha} \frac{X_t(v)}{\varepsilon_{a,t}} \quad (\text{A.97})$$

Substituting for $H_t(v)$ and $K_t(v)$ in the cost function their optimal quantities - $\tilde{H}_t(v)$ and $\tilde{K}_t(v)$ - and using condition (A.91) yields:

$$\begin{aligned} C_t(v) &= Z_t (1 - \varphi_s) \left[\frac{W_t}{Z_t} \frac{\alpha}{1-\alpha} \right]^{1-\alpha} \frac{X_t(v)}{\varepsilon_{a,t}} \\ &+ W_t (1 - \varphi_s) \left[\frac{Z_t}{W_t} \frac{1-\alpha}{\alpha} \right]^{\alpha} \frac{X_t(v)}{\varepsilon_{a,t}} + P_t^s \frac{\varphi_s X_t(v)}{\varepsilon_{a,t}} \end{aligned} \quad (\text{A.98})$$

The marginal cost is the derivative of the cost function with respect to output $X_t(v)$:

$$\begin{aligned} \frac{\partial C_t(v)}{\partial X_t(v)} = mc_t(v) &= \frac{Z_t}{\varepsilon_{a,t}} (1 - \varphi_s) \left[\frac{W_t}{Z_t} \frac{\alpha}{1-\alpha} \right]^{1-\alpha} \\ &+ \frac{W_t}{\varepsilon_{a,t}} (1 - \varphi_s) \left[\frac{Z_t}{W_t} \frac{1-\alpha}{\alpha} \right]^{\alpha} + \varphi_s \frac{P_t^s}{\varepsilon_{a,t}} \end{aligned} \quad (\text{A.99})$$

which can be simplified into the following formula with the weighted unit cost of value added and intermediate inputs:

$$mc_t(v) = (1 - \varphi_s) \frac{Z_t^{\alpha} W_t^{1-\alpha}}{\alpha^{\alpha} (1-\alpha)^{1-\alpha} \varepsilon_{a,t}} + \varphi_s \frac{P_t^s}{\varepsilon_{a,t}} \quad (\text{A.100})$$

A.3.3 Cobb-Douglas technology

The Cobb-Douglas specification implies a unit elasticity of substitution between labor and intermediate inputs, i.e. $\eta = 1$:

$$X_t(v) = \varepsilon_{a,t} H_t(v)^{(1-\varphi_s)} X_t^s(v)^{\varphi_s} \quad (\text{A.101})$$

The optimization problem of a representative intermediate goods producer can be formalized as:

$$\min_{H_t(v), X_t^s(v)} \left[W_t H_t(v) + P_t^s X_t^s(v) \right] \quad (\text{A.102})$$

s.t.

$$\varepsilon_{a,t} H_t(v)^{(1-\varphi_s)} X_t^s(v)^{\varphi_s} \geq \left[\frac{P_t(v)}{P_t} \right]^{-\mu} X R_t \quad (\text{A.103})$$

The corresponding Lagrangian is given by:

$$\begin{aligned} \mathcal{L}(H_t(v), X_{m,t}^s(v)) &= W_t H_t(v) + P_t^s X_t^s(v) \\ &- mc_t(v) \left(\varepsilon_{a,t} H_t(v)^{(1-\varphi_s)} X_t^s(v)^{\varphi_s} - \left[\frac{P_t(v)}{P_t} \right]^{-\mu} X R_t \right) \end{aligned} \quad (\text{A.104})$$

The first-order conditions of the cost minimization problem with respect to $H_t(v)$ and $X_t^s(v)$ are:

$$\begin{aligned} \frac{\partial \mathcal{L}(H_t(v), X_{m,t}^s(v))}{\partial H_t(v)} &= W_t - mc_t(v)(1 - \varphi_s) \varepsilon_{a,t} H_t(v)^{-\varphi_s} X_t^s(v)^{\varphi_s} \\ &= W_t - mc_t(v)(1 - \varphi_s) \frac{X_t(v)}{H_t(v)} = 0 \end{aligned} \quad (\text{A.105})$$

$$\begin{aligned} \frac{\partial \mathcal{L}(H_t(v), X_t^s(v))}{\partial X_t^s(v)} &= P_t^s - mc_t(v) \varphi_s \varepsilon_{a,t} H_t(v)^{1-\varphi_s} X_t^s(v)^{\varphi_s-1} \\ &= P_t^s - mc_t(v) \varphi_s \frac{X_t(v)}{X_t^s(v)} = 0 \end{aligned} \quad (\text{A.106})$$

Given that all the domestic intermediate goods producers are identical, the first-order conditions of the cost minimization problem in real terms with respect to labor and intermediate inputs given the Cobb-Douglas specification of technology are given by:

$$W_t = mc_t(1 - \varphi_s) \frac{X_t}{H_t} \quad (\text{A.107})$$

$$P_t^s = mc_t \varphi_s \frac{X_t}{X_t^s} \quad (\text{A.108})$$

Now take the following Cobb-Douglas technology with labor, capital, and intermediate inputs:

$$X_t(v) = \varepsilon_{a,t} \left[K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{(1-\varphi_s)} X_t^s(v)^{\varphi_s} \quad (\text{A.109})$$

A Lagrangian corresponding the cost minimization problem is given by:

$$\begin{aligned} \mathcal{L}(H_t(v), K_t(v), X_{m,t}^s(v)) &= W_t H_t(v) + Z_t K_t(v) + P_t^s X_t^s(v) \\ &- mc_t(v) \left(\varepsilon_{a,t} \left[K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{(1-\varphi_s)} X_t^s(v)^{\varphi_s} - \left[\frac{P_t(v)}{P_t} \right]^{-\mu} X R_t \right) \end{aligned} \quad (\text{A.110})$$

The first-order conditions with respect to $H_t(v)$, $K_t(v)$, and $X_t^s(v)$ are:

$$\begin{aligned} \frac{\partial \mathcal{L}(H_t(v), K_t(v), X_t^s(v))}{\partial H_t(v)} &= W_t - mc_t(v) \varepsilon_{a,t} (1 - \varphi_s) (1 - \alpha) \left[K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{-\varphi_s} \\ &\times X_t^s(v)^{\varphi_s} K_t(v)^\alpha H_t(v)^{-\alpha} = W_t - mc_t(v) (1 - \varphi_s) (1 - \alpha) \frac{X_t(v)}{K_t(v)^\alpha H_t(v)^{1-\alpha}} \\ &\times K_t(v)^\alpha H_t(v)^{-\alpha} = W_t - mc_t(v) (1 - \varphi_s) (1 - \alpha) \frac{X_t(v)}{H_t(v)} = 0 \end{aligned} \quad (\text{A.111})$$

$$\begin{aligned} \frac{\partial \mathcal{L}(H_t(v), K_t(v), X_t^s(v))}{\partial K_t(v)} &= Z_t - mc_t(v) \varepsilon_{a,t} (1 - \varphi_s) \alpha \left[K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{-\varphi_s} \\ &\times X_t^s(v)^{\varphi_s} K_t(v)^{\alpha-1} H_t(v)^{1-\alpha} = Z_t - mc_t(v) (1 - \varphi_s) \alpha \frac{X_t(v)}{K_t(v)^\alpha H_t(v)^{1-\alpha}} \\ &\times K_t(v)^{\alpha-1} H_t(v)^{1-\alpha} = Z_t - mc_t(v) (1 - \varphi_s) \alpha \frac{X_t(v)}{K_t(v)} = 0 \end{aligned} \quad (\text{A.112})$$

$$\begin{aligned} \frac{\partial \mathcal{L}(H_t(v), K_t(v), X_t^s(v))}{\partial X_t^s(v)} &= P_t^s - mc_t(v) \varphi_s \varepsilon_{a,t} \left[K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{(1-\varphi_s)} \\ &\times X_t^s(v)^{\varphi_s-1} = P_t^s - mc_t(v) \varphi_s \frac{X_t(v)}{X_t^s(v)} = 0 \end{aligned} \quad (\text{A.113})$$

All intermediate goods producers are identical. Therefore, the first-order conditions of the cost-minimization problem of all intermediate goods producers with respect to labor, capital, and intermediate inputs given the Cobb-Douglas specification of technology are, respectively:

$$W_t = mc_t (1 - \varphi_s) (1 - \alpha) \frac{X_t}{H_t} \quad (\text{A.114})$$

$$Z_t = mc_t (1 - \varphi_s) \alpha \frac{X_t}{K_t} \quad (\text{A.115})$$

$$P_t^s = mc_t \varphi_s \frac{X_t}{X_t^s} \quad (\text{A.116})$$

A.4 Optimization problems with long-term bonds

When households are allowed to invest in the domestic bonds only, Ricardian households are assumed to be maximizing their utility subject to consumption $C_{R,t}$, labor inputs $H_{R,t}$, and investments in the short-term and long-term bonds - $B_{S,t}$ and $B_{L,t}$, respectively:

$$C_{R,t} + B_{S,t} + (1 + \zeta_{b,t})P_{b,t}B_{L,t} + T_{R,t} = W_t H_{R,t} + \frac{R_{t-1}}{\pi_t} B_{S,t-1} + P_{b,t} \frac{R_{b,t}}{\pi_t} B_{L,t-1} + \Pi_t \quad (\text{A.117})$$

The Lagrangian for the Ricardian household's optimization problem is given by:

$$\mathcal{L}(C_{R,t}, H_{R,t}, B_{S,t}, B_{L,t}) = \mathbb{E}_t \sum_{k=0}^{\infty} (\beta_R)^k \left[\begin{array}{c} \frac{C_{R,t+k}^{1-\sigma_c}}{1-\sigma_c} - \vartheta_R \frac{H_{R,t+k}^{1+\varphi_h}}{1+\varphi_h} \\ - \varrho_{R,t+k} \left(\begin{array}{c} C_{R,t+k} + B_{S,t+k} \\ + (1 + \zeta_{b,t+k})P_{b,t+k}B_{L,t+k} \\ + T_{R,t+k} - W_{t+k}H_{R,t+k} \\ - \frac{R_{t-1+k}}{\pi_{t+k}} B_{S,t-1+k} \\ - P_{b,t+k} \frac{R_{b,t+k}}{\pi_{t+k}} B_{L,t-1+k} \\ - \Pi_{t+k} \end{array} \right) \end{array} \right] \quad (\text{A.118})$$

The first-order conditions with respect to $C_{R,t}$, $H_{R,t}$ are unchanged relative to the previous optimizations. The first-order conditions with respect to $B_{S,t}$, and $B_{L,t}$ are:

$$\frac{\partial \mathcal{L}(C_{R,t}, H_{R,t}, B_{S,t}, B_{L,t})}{\partial B_{S,t}} = -\varrho_{R,t} - \beta_R \varrho_{R,t+1} \frac{R_t}{\pi_{t+1}} = 0 \quad (\text{A.119})$$

$$\frac{\partial \mathcal{L}(C_{R,t}, H_{R,t}, B_{S,t}, B_{L,t})}{\partial B_{L,t}} = -\varrho_{R,t}(1 + \zeta_{b,t})P_{b,t} + \beta_R \varrho_{R,t+1}P_{b,t+1} \frac{R_{b,t+1}}{\pi_{t+1}} = 0 \quad (\text{A.120})$$

The first-order conditions result in the following Euler equations which determine the optimal holding of the short-term and long-term bonds:

$$1 = \mathbb{E}_t \left[\beta_R \frac{\varrho_{R,t+1}}{\varrho_{R,t}} \frac{R_t}{\pi_{t+1}} \right] \quad (\text{A.121})$$

$$(1 + \zeta_{b,t})P_{b,t} = \beta_R \mathbb{E}_t \left[\frac{\varrho_{R,t+1}}{\varrho_{R,t}} P_{b,t+1} \frac{R_{b,t+1}}{\pi_{t+1}} \right] \quad (\text{A.122})$$

A.5 Optimization problems with credit linkages

Now assume that the transaction costs in the domestic economy associated with investments in the long-term bonds are the following: $\zeta_t^{n,n}$ denotes transaction costs corresponding to domestic long-term bonds; $\zeta_t^{m,n}$ represents transaction costs associated with domestic investments in the country m 's long-term bonds. By symmetry, $\zeta_t^{n,m}$ denotes country m 's transaction costs associated with investments in the country n 's long-term bonds.

Provided that the domestic households are allowed to invest in foreign bonds, the utility maximization of the Ricardian households is subject to the following budget constraint:

$$\begin{aligned} C_{R,t} + B_{S,t} + (1 + \zeta_{b,t}^{n,n})P_{b,t}^n B_{L,t}^n + \sum_{\substack{m=1 \\ m \neq n}}^M s_t^{nm} (1 + \zeta_{b,t}^{m,n})P_{b,t}^m B_{L,t}^m + T_{R,t} \\ = W_t H_{R,t} + \frac{R_{t-1}}{\pi_t} B_{S,t-1} + P_{b,t}^n \frac{R_{b,t}^n}{\pi_t} B_{L,t-1}^n + \sum_{\substack{m=1 \\ m \neq n}}^M s_t^{nm} P_{b,t}^m \frac{R_{b,t}^m}{\pi_t} B_{L,t-1}^m + \Pi_t \end{aligned} \quad (\text{A.123})$$

The Lagrangian corresponding to the Ricardian household's optimization problem with credit linkages is given by:

$$\begin{aligned} \mathcal{L}(C_{R,t}, H_{R,t}, B_{S,t}, B_{L,t}^n, B_{L,t}^m) = \mathbb{E}_t \sum_{k=0}^{\infty} (\beta_R)^k \\ \times \left[\begin{aligned} & \frac{C_{R,t+k}^{1-\sigma_c}}{1-\sigma_c} - \vartheta_R \frac{H_{R,t+k}^{1+\varphi_h}}{1+\varphi_h} \\ & - \varrho_{R,t+k} \left(\begin{aligned} & C_{R,t+k} + B_{S,t+k} + (1 + \zeta_{b,t+k}^{n,n})P_{b,t+k}^n B_{L,t+k}^n \\ & + \sum_{\substack{m=1 \\ m \neq n}}^M s_{t+k}^{nm} (1 + \zeta_{b,t+k}^{m,n})P_{b,t+k}^m B_{L,t+k}^m + T_{R,t+k} \\ & - W_{t+k} H_{R,t+k} - \frac{R_{t-1+k}}{\pi_{t+k}} B_{S,t-1+k} - P_{b,t+k}^n \frac{R_{b,t+k}^n}{\pi_{t+k}} B_{L,t-1+k}^n \\ & - \sum_{\substack{m=1 \\ m \neq n}}^M s_{t+k}^{nm} P_{b,t+k}^m \frac{R_{b,t+k}^m}{\pi_{t+k}} B_{L,t-1+k}^m - \Pi_{t+k} \end{aligned} \right) \end{aligned} \right] \quad (\text{A.124}) \end{aligned}$$

The first-order conditions with respect to the short-term bonds $B_{S,t}$, as well as the domestic and foreign long-term bonds - respectively $B_{L,t}^n$ and $B_{L,t}^m$ - are:

$$\frac{\partial \mathcal{L}(C_{R,t}, H_{R,t}, B_{S,t}, B_{L,t}^n, B_{L,t}^m)}{\partial B_{S,t}} = -\varrho_{R,t} - \beta_R \varrho_{R,t+1} \frac{R_t}{\pi_{t+1}} = 0 \quad (\text{A.125})$$

$$\frac{\partial \mathcal{L}(C_{R,t}, H_{R,t}, B_{S,t}, B_{L,t}^n, B_{L,t}^m)}{\partial B_{L,t}^n} = -\varrho_{R,t} (1 + \zeta_{b,t}^{n,n}) P_{L,t} + \beta_R \varrho_{R,t+1} P_{L,t+1} \frac{R_{b,t+1}}{\pi_{t+1}} = 0 \quad (\text{A.126})$$

$$\begin{aligned} \frac{\partial \mathcal{L} \left(C_{R,t}, H_{R,t}, B_{S,t}, B_{L,t}^n, B_{L,t}^m \right)}{\partial B_{L,t}^m} &= -Q_{R,t} s_t^{nm} (1 + \zeta_{b,t}^{m,n}) P_{L,t}^m \\ &+ \beta_R Q_{R,t+1} s_{t+1}^{nm} P_{L,t+1}^m \frac{R_{b,t+1}^m}{\pi_{t+1}^m} = 0 \end{aligned} \quad (\text{A.127})$$

The first-order conditions from the Ricardian households' constrained utility maximization result in the following Euler equations which determine the optimal holding of the short-term and the domestic and foreign long-term bonds:

$$1 = \beta_R \mathbb{E}_t \left[\frac{Q_{R,t+1}}{Q_{R,t}} \frac{R_t}{\pi_{t+1}} \right] \quad (\text{A.128})$$

$$P_{L,t} Q_{R,t} (1 + \zeta_{b,t}^{n,n}) = \beta_R \mathbb{E}_t \left[Q_{R,t+1} P_{L,t+1} \frac{R_{b,t+1}}{\pi_{t+1}} \right] \quad (\text{A.129})$$

$$s_t^{nm} P_{L,t}^m Q_{R,t} (1 + \zeta_{b,t}^{m,n}) = \beta_R \mathbb{E}_t \left[Q_{R,t+1} s_{t+1}^{nm} P_{L,t+1}^m \frac{R_{b,t+1}^m}{\pi_{t+1}^m} \right] \quad (\text{A.130})$$

Assuming no arbitrage opportunities between investing in the domestic and foreign long-term bonds with equal maturities, the following relation between the domestic and foreign long-term interest rates must hold:

$$1 = \frac{\lambda_{R,t}}{R_{b,t+1}^n \beta_R P_{L,t+1}^n \lambda_{R,t+1}} (1 + \zeta_{b,t}^{n,n}) \pi_{t+1} \quad (\text{A.131})$$

$$1 = \frac{\lambda_{R,t}}{R_{b,t+1}^m \beta_R s_{t+1}^{nm} P_{L,t+1}^m \lambda_{R,t+1}} (1 + \zeta_{b,t}^{m,n}) \pi_{t+1}^m \quad (\text{A.132})$$

$$\frac{\lambda_{R,t}}{R_{b,t+1}^n \beta_R P_{L,t+1}^n \lambda_{R,t+1}} (1 + \zeta_{b,t}^{n,n}) \pi_{t+1} = \frac{\lambda_{R,t}}{R_{b,t+1}^m \beta_R s_{t+1}^{nm} P_{L,t+1}^m \lambda_{R,t+1}} (1 + \zeta_{b,t}^{m,n}) \pi_{t+1}^m \quad (\text{A.133})$$

which implies:

$$\mathbb{E}_t \left[\frac{s_{t+1}^{nm} P_{L,t+1}^m R_{b,t+1}^m}{(1 + \zeta_{b,t}^{m,n}) \pi_{t+1}^m} \right] = \mathbb{E}_t \left[\frac{P_{L,t+1} R_{b,t+1}}{(1 + \zeta_{b,t}^{n,n}) \pi_{t+1}} \right] \quad (\text{A.134})$$

the first-order Taylor approximation of which yields the following linearized long-term uncovered interest rate parity (UIP):

$$\begin{aligned} &\mathbb{E}_t (\hat{s}_{t+1}^{nm} - \hat{s}_t^{nm} + \hat{P}_{L,t+1}^m - \hat{P}_{L,t}^m + \hat{R}_{L,t+1}^m - \hat{R}_{L,t}^m - \hat{\pi}_{t+1}^m) \\ &= \mathbb{E}_t (\hat{P}_{L,t+1}^n - \hat{P}_{L,t}^n + \hat{R}_{L,t+1}^n - \hat{R}_{L,t}^n - \hat{\pi}_{t+1}^n) + \zeta_{b,t}^{m,n} - \zeta_{b,t}^{n,n} \end{aligned} \quad (\text{A.135})$$

where variables with hats denote log-deviations from the corresponding non-stochastic steady-state values.

In the foreign economy, by symmetry, the Euler equations associated with investments in

the long-term bonds are:

$$P_{L,t}^m Q_{R,t}^m (1 + \zeta_{b,t}^{m,m}) = \beta_R^m \mathbb{E}_t \left[Q_{R,t+1}^m P_{L,t+1}^m \frac{R_{b,t+1}^m}{\pi_{t+1}^m} \right] \quad (\text{A.136})$$

$$\frac{1}{s_t^{nm}} P_{L,t}^n Q_{R,t}^m (1 + \zeta_{b,t}^{n,m}) = \beta_R^m \mathbb{E}_t \left[Q_{R,t+1}^m \frac{1}{s_{t+1}^{nm}} P_{L,t+1}^n \frac{R_{b,t+1}^n}{\pi_{t+1}^m} \right] \quad (\text{A.137})$$

Assuming no arbitrage opportunities between the two implies:

$$\mathbb{E}_t \left[\frac{1}{s_{t+1}^{nm}} \frac{P_{L,t+1}^n R_{b,t+1}^n}{(1 + \zeta_{b,t}^{n,m}) \pi_{t+1}^m} \right] = \mathbb{E}_t \left[\frac{P_{L,t+1}^m R_{b,t+1}^m}{(1 + \zeta_{b,t}^{m,m}) \pi_{t+1}^m} \right] \quad (\text{A.138})$$

the first-order Taylor approximation of which gives:

$$\begin{aligned} & \mathbb{E}_t (\hat{s}_t^{nm} - \hat{s}_{t+1}^{nm} + \hat{P}_{L,t+1}^n - \hat{P}_{L,t}^n + \hat{R}_{L,t+1}^n - \hat{R}_{L,t}^n - \hat{\pi}_{t+1}) \\ &= \mathbb{E}_t (\hat{P}_{L,t+1}^m - \hat{P}_{L,t}^m + \hat{R}_{L,t+1}^m - \hat{R}_{L,t}^m - \hat{\pi}_{t+1}^m) + \zeta_{b,t}^{n,m} - \zeta_{b,t}^{m,m} \end{aligned} \quad (\text{A.139})$$

By subtracting (A.139) from (A.135) I get the following equality condition between transaction costs on domestic and foreign long-term bonds:

$$\zeta_{b,t}^{n,m} - \zeta_{b,t}^{m,m} = \zeta_{b,t}^{m,n} - \zeta_{b,t}^{n,n} \quad (\text{A.140})$$

Take now the country n 's Euler equation associated with investments in short-term bonds:

$$Q_{R,t} = \beta_R \mathbb{E}_t \left[Q_{R,t+1} \frac{R_t^n}{\pi_{t+1}} \right] \quad (\text{A.141})$$

and equate it with the Euler equation corresponding to the country n 's investment in domestic long-term bonds. This yields:

$$\frac{R_t^n}{\pi_{t+1}^n} = P_{L,t+1}^n \frac{R_{b,t+1}^n}{(1 + \zeta_{b,t}^{n,n}) \pi_{t+1}^n} \quad (\text{A.142})$$

which approximated to the first-order gives:

$$\hat{R}_t^n + \zeta_{b,t}^{n,n} = \mathbb{E}_t (\hat{P}_{L,t+1}^n - \hat{P}_{L,t}^n + \hat{R}_{L,t+1}^n) \quad (\text{A.143})$$

In the foreign economy, a corresponding condition results in:

$$\hat{R}_t^m + \zeta_{b,t}^{m,m} = \mathbb{E}_t (\hat{P}_{L,t+1}^m - \hat{P}_{L,t}^m + \hat{R}_{L,t+1}^m) \quad (\text{A.144})$$

Now use equations (A.143) and (A.144) to transform the long-run UIP conditions (A.135) and (A.139) corresponding to country n and m , respectively, into the following short-run UIP conditions:

$$\mathbb{E}_t \left(\hat{s}_{t+1}^{nm} - \hat{s}_t^{nm} + \hat{R}_t^m + \zeta_{b,t}^{m,m} - \hat{\pi}_{t+1}^m \right) = \mathbb{E}_t \left(\hat{R}_t^n + \zeta_{b,t}^{n,n} - \hat{\pi}_{t+1}^n + \zeta_{b,t}^{m,n} - \zeta_{b,t}^{n,n} \right) \quad (\text{A.145})$$

$$\mathbb{E}_t \left(\hat{R}_t^m + \zeta_{b,t}^{m,m} - \hat{\pi}_{t+1}^m + \zeta_{b,t}^{n,m} - \zeta_{b,t}^{m,m} \right) = \mathbb{E}_t \left(\hat{s}_t^{nm} - \hat{s}_{t+1}^{nm} + \hat{R}_t^n + \zeta_{b,t}^{n,n} - \hat{\pi}_{t+1}^n \right) \quad (\text{A.146})$$

Substituting (A.146) from (A.145) gives the following equality between transaction costs in any pair of countries:

$$\zeta_{b,t}^{m,m} + \zeta_{b,t}^{n,m} - \zeta_{b,t}^{m,m} - \zeta_{b,t}^{m,m} = \zeta_{b,t}^{n,n} - \zeta_{b,t}^{n,n} - \zeta_{b,t}^{m,n} + \zeta_{b,t}^{n,n} \quad (\text{A.147})$$

which can be simplified into:

$$\zeta_{b,t}^{n,m} - \zeta_{b,t}^{m,m} = -\zeta_{b,t}^{m,n} + \zeta_{b,t}^{n,n} \quad (\text{A.148})$$

By combining (A.148) with the previously derived equality between transaction costs (A.140) I arrive at the following equality between transaction costs in the domestic economy. That is, country n 's transaction costs associated with investments in foreign long-term bonds better be equal to transaction costs associated with investments in domestic long-term bonds:

$$\zeta_{b,t}^{m,n} - \zeta_{b,t}^{n,n} = -\zeta_{b,t}^{m,n} + \zeta_{b,t}^{n,n} \quad (\text{A.149})$$

$$\zeta_{b,t}^{m,n} = \zeta_{b,t}^{n,n} \quad (\text{A.150})$$

Using equality from (A.150), the implied short-term UIP condition described earlier by (A.135) becomes:

$$\mathbb{E}_t \left[\hat{s}_{t+1}^{nm} - \hat{s}_t^{nm} + \hat{R}_t^m + \zeta_{b,t}^{m,m} - \hat{\pi}_{t+1}^m \right] = \mathbb{E}_t \left[\hat{R}_t^n + \zeta_{b,t}^{n,n} - \hat{\pi}_{t+1}^n \right] \quad (\text{A.151})$$

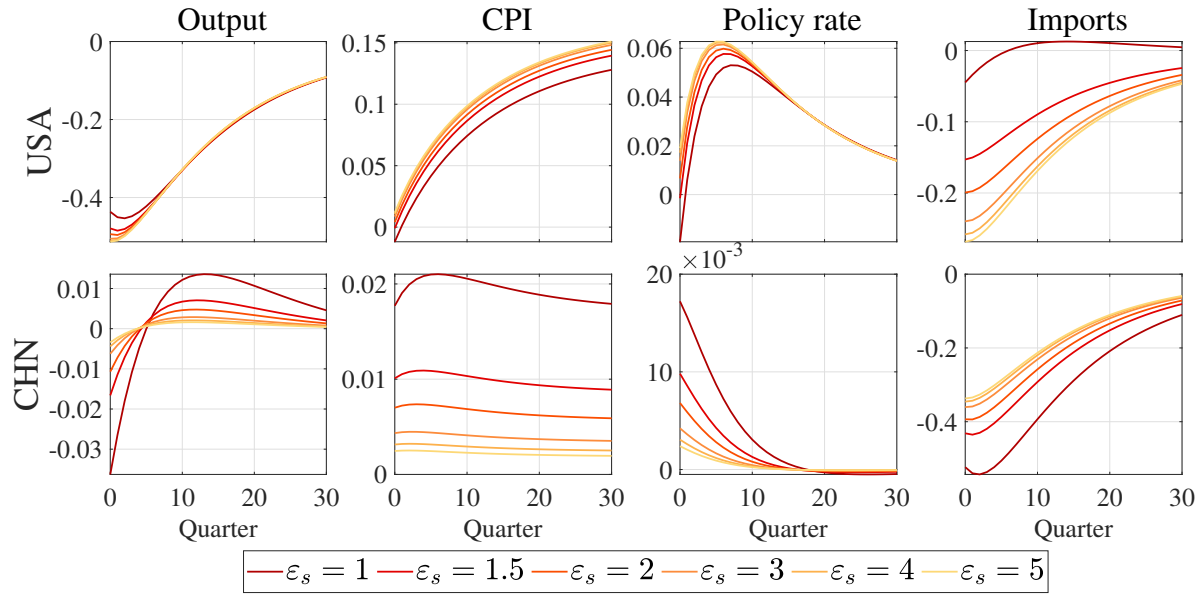
We can easily show that in the foreign economy the following relation must hold:

$$\zeta_{b,t}^{n,m} = \zeta_{b,t}^{m,m} \quad (\text{A.152})$$

and a symmetrical short-run UIP can be derived which can be used interchangeably with the one given by (A.151).

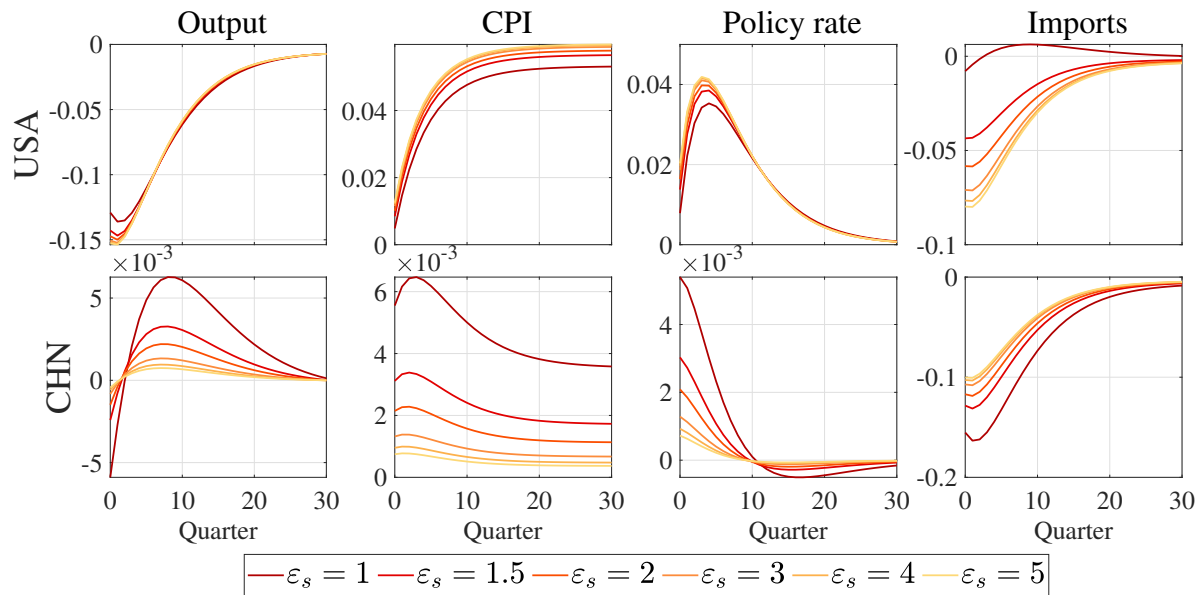
A.6 Sensitivity checks

Figure A.1: Sensitivity analysis: elasticity of substitution between domestic and imported intermediate inputs. Responses to US-originated TFP shock.



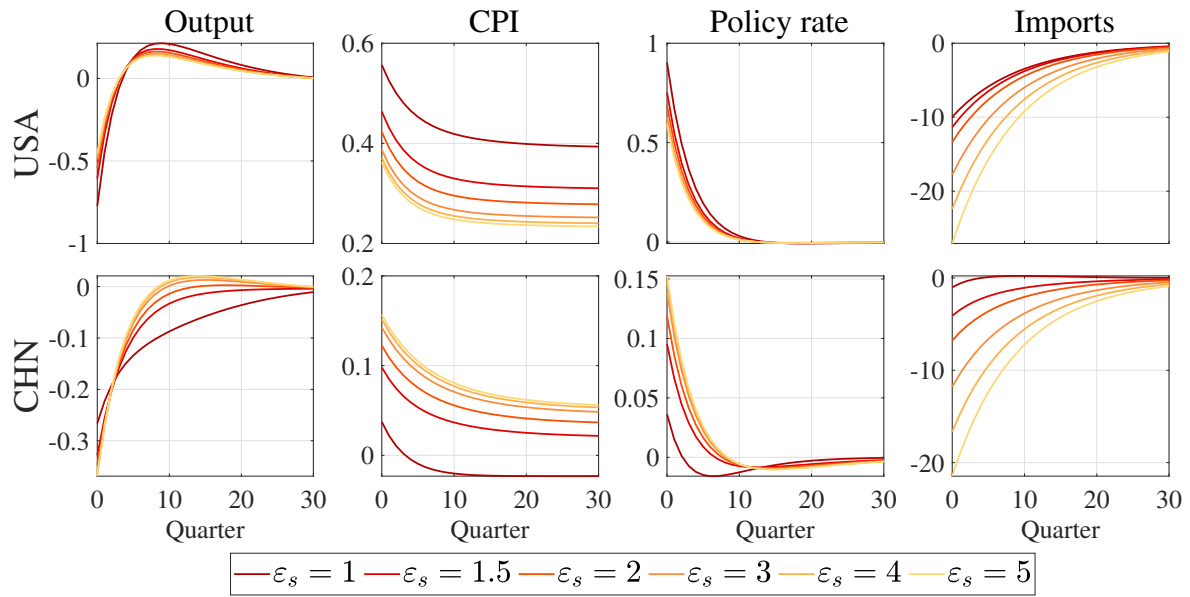
Notes: Simulations based on the model with supply chains (CES technology) and no long-term bonds.

Figure A.2: Sensitivity analysis: elasticity of substitution between domestic and imported intermediate inputs. Responses to US-originated labor supply shock.



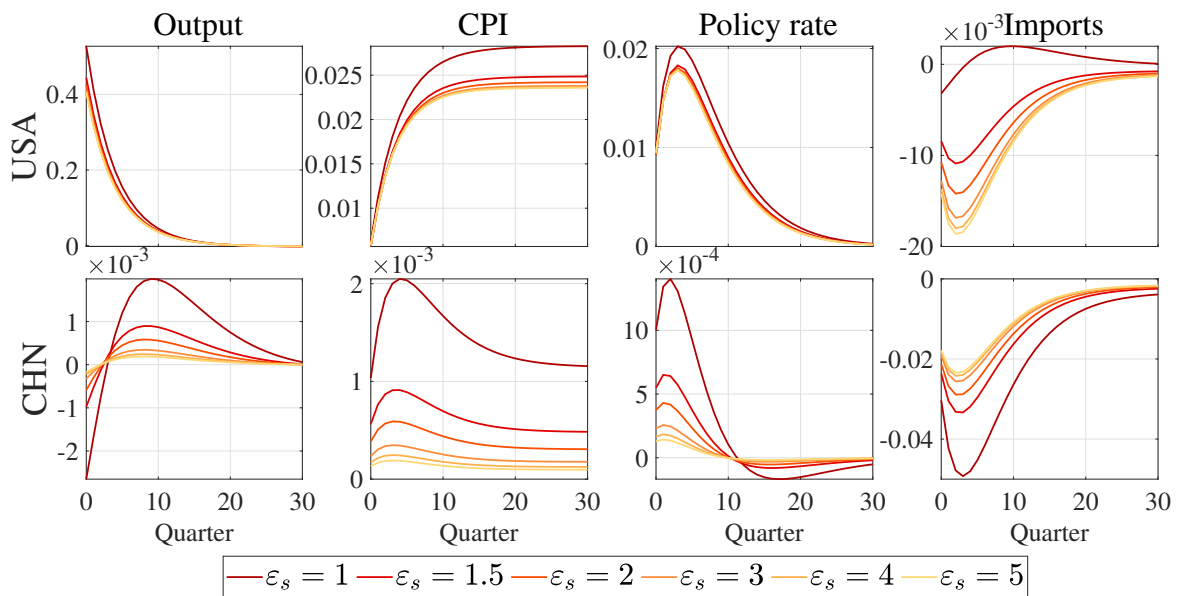
Notes: Simulations based on the model with supply chains (CES technology) and no long-term bonds.

Figure A.3: Sensitivity analysis: elasticity of substitution between domestic and imported intermediate inputs. Responses to a 10% increase in the US import price of traded goods.



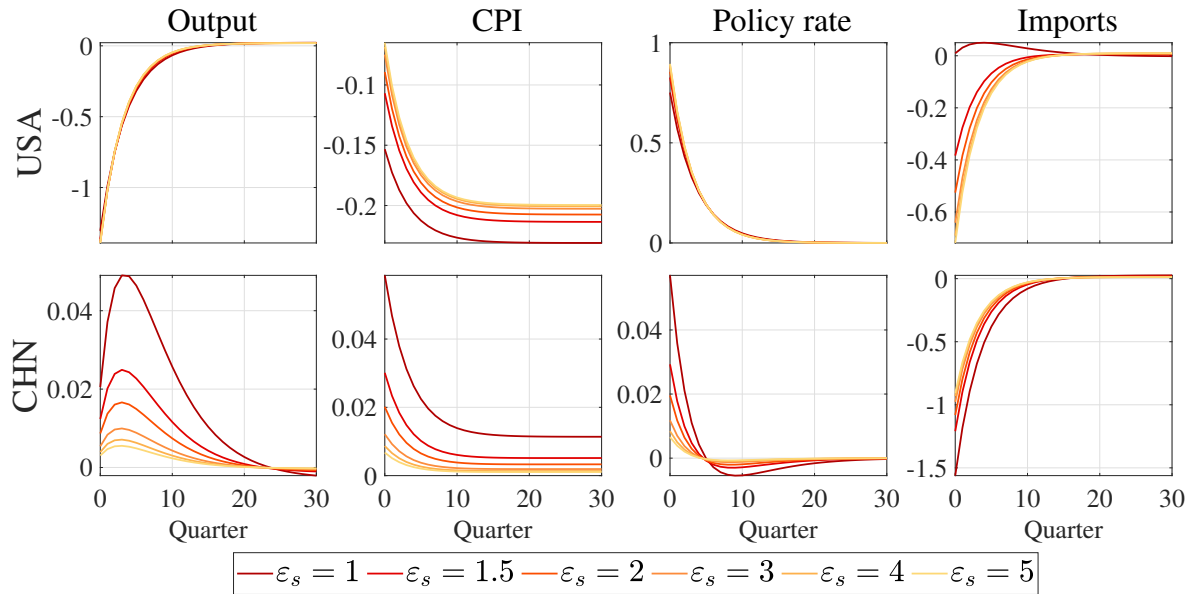
Notes: Simulations based on the model with supply chains (CES technology) and no long-term bonds.

Figure A.4: Sensitivity analysis: elasticity of substitution between domestic and imported intermediate inputs. Responses to US-originated government spending shock.



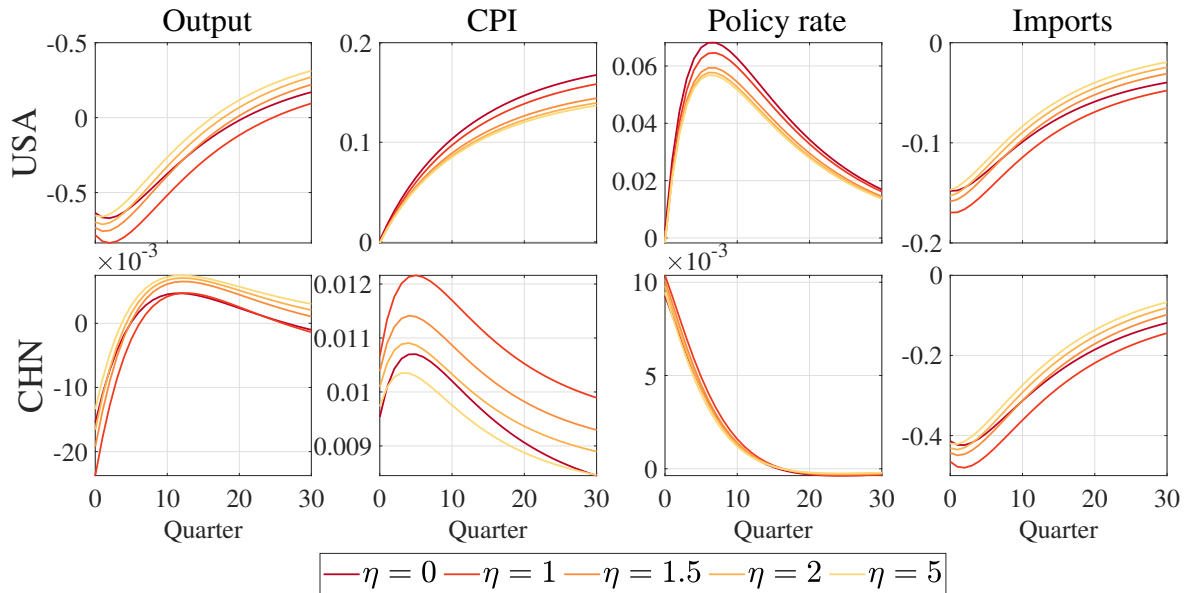
Notes: Simulations based on the model with supply chains (CES technology) and no long-term bonds.

Figure A.5: Sensitivity analysis: elasticity of substitution between domestic and imported intermediate inputs. Responses to 100 basis points US interest rate hike.



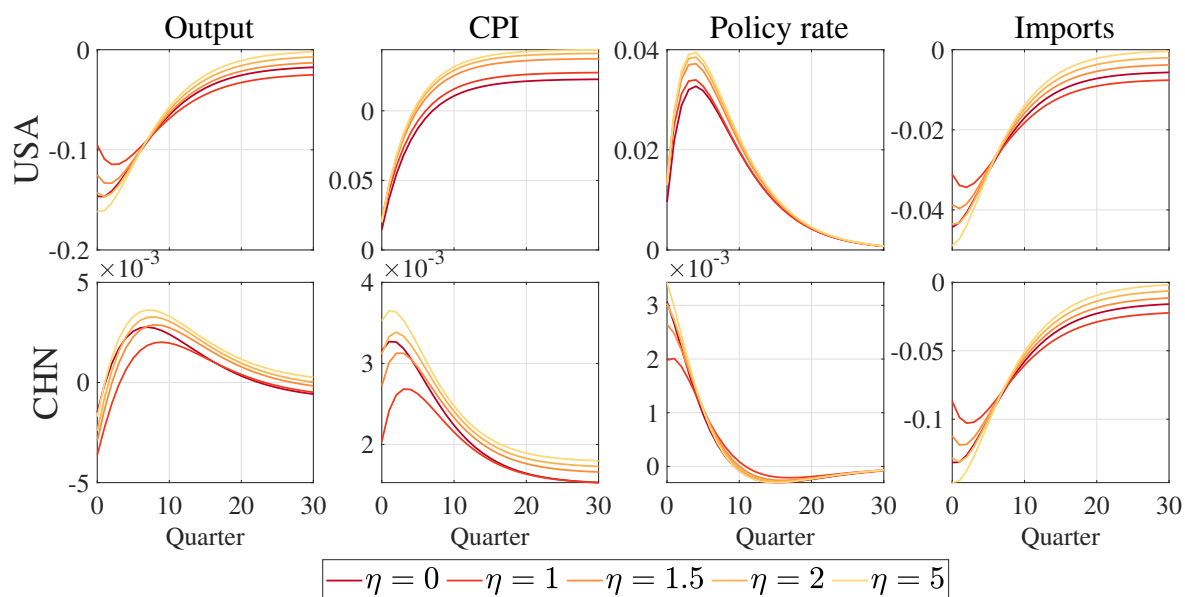
Notes: Simulations based on the model with supply chains (CES technology) and no long-term bonds.

Figure A.6: Sensitivity analysis: elasticity of substitution between intermediate inputs and value added. Responses to US-originated TFP shock.



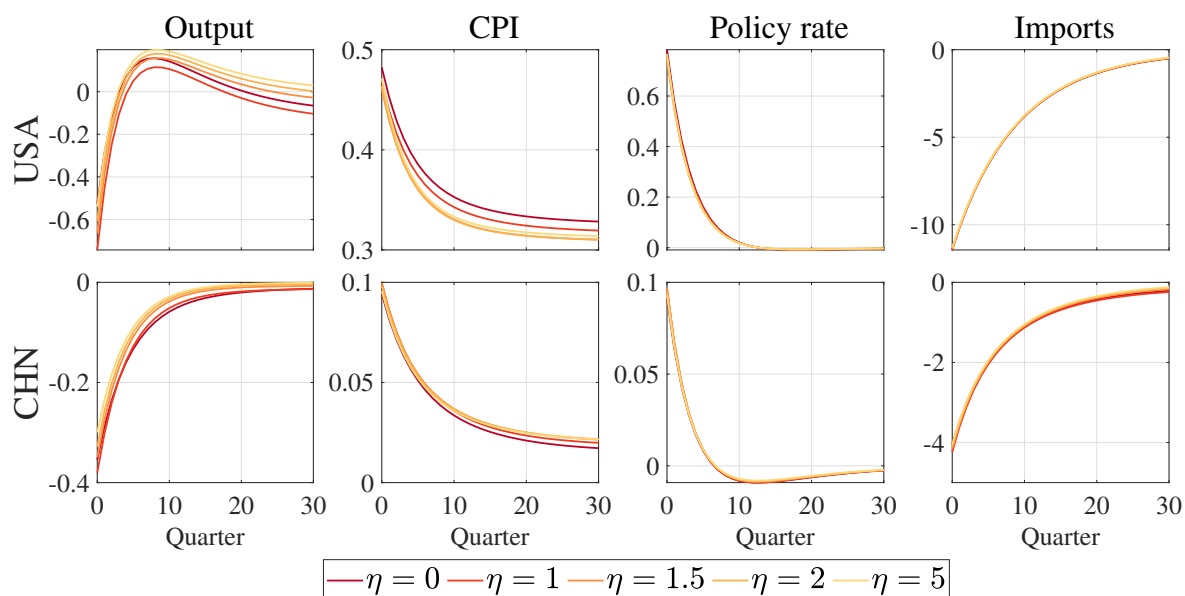
Notes: Simulations based on the models with supply chains and no long-term bonds.

Figure A.7: Sensitivity analysis: elasticity of substitution between intermediate inputs and value added. Responses to US-originated labor supply shock.



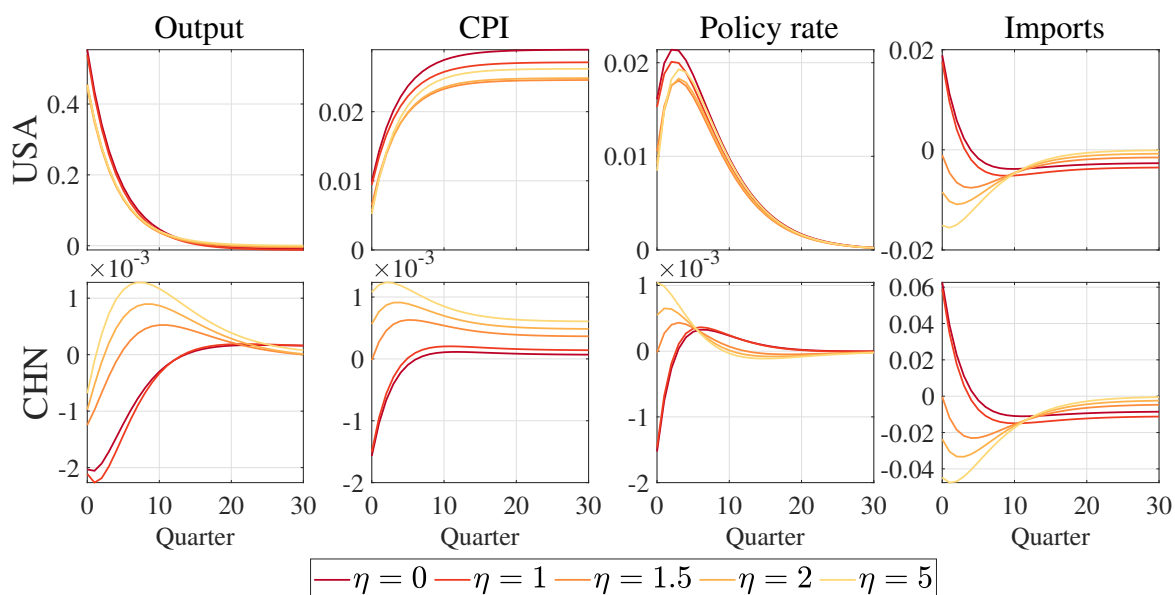
Notes: Simulations based on the models with supply chains and no long-term bonds.

Figure A.8: Sensitivity analysis: elasticity of substitution between intermediate inputs and value added. Responses to a 10% increase in the US import price of traded goods.



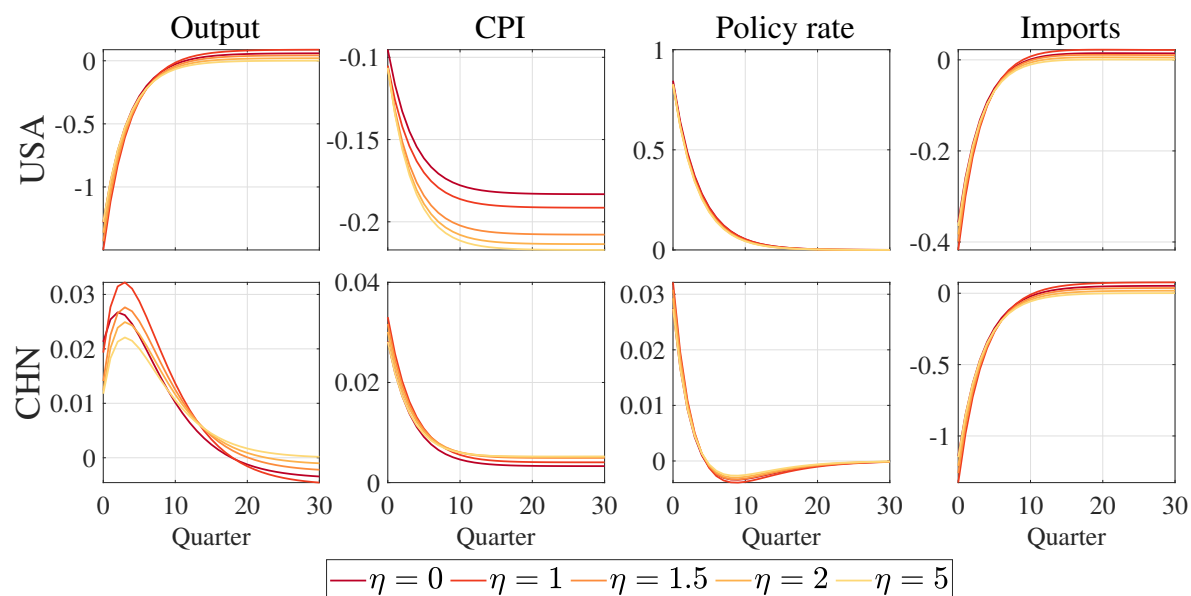
Notes: Simulations based on the models with supply chains and no long-term bonds.

Figure A.9: Sensitivity analysis: elasticity of substitution between intermediate inputs and value added. Responses to US-originated government spending shock.



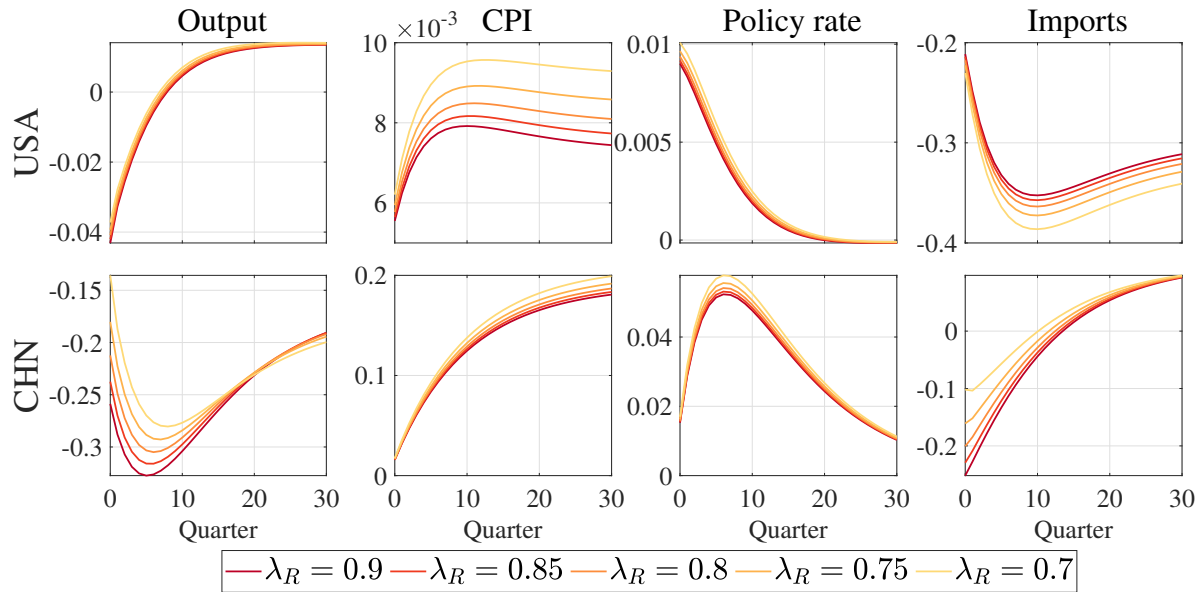
Notes: Simulations based on the models with supply chains and no long-term bonds.

Figure A.10: Sensitivity analysis: elasticity of substitution between intermediate inputs and value added. Responses to 100 basis points US interest rate hike.



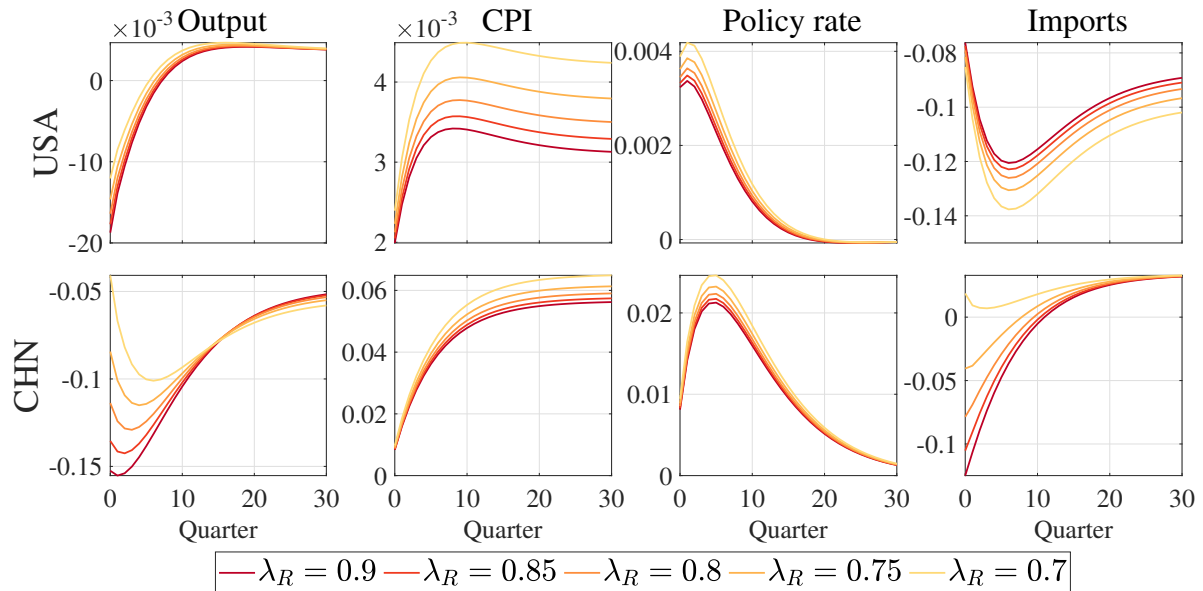
Notes: Simulations based on the models with supply chains and no long-term bonds.

Figure A.11: Sensitivity analysis: share of Ricardian households in China. Responses to China-originated TFP shock.



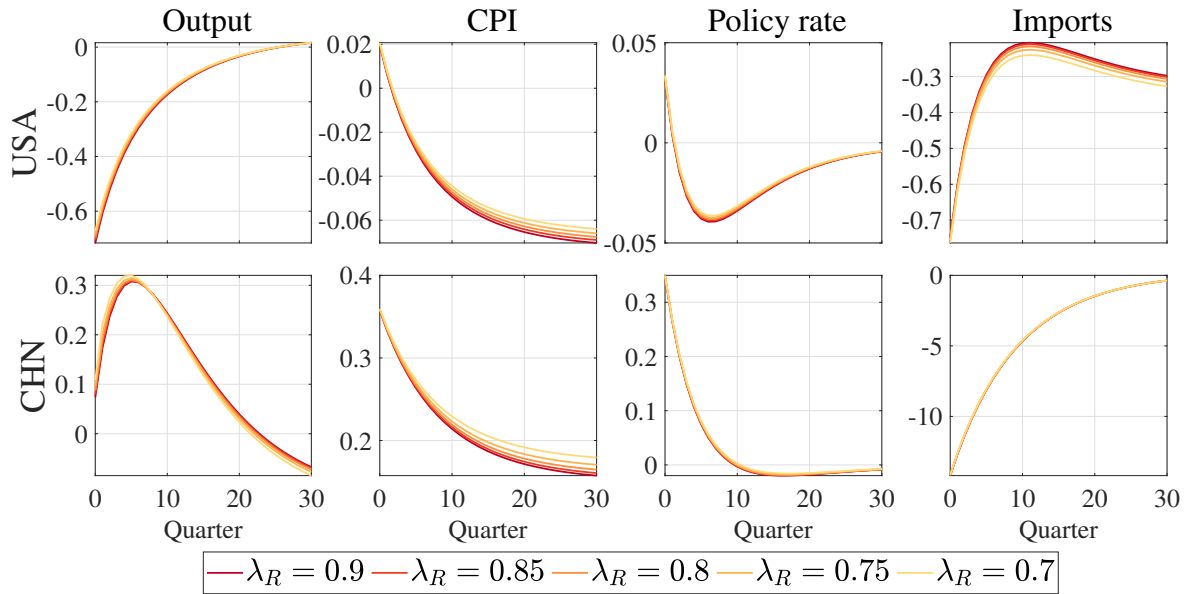
Notes: Simulations based on the model with financial linkages.

Figure A.12: Sensitivity analysis: share of Ricardian households in China. Responses to China-originated labor supply shock.



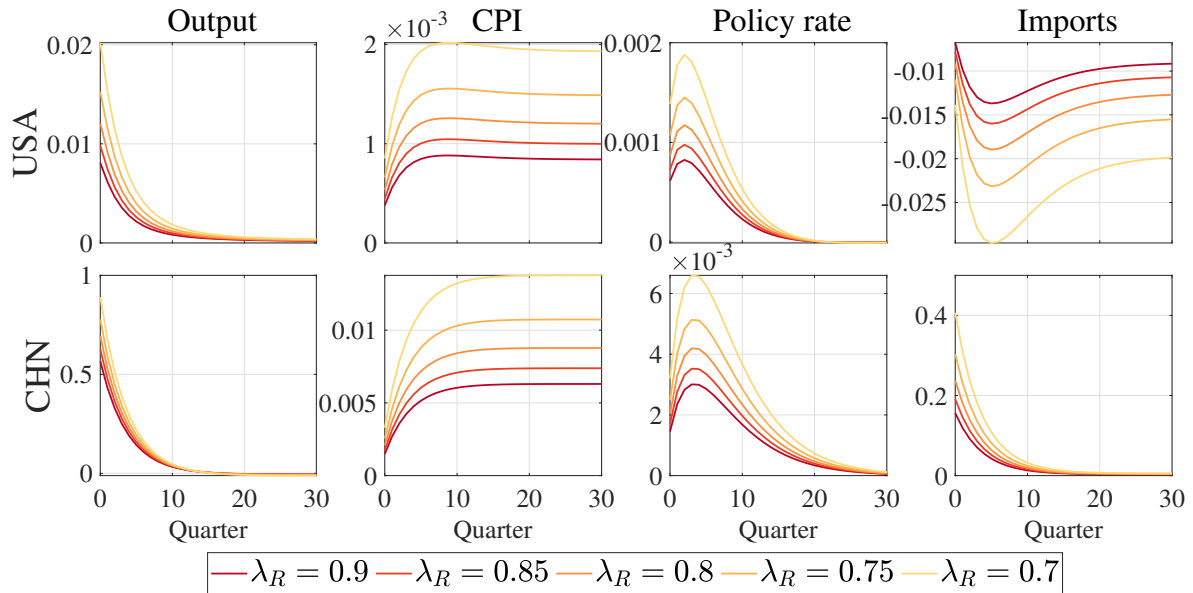
Notes: Simulations based on the model with financial linkages.

Figure A.13: Sensitivity analysis: share of Ricardian households in China. Responses to a 10% increase in the Chinese import price.



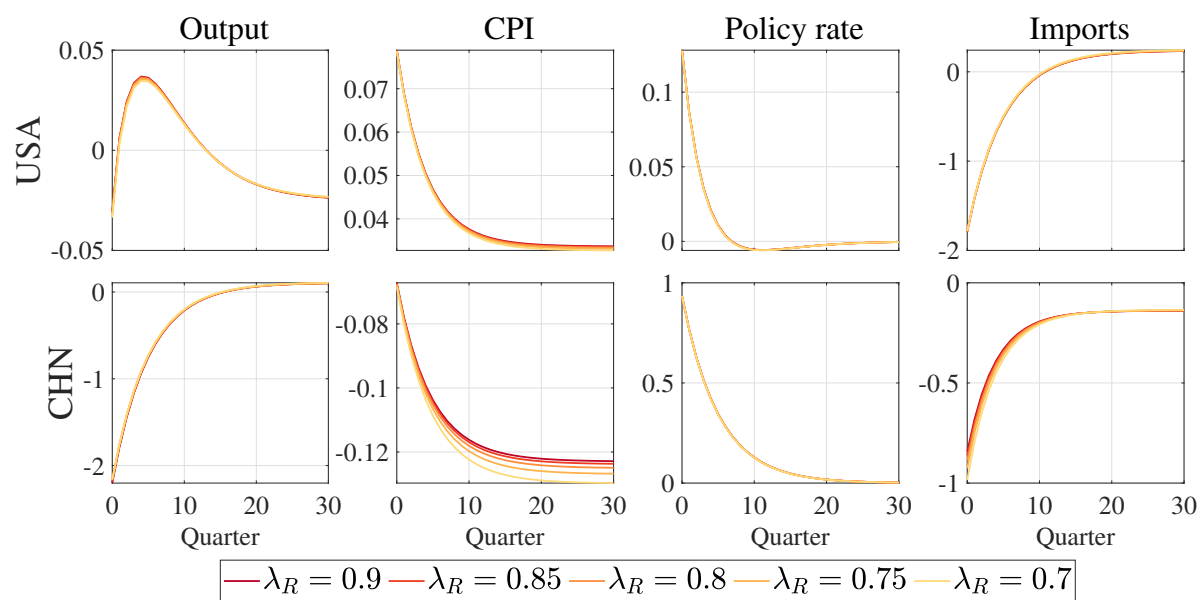
Notes: Simulations based on the model with financial linkages.

Figure A.14: Sensitivity analysis: share of Ricardian households in China. Responses to China-originated government spending shock.



Notes: Simulations based on the model with financial linkages.

Figure A.15: Sensitivity analysis: share of Ricardian households in China. Responses to 100 basis points Chinese interest rate hike.



Notes: Simulations based on the model with financial linkages.

Appendix B

Below we present the details of our benchmark multi-country model and its three extensions, setting out the optimisation problems and their solutions. In the second part of [Appendix B](#), we present the calibration of the benchmark model and the extensions. Finally, in the last part we outline the steady-state of the final configuration of the model and the steady-state with trade frictions.

Our model builds on the framework in [Gali and Monacelli \(2005\)](#) and disentangle three sectors from the common assumption of homogeneous firms: the goods sector ($i = 1$), the tradable services sector ($i = 2$) and the nontradable services sector ($i = 3$). The detailed classification of the sectors can be found in [Appendix B.8](#).

In the first extension, we distinguish between high-skilled and low-skilled households, allowing us to explore the implications of a skill-specific migration shock and cast our main analysis on the basis of a negative migration shock to the inflow of low-skilled labour from the EU into the UK. The next extension introduces supply chain networks similar to [Altinoglu \(2021\)](#), [Imura \(2019\)](#) or [Steinberg \(2020\)](#), in which producers combine labour, capital, and supplies - both domestic and foreign- to produce goods and services. In the final extension, we add financial frictions similar to [Gertler and Kiyotaki \(2010\)](#). We generalise the baseline model and the extension into a multi-country setting and calibrate it to the UK's withdrawal from the EU Single Market on conditions specified in the Trade and Cooperation Aggrement (TCA).

Each model configuration features monopolistically competitive goods and services producers, competitive retailers, importers, and capital goods producers, and both a fiscal and a monetary authority.

We consider a global model economy composed of M countries, with individual countries denoted by the index m ; and three sectors $i = \{1, 2, 3\}$ - that are also denoted by $s = \{1, 2, 3\}$ to in supplying goods and services to local households or to local sector i 's producers. In what follows, the optimisation problems and their solutions are presented for a representative economy. Variables associated with the representative economy, when necessary, are denoted

by h . Variables associated with foreign countries, in turn, are denoted by the m index. The optimisation problems and their solutions are symmetrical across countries.

B.1 Benchmark model

B.1.1 Households

The aggregate consumption of households, C_t , consists of consumption of all types of goods and services aggregated in the following manner:

$$C_t = \left[\sum_{i=1}^3 \gamma_i^{\frac{1}{\varepsilon_c}} (C_{i,t})^{\frac{\varepsilon_c-1}{\varepsilon_c}} \right]^{\frac{\varepsilon_c}{\varepsilon_c-1}} \quad (\text{B.1})$$

where $0 < \gamma_i < 1$ represents the share of i in the consumption basket and $\varepsilon_c \geq 1$ is the elasticity of substitution between goods, tradable services and nontradable services.

When $\varepsilon_c = 1$, the consumption basket (B.1) simplifies to:

$$C_t = \frac{\prod_{i=1}^3 C_{i,t}^{\gamma_i}}{\prod_{i=1}^3 \gamma_i^{\gamma_i}} \quad (\text{B.2})$$

where $C_{i,t}$ represents the consumption of locally-produced and imported i , all aggregated in the following way:

$$C_{i,t} = \left[\sum_{m=1}^M \gamma_i^{m \frac{1}{\eta}} (C_{i,t}^m)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \quad (\text{B.3})$$

where $\eta > 1$ is the elasticity of substitution between locally-produced and imported goods or services and $0 < \gamma_i^m < 1$ is the portion of i originally produced in country m in the total consumption of i and $\sum_{m=1}^M \gamma_i^m = 1$.

$C_{i,t}^m$ is the consumption index of i produced in country m (including i produced locally; for $m = h$):

$$C_{i,t}^m = \left[\int_0^1 C_{i,t}^m(j)^{\frac{\varepsilon_i}{\varepsilon_i-1}} dj \right]^{\frac{\varepsilon_i-1}{\varepsilon_i}} \quad (\text{B.4})$$

where $j \in [0, 1]$ is a continuum of varieties of i ; and $\varepsilon_i \geq 1$ is the elasticity of substitution between varieties of i .

Households optimise their consumption basket of domestic and imported goods, subject to the following aggregate expenditure on i :

$$P_{i,t} C_{i,t} = \sum_{m=1}^M P_{i,t}^{h,m} C_{i,t}^m \quad (\text{B.5})$$

where $P_{i,t}$ is the price index of i and $P_{i,t}^{h,m}$ represents local prices of domestically produced (for $m = h$) or imported i denominated in the domestic currency.

The optimisation problem is symmetric across all types of i . The Lagrangian associated with household's optimisation is given by:

$$\mathcal{L}(C_{i,t}^h, C_{i,t}^m) = \left[\sum_{m=1}^M \gamma_i^{m \frac{1}{\eta}} (C_{i,t}^m)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} - \varrho_{i,t}^c \left(\sum_{m=1}^M P_{i,t}^{h,m} C_{i,t}^m - P_{i,t} C_{i,t} \right) \quad (\text{B.6})$$

where $C_{i,t}^h$ represents consumption of i produced locally, i.e. $m = h$.

The first-order conditions of the optimisation problem w.r.t. $C_{i,t}^h$ and $C_{i,t}^m$ (for $m \neq h$) are as follows:

$$\frac{\partial \mathcal{L}(C_{i,t}^h, C_{i,t}^m)}{\partial C_{i,t}^h} = \gamma_i^{h \frac{1}{\eta}} (C_{i,t}^h)^{-\frac{1}{\eta}} \left[\sum_{m=1}^M \gamma_i^{m \frac{1}{\eta}} (C_{i,t}^m)^{\frac{\eta-1}{\eta}} \right]^{\frac{1}{\eta-1}} - \varrho_{i,t}^c P_{i,t}^h = 0 \quad (\text{B.7})$$

$$\frac{\partial \mathcal{L}(C_{i,t}^h, C_{i,t}^m)}{\partial C_{i,t}^m} = \gamma_i^{m \frac{1}{\eta}} (C_{i,t}^m)^{-\frac{1}{\eta}} \left[\sum_{m=1}^M \gamma_i^{m \frac{1}{\eta}} (C_{i,t}^m)^{\frac{\eta-1}{\eta}} \right]^{\frac{1}{\eta-1}} - \varrho_{i,t}^c P_{i,t}^{h,m} = 0 \quad (\text{B.8})$$

where $P_{i,t}^h$ represents the price of locally-produced i .

Combining and simplifying the first-order conditions - (B.7) and (B.8) - yields:

$$C_{i,t}^m = \frac{\gamma_i^m}{\gamma_i^h} \left[\frac{P_{i,t}^{h,m}}{P_{i,t}^h} \right]^{-\eta} C_{i,t}^h \quad (\text{B.9})$$

where $P_{i,t}$ is the consumer price index of sector i 's goods or services composed of the prices of any type of i consumed by the local households and weighted by their corresponding shares in the aggregate consumption basket:

$$P_{i,t} = \left[\sum_{m=1}^M \gamma_i^m (P_{i,t}^{h,m})^{1-\eta} \right]^{\frac{1}{1-\eta}} \quad (\text{B.10})$$

We substitute (B.9) into (B.5), which results in:

$$P_{i,t} C_{i,t} = P_{i,t}^h C_{i,t}^h + P_{i,t}^{h,m} \left[\frac{\gamma_i^m}{\gamma_i^h} \left[\frac{P_{i,t}^{h,m}}{P_{i,t}^h} \right]^{-\eta} C_{i,t}^h \right] \quad (\text{B.11})$$

Equation (B.11) simplifies into the following optimal allocation of the households' budget to locally produced i :

$$C_{i,t}^h = \gamma_i^h \left[\frac{P_{i,t}^h}{P_{i,t}} \right]^{-\eta} C_{i,t} \quad (\text{B.12})$$

Equation (B.12) is substituted back into (B.9) to obtain the optimal demand conditions for imported i :

$$C_{i,t}^m = \frac{\gamma_i^m}{\gamma_i^h} \left[\frac{P_{i,t}^{h,m}}{P_{i,t}} \right]^{-\eta} \left[\gamma_i^h \left[\frac{P_{i,t}^h}{P_{i,t}} \right]^{-\eta} C_{i,t} \right] \quad (\text{B.13})$$

Simplifying further yields the following optimal demand condition for the imported consumer good or service i :

$$C_{i,t}^m = \gamma_i^m \left[\frac{P_{i,t}^{h,m}}{P_{i,t}} \right]^{-\eta} C_{i,t} \quad (\text{B.14})$$

Finally, the Consumer Price Index (CPI) consists of the domestic price indices of i weighted by their corresponding shares in the consumption basket of households:

$$P_t = \prod_{i=1}^3 P_{i,t}^{\gamma_i} \quad (\text{B.15})$$

Representative household j chooses consumption, $C_t(j)$, labour supply to sector i , $L_{i,t}(j)$, and one-period risk-free bond holdings $B_{t+1}(j)$ to maximise its discounted lifetime utility:

$$\max_{C_t(j), L_{i,t}(j), B_{t+1}(j)} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U_t(j) \quad (\text{B.16})$$

where the utility function takes the form:

$$\max_{C_t(j), L_{i,t}(j), B_{t+1}(j)} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t(j)^{1-\sigma_c}}{1-\sigma_c} - \sum_{i=1}^3 \frac{\vartheta_i}{1+\varphi_h} L_{i,t}(j)^{1+\varphi_h} \right] \quad (\text{B.17})$$

where $0 < \beta < 1$ is the discount factor, $\sigma_c > 0$ is the inverse of the elasticity of intertemporal substitution of consumption, $\vartheta_i > 0$ is disutility from supplying high-skilled labour to sector i , and $\varphi_h > 0$ is the inverse of the Frisch elasticity of labour supply.

The maximisation problem of household j is subject to the sequence of intertemporal budget constraints of the form:

$$\begin{aligned} (1 + \tau_c) C_t(j) + B_{t+1}(j) + \sum_{i=1}^3 K_{i,t} &= R_t B_t(j) + R_{k,t} \sum_{i=1}^3 K_{i,t-1} \\ &+ \sum_{i=1}^3 (1 - \tau_w) W_{i,t} L_{i,t}(j) + \sum_{i=1}^3 \Pi_{i,t}(j) + TR_t \end{aligned} \quad (\text{B.18})$$

where R_t is the gross real risk-free interest paid for holding bonds from $t - 1$ to t ; $W_{i,t}$ is the real wage rate for supplying labour to sector i , and $R_{k,t}$ is the gross return on capital $K_{i,t}$ - equal for all i ; $0 \leq \tau_w < 1$ represents labour income tax rate, $0 \leq \tau_c < 1$ is the consumption tax rate; TR_t are government lump-sum transfers; and $\Pi_{i,t}$ are real profits from the ownership

of shares in sector i 's monopolistically competitive goods and services producers and capital goods producers given by:

$$\Pi_{i,t}(j) \equiv \underbrace{\left[P_{i,t}^h - mc_{i,t} \right] X_{i,t}(j)}_{\text{profits from goods and services producers}} + \underbrace{Q_{i,t} I_{i,t} - \left[1 + f \left(\frac{I_{i,t}}{I_{i,t-1}} \right) \right] I_{i,t}}_{\text{profits from capital goods producers}} \quad (\text{B.19})$$

where $mc_{i,t}$ is sector i 's real marginal cost, $Q_{i,t}$ is the price of capital specific to sector i , and $I_{i,t}$ is the sectoral investment. Gross return on capital is defined by:

$$R_{k,t+1} = \frac{Z_{i,t+1} + (1 - \delta) Q_{i,t+1}}{Q_{i,t}} \quad (\text{B.20})$$

where $Z_{i,t}$ is the rental price of capital $K_{i,t}$.

The Lagrangian for the representative household's optimisation problem is given by:

$$\begin{aligned} \mathcal{L}(C_t(j), L_{i,t}(j), B_{t+1}(j)) &= \frac{C_t(j)^{1-\sigma_c}}{1-\sigma_c} - \sum_{i=1}^3 \frac{\vartheta_h}{1+\varphi_i} L_{i,t}(j)^{1+\varphi_h} \\ &- \varrho_t^c(j) \left(\begin{aligned} &(1 + \tau_c) C_t(j) + B_{t+1}(j) + \sum_{i=1}^3 K_{i,t} - R_t B_t(j) \\ &- R_{k,t} \sum_{i=1}^3 K_{i,t-1} - \sum_{i=1}^3 (1 - \tau_w) W_{i,t} L_{i,t}(j) - \sum_{i=1}^3 \Pi_{i,t}(j) - TR_t \end{aligned} \right) \end{aligned} \quad (\text{B.21})$$

The first-order conditions with respect to $C_t(j)$, $L_{i,t}(j)$, and $B_{t+1}(j)$ are:

$$\frac{\partial \mathcal{L}(C_t(j), L_{i,t}(j), B_{t+1}(j))}{\partial C_t(j)} = C_{t-1}(j)^{-\sigma_c} - \varrho_t^c(j) (1 + \tau_c) = 0 \quad (\text{B.22})$$

$$\frac{\partial \mathcal{L}(C_t(j), L_{i,t}(j), B_{t+1}(j))}{\partial L_{i,t}(j)} = -\vartheta_i L_{i,t}(j)^{\varphi_h} + \varrho_t^c(j) (1 - \tau_w) W_{i,t} = 0 \quad (\text{B.23})$$

$$\frac{\partial \mathcal{L}(C_t(j), L_{i,t}(j), B_{t+1}(j))}{\partial B_{t+1}(j)} = -\varrho_t^c(j) + \beta \mathbb{E}_t \varrho_{t+1}^c(j) R_t = 0 \quad (\text{B.24})$$

All households are assumed to be identical, resulting in the following marginal utility of consumption condition, the optimal labour supply to sector i , and the conventional Euler equation:

$$\varrho_t^c = \frac{1}{(1 + \tau_c)} C_t^{-\sigma_c} \quad (\text{B.25})$$

$$\varrho_t^c (1 - \tau_w) W_{i,t} = \vartheta_i L_{i,t}^{\varphi_h} \quad (\text{B.26})$$

$$1 = \beta \mathbb{E}_t \left[R_t \frac{\varrho_{t+1}^c}{\varrho_t^c} \right] \quad (\text{B.27})$$

B.1.2 Firms

Capital goods producers

Capital goods producers operate in a perfectly competitive market; they purchase investment goods and transform them into new capital. Capital goods producers also refurbish the obsolete stock of goods and services producers at the end of each period. The new and repaired capital specific to sector i is sold to goods and services producers at price $Q_{i,t}$ and used for production in the next period.

Capital goods producers incur quadratic investment adjustment cost per unit of sector i 's defined as:

$$f\left(\frac{I_{i,t}}{I_{i,t-1}}\right) \equiv \Phi \left[\left(\frac{I_{i,t}}{I_{i,t-1}}\right) - 1\right]^2 \quad (\text{B.28})$$

where $\Phi > 0$ is the adjustment cost parameter.

Capital goods producers maximise their present discounted profits by choosing the optimal quantity of investment specific to sector i by solving the following problem:

$$\max_{I_{i,t}} \mathbb{E}_t \sum_{t=0}^{\infty} \beta \frac{q_{t+1}^c}{q_t^c} \left\{ Q_{i,t} I_{i,t} - \left[1 + f\left(\frac{I_{i,t}}{I_{i,t-1}}\right) \right] I_{i,t} \right\} \quad (\text{B.29})$$

The optimality condition yields the following Q -investment relation for capital goods as in [Gertler and Kiyotaki \(2010\)](#):

$$Q_{i,t} = 1 + f\left(\frac{I_{i,t}}{I_{i,t-1}}\right) + \frac{I_{i,t}}{I_{i,t-1}} f'\left(\frac{I_{i,t}}{I_{i,t-1}}\right) - \mathbb{E}_t \beta \frac{q_{t+1}}{q_t} \left(\frac{I_{i,t+1}}{I_{i,t}}\right)^2 f'\left(\frac{I_{i,t+1}}{I_{i,t}}\right) \quad (\text{B.30})$$

The aggregate capital stock in period t is given by the following law of motion for sector i 's capital:

$$K_{i,t} = I_{i,t} \left[1 - f\left(\frac{I_{i,t}}{I_{i,t-1}}\right) \right] + (1 - \delta) K_{i,t-1} \quad (\text{B.31})$$

where $0 < \delta < 1$ is the depreciation rate of capital.

Retailers

Competitive retailers purchase differentiated goods or services from either of the three sectors and combine them into a single good or service. Aggregate output of each sector's retailers is given by the following CES aggregate of a continuum of sector i 's differentiated intermediate output:

$$X_{i,t} = \left[\int_0^1 X_{i,t}(z)^{\frac{\varepsilon_i-1}{\varepsilon_i}} dz \right]^{\frac{\varepsilon_i}{\varepsilon_i-1}} \quad (\text{B.32})$$

where $\varepsilon_i > 0$ is the elasticity of substitution between differentiated varieties z of sector i 's goods or services.

The profit maximisation problem of the sector i 's retailer is given by:

$$\max_{X_{i,t}(z)} \left[P_{i,t}^h \left[\int_0^1 X_{i,t}(z)^{\frac{\varepsilon_i-1}{\varepsilon_i}} dz \right]^{\frac{\varepsilon_i}{\varepsilon_i-1}} - \int_0^1 P_{i,t}^h(z) X_{i,t}(z) dz \right] \quad (\text{B.33})$$

where $P_{i,t}^h$ is the price of a unit of sector i 's final output and $P_{i,t}^h(z)$ is the price of sector i 's differentiated good or service.

Therefore, the sector i retailers' demand for a typical variety of sector i 's intermediate good or service produced by a representative firm z is:

$$X_{i,t}(z) = \left[\frac{P_{i,t}^h(z)}{P_{i,t}^h} \right]^{-\varepsilon_i} X_{i,t} \quad (\text{B.34})$$

Finally, following the zero-profit condition, the sector i 's price of the final good or service can be defined by:

$$P_{i,t}^h = \left[\int_0^1 P_{i,t}^h(z)^{1-\varepsilon_i} dz \right]^{\frac{1}{1-\varepsilon_i}} \quad (\text{B.35})$$

Goods and services producers

Producers in each sector combine labour inputs, $L_{i,t}$, capital, $K_{i,t-1}$, both specific to sector i and transform them into a distinctive good or service. The standard technology of producing $X_{i,t}$ by a representative producer z is summarised by the following:

$$X_{i,t}(z) = A_{i,t} L_{i,t}(z)^{\alpha_i} K_{i,t-1}(z)^{1-\alpha_i} \quad (\text{B.36})$$

where $A_{i,t}$ Hicks-neutral and sector-specific productivity and $0 < \alpha_i < 1$ is the share of labour.

Sector i 's producers face the common sectoral wage rate $W_{i,t}$ and the rental price of capital $Z_{i,t}$, and plan their future production with a goal to minimise cost. Their optimisation problem can be formalised as:

$$\min_{L_{i,t}(z), K_{i,t-1}(z)} \left[W_{i,t} L_{i,t}(z) + Z_{i,t} K_{i,t-1}(z) \right] \quad (\text{B.37})$$

s.t.

$$A_{i,t} L_{i,t}(z)^{\alpha_i} K_{i,t-1}(z)^{1-\alpha_i} \geq \left[\frac{P_{i,t}^h(z)}{P_{i,t}^h} \right]^{-\varepsilon_i} X_{i,t} \quad (\text{B.38})$$

The corresponding Lagrangian is given by:

$$\begin{aligned} \mathcal{L}(L_{i,t}(z), K_{i,t-1}(z)) = & -W_{i,t}L_{i,t}(z) - Z_{i,t}K_{i,t-1}(z) \\ & + mc_{i,t}(z) \left(A_{i,t}L_{i,t}(z)^{\alpha_i}K_{i,t-1}(z)^{1-\alpha_i} - \left[\frac{P_{i,t}^h(z)}{P_{i,t}^h} \right]^{-\varepsilon_i} X_{i,t} \right) \end{aligned} \quad (\text{B.39})$$

The first-order conditions of the cost minimisation problem w.r.t. $L_{i,t}(z)$ and $K_{i,t-1}(z)$ are:

$$\frac{\partial \mathcal{L}(L_{i,t}(z), K_{i,t-1}(z))}{\partial L_{i,t}(z)} = -W_{i,t} + mc_{i,t}(z)\alpha_i \frac{X_{i,t}(z)}{L_{i,t}} = 0 \quad (\text{B.40})$$

$$\frac{\partial \mathcal{L}(L_{i,t}(z), K_{i,t-1}(z))}{\partial K_{i,t-1}(z)} = -Z_{i,t} + mc_{i,t}(z)(1-\alpha_i) \frac{X_{i,t}(z)}{K_{i,t-1}} = 0 \quad (\text{B.41})$$

Given that all producers in sector i are identical, the first-order conditions in real terms are given by:

$$W_{i,t} = mc_{i,t}\alpha_i \frac{X_{i,t}}{L_{i,t}} \quad (\text{B.42})$$

$$Z_{i,t} = mc_{i,t}(1-\alpha_i) \frac{X_{i,t}}{K_{i,t-1}} \quad (\text{B.43})$$

Real (flow) profit of the representative producer in sector i is given by:

$$\Pi_{i,t}(z) = P_{i,t}^h(z)X_{i,t}(z) - W_{i,t}L_{i,t}(z) - Z_{i,t}K_{i,t-1}(z) \quad (\text{B.44})$$

Given the optimal demands for the two factors derived in (B.42)-(B.43), the flow profit is given by:

$$\begin{aligned} \Pi_{i,t}(z) = & P_{i,t}^h(z)X_{i,t}(z) - mc_{i,t}(z)\alpha_i \frac{X_{i,t}(z)}{L_{i,t}(z)}L_{i,t}(z) \\ & - mc_{i,t}(z)(1-\alpha_i) \frac{X_{i,t}(z)}{K_{i,t-1}(z)}K_{i,t-1}(z) \end{aligned} \quad (\text{B.45})$$

$$\Pi_{i,t}(z) = P_{i,t}^h(z)X_{i,t}(z) - mc_{i,t}(z)X_{i,t}(z) \quad (\text{B.46})$$

The profit maximisation problem of a firm who is able to reset its price can be written as:

$$\max_{P_{i,t}^h(z)} \mathbb{E}_t \sum_{k_i=0}^{\infty} (\beta\theta_i)^{k_i} \varrho_{t+k_i}^c \frac{1}{P_{i,t+k_i}^h} \left[P_{i,t}^h(z)X_{i,t+k_i}(z) - mc_{i,t+k_i}(z)X_{i,t+k_i}(z) \right] \quad (\text{B.47})$$

$$\max_{P_{i,t}^h(z)} \mathbb{E}_t \sum_{k_i=0}^{\infty} (\beta\theta_i)^{k_i} \varrho_{t+k_i}^c \frac{1}{P_{i,t+k_i}^h} \left[P_{i,t}^h(z) \left[\frac{P_{i,t}^h(z)}{P_{i,t+k_i}^h} \right]^{-\varepsilon_i} X_{i,t+k_i} - mc_{i,t+k_i}(z) \left[\frac{P_{i,t}^h(z)}{P_{i,t+k_i}^h} \right]^{-\varepsilon_i} X_{i,t+k_i} \right] \quad (\text{B.48})$$

The first-order condition can be written as:

$$(1 - \varepsilon_i) \left(P_{i,t}^h(z) \right)^{-\varepsilon_i} \mathbb{E}_t \sum_{k_i=0}^{\infty} (\beta \theta_i)^{k_i} \varrho_{t+k_i}^c \left(P_{i,t+k_i}^h \right)^{\varepsilon_i-1} X_{i,t+k_i} + \varepsilon_i \left(P_{i,t}^h(i) \right)^{-\varepsilon_i-1} \mathbb{E}_t \sum_{k_i=0}^{\infty} (\beta \theta_i)^{k_i} \varrho_{t+k_i}^c mc_{i,t+k_i} \left(P_{i,t+k_i}^h \right)^{\varepsilon_i-1} X_{i,t+k_i} = 0 \quad (\text{B.49})$$

$$\tilde{P}_{i,t}^h(z) = \frac{\varepsilon_i}{\varepsilon_i - 1} \frac{\mathbb{E}_t \sum_{k_i=0}^{\infty} (\beta \theta_i)^{k_i} \varrho_{t+k_i}^c mc_{i,t+k_i} \left(P_{i,t+k_i}^h \right)^{\varepsilon_i-1} X_{i,t+k_i}}{\mathbb{E}_t \sum_{k_i=0}^{\infty} (\beta \theta_i)^{k_i} \varrho_{t+k_i}^c \left(P_{i,t+k_i}^h \right)^{\varepsilon_i-1} X_{i,t+k_i}} \quad (\text{B.50})$$

which can be written as:

$$\tilde{P}_{i,t}^h(z) = \frac{\varepsilon_i}{\varepsilon_i - 1} \frac{e_{i,t}}{f_{i,t}} \quad (\text{B.51})$$

where

$$e_{i,t} = \varrho_t^c mc_{i,t} \left(P_{i,t}^h \right)^{\varepsilon_i-1} X_{i,t} + \theta_i \beta \mathbb{E}_t e_{i,t+1} \quad (\text{B.52})$$

$$f_{i,t} = \varrho_t^c \left(P_{i,t}^h \right)^{\varepsilon_i-1} X_{i,t} + \theta_i \beta \mathbb{E}_t f_{i,t+1} \quad (\text{B.53})$$

Importers

There are perfectly competitive importers buying goods ($s = 1$), tradable services ($s = 2$), and nontradable services ($s = 3$) from foreign retailers and selling them at home to households as consumer goods and services. Importers face the risk of exchange rates' changes, tariffs, and NTBs.

Their goal is to maximise profits from selling s imported from all foreign countries:

$$\Pi_t^{imp} = \sum_{\substack{m=1 \\ m \neq h}}^M \sum_{s=1}^3 \Pi_{s,t}^m \quad (\text{B.54})$$

where $\Pi_{s,t}^m$ represent profits from imports of s from country m defined by:

$$\Pi_{s,t}^m \equiv P_{s,t}^{h,m} M_{s,t}^m - (1 + \tau_s^m) \nu_s^m s_t^m P_{s,t}^m M_{i,t}^m \quad (\text{B.55})$$

where τ_s^m and ν_s^m represent, respectively, tariffs and non-tariff barriers to trade in s with country

m ; and $M_{s,t}^m$ is the demand of local households for imports of s from country m :

$$M_{s,t}^m = C_{s,t}^m \quad (\text{B.56})$$

Importers choose the level of imports of type s $M_{s,t}^m$ by matching their marginal revenues with the marginal costs of imports. Profit maximisation conditions of perfectly competitive importers yield the following domestic pound-denominated prices of foreign s :

$$P_{s,t}^{h,m} = (1 + \tau_s^m) v_s^m s_t^m P_{s,t}^m \quad (\text{B.57})$$

The nominal exchange rate s_t^m is the price of a unit of a foreign currency expressed in the number of units of the local currency weighted by the shares of s in total trade with m :

$$s_t^m \equiv \prod_{s=1}^3 \left[\frac{P_{s,t}^m}{P_{s,t}^h} \right]^{v_s} \quad (\text{B.58})$$

B.1.3 Government

Fiscal policy

Government collects tariffs, if in place, from imports of goods and taxes from consumption and labour income and distributes them to households in the form of lump-sum transfers:

$$TR_t = \sum_{i=1}^3 \tau_w W_{i,t} L_{i,t} + \tau_c C_t + \sum_{m=1}^M \tau_i^m s_t^m P_{s=1,t}^m C_{s=1,t}^m \quad (\text{B.59})$$

The government also purchases a fixed share $0 \leq \chi_i < 1$ of local goods and services, where $G_{i,t} = \chi_i X_{i,t}$.

Monetary policy and market clearing conditions

Following [Schmitt-Grohé and Uribe \(2007\)](#) and [Faia and Monacelli \(2007\)](#), we model monetary policy using an implementable Taylor rule, where the central bank sets the short run nominal interest rate in response to observable variables. Therefore, the domestic monetary policy is formulated as a feedback rule, where the nominal interest rate r_t depends on its value from the previous period and the deviation of inflation π_t from its steady-state value π :

$$r_t = r_{t-1}^{\rho_r} \left[r \left(\frac{\pi_t}{\pi} \right)^{\varphi_\pi} \right]^{1-\rho_r} \quad (\text{B.60})$$

where $\varphi_\pi \geq 1$ is the central bank's weight on inflation and $0 \leq \rho_r < 1$ is the degree of smoothing in the setting of the policy rate.

The link between the nominal interest rate, r_t , and the real interest rate, R_t , is given by the following Fisher relation:

$$r_t = R_t \frac{\mathbb{E}_t P_{t+1}}{P_t} \quad (\text{B.61})$$

Finally, the market clearing conditions of sector i in the domestic economy h are given by:

$$X_{i,t} = \sum_{m=1}^M C_{i,t}^{mh} + G_{i,t} + \left[1 + f \left(\frac{I_{i,t}}{I_{i,t-1}} \right) \right] I_{i,t} \quad (\text{B.62})$$

The market clearing conditions imply that the total output in sector i equals to the sum of demands by households (domestic and foreign); the demand by the local government; and investment expenditures.

B.2 Extension (1): migration and heterogeneous households

B.2.1 Households

Native high-skilled household j chooses consumption $C_t^{hs}(j)$, labour supply to sector i $L_{i,t}^{hs,n}(j)$, and new one-period risk-free bond holdings $B_{t+1}(j)$ to maximise its discounted lifetime utility:

$$\max_{C_t^{hs}(j), L_{i,t}^{hs,n}(j), B_{t+1}(j)} \mathbb{E}_0 \sum_{t=0}^{\infty} (\beta_{hs})^t U_t^{hs}(j) \quad (\text{B.63})$$

where the utility function takes the form:

$$\max_{C_t^{hs}(j), L_{i,t}^{hs,n}(j), B_{t+1}(j)} \mathbb{E}_0 \sum_{t=0}^{\infty} (\beta_{hs})^t \left[\frac{C_t^{hs}(j)^{1-\sigma_{hs}}}{1-\sigma_{hs}} - \sum_{i=1}^3 \frac{\vartheta_i^{hs}}{1+\varphi_h} L_{i,t}^{hs,n}(j)^{1+\varphi_h} \right] \quad (\text{B.64})$$

where $0 < \beta_{hs} < 1$ is the discount factor, $\sigma_{hs} > 0$ is the inverse of the elasticity of intertemporal substitution of consumption, and $\vartheta_i^{hs} > 0$ denotes disutility from supplying high-skilled labour to sector i .

The maximisation problem of the high-skilled household j is subject to the sequence of

intertemporal budget constraints of the form:

$$(1 + \tau_c) C_t^{hs}(j) + B_{t+1}(j) + \sum_{i=1}^3 K_{i,t}(j) = R_t B_t(j) + R_{k,t} \sum_{i=1}^3 K_{i,t}(j) + \sum_{i=1}^3 (1 - \tau_w) W_{i,t}^{hs} L_{i,t}^{hs,n}(j) + \sum_{i=1}^3 \Pi_{i,t}(j) + TR_t^{hs}(j) \quad (\text{B.65})$$

where $W_{i,t}^{hs}$ is the real wage rate for supplying high-skilled labour to sector i and TR_t^{hs} are government transfers to high-skilled households.

The Lagrangian for the high-skilled household's optimisation problem is given by:

$$\mathcal{L}(C_t^{hs}(j), L_{i,t}^{hs,n}(j), B_{t+1}(j)) = \frac{C_t^{hs}(j)^{1-\sigma_{hs}}}{1-\sigma_{hs}} - \sum_{i=1}^3 \frac{\vartheta_i}{1+\varphi_i^{hs}} L_{i,t}^{hs,n}(j)^{1+\varphi_i^{hs}} - q_t^{hs}(j) \left((1 + \tau_c) C_t^{hs}(j) + B_{t+1}(j) + \sum_{i=1}^3 K_{i,t}(j) - R_t B_t(j) - R_{k,t} \sum_{i=1}^3 K_{i,t}(j) - \sum_{i=1}^3 (1 - \tau_w) W_{i,t}^{hs} L_{i,t}^{hs,n}(j) - \sum_{i=1}^3 \Pi_{i,t}(j) - TR_t^{hs}(j) \right) \quad (\text{B.66})$$

The first-order conditions for the high-skilled household with respect to, $C_t^{hs}(j)$, $L_{i,t}^{hs,n}(j)$, and $B_{t+1}(j)$ are:

$$\frac{\partial \mathcal{L}(C_t^{hs}(j), L_{i,t}^{hs,n}(j), B_{t+1}(j))}{\partial C_t^{hs}(j)} = C_t^{hs}(j)^{-\sigma_{hs}} - q_t^{hs}(j) (1 + \tau_c) = 0 \quad (\text{B.67})$$

$$\frac{\partial \mathcal{L}(C_t^{hs}(j), L_{i,t}^{hs,n}(j), B_{t+1}(j))}{\partial L_{i,t}^{hs,n}(j)} = -\vartheta_i^{hs} L_{i,t}^{hs,n}(j)^{\varphi_i^{hs}} + q_t^{hs}(j) (1 - \tau_w) W_{i,t}^{hs} = 0 \quad (\text{B.68})$$

$$\frac{\partial \mathcal{L}(C_t^{hs}(j), L_{i,t}^{hs,n}(j), B_{t+1}(j))}{\partial B_{t+1}(j)} = -q_t^{hs}(j) + \beta \mathbb{E}_t q_{t+1}^{hs}(j) R_t = 0 \quad (\text{B.69})$$

All high-skilled households are assumed to be identical, resulting in the following marginal utility of consumption condition, the optimal native labour supply to sector i , and the conventional Euler equation:

$$q_t^{hs} = \frac{1}{(1 + \tau_c)} C_t^{hs-\sigma_{hs}} \quad (\text{B.70})$$

$$q_t^{hs} (1 - \tau_w) W_{i,t}^{hs} = \vartheta_i^{hs} L_{i,t}^{hs,n \varphi_i^{hs}} \quad (\text{B.71})$$

$$1 = \beta \mathbb{E}_t \left[R_t \frac{q_{t+1}^{hs}}{q_t^{hs}} \right] \quad (\text{B.72})$$

Similarly, the low-skilled household j chooses consumption $C_t^{ls}(j)$ and low-skilled native

labour supply to sector i $L_{i,t}^{ls,n}(j)$ to maximise its discounted lifetime utility:

$$\max_{C_t^{ls}(j), L_{i,t}^{ls,n}(j)} \mathbb{E}_0 \sum_{t=0}^{\infty} (\beta_{ls})^t U_t^{ls}(j) \quad (\text{B.73})$$

where $\beta_{ls} < \beta_{hs}$, denoting that low-skilled households are more impatient than the high-skilled.

The utility function takes the form:

$$\max_{C_t^{ls}(j), L_{i,t}^{ls,n}(j)} \mathbb{E}_0 \sum_{t=0}^{\infty} (\beta_{ls})^t \left[\frac{C_t^{ls}(j)^{1-\sigma_{ls}}}{1-\sigma_{ls}} - \sum_{i=1}^3 \frac{\vartheta_i^{ls}}{1+\varphi_h} L_{i,t}^{ls,n}(j)^{1+\varphi_h} \right] \quad (\text{B.74})$$

where $\sigma_{ls} > 0$ is the inverse of the elasticity of intertemporal substitution of consumption and $\vartheta_i^{ls} > 0$ represents the disutility of supplying low-skilled labour parameters.

The maximisation problem of the low-skilled household j is subject to the sequence of budget constraints in the form:

$$(1 + \tau_c) C_t^{ls}(j) = \sum_{i=1}^3 (1 - \tau_w) W_{i,t}^{ls} L_{i,t}^{ls,n}(j) + TR_t^{ls}(j) \quad (\text{B.75})$$

where $W_{i,t}^{ls}$ is the real wage rate for supplying low-skilled labour to sector i and TR_t^{ls} are lump-sum transfers from the government.

The corresponding Lagrangian for the low-skilled household is given by:

$$\begin{aligned} \mathcal{L} \left(C_t^{ls}(j), L_{i,t}^{ls,n}(j) \right) &= \frac{C_t^{ls}(j)^{1-\sigma_{ls}}}{1-\sigma_{ls}} - \sum_{i=1}^3 \frac{\vartheta_i^{ls}}{1+\varphi_h} L_{i,t}^{ls,n}(j)^{1+\varphi_h} \\ &- \varrho_t^{ls}(j) \left((1 + \tau_c) C_t^{ls}(j) - \sum_{i=1}^3 (1 - \tau_w) W_{i,t}^{ls} L_{i,t}^{ls,n}(j) - TR_t^{ls}(j) \right) \end{aligned} \quad (\text{B.76})$$

The first-order conditions for low-skilled households with respect to $C_t^{ls}(i)$ and $L_{i,t}^{ls,n}(j)$ are respectively:

$$\frac{\partial \mathcal{L} \left(C_t^{ls}(j), L_{i,t}^{ls,n}(j) \right)}{\partial C_t^{ls}(j)} = C_t^{ls}(j)^{-\sigma_{ls}} - \varrho_t^{ls}(j) (1 + \tau_c) = 0 \quad (\text{B.77})$$

$$\frac{\partial \mathcal{L} \left(C_t^{ls}(j), L_{i,t}^{ls,n}(j) \right)}{\partial L_{i,t}^{ls,n}(j)} = -\vartheta_i^{ls} L_{i,t}^{ls,n}(j)^{\varphi_h} + \varrho_t^{ls}(j) (1 - \tau_w) W_{i,t}^{ls} = 0 \quad (\text{B.78})$$

All low-skilled households are assumed to be identical, resulting in the following marginal

utility w.r.t. low-skilled households' consumption and the optimal low-skilled labour supply:

$$q_t^{ls} = \frac{1}{(1 + \tau_c)} C_t^{ls - \sigma_{ls}} \quad (\text{B.79})$$

$$q_t^{ls} (1 - \tau_w) W_{i,t}^{ls} = \vartheta_i^{ls} L_{i,t}^{ls, n \varphi_h} \quad (\text{B.80})$$

We aggregate consumption of high- and low-skilled households in the following way:

$$C_t = \lambda_{hs} C_t^{hs} + (1 - \lambda_{hs}) C_t^{ls} \quad (\text{B.81})$$

where $0 < \lambda^{hs} < 1$ is the share in high-skilled households in the entire economy; and disaggregate it into consumption of domestic and imported goods and services as in [Appendix B.1](#).

Following [Canova and Ravn \(2000\)](#), we maintain that at the beginning of each period, all living workers face a probability of death $v \in (0, 1)$, which is independent of age or skill type. The surviving share of workers $(1 - v)$ is joined by the new-born cohort which replaces the population of workers who died at the beginning of the period.

We also assume that workers cannot migrate between the sectors. However, the newborn workers can become either low-skilled or high-skilled with the probability ρ_i^{hs} of becoming high-skilled at birth, joining the workforce immediately after birth. Labour inputs of the existing sector i 's high-skilled and low-skilled workforce evolve in the following manner:

$$L_{i,t+1}^{hs} = (1 - v) L_{i,t}^{hs, n} + v \rho_i^{hs} L_{i,t}^n \quad (\text{B.82})$$

$$L_{i,t+1}^{ls} = (1 - v) L_{i,t}^{ls, n} + v (1 - \rho_i^{hs}) L_{i,t}^n + \gamma_i^{m, ls} \varepsilon_t^{m, ls} \quad (\text{B.83})$$

where $L_{i,t}^n \equiv L_{i,t}^{hs, n} + L_{i,t}^{ls, n}$ represents total native workforce in sector i ; $0 \leq \gamma_i^{m, ls} \leq 1$ governs the distribution of low-skilled migrants across sectors; and $\varepsilon_t^{m, ls}$ denotes the inflow of low-skilled labour from country m , which joins the local low-skilled workforce. The evolution of low-skilled newcomers follows the form:⁴⁷

$$\varepsilon_t^{m, ls} = \rho^m \varepsilon_{t-1}^{m, ls} + \sigma_t^{m, ls}; \quad \sigma_t^{m, ls} \sim (0, \sigma^{m, ls}) \quad (\text{B.84})$$

where $0 \leq \rho^m < 1$ captures persistence of immigration from m and $\sigma_t^{m, ls}$ is the zero-mean,

⁴⁷The migration shock enters in both countries' low-skilled labour law of motion equations with an opposite sign. That is, a negative shock to the low-skilled immigration into the domestic economy has a counterpart in an equal-sized positive shock to the total supply of low-skilled labour in country m .

uncorrelated innovation with standard deviation $\sigma^{m,ls}$.

Finally, high-skilled and low-skilled labour inputs are aggregated into total hours $L_{i,t}$ employed by sector i :

$$L_{i,t} = \left[\omega_i^{hs} \left(L_{i,t}^{hs} \right)^{(1-\rho_l)} + \left(L_{i,t}^{ls} \right)^{(1-\rho_l)} \right]^{\frac{1}{(1-\rho_l)}} \quad (\text{B.85})$$

where $\omega_i^{hs} > 1$ represents relative productivity of high-skilled relative to low-skilled workers and $0 < \rho_l < 1$ is the elasticity of substitution between the two.

B.2.2 Firms

Goods and services producers

Sector i 's producers face the common sectoral wage rates $W_{i,t}^{hs}$ and $W_{i,t}^{ls}$, and the rental price of capital $Z_{i,t}$ and plan their future production with a goal to minimise cost. Their optimisation problem can be formalised as:

$$\min_{L_{i,t}^{hs}(z), L_{i,t}^{ls}(z), K_{i,t-1}(z)} \left[W_{i,t}^{hs} L_{i,t}^{hs}(z) + W_{i,t}^{ls} L_{i,t}^{ls}(z) + Z_{i,t} K_{i,t-1}(z) \right] \quad (\text{B.86})$$

s.t.

$$A_{i,t} L_{i,t}(z)^{\alpha_i} K_{i,t-1}(z)^{1-\alpha_i} \geq \left[\frac{P_{i,t}^h(z)}{P_{i,t}^h} \right]^{-\varepsilon_i} X_{i,t} \quad (\text{B.87})$$

The corresponding Lagrangian is given by:

$$\begin{aligned} \mathcal{L} \left(L_{i,t}^{hs}(z), L_{i,t}^{ls}(z), K_{i,t-1}(z) \right) = & -W_{i,t}^{hs} L_{i,t}^{hs}(z) - W_{i,t}^{ls} L_{i,t}^{ls}(z) - Z_{i,t} K_{i,t-1}(z) \\ & + mc_{i,t}(z) \left(A_{i,t} \left[\omega_i^{hs} \left(L_{i,t}^{hs}(z) \right)^{(1-\rho_l)} + \left(L_{i,t}^{ls}(z) \right)^{(1-\rho_l)} \right]^{\frac{\alpha_i}{1-\rho_l}} K_{i,t-1}(z)^{1-\alpha_i} \right. \\ & \left. - \left[\frac{P_{i,t}^h(z)}{P_{i,t}^h} \right]^{-\varepsilon_i} X_{i,t} \right) \end{aligned} \quad (\text{B.88})$$

The first-order conditions of the cost minimisation problem w.r.t. $L_{i,t}^{hs}(z)$, $L_{i,t}^{ls}(z)$, and $K_{i,t-1}(z)$ are:

$$\frac{\partial \mathcal{L} \left(L_{i,t}^{hs}(z), L_{i,t}^{ls}(z), K_{i,t-1}(z) \right)}{\partial L_{i,t}^{hs}(z)} = -W_{i,t}^{hs} + mc_{i,t}(z) \alpha_i \omega_i^{hs} \frac{X_{i,t}(z)}{L_{i,t}(z)^{1-\rho_l} L_{i,t}^{hs}(z)^{\rho_l}} = 0 \quad (\text{B.89})$$

$$\frac{\partial \mathcal{L} \left(L_{i,t}^{hs}(z), L_{i,t}^{ls}(z), K_{i,t-1}(z) \right)}{\partial L_{i,t}^{ls}(z)} = -W_{i,t}^{ls} + mc_{i,t}(z) \alpha_i \frac{X_{i,t}(z)}{L_{i,t}(z)^{1-\rho_l} L_{i,t}^{ls}(z)^{\rho_l}} = 0 \quad (\text{B.90})$$

$$\frac{\partial \mathcal{L} \left(L_{i,t}^{hs}(z), L_{i,t}^{ls}(z), K_{i,t-1}(z) \right)}{\partial K_{i,t-1}(z)} = -Z_{i,t} + mc_{i,t}(z)(1 - \alpha_i) \frac{X_{i,t}(z)}{K_{i,t-1}} = 0 \quad (\text{B.91})$$

Given that all producers in sector i are identical, the first-order conditions in real terms are given by:

$$W_{i,t}^{hs} = mc_{i,t} \alpha_i \omega_i^{hs} \frac{X_{i,t}}{(L_{i,t})^{1-\rho_l} (L_{i,t}^{hs})^{\rho_l}} \quad (\text{B.92})$$

$$W_{i,t}^{ls} = mc_{i,t} \alpha_i \frac{X_{i,t}}{(L_{i,t})^{1-\rho_l} (L_{i,t}^{ls})^{\rho_l}} \quad (\text{B.93})$$

$$Z_{i,t} = mc_{i,t}(1 - \alpha_i) \frac{X_{i,t}}{K_{i,t-1}} \quad (\text{B.94})$$

Real (flow) profit of the representative producer in sector i is given by:

$$\Pi_{i,t}(z) = P_{i,t}^h(z) X_{i,t}(z) - W_{i,t}^{hs} L_{i,t}^{hs}(z) - W_{i,t}^{ls} L_{i,t}^{ls}(z) - Z_{i,t} K_{i,t-1}(i) \quad (\text{B.95})$$

Given the optimal demands for the five factors derived in (B.92)-(B.94), the flow profit is given by:

$$\begin{aligned} \Pi_{i,t}(z) = & P_{i,t}^h(z) X_{i,t}(z) - mc_{i,t}(z) \alpha_i \omega_i^{hs} \frac{X_{i,t}(z)}{L_{i,t}(z)^{1-\rho_l} L_{i,t}^{hs}(z)^{\rho_l-1}} \\ & - mc_{i,t}(z) \alpha_i \frac{X_{i,t}(z)}{L_{i,t}(z)^{1-\rho_l} L_{i,t}^{ls}(z)^{\rho_l-1}} - mc_{i,t}(z)(1 - \alpha_i) X_{i,t}(z) \end{aligned} \quad (\text{B.96})$$

$$\begin{aligned} \Pi_{i,t}(z) = & P_{i,t}^h(z) X_{i,t}(z) - mc_{i,t}(z) \alpha_i \omega_i^{hs} \frac{X_{i,t}(z)}{\omega_i^{hs} + L_{i,t}^{ls}(z)^{1-\rho_l} L_{i,t}^{hs}(z)^{\rho_l-1}} \\ & - mc_{i,t}(z) \alpha_i \frac{X_{i,t}(z)}{\omega_i^{hs} L_{i,t}^{hs}(z)^{1-\rho_l} L_{i,t}^{ls}(z)^{\rho_l-1} + 1} - mc_{i,t}(z)(1 - \alpha_i) X_{i,t}(z) \end{aligned} \quad (\text{B.97})$$

$$\begin{aligned} \Pi_{i,t}(j) = & P_{i,t}^h(j) X_{i,t}(z) - mc_{i,t}(z) \alpha_i \omega_i^{hs} \frac{X_{i,t}(z)}{\omega_i^{hs} + L_{i,t}^{ls}(z)^{1-\rho_l} L_{i,t}^{hs}(z)^{\rho_l-1}} \\ & - mc_{i,t}(z) \alpha_i \frac{X_{i,t}(z)}{\omega_i^{hs} L_{i,t}^{hs}(z)^{1-\rho_l} L_{i,t}^{ls}(z)^{\rho_l-1} + 1} - mc_{i,t}(z)(1 - \alpha_i) X_{i,t}(z) \end{aligned} \quad (\text{B.98})$$

$$\begin{aligned} \Pi_{i,t}(z) = & P_{i,t}^h(z) X_{i,t}(j) - mc_{i,t}(z) \alpha_i \omega_i^{hs} \frac{X_{i,t}(z) L_{i,t}^{hs}(z)^{1-\rho_l}}{L_{i,t}(z)^{1-\rho_l}} \\ & - mc_{i,t}(z) \alpha_i \frac{X_{i,t}(z) L_{i,t}^{ls}(z)^{1-\rho_l}}{L_{i,t}(z)^{1-\rho_l}} - mc_{i,t}(z) \alpha_i X_{i,t}(z) \end{aligned} \quad (\text{B.99})$$

$$\Pi_{i,t}(j) = P_{i,t}^h(j) X_{i,t}(j) - mc_{i,t}(z) X_{i,t}(z) \left(\alpha_i \omega_i^{hs} \frac{L_{i,t}^{hs}(z)^{1-\rho_l}}{L_{i,t}(z)^{1-\rho_l}} + \alpha_i \frac{L_{i,t}^{ls}(z)^{1-\rho_l}}{L_{i,t}(z)^{1-\rho_l}} + (1 - \alpha_i) \right) \quad (\text{B.100})$$

$$\Pi_{i,t}(z) = P_{i,t}^h(z) X_{i,t}(z) - mc_{i,t}(z) X_{i,t}(z) \quad (\text{B.101})$$

The rest of the pricing problem of firms follows equations (B.47)-(B.53) from [Appendix B.1](#).

B.2.3 Government

Fiscal policy

Government collects tariffs from imports of goods and taxes on consumption and labour income as in [Appendix B.1](#). Total transfers are distributed to high-skilled and low-skilled households in the following way:

$$TR_t = \lambda_{hs} TR_t^{hs} + (1 - \lambda_{hs}) TR_t^{ls} \quad (\text{B.102})$$

The value of aggregate transfers is:

$$TR_t = \sum_{i=1}^3 \tau_w \left(W_{i,t}^{hs} L_{i,t}^{hs} + W_{i,t}^{ls} L_{i,t}^{ls} \right) + \tau_c \left(C_t^{hs} + C_t^{ls} \right) + \sum_{m=1}^M \tau_i^m s_t^m P_{s=1,t}^m C_{s=1,t}^m \quad (\text{B.103})$$

B.3 Extension (2): supply chain networks

Producers in each sector combine domestic and migrant labour inputs, $L_{i,t}$, capital $K_{i,t-1}$, both specific to sector i , and inputs in the form of domestic and foreign goods ($i = 1$), tradable services ($i = 2$), and nontradable services ($i = 3$) supplied by both domestic retailers and importers, and transform them into a distinctive good or service. In a similar way to [Altinoglu \(2021\)](#), [Imura \(2019\)](#) or [Steinberg \(2020\)](#), the technology of producing $X_{i,t}$ by a representative producer z is summarised by:

$$X_{i,t}(z) = A_{i,t} \left[\prod_{s=1}^3 X_{i,t}^s(z) \omega_i^s \right]^{\zeta_i} \left[L_{i,t}(z)^{\alpha_i} K_{i,t-1}(z)^{1-\alpha_i} \right]^{1-\zeta_i} \quad (\text{B.104})$$

where $0 < \zeta_i < 1$ is the share of all intermediate inputs and $0 < \omega_i^s < 1$ is the share of intermediate inputs of type s in the total use of supplies.

Each type of supplies can be either domestic, purchased from local retailers, or foreign, purchased from importers. Therefore, $X_{i,t}^s$ is a composite index of supplies s used in the

domestic sector i and originally produced in country $m \in M$:

$$X_{i,t}^s(z) = \left[\sum_{m=1}^M (\omega_{i,m}^s)^{\frac{1}{\eta_s}} X_{i,t}^{s,m}(z)^{\frac{\eta_s-1}{\eta_s}} \right]^{\frac{\eta_s}{\eta_s-1}} \quad (\text{B.105})$$

where $0 \leq \omega_{i,m}^s \leq 1$ denotes the share of supplies of type s delivered from country m in the total use of supplies of type s in the domestic sector i and $\eta_s > 0$ is the Armington elasticity of substitution between domestic and imported supplies.

Sector i 's producers face the common sectoral wage rates $W_{i,t}^{hs}$ and $W_{i,t}^{ls}$, rental price of capital $Z_{i,t}$, and the sector i 's price index of type- s supplies $P_{i,t}^s$, and plan their future production with a goal to minimise cost. Their optimisation problem can be formalised as:

$$\min_{L_{i,t}^{hs}(z), L_{i,t}^{ls}(z), K_{i,t-1}(z), X_{i,t}^s(z)} \left[\begin{aligned} &W_{i,t}^{hs} L_{i,t}^{hs}(z) + W_{i,t}^{ls} L_{i,t}^{ls}(z) \\ &+ Z_{i,t} K_{i,t-1}(z) + \sum_{s=1}^3 P_{i,t}^s X_{i,t}^s(z) \end{aligned} \right] \quad (\text{B.106})$$

s.t.

$$A_{i,t} \left[\prod_{s=1}^3 X_{i,t}^s(z)^{\omega_i^s} \right]^{\zeta_i} \left[L_{i,t}(z)^{\alpha_i} K_{i,t-1}(z)^{1-\alpha_i} \right]^{1-\zeta_i} \geq \left[\frac{P_{i,t}^h(z)}{P_{i,t}^h} \right]^{-\varepsilon_i} X_{i,t} \quad (\text{B.107})$$

The corresponding Lagrangian is given by:

$$\begin{aligned} \mathcal{L} \left(L_{i,t}^{hs}(z), L_{i,t}^{ls}(z), K_{i,t-1}(z), X_{i,t}^s(z) \right) = & -W_{i,t}^{hs} L_{i,t}^{hs}(z) - W_{i,t}^{ls} L_{i,t}^{ls}(z) \\ & - Z_{i,t} K_{i,t-1}(z) - \sum_{s=1}^3 P_{i,t}^s X_{i,t}^s(z) \\ & + mC_{i,t}(z) \left(\begin{aligned} &A_{i,t} \left[\prod_{s=1}^3 X_{i,t}^s(z)^{\omega_i^s} \right]^{\zeta_i} \\ &\times \left[\left(\omega_i^{hs} L_{i,t}^{hs}(z)^{(1-\rho_l)} + L_{i,t}^{ls}(z)^{(1-\rho_l)} \right)^{\frac{\alpha_i}{1-\rho_l}} K_{i,t-1}(z)^{1-\alpha_i} \right]^{1-\zeta_i} \\ &- \left[\frac{P_{i,t}^h(z)}{P_{i,t}^h} \right]^{-\varepsilon_i} X_{i,t} \end{aligned} \right) \end{aligned} \quad (\text{B.108})$$

The first-order conditions of the cost minimisation problem w.r.t. $L_{i,t}^{hs}(z)$, $L_{i,t}^{ls}(z)$, $K_{i,t-1}(z)$, and $X_{i,t}^s(z)$ are:

$$\begin{aligned} \frac{\partial \mathcal{L} \left(L_{i,t}^{hs}(z), L_{i,t}^{ls}(z), K_{i,t-1}(z), X_{i,t}^s(z) \right)}{\partial L_{i,t}^{hs}(z)} &= -W_{i,t}^{hs} \\ + mC_{i,t}(z) (1 - \zeta_i) \alpha_i \omega_i^{hs} \frac{X_{i,t}(z)}{L_{i,t}(z)^{1-\rho_l} L_{i,t}^{hs}(z)^{\rho_l}} &= 0 \end{aligned} \quad (\text{B.109})$$

$$\begin{aligned} \frac{\partial \mathcal{L} \left(L_{i,t}^{hs}(z), L_{i,t}^{ls}(z), K_{i,t-1}(z), X_{i,t}^s(z) \right)}{\partial L_{i,t}^{ls}(z)} &= -W_{i,t}^{ls} \\ + mc_{i,t}(z)(1 - \zeta_i)\alpha_i \frac{X_{i,t}(z)}{L_{i,t}(z)^{1-\rho_l} L_{i,t}^{ls}(z)^{\rho_l}} &= 0 \end{aligned} \quad (\text{B.110})$$

$$\begin{aligned} \frac{\partial \mathcal{L} \left(L_{i,t}^{hs}(z), L_{i,t}^{ls}(z), K_{i,t-1}(z), X_{i,t}^s(z) \right)}{\partial K_{i,t-1}(z)} &= -Z_{i,t} \\ + mc_{i,t}(z)(1 - \alpha_i)(1 - \zeta_i) \frac{X_{i,t}(z)}{K_{i,t-1}} &= 0 \end{aligned} \quad (\text{B.111})$$

$$\begin{aligned} \frac{\partial \mathcal{L} \left(L_{i,t}^{hs}(z), L_{i,t}^{ls}(z), K_{i,t-1}(z), X_{i,t}^s(z) \right)}{\partial X_{i,t}^s(z)} &= -P_{i,t}^s \\ + mc_{i,t}(z)\zeta_i\omega_i^s \frac{X_{i,t}(z)}{X_{i,t}^s(z)} &= 0 \end{aligned} \quad (\text{B.112})$$

Given that all producers in sector i are identical, the first-order conditions in real terms are given by:

$$W_{i,t}^{hs} = mc_{i,t}(1 - \zeta_i)\alpha_i\omega_i^{hs} \frac{X_{i,t}}{L_{i,t}^{1-\rho_l} L_{i,t}^{hs\rho_l}} \quad (\text{B.113})$$

$$W_{i,t}^{ls} = mc_{i,t}(1 - \zeta_i)\alpha_i \frac{X_{i,t}}{L_{i,t}^{1-\rho_l} L_{i,t}^{ls\rho_l}} \quad (\text{B.114})$$

$$Z_{i,t} = mc_{i,t}(1 - \zeta_i)(1 - \alpha_i) \frac{X_{i,t}}{K_{i,t-1}} \quad (\text{B.115})$$

$$P_{i,t}^{s,m} = mc_{i,t}\zeta_i\omega_i^s \frac{X_{i,t}}{X_{i,t}^s} \quad (\text{B.116})$$

Real (flow) profit of the representative producer in sector i is given by:

$$\Pi_{i,t}(z) = P_{i,t}^h(z)X_{i,t}(z) - W_{i,t}^{hs}L_{i,t}^{hs}(z) - W_{i,t}^{ls}L_{i,t}^{ls}(z) - Z_{i,t}K_{i,t-1}(i) - \sum_{s=1}^3 P_{i,t}^s X_{i,t}^s(z) \quad (\text{B.117})$$

Given the optimal demands for the four factors derived in (B.113)-(B.116), the flow profit is given by:

$$\begin{aligned} \Pi_{i,t}(j) &= P_{i,t}^h(z)X_{i,t}(z) - mc_{i,t}(z)(1 - \zeta_i)\alpha_i\omega_i^{hs} \frac{X_{i,t}(z)}{L_{i,t}(z)^{1-\rho_l} L_{i,t}^{hs}(z)^{\rho_l-1}} \\ &\quad - mc_{i,t}(z)(1 - \zeta_i)\alpha_i \frac{X_{i,t}(z)}{L_{i,t}(z)^{1-\rho_l} L_{i,t}^{ls}(z)^{\rho_l-1}} - mc_{i,t}(z)(1 - \zeta_i)(1 - \alpha_i)X_{i,t}(z) \\ &\quad - \sum_{s=1}^3 mc_{i,t}(z)\zeta_i\omega_i^s X_{i,t}(z) \end{aligned} \quad (\text{B.118})$$

Since $\sum_{s=1}^3 \omega_i^s = 1$, the equality above simplifies to:

$$\begin{aligned} \Pi_{i,t}(j) = & P_{i,t}^h(j) X_{i,t}(z) - mc_{i,t}(z)(1 - \zeta_i) \alpha_i \omega_i^{hs} \frac{X_{i,t}(z)}{\omega_i^{hs} + L_{i,t}^{ls}(z)^{1-\rho_l} L_{i,t}^{hs}(z)^{\rho_l-1}} \\ & - mc_{i,t}(z)(1 - \zeta_i) \alpha_i \frac{X_{i,t}(z)}{\omega_i^{hs} L_{i,t}^{hs1-\rho_l} L_{i,t}^{ls}(z)^{\rho_l-1} + 1} \\ & - mc_{i,t}(z)(1 - \zeta_i)(1 - \alpha_i) X_{i,t}(z) - mc_{i,t}(z) \zeta_i X_{i,t}(z) \end{aligned} \quad (\text{B.119})$$

$$\begin{aligned} \Pi_{i,t}(z) = & P_{i,t}^h(z) X_{i,t}(j) - mc_{i,t}(z)(1 - \zeta_i) \alpha_i \omega_i^{hs} \frac{X_{i,t}(z) L_{i,t}^{hs}(z)^{1-\rho_l}}{L_{i,t}(z)^{1-\rho_l}} \\ & - mc_{i,t}(z)(1 - \zeta_i) \alpha_i \frac{X_{i,t}(z) L_{i,t}^{ls1-\rho_l}}{L_{i,t}(z)^{1-\rho_l}} - mc_{i,t}(z)(1 - \zeta_i)(1 - \alpha_i) X_{i,t}(z) \\ & - mc_{i,t}(z) \zeta_i X_{i,t}(z) \end{aligned} \quad (\text{B.120})$$

$$\begin{aligned} \Pi_{i,t}(j) = & P_{i,t}^h(j) X_{i,t}(j) \\ & - mc_{i,t}(z) X_{i,t}(z) \left((1 - \zeta_i) \alpha_i \omega_i^{hs} \frac{L_{i,t}^{hs}(z)^{1-\rho_l}}{L_{i,t}(z)^{1-\rho_l}} + (1 - \zeta_i) \alpha_i \frac{L_{i,t}^{ls}(z)^{1-\rho_l}}{L_{i,t}(z)^{1-\rho_l}} \right. \\ & \left. + (1 - \zeta_i)(1 - \alpha_i) + \zeta_i \right) \end{aligned} \quad (\text{B.121})$$

$$\Pi_{i,t}(z) = P_{i,t}^h(z) X_{i,t}(z) - mc_{i,t}(z) X_{i,t}(z) \quad (\text{B.122})$$

The rest of the pricing problem of firms follows equations (B.47)-(B.53) from [Appendix B.1](#).

Goods and services producers choose between domestic and imported supplies, subject to the following aggregate expenditure on s :

$$P_{i,t}^s X_{i,t}^s = \sum_{m=1}^M P_{i,t}^{h,m} X_{i,t}^{s,m} \quad (\text{B.123})$$

where $X_{i,t}^{s,m}$ represent supplies originally produced in country m .

The optimisation problem is symmetric across all three types of s . The Lagrangian associated with optimisation is given by:

$$\mathcal{L}(X_{i,t}^{s,h}, X_{i,t}^{s,m}) = \left[\sum_{m=1}^M (\omega_i^{s,m})^{\frac{1}{\eta_s}} (X_{i,t}^{s,m})^{\frac{\eta_s-1}{\eta_s}} \right]^{\frac{\eta_s}{\eta_s-1}} - \mathcal{Q}_{i,t}^s \left(\sum_{m=1}^M P_{i,t}^{h,m} X_{i,t}^{s,m} - P_{i,t}^s X_{i,t}^s \right) \quad (\text{B.124})$$

where $X_{i,t}^{s,h}$ represents type- s supplies produced locally, i.e. $m = h$.

The first-order conditions of the optimisation problem w.r.t. $X_{i,t}^{s,h}$ and $X_{i,t}^{s,m}$ (for $m \neq h$) are

as follows:

$$\frac{\partial \mathcal{L}(X_{i,t}^{s,h}, X_{i,t}^{s,m})}{\partial X_{i,t}^{s,h}} = \left(\omega_i^{s,h}\right)^{\frac{1}{\eta_s}} \left(X_{i,t}^{s,h}\right)^{-\frac{1}{\eta_s}} \left[\sum_{m=1}^M \left(\omega_i^{s,m}\right)^{\frac{1}{\eta_s}} \left(X_{i,t}^m\right)^{\frac{\eta_s-1}{\eta_s}} \right]^{\frac{1}{\eta_s-1}} \quad (\text{B.125})$$

$$-\varrho_{i,t}^s P_{i,t}^h = 0$$

$$\frac{\partial \mathcal{L}(X_{i,t}^{s,h}, X_{i,t}^{s,m})}{\partial X_{i,t}^{s,m}} = \left(\omega_i^{s,m}\right)^{\frac{1}{\eta_s}} \left(X_{i,t}^{s,m}\right)^{-\frac{1}{\eta_s}} \left[\sum_{m=1}^M \left(\omega_i^{s,m}\right)^{\frac{1}{\eta_s}} \left(X_{i,t}^m\right)^{\frac{\eta_s-1}{\eta_s}} \right]^{\frac{1}{\eta_s-1}} \quad (\text{B.126})$$

$$-\varrho_{i,t}^s P_{i,t}^{h,m} = 0$$

Combining and simplifying the first-order conditions - (B.125) and (B.126) - yields:

$$X_{i,t}^{s,m} = \frac{\omega_i^{s,m}}{\omega_i^{s,h}} \left[\frac{P_{i,t}^h}{P_{i,t}^s} \right]^{-\eta_s} X_{i,t}^{s,h} \quad (\text{B.127})$$

where $P_{i,t}^s$ is the price index of sector i 's producers composed of the prices of domestic and foreign s weighted by their corresponding shares in i 's demand for s :

$$P_{i,t}^s = \left[\sum_{m=1}^M \omega_i^{s,m} \left(P_{i,t}^{h,m}\right)^{1-\eta_s} \right]^{\frac{1}{1-\eta_s}} \quad (\text{B.128})$$

We substitute (B.127) into (B.123), which results in:

$$P_{i,t}^s X_{i,t}^s = P_{i,t}^h X_{i,t}^{s,h} + P_{i,t}^{s,m} \left[\frac{\omega_i^{s,m}}{\omega_i^{s,h}} \left[\frac{P_{i,t}^{h,m}}{P_{i,t}^s} \right]^{-\eta_s} X_{i,t}^{s,h} \right] \quad (\text{B.129})$$

Equation (B.129) simplifies into the following optimal allocation of sector i 's budget to locally produced s :

$$X_{i,t}^{s,h} = \omega_i^{s,h} \left[\frac{P_{i,t}^h}{P_{i,t}^s} \right]^{-\eta_s} X_{i,t}^s \quad (\text{B.130})$$

Equation (B.130) is substituted back into (B.127) to obtain the optimal demand conditions for imported s :

$$X_{i,t}^{s,m} = \frac{\omega_i^{s,m}}{\omega_i^{s,h}} \left[\frac{P_{i,t}^{s,m}}{P_{i,t}^s} \right]^{-\eta_s} \left[\omega_i^{s,h} \left[\frac{P_{i,t}^h}{P_{i,t}^s} \right]^{-\eta_s} X_{i,t}^s \right] \quad (\text{B.131})$$

Simplifying further yields the following optimal demand condition for s imported from m :

$$X_{i,t}^{s,m} = \omega_i^{s,m} \left[\frac{P_{i,t}^{s,m}}{P_{i,t}^s} \right]^{-\eta_s} X_{i,t}^s \quad (\text{B.132})$$

B.3.1 Importers

There are perfectly competitive importers buying goods, and services from foreign retailers and selling them at home, either to households as consumer goods and services or to firms as intermediate inputs.

Their goal is to maximise profits from selling i imported from all foreign countries:

$$\Pi_t^{imp} = \sum_{\substack{m=1 \\ m \neq h}}^M \sum_{s=1}^3 \Pi_{s,t}^m \quad (\text{B.133})$$

where $\Pi_{s,t}^m$ represent profits from imports of s from country m defined by:

$$\Pi_{s,t}^m \equiv P_{s,t}^{h,m} M_{s,t}^m - (1 + \tau_s^m) \nu_s^m s_t^m P_{s,t}^m M_{s,t}^m \quad (\text{B.134})$$

where $M_{s,t}^m$ is the demand of local households and producers in each sector of the domestic economy for imports of s from country m :

$$M_{s,t}^m = C_{s,t}^m + \sum_{i=1}^3 X_{i,t}^{s,m} \quad (\text{B.135})$$

B.3.2 Government

Fiscal policy

The value of government transfers is:

$$\begin{aligned} TR_t = & \sum_{i=1}^3 \tau_w \left(W_{i,t}^{hs} L_{i,t}^{hs} + W_{i,t}^{ls} L_{i,t}^{ls} \right) + \tau_c \left(C_t^{hs} + C_t^{ls} \right) \\ & + \sum_{m=1}^M \sum_{i=1}^3 \tau_i^m s_t^m P_{s=1,t}^m \left(C_{i=1,t}^m + X_{i,t}^{s=1,m} \right) \end{aligned} \quad (\text{B.136})$$

The first-order conditions of households remain unchanged.

B.3.3 Market clearing conditions

The market clearing conditions of sector i in the domestic economy h are given by:

$$X_{i,t} = \sum_{m=1}^M C_{i,t}^{m,h} + \sum_{m=1}^M \sum_{s=1}^3 X_{s,t}^{i,h} + G_{i,t} + \left[1 + f \left(\frac{I_{i,t}}{I_{i,t-1}} \right) \right] I_{i,t} \quad (\text{B.137})$$

that is, total output in sector i equals the sum of demands by domestic and foreign households, the demand by the three sectors (domestic and foreign) which re-use sector i 's good or service as an intermediate input; the demand by the local government; and investment expenditures.

B.4 Extension (3): banks

B.4.1 Households

Representative native high-skilled household j chooses consumption $C_t^{hs}(j)$, labour supply to sector i $L_{i,t}^{hs,n}(j)$, and a sum of new bonds $B_{t+1}(j)$ and bank deposits $D_{t+1}(j)$ to maximise its discounted lifetime utility (B.63).

The maximisation problem of the high-skilled household j is subject to the sequence of intertemporal budget constraints of the form:

$$(1 + \tau_c) C_t^{hs}(j) + B_{t+1}(j) + D_{t+1}(j) = R_t B_t(j) + R_t D_t(j) + \sum_{i=1}^3 (1 - \tau_w) W_{i,t}^{hs} L_{i,t}^{hs,n}(j) + \sum_{i=1}^3 \Pi_{i,t}(j) + TR_t^{hs} \quad (\text{B.138})$$

Banks

Goods and services producers finance investment plans by borrowing from domestic banks. At the end of t , firms purchase new capital at the price $Q_{i,t}$ issuing a claim for each unit. Consequently, the assets in the banking sector are backed by the amount of real capital. A representative bank z holds total assets S_t composed of lending to three sectors of the economy.

Liabilities of banks are composed of deposits D_t held by high-skilled households and the net worth N_t . Therefore, the balance sheet of an individual bank is as follows:

$$S_t(z) = N_t(z) + D_t(z) \quad (\text{B.139})$$

The net worth accumulation of a representative bank is equal to the payoff from assets net of payments for liabilities:

$$N_t(z) = R_{k,t} S_{t-1}(z) - R_t D_{t-1}(z) \quad (\text{B.140})$$

where $R_{k,t}$ is the return on assets held by producers.⁴⁸

⁴⁸We assume no arbitrage between sectors and, therefore, $R_{k,t}$ is equal across the three types of capital

At the end of each period, an individual bank maximises the present value of its future dividends where $0 < \theta_b < 1$ accounts for the survival rate of banks:

$$V_t = \max_{S_t(z), D_t(z)} \mathbb{E}_t \left[\sum_{k=0}^{\infty} (1 - \theta_b) \theta_b^{k-1} \beta_{hs} \frac{q_{t+1}^{hs}}{q_t^{hs}} N_{t+1}(z) \right] \quad (\text{B.141})$$

The maximisation problem of a representative bank z is subject to the incentive constraint of banks to diverting funds expressed, where the value of the individual bank $V_t(\cdot)$ must be at least as large as the gain from diverting funds as:

$$V_t(S_t(z), D_t(z)) \geq \lambda S_t(z) \quad (\text{B.142})$$

where $0 < \lambda < 1$ is the share of diverted funds.

The corresponding Bellman equation is as follows:

$$V_{t-1}(S_{t-1}(z), D_{t-1}(z)) = \mathbb{E}_{t-1} \theta_b^{k-1} \beta_{hs} \frac{q_t^{hs}}{q_{t-1}^{hs}} \left[(1 - \theta_b) N_t(z) + \theta_b (\max_{S_t, D_t} V_t(S_t(z), D_t(z))) \right] \quad (\text{B.143})$$

The bank's optimisation problem is solved by guessing a linear value function on assets and deposits:

$$V_t(S_t(z), D_t(z)) = v_{s,t} S_t(z) - v_{d,t} D_t(z) \quad (\text{B.144})$$

where $v_{s,t}$ and $v_{d,t}$ are the time-varying marginal values of assets and deposits.

The Lagrangian is formalised as:

$$\mathcal{L}(S_t(z), D_t(z)) = v_{s,t} S_t(z) - v_{d,t} D_t(z) - \mu_{b,t} [S_t(z) - v_{s,t} S_t(z) + v_{d,t} D_t(z)] \quad (\text{B.145})$$

The first-order conditions are expressed as follows:

$$v_{s,t} - \mu_{b,t}(\lambda - v_{s,t}) = 0 \quad (\text{B.146})$$

$$-v_{d,t} - \mu_{b,t} v_{d,t} = 0 \quad (\text{B.147})$$

$$\lambda S_t(z) - v_{s,t} S_t + v_{d,t} D_t(z) = 0 \quad (\text{B.148})$$

where $\mu_{b,t}$ is the Lagrange multiplier. From equation (B.146), we obtain an expression for the Lagrange multiplier:

$$\mu_{b,t} = \frac{v_{s,t}}{\lambda - v_{s,t}} \quad (\text{B.149})$$

Using (B.148) and the balance sheet of the z bank (B.139), we isolate for deposits as follows:

$$D_t(z) = S_t(z) - N_t(z) \quad (\text{B.150})$$

It allows to obtain the following expression:

$$S_t(z) - v_{s,t}S_t(z) + v_{d,t}(S_t(z) - N_t(z)) = 0 \quad (\text{B.151})$$

$$S_t(z) \left[\lambda - \left(\frac{v_{s,t}}{Q_{i,t}} - v_{d,t} \right) \right] = v_{d,t}N_t(z) \quad (\text{B.152})$$

where $\mu_t = \frac{v_{s,t}}{Q_{i,t}} - v_{d,t}$ is the excess value of the banks' assets over deposits, also known as the excess return on capital, which simplifies equation (B.152) as follows

$$S_t(z) (\lambda - \mu_t) = v_{d,t}N_t(z) \quad (\text{B.153})$$

Equation (B.153) can be re-expressed as the leverage ratio ϕ_t , which is equal to the value of assets over the net worth:

$$\phi_t = \frac{S_t(z)}{N_t(z)} = \frac{v_{d,t}}{\lambda - \mu_t} \quad (\text{B.154})$$

We verify the functional form of the value function plugging (B.144) into the Bellman equation (B.143) and using $D_t(z) = S_t(z) - N_t(z)$:

$$V_t(S_t(z), D_t(z)) = \mathbb{E}_t \beta \frac{Q_{t+1}^{hs}}{Q_t^{hs}} \left[(1 - \theta_b) N_t(z) + \theta_b (v_{s,t}S_t(z) - v_{d,t}(S_t(z) - N_t(z))) \right] \quad (\text{B.155})$$

$$V_t(S_t(z), D_t(z)) = \mathbb{E}_t \beta \frac{Q_{t+1}^{hs}}{Q_t^{hs}} \left[(1 - \theta_b) N_t(z) + \theta_b \left(\left(\frac{v_{s,t}}{Q_{s,t}} - v_{d,t} \right) S_t(z) + v_{d,t}N_t(z) \right) \right] \quad (\text{B.156})$$

Taking the definition of μ_t , the expression above is written as follows:

$$V_t(S_t(z), D_t(z)) = \mathbb{E}_t \beta_{hs} \frac{Q_{t+1}^{hs}}{Q_t^{hs}} [(1 - \theta_b) N_t(z) + \theta_b (\mu_t S_t(z) + v_{d,t}N_t(z))] \quad (\text{B.157})$$

$$V_t(S_t(z), D_t(z)) = \mathbb{E}_t \beta_{hs} \frac{Q_{t+1}^{hs}}{Q_t^{hs}} N_t(z) [(1 - \theta_b) + \theta_b (\mu_t \phi_t + v_{d,t})] \quad (\text{B.158})$$

We replace the net worth earnings $N_t(z) = R_{k,t}S_{t-1}(z) - R_tD_{t-1}(z)$ taken from equation (B.140) into equation (B.158) and roll it one period ahead yielding:

$$V_t(S_t(z), D_t(z)) = \mathbb{E}_t \beta_{hs} \frac{Q_{t+1}^{hs}}{Q_t^{hs}} \Omega_{t+1} (R_{k,t+1}S_t - R_{t+1}D_t) \quad (\text{B.159})$$

where $\Omega_t = (1 - \theta_b) + \theta (\mu_{s,t}\phi_t + v_{d,t})$ is the shadow value of net worth. We obtain expressions for assets, deposits and the excess value of assets over deposits. The first-order conditions for assets, deposits and the excess of marginal assets to deposits are as follows:

$$v_{s,t} = \mathbb{E}_t \beta_{hs} \frac{q_{t+1}^{hs}}{q_t^{hs}} \Omega_{t+1} R_{k,t+1} \quad (\text{B.160})$$

$$v_{d,t} = \mathbb{E}_t \beta_{hs} \frac{q_{t+1}^{hs}}{q_t^{hs}} \Omega_{t+1} R_{t+1} \quad (\text{B.161})$$

$$\mu_t = \mathbb{E}_t \beta_{hs} \frac{q_{t+1}^{hs}}{q_t^{hs}} \Omega_{t+1} (R_{k,t+1} - R_{t+1}) \quad (\text{B.162})$$

We assume that banks are homogeneous, the aggregation is straightforward. The banks' balance sheet and the aggregate net worth of banks are expressed as follows:

$$S_t = \phi_t N_t \quad (\text{B.163})$$

$$N_t = (\theta_b + \kappa) R_{k,t} S_{t-1} - \theta_b R_t D_{t-1} \quad (\text{B.164})$$

where κ denote the fraction of assets that are provided as 'starting funds' every period.

B.5 Calibration

The calibration of the benchmark model and the extensions is largely based on the *World Input-Output Database* (WIOD) as in [Timmer et al. \(2015\)](#) and OECD. The values of the remaining parameters are consistent with relevant literature as presented in [Table B.1](#). Finally, we match the sizes of the three sectors in each country by calibrating the steady-state labour supply in each sector.

We calibrate the benchmark model and the extensions for the UK, the EU and the non-EU trading partners, which are composed of two distinct group of countries: advanced economies (AE) and emerging economies (EE).

B.5.1 Benchmark model

Given that in this version of the model households consume all imported goods and services, the γ_i and γ_i^m parameters are calculated using the WIOD 2014 by assuming that households (and governments) are the only consumers of all goods and services - domestic and foreign. The shares of goods, tradable and nontradeable services in the consumption baskets of the UK

Table B.1: Calibrated parameters of the benchmark model.

Parameter		UK	EU	AE	EE	Source
<i>Households</i>						
Discount factor	β	0.990	0.990	0.990	0.990	I05
CRRRA	σ_c	0.660	0.720	0.740	0.440	HO10; SW07; SW03; ZG13
Frisch labour elasticity	φ_h	0.342	0.281	0.276	0.200	M11; V13; BDL16; LL17
e.o.s. domestic and imported output	η	1.770	1.770	1.770	1.770	HO10
Labour disutility	$\vartheta_{i=1}$	1.819	0.296	0.226	0.232	Target value
Labour disutility	$\vartheta_{i=2}$	0.852	0.131	0.142	0.197	Target value
Labour disutility	$\vartheta_{i=3}$	0.893	0.171	0.125	0.194	Target value
Share of goods in consumption	$\gamma_{i=1}$	0.228	0.313	0.307	0.594	WIOD
Share of tradable services in consumption	$\gamma_{i=2}$	0.337	0.324	0.303	0.177	WIOD
Share of nontradable services in consumption	$\gamma_{i=3}$	0.434	0.363	0.390	0.229	WIOD
<i>Production</i>						
Labour share	$\alpha_{i=1}$	0.653	0.615	0.603	0.695	WIOD
Labour share	$\alpha_{i=2}$	0.694	0.715	0.720	0.641	WIOD
Labour share	$\alpha_{i=3}$	0.648	0.620	0.611	0.682	WIOD
Calvo parameter	θ	0.760	0.740	0.660	0.622	FMZ11; SW07; SW03; R16
e.o.s. among varieties	$\varepsilon_{i=1}$	6.000	6.000	6.000	6.000	CV12
e.o.s. among varieties	$\varepsilon_{i=2}$	4.000	4.000	4.000	4.000	CV12
e.o.s. among varieties	$\varepsilon_{i=3}$	3.000	3.000	3.000	3.000	CV12
Depreciation rate	δ	0.025	0.025	0.025	0.025	HO10; DN07; FM07
Adjustment cost	Φ	6.000	6.000	6.000	6.000	BT17
<i>Fiscal and monetary policy</i>						
Labour income tax rate	τ_w	0.233	0.289	0.215	0.199	OECD
Consumption tax rate	τ_c	0.200	0.221	0.064	0.170	OECD
Interest rate persistence	ρ_r	0.881	0.870	0.810	0.980	HO10; ALL07; SW07; R16
Taylor Rule parameter	φ_π	1.113	1.680	2.030	1.744	HO10; SW07; SW03; R16
<i>Shocks</i>						
Non-tariff barriers	$\nu_{i=1}$	3.69%	3.69%	-	-	FBT09; DHO17
Non-tariff barriers	$\nu_{i=2}$	1.63%	1.63%	-	-	FBT09; DHO17
Non-tariff barriers	$\nu_{i=3}$	1.63%	1.63%	-	-	FBT09; DHO17
Tariffs	$\tau_{i=1}$	-1.49%; -2.94%	-	-1.49%	-2.94%	GJMP12

Note: Abbreviations used in the table are as follows: ALL07: Adolfson et al. (2007); BDL16: Banerjee et al. (2016); BT17: Bhattarai and Trzeciakiewicz (2017); CV12: Christopoulou and Vermeulen (2012); DN07: DiCecio and Nelson (2007); FM07: Faia and Monacelli (2007); FMZ11: Faccini et al. (2011); HO10: Harrison and Oomen (2010); I05: Iacoviello (2005); LL17: Li and Liu (2017); M11: Millard (2011); R16: Razafindrabe (2016); SW03: Smets and Wouters (2003); SW07: Smets and Wouters (2007); V16: Villa (2016); ZG13: Zheng and Guo (2013).

households correspond to $\gamma_{i=1}$ equal to 22.8%, $\gamma_{i=2}$ is 33.7%, and $\gamma_{i=3}$ represents 43.4%. The corresponding shares of goods, tradable and nontradable services in the consumption baskets of EU households are, respectively, 31.3%, 32.3%, and 36.2%. The consumption baskets of households in the non-EU trading partners include data on the AE and EE. The share of goods in the consumption baskets $\gamma_{i=1}$ in these countries is 30.7% and 59.4%, respectively. The share of tradable services in the consumption baskets of AE and EE households $\gamma_{i=2}$ corresponds to 30.3% and 17.7%, respectively. And, the share of nontradable services $\gamma_{i=3}$ represents 39.0% and 22.8% for the AE and EE, respectively.

The γ_i^m parameters in the benchmark model are presented in Table B.2, γ_i^m are a share of goods or services originally produced in m in the total consumption of i . Thus, each column and block sum to 100. For instance, 26.5% percent of goods consumed by the UK households

are goods imported from the EU. The darker the shade in a cell, the greater the intensity of demand for a particular good or service.

Table B.2: Benchmark model: composition of consumption in the four countries.

Country of origin	$i = 1$ (UK)	$i = 1$ (EU)	$i = 1$ (AE)	$i = 1$ (EE)
$m = UK$	58.794	1.66	0.501	0.157
$m = EU$	26.521	87.043	1.334	1.709
$m = AE$	6.633	4.424	97.829	3.704
$m = EE$	8.051	6.872	0.331	94.43

Country of origin	$i = 2$ (UK)	$i = 2$ (EU)	$i = 2$ (AE)	$i = 2$ (EE)
$m = UK$	91.266	1.905	0.506	0.203
$m = EU$	6.413	93.562	1.334	1.163
$m = AE$	1.971	3.469	97.829	1.056
$m = EE$	0.348	1.064	0.331	97.578

Country of origin	$i = 3$ (UK)	$i = 2$ (EU)	$i = 2$ (AE)	$i = 2$ (EE)
$m = UK$	97.032	0.239	0.071	0.037
$m = EU$	2.034	98.617	0.258	0.331
$m = AE$	0.607	0.771	99.528	0.378
$m = EE$	0.327	0.372	0.142	99.254

B.5.2 Extension (1): migration flows and heterogeneous households

With the introduction of migration flows and heterogeneous households with distinct labour skill levels, we adjust the calibration accordingly. Table B.3 presents the additional parameters in the top panel. Following Iacoviello (2005), we set the discount factor of high and low-skilled households β_{hs} and β_{ls} at 0.99 and 0.97 respectively, implying a risk-free annualised quarterly interest rate of 4% and 12%.

We differentiate between the relative risk aversion coefficients of high-skilled households, σ_{hs} , and the low-skilled households, σ_{ls} , to match the average values for the population of each of the four countries, as presented in Table B.3. The disutility parameters of high-skilled, ϑ_i^{hs} , and low-skilled labour, ϑ_i^{ls} , are calibrated such that labour demand matches with the labour supply in the steady-state.

On the migration parameters, the death rate v is set at 0.025 in each country, implying that 2.5% of the labour force is replaced every year as Canova and Ravn (2000). In turn, the elasticity of substitution between high-skilled and low-skilled labour inputs falls inside the $0 < \rho_l < 1$ interval, indicating that the two types of workers are gross substitutes. We use the value of 0.40 for each country, following Autor et al. (1998).

We set the shares of high-skilled workers $\rho_{i=1}^{hs}$ for $i = 1$ at 42% for the UK, 54.1% for the EU, 69.2% for the AE and 13.8% for the EE based on the *Database on Immigrants in OECD Countries*

Table B.3: Calibrated parameters of extension (1): migration and heterogeneous households.

Parameter		UK	EU	AE	EE	Source
<i>Heterogeneous households</i>						
Discount factor	β_{hs}	0.990	0.990	0.990	0.990	I05
Discount factor	β_{ls}	0.970	0.970	0.970	0.970	I05
CRRRA	σ_{hs}	0.839	0.860	0.811	0.935	HO10; SW03; SW07; ZG13
CRRRA	σ_{ls}	0.495	0.540	0.555	0.330	HO10; SW03; SW07; ZG13
Productivity premium	ω^{hs}	1.963	1.918	2.116	2.776	OECD
e.o.s. high- vs low-skilled labour	ρ_l	0.400	0.400	0.400	0.400	AKK98
Death rate	v	0.025	0.025	0.025	0.025	CR00
Share of high-skilled workers	λ_{hs}	0.495	0.572	0.727	0.189	OECD
Share of high-skilled workers	$\rho_{i=1}^{hs}$	0.420	0.541	0.692	0.138	OECD
Share of high-skilled workers	$\rho_{i=2}^{hs}$	0.501	0.625	0.780	0.366	OECD
Share of high-skilled workers	$\rho_{i=3}^{hs}$	0.596	0.726	0.775	0.505	OECD
Labour disutility	$\theta_{i=1}^{hs}$	0.335	0.036	0.035	0.035	Target value
Labour disutility	$\theta_{i=2}^{hs}$	0.144	0.015	0.021	0.021	Target value
Labour disutility	$\theta_{i=3}^{hs}$	0.138	0.018	0.018	0.019	Target value
Labour disutility	$\theta_{i=1}^{ls}$	0.756	0.231	0.383	0.139	Target value
Labour disutility	$\theta_{i=2}^{ls}$	0.413	0.121	0.307	0.183	Target value
Labour disutility	$\theta_{i=3}^{ls}$	0.528	0.200	0.266	0.229	Target value
<i>Shocks</i>						
Persistence: migration	ρ_{ω}^m	0.965	0.965	-	-	ONS
Migration	$\sigma^{m,ls}$	-0.067	0.067	-	-	Authors' calculation

Note: Abbreviations used in the table are as follows: AKK98: Autor et al. (1998); CR00: Canova and Ravn (2000); HO10: Harrison and Oomen (2010); I05: Iacoviello (2005); SW03: Smets and Wouters (2003); SW07: Smets and Wouters (2007); ZG13: Zheng and Guo (2013).

(DIOC). The corresponding values for tradable services, $\rho_{i=2}^{hs}$, are, respectively, 50%, 62.5%, 78.0% and 36.6%. The shares of high-skilled workers in the nontradable services $\rho_{i=3}^{hs}$ are set at 59.6% for the UK, 72.6% for the EU, 77.5% for the AE, and 50.5% for the EE.

B.5.3 Extension (2): supply chains networks

This section presents the calibration of the extended model with supply chains, migration and heterogeneous labour as observed in Table B.4. The parameters on the share of goods, tradable and nontradable services in the consumption baskets of households γ_i and γ_i^m are calibrated using the WIOD 2014.

The share of goods in the UK households' consumption basket, $\gamma_{i=1}$ is 16.8%. The corresponding shares for the EU, AE, and EE are, respectively, 24.2%, 17.1%, and 40.9%. Similarly, the share of tradable services in the total consumption basket, $\gamma_{i=2}$, equals 20.6% in the UK, 20.5% in the EU, 20.4% in the AE, and 17.9% in the EE. Finally, the corresponding shares of nontradable services, $\gamma_{i=3}$, is 62.6% in the UK, 55.3% in the EU, 62.5% in the AE, and 41.2% in the EE. The γ_i^m parameters for the model with supply chains and heterogeneous households are presented in Table B.5.

Table B.4: Calibrated parameters of extension (2): supply chains networks.

Parameter		UK	EU	AE	EE	Source
<i>Heterogeneous households</i>						
Labour disutility	$\vartheta_{i=1}^{hs}$	0.097	0.003	0.008	0.008	Target value
Labour disutility	$\vartheta_{i=2}^{hs}$	0.444	0.038	0.051	0.115	Target value
Labour disutility	$\vartheta_{i=3}^{hs}$	0.385	0.048	0.028	0.021	Target value
Labour disutility	$\vartheta_{i=1}^{ls}$	0.054	0.004	0.024	0.003	Target value
Labour disutility	$\vartheta_{i=2}^{ls}$	0.318	0.080	0.277	0.076	Target value
Labour disutility	$\vartheta_{i=3}^{ls}$	0.367	0.140	0.151	0.019	Target value
<i>Supply chain networks</i>						
Share of goods in consumption	$\gamma_{i=1}$	0.168	0.242	0.171	0.409	WIOD
Share of tradable services in consumption	$\gamma_{i=2}$	0.206	0.205	0.204	0.179	WIOD
Share of nontradable services in consumption	$\gamma_{i=3}$	0.626	0.553	0.625	0.412	WIOD
Share of supplies in production	$\zeta_{i=1}$	0.579	0.634	0.598	0.679	WIOD
Share of supplies in production	$\zeta_{i=2}$	0.447	0.465	0.405	0.410	WIOD
Share of supplies in production	$\zeta_{i=3}$	0.379	0.373	0.390	0.501	WIOD
e.o.s. domestic and imported supplies	η_s	1.770	1.770	1.770	1.770	HO10

Note: Abbreviations used in the table are as follows: HO10: [Harrison and Oomen \(2010\)](#).

In the production sector, the shares of intermediate inputs in each sector, ζ_i , are calculated using data from 2014 WIOT on the ratios of total intermediate demand to output. The resulting shares of intermediate inputs in the goods sector, $\zeta_{i=1}$, in the UK, EU, AE and EE are, respectively, given by 0.579, 0.634, 0.598 and 0.679. The corresponding shares of the tradable services sector, $\zeta_{i=2}$, are 0.447, 0.465, 0.405 and 0.410, and for the nontradable service sector, $\zeta_{i=3}$, are equal to 0.379, 0.373, 0.39 and 0.501, respectively.

Table B.5: Supply chains model: composition of consumption in the four countries

Country of origin	$i = 1$ (UK)	$i = 1$ (EU)	$i = 1$ (AE)	$i = 1$ (EE)
$m = UK$	44.6	1.572	0.569	0.323
$m = EU$	37.874	87.162	5.21	2.865
$m = AE$	4.864	3.412	82.222	2.87
$m = EE$	12.662	7.849	12.004	93.942
Country of origin	$i = 2$ (UK)	$i = 2$ (EU)	$i = 2$ (AE)	$i = 2$ (EE)
$m = UK$	91.266	1.905	0.506	0.203
$m = EU$	6.413	93.562	1.334	1.163
$m = AE$	1.971	3.469	97.829	1.056
$m = EE$	0.348	1.064	0.331	97.578
Country of origin	$i = 3$ (UK)	$i = 3$ (EU)	$i = 3$ (AE)	$i = 3$ (EE)
$m = UK$	92.022	1.614	0.493	0.349
$m = EU$	5.848	95.367	1.241	1.183
$m = AE$	1.918	2.478	97.981	0.755
$m = EE$	0.212	0.535	0.285	99.713

The supply chain parameters $\omega_i^{s,m}$ are calculated with data from the 2014 WIOT, and are summarised in [Table B.6](#). It represents the share of inputs purchased by the sector identified

in that column from the sector-country pair identified in that row. For example, the entry in the first row of the second column suggests that 38.72 % of all intermediate inputs in the UK's good sector comes from the sector's own output. The darker the shade in a cell, the greater the resource intensity of the input in the relevant row in the use of the sector in that column.

Table B.6 presents the $\omega_i^{s,m}$ parameters as a share of inputs demanded per sector. Thus the rows with $s = 1$ sum up to 100. It suggests that 22.48% of goods used as supplies in the UK's goods sector are goods imported from the EU. In contrast, 1.73% of goods used as supplies by the EU's goods sector are goods imported from the UK. Columns in **Table B.7** sum up to 300 as there are three types of supplies s in the i 's use of intermediate inputs.

B.5.4 Extension (3): banks

The extended model with the three extensions is calibrated using information on the banking sector to match the related parameters. We set the survival rate of banks θ_b at 0.968 for the UK, 0.972 for the EU, 0.969 for the AE and 0.965 for the EE to match a UK leverage ratio of around 5, as reported in the 2020 *Financial Stability Report*. For the EU, AE, and EE, the survival rate matches a leverage ratio of around 4, following the benchmark figures calculated by **Villa (2016)** and **Gertler and Kiyotaki (2010)**, respectively. This suggests a lifetime equivalent of 7.9, 8.8, 8.1, and 7.1 years on average for the UK and the EU, AE, and EE, respectively.

We set the proportion of diverted funds λ in the UK, EU, AE, and EE at 0.248, 0.366, 0.183, and 0.338 to match the average yearly credit spread at 180 basis points for the UK, 250 for the EU, 110 for the AE and 300 for the EE. The fraction of starting funds as a ratio of assets is set at 0.2% as in **Gertler and Kiyotaki (2010)** and **Gertler and Karadi (2011)**

Table B.6: Summary of the supply chain parameters.

Supplier	$i = 1$ (UK)	$i = 2$ (UK)	$i = 3$ (UK)
$s = 1, m = UK$	38.723	6.301	14.759
$s = 2, m = UK$	21.079	62.786	30.815
$s = 3, m = UK$	13.943	20.208	42.614
$s = 1, m = EU$	13.749	2.317	4.462
$s = 2, m = EU$	2.071	4.176	2.229
$s = 3, m = EU$	0.97	0.748	1.181
$s = 1, m = AE$	4.938	0.676	1.455
$s = 2, m = AE$	0.353	1.537	0.613
$s = 3, m = AE$	0.171	0.274	0.343
$s = 1, m = EE$	3.758	0.657	1.302
$s = 2, m = EE$	0.133	0.245	0.13
$s = 3, m = EE$	0.113	0.074	0.097

Supplier	$i = 1$ (EU)	$i = 2$ (EU)	$i = 3$ (EU)
$s = 1, m = UK$	1.052	0.198	0.383
$s = 2, m = UK$	0.422	1.521	0.565
$s = 3, m = UK$	0.08	0.093	0.121
$s = 1, m = EU$	52.973	10.37	20.789
$s = 2, m = EU$	14.946	21.899	40.948
$s = 3, m = EU$	14.946	21.899	40.948
$s = 1, m = AE$	2.887	0.643	1.122
$s = 2, m = AE$	0.946	2.84	0.916
$s = 3, m = AE$	0.299	0.3	0.446
$s = 1, m = EE$	4.086	0.712	1.478
$s = 2, m = EE$	0.406	0.697	0.358
$s = 3, m = EE$	0.245	0.075	0.162

Supplier	$i = 1$ (AE)	$i = 2$ (AE)	$i = 3$ (AE)
$s = 1, m = UK$	0.317	0.084	0.15
$s = 2, m = UK$	0.112	0.32	0.187
$s = 3, m = UK$	0.02	0.031	0.048
$s = 1, m = EU$	0.33	0.888	0.455
$s = 2, m = EU$	0.97	0.888	0.455
$s = 3, m = EU$	0.098	0.104	0.177
$s = 1, m = AE$	63.036	12.083	26.136
$s = 2, m = AE$	18.503	64.4	36.687
$s = 3, m = AE$	10.258	20.27	33.073
$s = 1, m = EE$	4.892	1.068	1.898
$s = 2, m = EE$	0.123	0.171	0.115
$s = 3, m = EE$	0.089	0.042	0.067

Supplier	$i = 1$ (EE)	$i = 2$ (EE)	$i = 3$ (EU)
$s = 1, m = UK$	0.094	0.036	0.07
$s = 2, m = UK$	0.023	0.057	0.027
$s = 3, m = UK$	0.003	0.014	0.008
$s = 1, m = EU$	0.146	0.554	0.204
$s = 2, m = EU$	0.146	0.554	0.204
$s = 3, m = EU$	0.055	0.109	0.09
$s = 1, m = AE$	3.118	1.402	1.588
$s = 2, m = AE$	0.137	0.555	0.221
$s = 3, m = AE$	0.082	0.113	0.078
$s = 1, m = EE$	72.968	25.612	49.405
$s = 2, m = EE$	11.375	45.139	19.927
$s = 3, m = EE$	10.942	25.684	27.531

Table B.7: Supply chains model: the supply chain parameters; as percent of total supplies of type $s = \{1, 2, 3\}$.

Supplier	$i = 1$ (UK)	$i = 1$ (EU)	$i = 1$ (AE)	$i = 1$ (EE)
$s = 1, m = UK$	63.306	1.725	0.451	0.122
$s = 1, m = EU$	22.478	86.844	3.153	1.369
$s = 1, m = AE$	8.073	4.733	89.454	4.037
$s = 1, m = EE$	6.144	6.699	6.942	94.472
$s = 2, m = UK$	89.183	1.802	0.59	0.198
$s = 2, m = EU$	8.764	92.427	1.728	1.252
$s = 2, m = AE$	1.492	4.039	97.039	1.171
$s = 2, m = EE$	0.562	1.732	0.644	97.379
$s = 3, m = UK$	91.749	0.511	0.193	0.028
$s = 3, m = EU$	6.38	95.998	0.937	0.492
$s = 3, m = AE$	1.125	1.918	98.018	0.741
$s = 3, m = EE$	0.746	1.573	0.852	98.739

Supplier	$i = 2$ (UK)	$i = 2$ (EU)	$i = 2$ (AE)	$i = 2$ (EE)
$s = 1, m = UK$	63.321	1.665	0.609	0.13
$s = 1, m = EU$	23.283	86.971	3.917	2.612
$s = 1, m = AE$	6.796	5.391	87.724	5.048
$s = 1, m = EE$	6.6	5.974	7.75	92.211
$s = 2, m = UK$	91.332	2.315	0.486	0.122
$s = 2, m = EU$	6.075	92.303	1.35	1.196
$s = 2, m = AE$	2.236	4.322	97.905	1.199
$s = 2, m = EE$	0.357	1.061	0.259	97.483
$s = 3, m = UK$	94.853	0.416	0.152	0.054
$s = 3, m = EU$	3.512	97.908	0.509	0.422
$s = 3, m = AE$	1.288	1.34	99.134	0.436
$s = 3, m = EE$	0.348	0.337	0.204	99.088

Supplier	$i = 3$ (UK)	$i = 3$ (EU)	$i = 3$ (AE)	$i = 3$ (EE)
$s = 1, m = UK$	67.155	1.609	0.514	0.135
$s = 1, m = EU$	20.304	87.454	3.454	1.64
$s = 1, m = AE$	6.619	4.719	89.532	3.06
$s = 1, m = EE$	5.922	6.218	6.501	95.166
$s = 2, m = UK$	91.207	1.636	0.5	0.133
$s = 2, m = EU$	6.596	94.675	1.215	1.003
$s = 2, m = AE$	1.813	2.652	97.979	1.083
$s = 2, m = EE$	0.384	1.037	0.306	97.782
$s = 3, m = UK$	96.334	0.29	0.142	0.029
$s = 3, m = EU$	2.671	98.249	0.53	0.323
$s = 3, m = AE$	0.776	1.071	99.127	0.282
$s = 3, m = EE$	0.219	0.39	0.2	99.366

Table B.8: Calibrated parameters of extension (3): banks.

Parameter		UK	EU	AE	EE	Source
<i>Heterogeneous households</i>						
Labour disutility	$\theta_{i=1}^{hs}$	0.097	0.003	0.006	0.008	Target value
Labour disutility	$\theta_{i=2}^{hs}$	0.452	0.039	0.051	0.117	Target value
Labour disutility	$\theta_{i=3}^{hs}$	0.388	0.048	0.028	0.021	Target value
Labour disutility	$\theta_{i=1}^{ls}$	0.054	0.004	0.024	0.002	Target value
Labour disutility	$\theta_{i=2}^{ls}$	0.317	0.080	0.277	0.075	Target value
Labour disutility	$\theta_{i=3}^{ls}$	0.363	0.136	0.150	0.019	Target value
Share of migrants in $i = 1$	$\gamma_{i=1}^{m,ls}$	0.512	-	-	-	Target value
Share of migrants in $i = 2$	$\gamma_{i=2}^{m,ls}$	0.238	-	-	-	Target value
Share of migrants in $i = 3$	$\gamma_{i=3}^{m,ls}$	0.250	-	-	-	Target value
<i>Banks</i>						
Survival rate	θ_b	0.968	0.972	0.969	0.965	Target value
Fraction of diverted funds	λ	0.248	0.366	0.183	0.338	Target value
Fraction of starting funds	ω	0.002	0.002	0.002	0.002	GK10; GK11

Note: Abbreviations used in the table are as follows: GK10: [Gertler and Kiyotaki \(2010\)](#); GK11: [Gertler and Karadi \(2011\)](#).

B.6 Trade relocation

Permanent NTBs and tariff shocks lead to permanent changes in bilateral trade flows. To illustrate trade relocation under new frictions (and under liberalised trade between the UK and the rest of the world - AE and EE) we recalculate input-output linkages as presented in [Table B.6](#) for pre-Brexit trade given post-Brexit level of NTBs (or liberalised trade with AE and EE).⁴⁹

The values in [Table B.9](#) are percentage differences between the pre- and post-Brexit post-output linkages in intermediate goods trade of the UK (top panel) and EU producers (bottom panel). Negative (red) values mean that the trade linkage decreased between the two sectors (and countries), while positive (green) values mean the opposite. The introduction of NTBs to trade in goods across the UK-EU border results in a decline in imports of goods from the EU by the UK producers (fourth row of the top panel) and domestic goods to a lesser extent (top row). In contrast, the reliance on domestic services grows (second and third rows). In the EU (bottom panel of [Table B.9](#)), the primary effect of NTBs to trade in goods with the UK is, unsurprisingly, a fall in imports from the UK (top row of the bottom panel in [Table B.9](#)). Similarly to the situation in the UK, EU producers also decrease their reliance on domestic (EU) goods and increase the use of domestic services. In both countries, the most affected is the

⁴⁹To calculate post-Brexit input-output trade linkages, we use the steady-state values of trade flows under post-Brexit levels of NTBs or lower tariffs on UK imports from AE and EE (and *vice versa*) and compare these values with the input-output linkages from [Table B.6](#).

Table B.9: Summary of the supply chain parameters under NTBs to trade in goods relative to benchmark model; percentage points differences.

Supplier	$i = 1$ (UK)	$i = 2$ (UK)	$i = 3$ (UK)
$s = 1, m = UK$	−0.121	−0.047	−0.084
$s = 2, m = UK$	0.104	0.052	0.049
$s = 3, m = UK$	0.069	0.017	0.068
$s = 1, m = EU$	−0.895	−0.16	−0.301
$s = 2, m = EU$	0.01	0.003	0.004
$s = 3, m = EU$	0.005	0.001	0.002
$s = 1, m = AE$	−0.015	−0.005	−0.008
$s = 2, m = AE$	0.002	0.001	0.001
$s = 3, m = AE$	0.001	0	0.001
$s = 1, m = EE$	−0.012	−0.005	−0.007
$s = 2, m = EE$	0.001	0	0
$s = 3, m = EE$	0.001	0	0

Supplier	$i = 1$ (EU)	$i = 2$ (EU)	$i = 3$ (EU)
$s = 1, m = UK$	−0.066	−0.012	−0.024
$s = 2, m = UK$	0	0	0
$s = 3, m = UK$	0	0	0
$s = 1, m = EU$	−0.013	−0.005	−0.009
$s = 2, m = EU$	0.008	0.004	0.005
$s = 3, m = EU$	0.006	0.002	0.006
$s = 1, m = AE$	−0.001	0	−0.001
$s = 2, m = AE$	0	0	0
$s = 3, m = AE$	0	0	0
$s = 1, m = EE$	−0.001	0	−0.001
$s = 2, m = EE$	0	0	0
$s = 3, m = EE$	0	0	0

goods sector (first column).

Table B.10 presents the differences between post- and pre-Brexit input-output linkages given increased NTBs to trade in services between the UK and EU. In contrast to NTBs in goods trade, NTBs in services trade lead to a decline in the reliance of both UK and EU producers on imported and domestic services. In case of the UK producers, the primary effect is the decline in imports of services from the EU. In the EU, the effect is lower imports of services from the UK. Both UK and EU producers increase their use of goods in production. Evidently, the sector where the effect of NTBs is most significant is the tradable services sector (middle column).

Finally, Table B.11 presents relocation of UK trade relative to pre-Brexit trade linkages when the UK liberalises trade with both AE and EE. Clearly, it leads to a significant increase in UK imports of goods from AE and EE (dark green cells) and a decline of the UK's reliance on local services (second and third row).

Table B.10: Summary of the supply chain parameters under NTBs to trade in services relative to benchmark model; percentage points differences.

Supplier	$i = 1$ (UK)	$i = 2$ (UK)	$i = 3$ (UK)
$s = 1, m = UK$	0.019	0.005	0.008
$s = 2, m = UK$	-0.019	-0.012	-0.016
$s = 3, m = UK$	-0.007	0.005	0.005
$s = 1, m = EU$	0.007	0.002	0.002
$s = 2, m = EU$	-0.06	-0.119	-0.064
$s = 3, m = EU$	-0.028	-0.021	-0.033
$s = 1, m = AE$	0.002	0.001	0.001
$s = 2, m = AE$	0	0	0
$s = 3, m = AE$	0	0	0
$s = 1, m = EE$	0.002	0.001	0.001
$s = 2, m = EE$	0	0	0
$s = 3, m = EE$	0	0	0

Supplier	$i = 1$ (EU)	$i = 2$ (EU)	$i = 3$ (EU)
$s = 1, m = UK$	0	0	0
$s = 2, m = UK$	-0.012	-0.043	-0.016
$s = 3, m = UK$	-0.002	-0.003	-0.003
$s = 1, m = EU$	0.004	0.003	0.002
$s = 2, m = EU$	-0.005	-0.007	-0.005
$s = 3, m = EU$	0	0.004	0.003
$s = 1, m = AE$	0	0	0
$s = 2, m = AE$	0	0	0
$s = 3, m = AE$	0	0	0
$s = 1, m = EE$	0	0	0
$s = 2, m = EE$	0	0	0
$s = 3, m = EE$	0	0	0

Table B.11: Summary of the supply chain parameters under liberalised trade relative to benchmark model; percentage points differences.

Supplier	$i = 1$ (UK)	$i = 2$ (UK)	$i = 3$ (UK)
$s = 1, m = UK$	0.046	0.017	0.032
$s = 2, m = UK$	-0.04	-0.019	-0.019
$s = 3, m = UK$	-0.026	-0.006	-0.026
$s = 1, m = EU$	0.016	0.006	0.01
$s = 2, m = EU$	-0.004	-0.001	-0.001
$s = 3, m = EU$	-0.002	0	-0.001
$s = 1, m = AE$	0.139	0.02	0.043
$s = 2, m = AE$	-0.001	0	0
$s = 3, m = AE$	0	0	0
$s = 1, m = EE$	0.208	0.037	0.074
$s = 2, m = EE$	0	0	0
$s = 3, m = EE$	0	0	0

B.7 Steady-state

This section presents the steady-state conditions for the extended model presented above as the final - third- extension of the benchmark configuration. The frictionless steady-state conditions incorporate the assumption that all prices of local goods and services are equal to unity and there is no migration across countries. To calculate the steady-state with frictions, we relax the assumption that all prices and price indices are equal to unity in the steady-state.

Therefore, in the frictionless configuration $\varepsilon^{m,ls} = 0$; $\tau_i^m = 0$, and $v_i^m = 1$. In the model with frictions both τ_i^m and v_i^m may be different from the values above. We assume the economy only temporarily departs from its steady-state under the migration shocks, because of the stochastic character of migration.

The steady-state conditions of all countries are identical. Therefore, in what follows, we present the exposition of the steady-state of a representative economy. As earlier, variables associated with the representative economy, when necessary, are denoted by the h index. Foreign countries, in turn, are denoted using the m index.

B.7.1 Households

The steady-state value of the real interest rate R is equal to the nominal interest rate $r + 1$, which in turn is given by:

$$r = \frac{1}{\beta_{hs}} - 1 \quad (\text{B.165})$$

High-skilled households

Native labour supply is calibrated to match the steady-state output of each sector and country by assuming that the total labour supply in the domestic goods sector is normalised to unity:

$$L_i^{hs,n} = \rho_i^{hs} \Omega_i \quad (\text{B.166})$$

where $\Omega_i > 0$ is the scaling scaling parameters.

Hours worked incorporate the labour supply of high-skilled migrants. Since we assume that there is no migration across countries, total hours worked are identical to native labour supply:

$$L_i^{hs} = L_i^{hs,n} \quad (\text{B.167})$$

Consumption of high-skilled households is derived by transforming the budget constraint and assuming that households do not hold debt in the steady-state (that is $B = 0$), which

results in:

$$C^{hs} = \frac{1}{(1 + \tau_c)} \left[(1 - \tau_w) \sum_{i=1}^3 W_i^{hs} L_i^{hs} + (1 - R)D + \sum_{i=1}^3 \Pi_i + TR^{hs} \right] \quad (\text{B.168})$$

where steady-state deposits D and government transfers $TR^{hs} = \lambda_{hs}$ are derived at the later stage.

The steady-state profits in sector i are defined by:

$$\Pi_i = (1 - mc_i) X_i \quad (\text{B.169})$$

where mc_i and X_i are the values subject to optimisation by firms.

The first-order conditions for the steady-state w.r.t. consumption are:

$$q^{hs} = \frac{1}{(1 + \tau_c)} C^{hs - \sigma_{hs}} \quad (\text{B.170})$$

The disutility of labour parameters ϑ_i^{hs} are calculated to match labour demands of sector i 's producers:

$$\vartheta_i^{hs} = q_i^{hs} (1 - \tau_w) W_i^{hs} L_i^{hs - \varphi_h} \quad (\text{B.171})$$

Low-skilled households

Similar to the case with high-skilled households, native labour supply of low-skilled households is calibrated to match the steady-state output of all domestic sectors:

$$L_i^{ls,n} = (1 - \rho_i^{hs}) \Omega_i \quad (\text{B.172})$$

Again, since there is no migration, total low-skilled hours are identical to the native labour supply given above. Therefore:

$$L_i^{ls} = L_i^{ls,n} \quad (\text{B.173})$$

Consumption of low-skilled households is derived by transforming the budget constraint, which results in:

$$C^{ls} = \frac{1}{(1 + \tau_c)} \left[\sum_{i=1}^3 W_i^{ls} L_i^{ls} + TR^{ls} \right] \quad (\text{B.174})$$

where transfers $TR^{ls} = (1 - \lambda_{hs})TR$ and total transfers TR are calculated as a sum of government's income from taxes and tariffs; and the share of high-skilled households λ_{hs} is defined

as:

$$\lambda_{hs} \equiv \frac{\sum_{i=1}^3 L_i^{hs}}{\sum_{i=1}^3 L_i^{hs} + \sum_{i=1}^3 L_i^{ls}} \quad (\text{B.175})$$

The first-order conditions for the steady-state w.r.t. consumption are:

$$\varrho^{ls} = \frac{1}{(1 + \tau_c)} C^{ls - \sigma_{ls}} \quad (\text{B.176})$$

The disutility of labour parameters ϑ_i^{ls} are calculated to match labour demand by sector i 's firms:

$$\vartheta_i^{ls} = \varrho_i^{ls} (1 - \tau_w) W_i^{ls} L_i^{ls - \varphi_h} \quad (\text{B.177})$$

Aggregation of labour

High-skilled and low-skilled labour supplied to sector i 's firms are aggregated into the following CES index:

$$L_i = \left[\omega_i^{hs} \left(L_i^{hs} \right)^{(1-\rho_l)} + \left(L_i^{ls} \right)^{(1-\rho_l)} \right]^{\frac{1}{(1-\rho_l)}} \quad (\text{B.178})$$

Consumption preferences

The sum of consumption of the two types of households C^{hs} and C^{ls} makes up the aggregate consumption:

$$C = \lambda_{hs} C^{hs} + (1 - \lambda_{hs}) C^{ls} \quad (\text{B.179})$$

Aggregate consumption C , in turn, is allocated into the consumption of goods $C_{i=1}$, tradable services $C_{i=2}$ and nontradable services $C_{i=3}$ in the following manner:

$$C_i = \gamma_i C \quad (\text{B.180})$$

The demand conditions of households for locally produced and imported i are given by:

$$C_i^m = \gamma_i^m \left(P_i^{h,m} \right)^{-\eta} C_i \quad (\text{B.181})$$

where $P_i^{h,m}$ represent consumer prices of locally-produced i (for $m = h$) or imported i (for $m \neq h$):

$$P_i^{h,m} = (1 + \tau_i^m) v_i^m s^m P_i^m \quad (\text{B.182})$$

and the price indices are:

$$P_i = \left[\sum_{m=1}^M \gamma_i^m \left(P_i^{h,m} \right)^{1-\eta} \right]^{\frac{1}{1-\eta}} \quad (\text{B.183})$$

Finally, the steady-state CPI is:

$$P = \prod_{i=1}^3 P_i^{\gamma_i} \quad (\text{B.184})$$

Firms

Importers

Importers set the prices of foreign goods and services. For $\tau_i^m = 0$ and $\nu_i^m = 1$, the nominal exchange rates s^m are equal to unity. Otherwise:

$$s^m \equiv \prod_{i=1}^3 \left[\frac{P_i^m}{P_i^h} \right]^{\rho_i^m} \quad (\text{B.185})$$

where ρ_i is the share of trade in i with m in total trade with m .

Financial services and production sectors

The productivity $A_i = 1$. Therefore, the steady-state level of sector i 's output is:

$$X_i = \left[\prod_{m=1}^M X_i^s \omega_i^s \right]^{\zeta_i} \left[L_i^{\alpha_i} K_i^{1-\alpha_i} \right]^{1-\zeta_i} \quad (\text{B.186})$$

The marginal cost in the sector i 's firms is:

$$mc_i = \frac{\varepsilon_i - 1}{\varepsilon_i} P_i^h \quad (\text{B.187})$$

The steady-state demand conditions for type- s supplies are:

$$X_i^s = mc_i \zeta_i \omega_i^s \frac{X_i}{P_i^s} \quad (\text{B.188})$$

where X_i^s is further divided into domestic supplies (when $m = h$) or imported supplies (when $m \neq h$):

$$X_i^{s,m} = \omega_i^{s,m} \left(P_i^{m,h} \right)^{-\eta_s} X_i^s \quad (\text{B.189})$$

and P_i^s is the sector i 's price index of type- s supplies:

$$P_i^s = \left[\sum_{m=1}^M \omega_i^{s,m} \left(P_i^{h,m} \right)^{1-\eta_s} \right]^{\frac{1}{1-\eta_s}} \quad (\text{B.190})$$

The optimal wages and capital stock are:

$$W^{hs} = mc_i(1 - \zeta_i)\alpha_i\omega_i^{hs} \frac{X_i}{L_i^{1-\rho_l} L_i^{hs\rho_l}} \quad (\text{B.191})$$

$$W^{ls} = mc_i(1 - \zeta_i)\alpha_i \frac{X_i}{L_i^{1-\rho_l} L_i^{ls\rho_l}} \quad (\text{B.192})$$

$$K_i = mc_i(1 - \zeta_i)(1 - \alpha_i) \frac{X_i}{Z_i} \quad (\text{B.193})$$

where $Z_i \equiv R_k - (1 - \delta)$ and R_k equals to the sum of the steady-state nominal interest rate r and the spread and is equal across all types of K_i .

Capital goods producers

Capital goods producers operate in a perfectly competitive market; they purchase investment goods and transform them into new capital. Capital producers also refurbish the obsolete stock of wholesale producers at the end of each period. The new and repaired capital specific to sector i is to wholesale producers at price $Q_{i,t}$, used for production in the next period.

Capital goods producers incur quadratic investment adjustment cost per unit of sector i 's defined as:

$$f\left(\frac{I_i}{I_i}\right) \equiv \Phi \left[\left(\frac{I_i}{I_i} \right) - 1 \right]^2 = 0 \quad (\text{B.194})$$

where $\Phi > 0$ is the adjustment cost parameter. In the steady-state the price of capital is:

$$Q_i = 1 \quad (\text{B.195})$$

The aggregate capital stock for the i sector is defined as follows:

$$K_i = \frac{I_i}{\delta} \quad (\text{B.196})$$

B.7.2 Banks

Total assets S are composed of loans to the three sectors as follows:

$$S = \sum_{i=1}^3 K_i \quad (\text{B.197})$$

The net worth accumulation of a representative bank is equal to the payoff from assets net of payments for liabilities:

$$N = \frac{1}{1 - \theta_b R} [(\theta_b + \kappa) R_k S - \theta_b R S] \quad (\text{B.198})$$

where θ_b is the survival rate of banks, κ denotes the fraction of assets that are provided as starting funds to the new banks, and R_i^k is the return on assets held by sector i 's producers.

Therefore, the balance sheet of the banking sector is as follows:

$$S = N + D = \phi N \quad (\text{B.199})$$

where the liabilities are composed of deposits D held by high-skilled households and the net worth N . The leverage ratio ϕ is equal to asset values over net worth:

$$\phi = \frac{S}{N} = \frac{v_d}{\lambda - \mu} \quad (\text{B.200})$$

From the first order conditions, we obtain the following expressions for assets, deposits, the excess value of assets over deposits, and the shadow value of net worth as follows:

$$v_s = \Omega R_k \quad (\text{B.201})$$

$$v_d = \Omega R \quad (\text{B.202})$$

$$\mu = \Omega (R_k - R) \quad (\text{B.203})$$

$$\Omega = (1 - \theta) + \theta (\mu \phi + v_d) \quad (\text{B.204})$$

B.7.3 Government and market clearing

A fixed share of each domestic sector i 's goods and services is assumed to be purchased by the government. Therefore:

$$G_i = \chi_i X_i \quad (\text{B.205})$$

The government's transfers TR are the sum of income from taxes and tariffs, if in place, are equal to zero in the steady-state, which results in:

$$TR = \tau_w \left(\sum_{i=1}^3 W_i^{hs} L_i^{hs} + \sum_{i=1}^3 W_i^{ls} L_i^{ls} \right) + \tau_c (C^{hs} + C^{ls}) + \tau_i^m (C_i^m + X_i^{s,m}) \quad (\text{B.206})$$

and

$$TR^{hs} = \lambda_{hs} TR \quad (\text{B.207})$$

$$TR^{ls} = (1 - \lambda_{hs}) TR \quad (\text{B.208})$$

Finally, the following market clearing conditions for sector i in the domestic economy hold in the steady-state:

$$X_i = \sum_{m=1}^M \sum_{s=1}^3 \left(X_s^{i,m} + C_i^m \right) + G_i + I_i \quad (\text{B.209})$$

which means that the total output in sector i equals the sum of demands by both sectors (domestic and foreign) which re-use sector i 's good or service produced locally as an intermediate input, the domestic and foreign households' demand, the demand by the local government, and investment expenditures.

B.8 Sector classification

Table B.12: Translation table for NACE Rev.2 classification.

Sector	NACE Rev.2 classification
Goods sector ($i = 1$)	Crop and animal production, hunting and related service activities; Forestry and logging; Fishing and aquaculture; Mining and quarrying; Manufacture of food products, beverages and tobacco products; Manufacture of textiles, wearing apparel and leather products; Manufacture of wood and of products of wood and cork, except furniture, manufacture of articles of straw and plaiting materials; Manufacture of paper and paper products; Printing and reproduction of recorded media; Manufacture of coke and refined petroleum products; Manufacture of chemicals and chemical products; Manufacture of basic pharmaceutical products and pharmaceutical preparations; Manufacture of rubber and plastic products; Manufacture of other non-metallic mineral products; Manufacture of basic metals; Manufacture of fabricated metal products, except machinery and equipment; Manufacture of computer, electronic and optical products; Manufacture of electrical equipment; Manufacture of machinery and equipment n.e.c.; Manufacture of motor vehicles, trailers and semi-trailers; Manufacture of other transport equipment; Manufacture of furniture, other manufacturing;
Tradable services sector ($i = 2$)	Financial service activities, except insurance and pension funding; Insurance, reinsurance and pension funding, except compulsory social security; Activities auxiliary to financial services and insurance activities; Wholesale and retail trade and repair of motor vehicles and motorcycles; Wholesale trade, except of motor vehicles and motorcycles; Air transport; Warehousing and support activities for transportation; Publishing activities; Motion picture, video and television programme production, sound recording and music publishing activities, programming and broadcasting activities; Telecommunications; Computer programming, consultancy and related activities, information service activities; Legal and accounting activities, activities of head offices, management consultancy activities; Architectural and engineering activities, technical testing and analysis; Scientific research and development; Advertising and market research; Other professional, scientific and technical activities, veterinary activities; Administrative and support service activities;
Nontradable services sector ($i = 3$)	Repair and installation of machinery and equipment; Electricity, gas, steam and air conditioning supply; Real estate activities; Water collection, treatment and supply; Sewerage, waste collection, treatment and disposal activities, materials recovery, remediation activities and other waste management services; Construction; Retail trade, except of motor vehicles and motorcycles; Land transport and transport via pipelines; Water transport; Public administration and defence, compulsory social security; Education; Human health and social work activities; Other service activities; Activities of households as employers, undifferentiated goods- and services-producing activities of households for own use; Activities of extraterritorial organizations and bodies.

B.9 Sensitivity analysis

Table B.13: Responses to shocks to the UK's net high-skilled migration (final model).

	Fall in net EU high-skilled migration by 124,200				Increase in net AE high-skilled migration by 124,200				Increase in net EE high-skilled migration by 124,200			
	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE
Aggregate output	-0.56	0.07	0.00	0.00	0.33	0.00	-0.04	0.00	0.33	0.00	0.00	-0.04
Output ($i = 1$)	-0.46	0.03	0.00	0.00	0.27	0.00	-0.03	0.00	0.27	0.01	0.00	-0.03
Output ($i = 2$)	-0.62	0.08	0.00	0.00	0.37	0.01	-0.05	0.00	0.37	0.01	0.00	-0.10
Output ($i = 3$)	-0.55	0.09	0.00	0.00	0.33	0.00	-0.03	0.00	0.33	0.00	0.00	-0.04
Consumption	-0.17	0.03	0.00	0.00	0.09	0.00	-0.01	0.00	0.09	0.00	0.00	-0.01
Investment	-0.61	0.08	0.00	0.00	0.32	0.01	-0.04	0.00	0.32	0.01	0.00	-0.05
Deposits	-0.32	0.04	0.00	0.00	0.18	0.00	-0.02	0.00	0.18	0.00	0.00	-0.02
Assets	-0.35	0.05	0.00	0.00	0.21	0.00	-0.03	0.00	0.21	0.00	0.00	-0.03
Hours worked	-0.75	0.05	0.00	0.00	0.46	0.00	-0.04	0.00	0.46	0.00	0.00	-0.03
CPI	0.11	-0.02	0.00	0.00	-0.07	0.00	0.01	0.00	-0.07	0.00	0.00	0.01
Consumption of UK goods and services	-0.41	-0.37	-0.40	-0.36	0.25	0.26	0.25	0.24	0.25	0.26	0.26	0.23
Consumption of EU goods and services	0.04	0.06	0.02	0.03	-0.03	0.00	0.00	-0.01	-0.03	0.00	0.00	-0.02
Consumption of AE goods and services	0.02	0.02	0.00	0.02	-0.05	-0.02	-0.03	-0.03	-0.03	0.00	0.00	-0.02
Consumption of EE goods and services	0.00	0.00	-0.02	0.00	-0.02	0.01	0.01	0.00	-0.03	0.00	0.00	-0.03
Purchases of UK supplies	-0.72	-0.35	-0.39	-0.36	0.43	0.26	0.23	0.23	0.43	0.26	0.26	0.20
Purchases of EU supplies	-0.22	0.08	0.02	0.03	0.12	0.01	-0.02	-0.01	0.13	0.01	0.00	-0.04
Purchases of AE supplies	-0.24	0.04	0.00	0.02	0.10	-0.02	-0.04	-0.03	0.12	0.01	0.00	-0.04
Purchases of EE supplies	-0.23	0.01	-0.02	0.00	0.11	0.02	0.00	0.00	0.10	0.00	0.00	-0.05

Notes: Values are defined in relation to the initial steady-state and are expressed as average percentage deviations over the decade 2021-2031; the size of the migration shock as in Table B.3; the persistence of migration from the AE and EE is 0.9323.

Table B.14: Sensitivity analysis: elasticity of substitution between domestic and foreign supplies (η_s).

	Fall in net EU low-skilled migration by 124,200				Non-tariff barriers to trade in goods				Non-tariff barriers to trade in services				Elimination of UK-AE tariffs on goods				Elimination of UK-EE tariffs on goods			
	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE
$\eta_s = 0$																				
Aggregate output	-0.18	0.03	0.00	0.00	-0.69	-0.15	0.00	-0.02	-0.18	-0.04	0.00	0.00	0.09	0.00	0.01	0.00	0.18	0.01	0.00	0.04
Output ($i = 1$)	-0.12	0.01	0.00	0.00	-1.64	-0.34	-0.01	-0.03	-0.11	-0.03	0.00	0.00	0.26	0.01	0.02	0.00	0.42	0.02	0.00	0.05
Output ($i = 2$)	-0.17	0.03	0.00	0.00	-0.50	-0.10	0.00	-0.02	-0.30	-0.08	0.00	0.00	0.05	0.00	0.01	0.00	0.13	0.00	0.00	0.03
Output ($i = 3$)	-0.20	0.04	0.00	0.00	-0.49	-0.05	0.01	-0.02	-0.14	-0.03	0.00	0.00	0.05	0.00	0.00	0.00	0.13	0.00	0.00	0.02
Consumption	-0.14	0.02	0.00	0.00	-0.69	-0.01	0.01	-0.01	-0.11	-0.02	0.00	0.00	0.05	0.00	0.00	0.00	0.19	-0.01	-0.01	0.02
Investment	-0.17	0.03	0.00	0.00	-1.44	-0.25	0.00	-0.04	-0.34	-0.08	0.00	-0.01	0.15	0.01	0.02	0.01	0.38	0.01	0.00	0.06
Deposits	-0.09	0.02	0.00	0.00	-0.56	-0.10	0.00	-0.01	-0.13	-0.03	0.00	0.00	0.06	0.00	0.01	0.00	0.15	0.00	0.00	0.02
Assets	-0.10	0.02	0.00	0.00	-0.79	-0.13	0.00	-0.02	-0.18	-0.04	0.00	0.00	0.08	0.00	0.01	0.00	0.21	0.00	0.00	0.03
Hours worked	-0.26	0.02	0.00	0.00	-0.53	-0.23	-0.01	-0.03	-0.09	-0.02	0.00	0.00	0.09	0.01	0.01	0.00	0.14	0.02	0.00	0.04
$\eta_s = 3$																				
Aggregate output	-0.28	0.04	0.00	0.00	-0.55	-0.19	0.00	-0.01	-0.25	-0.05	0.00	0.00	0.13	0.01	0.01	0.00	0.14	0.01	0.00	0.03
Output ($i = 1$)	-0.28	0.01	0.00	0.00	-2.47	-0.49	-0.02	-0.01	-0.10	-0.02	0.00	0.00	0.54	0.01	0.04	0.00	0.62	0.02	0.01	0.05
Output ($i = 2$)	-0.32	0.05	0.00	0.00	0.04	-0.09	-0.01	-0.01	-0.49	-0.10	0.00	0.00	0.04	0.00	0.01	0.00	-0.02	0.01	0.00	0.01
Output ($i = 3$)	-0.25	0.05	0.00	0.00	-0.27	-0.05	0.00	-0.01	-0.14	-0.03	0.00	0.00	0.05	0.00	0.00	0.00	0.07	0.00	0.00	0.01
Consumption	-0.13	0.02	0.00	0.00	-0.77	0.00	0.01	0.00	-0.07	-0.02	0.00	0.00	0.05	0.00	0.00	0.00	0.21	-0.01	-0.01	0.01
Investment	-0.32	0.05	0.00	0.00	-1.27	-0.33	-0.01	-0.02	-0.47	-0.09	0.00	0.00	0.24	0.01	0.03	0.00	0.32	0.01	0.00	0.06
Deposits	-0.15	0.02	0.00	0.00	-0.51	-0.14	0.00	-0.01	-0.19	-0.04	0.00	0.00	0.10	0.00	0.01	0.00	0.13	0.00	0.00	0.02
Assets	-0.18	0.03	0.00	0.00	-0.67	-0.16	0.00	-0.01	-0.24	-0.04	0.00	0.00	0.12	0.00	0.01	0.00	0.17	0.01	0.00	0.03
Hours worked	-0.38	0.02	0.00	0.00	-0.61	-0.34	-0.01	-0.02	-0.15	-0.02	0.00	0.00	0.18	0.01	0.02	0.00	0.15	0.02	0.01	0.03

Notes: Values are defined in relation to the initial steady-state and are expressed as average percentage deviations over the decade 2021-2031; sizes of the shocks as in Table B.1 and Table B.3. The values of η_s are equal across countries and sectors.

Table B.15: Responses to shocks with different consumption baskets of high-skilled and low-skilled households (final model).

	Fall in net EU low-skilled migration by 124,200				Non-tariff barriers to trade in goods				Non-tariff barriers to trade in services				Elimination of UK-AE tariffs on goods				Elimination of UK-EE tariffs on goods			
	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE
	HS: $\gamma_{i=1} \downarrow 1$ p.p.; $\gamma_{i=2} \uparrow 2$ p.p.; $\gamma_{i=3} \downarrow 1$ p.p.;								LS: $\gamma_{i=1} \uparrow 1$ p.p.; $\gamma_{i=2} \downarrow 2$ p.p.; $\gamma_{i=3} \uparrow 1$ p.p.;											
Aggregate output	-0.29	0.04	0.00	0.00	-0.69	-0.22	-0.01	-0.02	-0.28	-0.05	0.00	0.00	0.13	0.01	0.02	0.00	0.15	0.01	0.00	0.03
Output ($i = 1$)	-0.26	0.02	0.00	0.00	-2.35	-0.49	-0.02	-0.02	-0.15	-0.03	0.00	0.00	0.46	0.01	0.04	0.00	0.58	0.02	0.01	0.05
Output ($i = 2$)	-0.32	0.05	0.00	0.00	-0.27	-0.14	-0.01	-0.02	-0.51	-0.10	0.00	0.00	0.07	0.01	0.01	0.00	0.04	0.01	0.00	0.02
Output ($i = 3$)	-0.29	0.05	0.00	0.00	-0.39	-0.10	0.00	-0.01	-0.18	-0.04	0.00	0.00	0.05	0.00	0.01	0.00	0.07	0.00	0.00	0.02
Consumption	-0.12	0.02	0.00	0.00	-0.47	0.01	0.02	0.00	0.01	-0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.15	-0.01	0.00	0.01
Investment	-0.31	0.05	0.00	0.00	-1.35	-0.38	-0.02	-0.03	-0.48	-0.10	0.00	0.00	0.21	0.01	0.03	0.01	0.31	0.02	0.00	0.06
Deposits	-0.14	0.02	0.00	0.00	-0.55	-0.15	-0.01	-0.01	-0.20	-0.04	0.00	0.00	0.09	0.00	0.01	0.00	0.12	0.01	0.00	0.03
Assets	-0.19	0.03	0.00	0.00	-0.71	-0.19	-0.01	-0.01	-0.24	-0.05	0.00	0.00	0.11	0.01	0.01	0.00	0.16	0.01	0.00	0.03
Hours worked	-0.39	0.03	0.00	0.00	-0.77	-0.35	-0.02	-0.02	-0.21	-0.03	0.00	0.00	0.18	0.01	0.02	0.00	0.17	0.02	0.01	0.03
CPI	0.02	0.00	0.00	0.00	0.08	-0.01	0.00	0.00	0.01	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	-0.02	0.00	0.00	0.00
Consumption of UK goods and services	-0.28	-0.11	-0.14	-0.14	-0.27	-2.62	0.52	0.46	-0.01	-1.42	0.08	0.03	0.00	-0.04	1.13	-0.05	0.05	-0.14	-0.15	3.35
Consumption of EU goods and services	-0.15	0.05	0.00	0.00	-5.40	0.02	0.15	0.11	-0.70	-0.01	0.03	0.00	0.03	0.00	0.00	-0.01	0.19	-0.01	-0.01	0.02
Consumption of AE goods and services	-0.16	0.04	0.00	0.00	-0.79	-0.09	0.01	-0.02	-0.08	-0.04	0.00	-0.03	1.55	-0.01	0.00	-0.01	0.20	0.00	0.00	0.03
Consumption of EE goods and services	-0.16	0.04	0.00	0.00	-0.76	-0.07	0.04	0.00	-0.05	-0.02	0.03	0.00	0.03	0.00	0.01	0.00	5.02	-0.02	-0.03	0.01
Purchases of UK supplies	-0.34	-0.11	-0.14	-0.14	-0.74	-2.49	0.49	0.44	-0.30	-1.64	0.08	0.02	0.17	-0.03	1.27	-0.05	0.16	-0.13	-0.14	3.78
Purchases of EU supplies	-0.18	0.04	0.00	0.00	-5.64	-0.24	0.13	0.10	-1.36	-0.05	0.03	0.00	0.33	0.01	0.03	-0.01	0.50	0.01	-0.01	0.04
Purchases of AE supplies	-0.19	0.03	0.00	0.00	-2.05	-0.40	-0.01	-0.03	-0.32	-0.08	0.00	-0.03	2.09	0.00	0.02	-0.01	0.51	0.01	0.00	0.05
Purchases of EE supplies	-0.18	0.02	0.00	0.00	-2.39	-0.46	0.02	-0.01	-0.24	-0.04	0.03	0.00	0.40	0.01	0.04	0.00	5.31	-0.01	-0.02	0.03

Notes: Values are defined in relation to the initial steady-state and are expressed as average percentage deviations over the decade 2021-2031; sizes of the shocks as in Table B.1 and Table B.3.

Table B.16: Sensitivity analysis: Calvo parameter (θ_p).

	Fall in net EU low-skilled migration by 124,200				Non-tariff barriers to trade in goods				Non-tariff barriers to trade in services				Elimination of UK-AE tariffs on goods				Elimination of UK-EE tariffs on goods			
	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE
$\theta_p = 0$																				
Aggregate output	-0.27	0.04	0.00	0.00	-0.51	-0.16	0.00	-0.01	-0.20	-0.04	0.00	0.00	0.11	0.00	0.01	0.00	0.12	0.01	0.00	0.03
Output ($i = 1$)	-0.26	0.02	0.00	0.00	-2.11	-0.42	-0.01	-0.01	-0.09	-0.02	0.00	0.00	0.43	0.01	0.03	0.00	0.52	0.02	0.01	0.04
Output ($i = 2$)	-0.31	0.05	0.00	0.00	-0.03	-0.08	0.00	-0.01	-0.40	-0.08	0.00	0.00	0.04	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Output ($i = 3$)	-0.26	0.05	0.00	0.00	-0.26	-0.04	0.00	-0.01	-0.12	-0.03	0.00	0.00	0.04	0.00	0.00	0.00	0.06	0.00	0.00	0.01
Consumption	-0.14	0.02	0.00	0.00	-0.71	0.00	0.01	0.00	-0.08	-0.02	0.00	0.00	0.04	0.00	0.00	0.00	0.19	-0.01	-0.01	0.01
Investment	-0.31	0.05	0.00	0.00	-1.23	-0.28	-0.01	-0.02	-0.40	-0.08	0.00	0.00	0.20	0.01	0.02	0.00	0.31	0.01	0.00	0.06
Deposits	-0.13	0.02	0.00	0.00	-0.53	-0.13	0.00	-0.01	-0.17	-0.03	0.00	0.00	0.09	0.00	0.01	0.00	0.13	0.00	0.00	0.02
Assets	-0.19	0.03	0.00	0.00	-0.61	-0.14	0.00	-0.01	-0.20	-0.04	0.00	0.00	0.10	0.00	0.01	0.00	0.15	0.00	0.00	0.03
Hours worked	-0.37	0.02	0.00	0.00	-0.52	-0.29	-0.01	-0.01	-0.11	-0.02	0.00	0.00	0.15	0.01	0.02	0.00	0.12	0.02	0.01	0.03
$\theta_p = 0.9$																				
Aggregate output	-0.21	0.03	0.00	0.00	-0.82	-0.22	-0.01	-0.03	-0.27	-0.06	0.00	0.00	0.14	0.01	0.02	0.00	0.21	0.01	0.00	0.05
Output ($i = 1$)	-0.19	0.01	0.00	0.00	-2.43	-0.50	-0.02	-0.03	-0.13	-0.04	0.00	0.00	0.47	0.01	0.04	0.01	0.61	0.02	0.01	0.06
Output ($i = 2$)	-0.23	0.04	0.00	0.00	-0.37	-0.13	-0.01	-0.02	-0.50	-0.10	0.00	0.00	0.07	0.01	0.01	0.00	0.09	0.01	0.00	0.03
Output ($i = 3$)	-0.20	0.04	0.00	0.00	-0.54	-0.08	0.00	-0.02	-0.18	-0.04	0.00	0.00	0.06	0.00	0.00	0.00	0.14	0.00	0.00	0.03
Consumption	-0.12	0.02	0.00	0.00	-0.80	-0.01	0.01	-0.01	-0.10	-0.02	0.00	0.00	0.05	0.00	0.00	0.00	0.22	-0.01	-0.01	0.02
Investment	-0.23	0.03	0.00	0.00	-1.54	-0.33	-0.01	-0.03	-0.47	-0.09	0.00	0.00	0.23	0.01	0.02	0.01	0.40	0.01	0.00	0.07
Deposits	-0.12	0.02	0.00	0.00	-0.59	-0.13	0.00	-0.01	-0.18	-0.04	0.00	0.00	0.09	0.00	0.01	0.00	0.15	0.00	0.00	0.03
Assets	-0.12	0.02	0.00	0.00	-0.92	-0.18	-0.01	-0.02	-0.26	-0.05	0.00	0.00	0.13	0.00	0.01	0.00	0.24	0.01	0.00	0.04
Hours worked	-0.31	0.02	0.00	0.00	-0.76	-0.34	-0.02	-0.03	-0.16	-0.03	0.00	0.00	0.17	0.01	0.02	0.00	0.19	0.02	0.01	0.05

Notes: Values are defined in relation to the initial steady-state and are expressed as average percentage deviations over the decade 2021-2031; sizes of the shocks as in [Table B.1](#) and [Table B.3](#). The values of θ_p are equal across countries and sectors.

Table B.17: Sensitivity analysis: survival rate of banks (θ_b).

	Fall in net EU low-skilled migration by 124,200				Non-tariff barriers to trade in goods				Non-tariff barriers to trade in services				Elimination of UK-AE tariffs on goods				Elimination of UK-EE tariffs on goods			
	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE
$\theta_b = 0.75$																				
Aggregate output	-0.24	0.04	0.00	0.00	-0.55	-0.17	0.00	-0.01	-0.21	-0.04	0.00	0.00	0.11	0.00	0.01	0.00	0.13	0.01	0.00	0.03
Output ($i = 1$)	-0.23	0.01	0.00	0.00	-2.16	-0.43	-0.02	-0.01	-0.09	-0.02	0.00	0.00	0.44	0.01	0.03	0.00	0.53	0.02	0.01	0.04
Output ($i = 2$)	-0.27	0.04	0.00	0.00	-0.08	-0.08	0.00	-0.01	-0.42	-0.09	0.00	0.00	0.04	0.00	0.00	0.00	0.01	0.00	0.00	0.01
Output ($i = 3$)	-0.23	0.05	0.00	0.00	-0.30	-0.04	0.00	-0.01	-0.12	-0.03	0.00	0.00	0.04	0.00	0.00	0.00	0.07	0.00	0.00	0.01
Consumption	-0.13	0.02	0.00	0.00	-0.72	0.00	0.01	0.00	-0.08	-0.02	0.00	0.00	0.04	0.00	0.00	0.00	0.20	-0.01	-0.01	0.01
Investment	-0.26	0.04	0.00	0.00	-1.19	-0.28	-0.01	-0.02	-0.39	-0.08	0.00	0.00	0.20	0.01	0.02	0.00	0.30	0.01	0.00	0.06
Deposits	-0.14	0.02	0.00	0.00	-0.52	-0.12	0.00	-0.01	-0.17	-0.03	0.00	0.00	0.09	0.00	0.01	0.00	0.13	0.00	0.00	0.02
Assets	-0.14	0.02	0.00	0.00	-0.56	-0.12	0.00	-0.01	-0.18	-0.03	0.00	0.00	0.09	0.00	0.01	0.00	0.14	0.00	0.00	0.02
Hours worked	-0.34	0.02	0.00	0.00	-0.57	-0.29	-0.01	-0.01	-0.12	-0.02	0.00	0.00	0.15	0.01	0.02	0.00	0.13	0.02	0.01	0.03
$\theta_b = 0.975$																				
Aggregate output	-0.25	0.04	0.00	0.00	-0.61	-0.18	0.00	-0.01	-0.23	-0.05	0.00	0.00	0.12	0.01	0.01	0.00	0.15	0.01	0.00	0.03
Output ($i = 1$)	-0.23	0.01	0.00	0.00	-2.22	-0.44	-0.02	-0.02	-0.10	-0.03	0.00	0.00	0.45	0.01	0.03	0.00	0.55	0.02	0.01	0.05
Output ($i = 2$)	-0.28	0.04	0.00	0.00	-0.14	-0.09	0.00	-0.01	-0.43	-0.09	0.00	0.00	0.05	0.00	0.01	0.00	0.03	0.01	0.00	0.02
Output ($i = 3$)	-0.23	0.05	0.00	0.00	-0.36	-0.05	0.00	-0.01	-0.14	-0.03	0.00	0.00	0.05	0.00	0.00	0.00	0.09	0.00	0.00	0.02
Consumption	-0.14	0.02	0.00	0.00	-0.74	0.00	0.01	0.00	-0.08	-0.02	0.00	0.00	0.04	0.00	0.00	0.00	0.20	-0.01	-0.01	0.01
Investment	-0.26	0.04	0.00	0.00	-1.35	-0.30	-0.01	-0.02	-0.42	-0.08	0.00	0.00	0.21	0.01	0.02	0.00	0.34	0.01	0.00	0.06
Deposits	-0.12	0.02	0.00	0.00	-0.53	-0.13	0.00	-0.01	-0.17	-0.03	0.00	0.00	0.09	0.00	0.01	0.00	0.13	0.00	0.00	0.02
Assets	-0.15	0.02	0.00	0.00	-0.72	-0.15	0.00	-0.01	-0.22	-0.04	0.00	0.00	0.11	0.00	0.01	0.00	0.18	0.00	0.00	0.03
Hours worked	-0.34	0.02	0.00	0.00	-0.60	-0.30	-0.01	-0.02	-0.13	-0.02	0.00	0.00	0.15	0.01	0.02	0.00	0.14	0.02	0.01	0.03

Notes: Values are defined in relation to the initial steady-state and are expressed as average percentage deviations over the decade 2021-2031; sizes of the shocks as in [Table B.1](#) and [Table B.3](#). The values of θ_b are equal across countries.

Table B.18: Sensitivity analysis: Taylor rule parameter (φ_π).

	Fall in net EU low-skilled migration by 124,200				Non-tariff barriers to trade in goods				Non-tariff barriers to trade in services				Elimination of UK-AE tariffs on goods				Elimination of UK-EE tariffs on goods			
	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE
$\varphi_\pi = 0.5$																				
Aggregate output	-0.25	0.04	0.00	0.00	-0.62	-0.18	0.00	-0.01	-0.23	-0.05	0.00	0.00	0.12	0.00	0.01	0.00	0.15	0.01	0.00	0.03
Output ($i = 1$)	-0.23	0.01	0.00	0.00	-2.25	-0.44	-0.02	-0.02	-0.11	-0.03	0.00	0.00	0.45	0.01	0.04	0.00	0.56	0.02	0.01	0.05
Output ($i = 2$)	-0.28	0.04	0.00	0.00	-0.20	-0.09	0.00	-0.01	-0.44	-0.09	0.00	0.00	0.05	0.00	0.01	0.00	0.05	0.00	0.00	0.02
Output ($i = 3$)	-0.23	0.04	0.00	0.00	-0.33	-0.06	0.00	-0.01	-0.14	-0.03	0.00	0.00	0.05	0.00	0.00	0.00	0.08	0.00	0.00	0.02
Consumption	-0.13	0.02	0.00	0.00	-0.55	-0.01	0.01	0.00	-0.07	-0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.14	0.00	0.00	0.01
Investment	-0.26	0.04	0.00	0.00	-1.27	-0.30	-0.01	-0.02	-0.42	-0.08	0.00	0.00	0.21	0.01	0.02	0.00	0.32	0.01	0.00	0.06
Deposits	-0.13	0.02	0.00	0.00	-0.52	-0.13	0.00	-0.01	-0.17	-0.03	0.00	0.00	0.09	0.00	0.01	0.00	0.13	0.00	0.00	0.03
Assets	-0.15	0.02	0.00	0.00	-0.67	-0.15	0.00	-0.01	-0.22	-0.04	0.00	0.00	0.11	0.00	0.01	0.00	0.17	0.01	0.00	0.03
Hours worked	-0.35	0.02	0.00	0.00	-0.67	-0.30	-0.01	-0.01	-0.14	-0.02	0.00	0.00	0.16	0.01	0.02	0.00	0.17	0.01	0.00	0.04
$\varphi_\pi = 3$																				
Aggregate output	-0.25	0.04	0.00	0.00	-0.59	-0.18	0.00	-0.01	-0.22	-0.05	0.00	0.00	0.12	0.01	0.01	0.00	0.14	0.01	0.00	0.03
Output ($i = 1$)	-0.23	0.01	0.00	0.00	-2.18	-0.44	-0.02	-0.02	-0.10	-0.03	0.00	0.00	0.44	0.01	0.03	0.00	0.54	0.02	0.01	0.05
Output ($i = 2$)	-0.28	0.04	0.00	0.00	-0.08	-0.09	0.00	-0.01	-0.42	-0.09	0.00	0.00	0.04	0.00	0.01	0.00	0.01	0.01	0.00	0.02
Output ($i = 3$)	-0.24	0.05	0.00	0.00	-0.37	-0.05	0.00	-0.01	-0.14	-0.03	0.00	0.00	0.05	0.00	0.00	0.00	0.09	0.00	0.00	0.02
Consumption	-0.16	0.03	0.00	0.00	-0.91	0.01	0.01	0.00	-0.10	-0.02	0.00	0.00	0.06	0.00	0.00	0.00	0.26	-0.01	-0.01	0.01
Investment	-0.30	0.05	0.00	0.00	-1.40	-0.30	-0.01	-0.02	-0.43	-0.08	0.00	0.00	0.21	0.01	0.02	0.00	0.36	0.01	0.00	0.06
Deposits	-0.14	0.02	0.00	0.00	-0.55	-0.12	0.00	-0.01	-0.17	-0.03	0.00	0.00	0.09	0.00	0.01	0.00	0.14	0.00	0.00	0.02
Assets	-0.17	0.03	0.00	0.00	-0.76	-0.15	0.00	-0.01	-0.22	-0.04	0.00	0.00	0.11	0.00	0.01	0.00	0.20	0.00	0.00	0.03
Hours worked	-0.34	0.02	0.00	0.00	-0.53	-0.31	-0.02	-0.02	-0.12	-0.02	0.00	0.00	0.15	0.01	0.02	0.00	0.12	0.02	0.01	0.03

Notes: Values are defined in relation to the initial steady-state and are expressed as average percentage deviations over the decade 2021-2031; sizes of the shocks as in [Table B.1](#) and [Table B.3](#). The values of φ_π are equal across countries.

Table B.19: Sensitivity analysis: persistence of nominal interest rate (ρ_r).

	Fall in net EU low-skilled migration by 124,200				Non-tariff barriers to trade in goods				Non-tariff barriers to trade in services				Elimination of UK-AE tariffs on goods				Elimination of UK-EE tariffs on goods			
	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE
$\rho_r = 0$																				
Aggregate output	-0.25	0.04	0.00	0.00	-0.61	-0.18	0.00	-0.01	-0.23	-0.05	0.00	0.00	0.12	0.01	0.01	0.00	0.15	0.01	0.00	0.03
Output ($i = 1$)	-0.23	0.01	0.00	0.00	-2.22	-0.44	-0.02	-0.02	-0.10	-0.03	0.00	0.00	0.45	0.01	0.03	0.00	0.55	0.02	0.01	0.04
Output ($i = 2$)	-0.28	0.04	0.00	0.00	-0.14	-0.09	0.00	-0.01	-0.43	-0.09	0.00	0.00	0.05	0.00	0.01	0.00	0.03	0.01	0.00	0.01
Output ($i = 3$)	-0.23	0.05	0.00	0.00	-0.36	-0.05	0.00	-0.01	-0.14	-0.03	0.00	0.00	0.05	0.00	0.00	0.00	0.09	0.00	0.00	0.02
Consumption	-0.13	0.02	0.00	0.00	-0.74	0.00	0.01	0.00	-0.09	-0.02	0.00	0.00	0.05	0.00	0.00	0.00	0.20	-0.01	-0.01	0.01
Investment	-0.27	0.04	0.00	0.00	-1.36	-0.30	-0.01	-0.02	-0.43	-0.08	0.00	0.00	0.21	0.01	0.02	0.00	0.35	0.01	0.00	0.06
Deposits	-0.13	0.02	0.00	0.00	-0.54	-0.13	0.00	-0.01	-0.17	-0.03	0.00	0.00	0.09	0.00	0.01	0.00	0.14	0.00	0.00	0.02
Assets	-0.16	0.02	0.00	0.00	-0.73	-0.15	0.00	-0.01	-0.22	-0.04	0.00	0.00	0.11	0.00	0.01	0.00	0.19	0.00	0.00	0.03
Hours worked	-0.35	0.02	0.00	0.00	-0.60	-0.30	-0.01	-0.02	-0.13	-0.02	0.00	0.00	0.15	0.01	0.02	0.00	0.14	0.02	0.01	0.03
$\rho_r = 0.99$																				
Aggregate output	-0.25	0.03	0.00	0.00	-0.61	-0.18	0.00	-0.01	-0.23	-0.05	0.00	0.00	0.12	0.01	0.01	0.00	0.15	0.01	0.00	0.03
Output ($i = 1$)	-0.23	0.01	0.00	0.00	-2.23	-0.44	-0.02	-0.02	-0.10	-0.03	0.00	0.00	0.45	0.01	0.04	0.00	0.55	0.02	0.01	0.05
Output ($i = 2$)	-0.28	0.04	0.00	0.00	-0.16	-0.09	0.00	-0.01	-0.43	-0.09	0.00	0.00	0.05	0.00	0.01	0.00	0.03	0.01	0.00	0.02
Output ($i = 3$)	-0.23	0.04	0.00	0.00	-0.34	-0.05	0.00	-0.01	-0.14	-0.03	0.00	0.00	0.05	0.00	0.00	0.00	0.09	0.00	0.00	0.02
Consumption	-0.14	0.02	0.00	0.00	-0.66	0.00	0.01	0.00	-0.08	-0.02	0.00	0.00	0.04	0.00	0.00	0.00	0.18	-0.01	-0.01	0.01
Investment	-0.26	0.04	0.00	0.00	-1.31	-0.30	-0.01	-0.02	-0.42	-0.08	0.00	0.00	0.21	0.01	0.02	0.00	0.33	0.01	0.00	0.06
Deposits	-0.13	0.02	0.00	0.00	-0.52	-0.13	0.00	-0.01	-0.17	-0.03	0.00	0.00	0.09	0.00	0.01	0.00	0.13	0.00	0.00	0.02
Assets	-0.15	0.02	0.00	0.00	-0.70	-0.15	0.00	-0.01	-0.22	-0.04	0.00	0.00	0.11	0.00	0.01	0.00	0.18	0.01	0.00	0.03
Hours worked	-0.34	0.02	0.00	0.00	-0.63	-0.30	-0.01	-0.02	-0.13	-0.02	0.00	0.00	0.16	0.01	0.02	0.00	0.15	0.02	0.01	0.03

Notes: Values are defined in relation to the initial steady-state and are expressed as average percentage deviations over the decade 2021-2031; sizes of the shocks as in Table B.1 and Table B.3. The values of ρ_r are equal across countries.

Table B.20: Sensitivity analysis: investment adjustment cost (Φ).

	Fall in net EU low-skilled migration by 124,200				Non-tariff barriers to trade in goods				Non-tariff barriers to trade in services				Elimination of UK-AE tariffs on goods				Elimination of UK-EE tariffs on goods			
	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE
$\Phi = 1$																				
Aggregate output	-0.27	0.04	0.00	0.00	-0.70	-0.20	-0.01	-0.02	-0.25	-0.05	0.00	0.00	0.13	0.01	0.01	0.00	0.17	0.01	0.00	0.04
Output ($i = 1$)	-0.25	0.02	0.00	0.00	-2.41	-0.48	-0.02	-0.02	-0.12	-0.03	0.00	0.00	0.48	0.01	0.04	0.00	0.60	0.02	0.01	0.05
Output ($i = 2$)	-0.30	0.05	0.00	0.00	-0.20	-0.11	-0.01	-0.01	-0.48	-0.10	0.00	0.00	0.06	0.00	0.01	0.00	0.04	0.01	0.00	0.02
Output ($i = 3$)	-0.25	0.05	0.00	0.00	-0.43	-0.06	0.00	-0.01	-0.16	-0.04	0.00	0.00	0.06	0.00	0.00	0.00	0.11	0.00	0.00	0.02
Consumption	-0.14	0.02	0.00	0.00	-0.76	-0.01	0.01	0.00	-0.09	-0.02	0.00	0.00	0.05	0.00	0.00	0.00	0.21	-0.01	-0.01	0.02
Investment	-0.31	0.05	0.00	0.00	-1.50	-0.33	-0.01	-0.03	-0.47	-0.09	0.00	0.00	0.23	0.01	0.02	0.00	0.38	0.01	0.00	0.07
Deposits	-0.16	0.03	0.00	0.00	-0.65	-0.15	0.00	-0.01	-0.21	-0.04	0.00	0.00	0.10	0.00	0.01	0.00	0.17	0.00	0.00	0.03
Assets	-0.18	0.03	0.00	0.00	-0.82	-0.17	0.00	-0.01	-0.25	-0.05	0.00	0.00	0.12	0.00	0.01	0.00	0.21	0.01	0.00	0.03
Hours worked	-0.36	0.02	0.00	0.00	-0.67	-0.32	-0.02	-0.02	-0.14	-0.02	0.00	0.00	0.16	0.01	0.02	0.00	0.16	0.02	0.01	0.04
$\Phi = 12$																				
Aggregate output	-0.24	0.03	0.00	0.00	-0.57	-0.17	0.00	-0.01	-0.21	-0.04	0.00	0.00	0.11	0.00	0.01	0.00	0.14	0.01	0.00	0.03
Output ($i = 1$)	-0.22	0.01	0.00	0.00	-2.11	-0.42	-0.01	-0.01	-0.09	-0.02	0.00	0.00	0.43	0.01	0.03	0.00	0.52	0.02	0.01	0.04
Output ($i = 2$)	-0.27	0.04	0.00	0.00	-0.11	-0.08	0.00	-0.01	-0.41	-0.08	0.00	0.00	0.04	0.00	0.01	0.00	0.02	0.00	0.00	0.01
Output ($i = 3$)	-0.22	0.04	0.00	0.00	-0.32	-0.05	0.00	-0.01	-0.13	-0.03	0.00	0.00	0.04	0.00	0.00	0.00	0.08	0.00	0.00	0.01
Consumption	-0.13	0.02	0.00	0.00	-0.73	0.00	0.01	0.00	-0.08	-0.02	0.00	0.00	0.04	0.00	0.00	0.00	0.20	-0.01	-0.01	0.01
Investment	-0.24	0.04	0.00	0.00	-1.24	-0.28	-0.01	-0.02	-0.39	-0.08	0.00	0.00	0.19	0.01	0.02	0.00	0.32	0.01	0.00	0.05
Deposits	-0.12	0.02	0.00	0.00	-0.48	-0.11	0.00	-0.01	-0.16	-0.03	0.00	0.00	0.08	0.00	0.01	0.00	0.12	0.00	0.00	0.02
Assets	-0.15	0.02	0.00	0.00	-0.69	-0.14	0.00	-0.01	-0.21	-0.04	0.00	0.00	0.10	0.00	0.01	0.00	0.18	0.00	0.00	0.03
Hours worked	-0.34	0.02	0.00	0.00	-0.56	-0.29	-0.01	-0.02	-0.12	-0.02	0.00	0.00	0.15	0.01	0.02	0.00	0.13	0.02	0.01	0.03

Notes: Values are defined in relation to the initial steady-state and are expressed as average percentage deviations over the decade 2021-2031; sizes of the shocks as in Table B.1 and Table B.3. The values of Φ are equal across countries and sectors.

Table B.21: Sensitivity analysis: share of low-skilled workers ($1-\rho_i^{hs}$).

	Fall in net EU low-skilled migration by 124,200				Non-tariff barriers to trade in goods				Non-tariff barriers to trade in services				Elimination of UK-AE tariffs on goods				Elimination of UK-EE tariffs on goods			
	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE	UK	EU	AE	EE
	$(1 - \rho_i^{hs}) \downarrow 10 \text{ p.p.}$																			
Aggregate output	-0.24	0.04	0.00	0.00	-0.59	-0.17	0.00	-0.01	-0.21	-0.04	0.00	0.00	0.11	0.00	0.01	0.00	0.15	0.01	0.00	0.03
Output ($i = 1$)	-0.23	0.01	0.00	0.00	-2.17	-0.42	-0.01	-0.01	-0.09	-0.02	0.00	0.00	0.44	0.01	0.03	0.00	0.54	0.02	0.01	0.04
Output ($i = 2$)	-0.28	0.04	0.00	0.00	-0.12	-0.08	0.00	-0.01	-0.42	-0.09	0.00	0.00	0.04	0.00	0.01	0.00	0.03	0.00	0.00	0.01
Output ($i = 3$)	-0.22	0.05	0.00	0.00	-0.34	-0.05	0.00	-0.01	-0.12	-0.03	0.00	0.00	0.04	0.00	0.00	0.00	0.09	0.00	0.00	0.01
Consumption	-0.12	0.02	0.00	0.00	-0.73	0.00	0.01	0.00	-0.08	-0.02	0.00	0.00	0.04	0.00	0.00	0.00	0.21	-0.01	-0.01	0.01
Investment	-0.26	0.04	0.00	0.00	-1.32	-0.28	0.00	-0.02	-0.40	-0.08	0.00	0.00	0.21	0.01	0.02	0.00	0.34	0.01	0.00	0.06
Deposits	-0.13	0.02	0.00	0.00	-0.53	-0.12	0.00	-0.01	-0.16	-0.03	0.00	0.00	0.09	0.00	0.01	0.00	0.14	0.00	0.00	0.02
Assets	-0.15	0.02	0.00	0.00	-0.71	-0.14	0.00	-0.01	-0.21	-0.04	0.00	0.00	0.11	0.00	0.01	0.00	0.18	0.00	0.00	0.03
Hours worked	-0.35	0.02	0.00	0.00	-0.57	-0.29	-0.01	-0.01	-0.12	-0.02	0.00	0.00	0.15	0.01	0.02	0.00	0.14	0.02	0.00	0.03
	$(1 - \rho_i^{hs}) \uparrow 10 \text{ p.p.}$																			
Aggregate output	-0.26	0.04	0.00	0.00	-0.64	-0.19	-0.01	-0.02	-0.24	-0.05	0.00	0.00	0.12	0.01	0.01	0.00	0.15	0.01	0.00	0.03
Output ($i = 1$)	-0.24	0.01	0.00	0.00	-2.26	-0.46	-0.02	-0.02	-0.11	-0.03	0.00	0.00	0.45	0.01	0.04	0.00	0.57	0.02	0.01	0.05
Output ($i = 2$)	-0.29	0.04	0.00	0.00	-0.16	-0.11	-0.01	-0.01	-0.45	-0.09	0.00	0.00	0.05	0.00	0.01	0.00	0.03	0.01	0.00	0.02
Output ($i = 3$)	-0.25	0.05	0.00	0.00	-0.38	-0.07	0.00	-0.01	-0.16	-0.03	0.00	0.00	0.05	0.00	0.00	0.00	0.09	0.00	0.00	0.02
Consumption	-0.16	0.03	0.00	0.00	-0.76	-0.01	0.01	-0.01	-0.10	-0.02	0.00	0.00	0.05	0.00	0.00	0.00	0.20	-0.01	-0.01	0.02
Investment	-0.29	0.04	0.00	0.00	-1.39	-0.32	-0.01	-0.03	-0.45	-0.09	0.00	0.00	0.22	0.01	0.02	0.00	0.35	0.01	0.00	0.06
Deposits	-0.13	0.02	0.00	0.00	-0.55	-0.13	0.00	-0.01	-0.18	-0.04	0.00	0.00	0.09	0.00	0.01	0.00	0.14	0.00	0.00	0.03
Assets	-0.17	0.02	0.00	0.00	-0.74	-0.16	0.00	-0.01	-0.23	-0.05	0.00	0.00	0.11	0.00	0.01	0.00	0.19	0.01	0.00	0.03
Hours worked	-0.35	0.02	0.00	0.00	-0.63	-0.32	-0.02	-0.02	-0.14	-0.02	0.00	0.00	0.16	0.01	0.02	0.00	0.15	0.02	0.01	0.03

Notes: Values are defined in relation to the initial steady-state and are expressed as average percentage deviations over the decade 2021-2031; sizes of the shocks as in Table B.1 and Table B.3. The values of $(1 - \rho_i^{hs})$ are lower (higher) by 10 p.p. in each country and sector. Changes in the values of $(1 - \rho_i^{hs})$ translate proportionately into the changes of the share of hand-to-mouth households $(1 - \lambda_{hs})$ in each country.

Appendix C

The derivations presented in [Appendix C.1-Appendix C.3](#) correspond to the model versions outlined in their more condensed forms in [Chapter 1.2](#) of this thesis. In each model version I consider a world consisting of M countries. In each country there are households, competitive retailers, monopolistically competitive intermediate goods producers, and a government pursuing monetary and fiscal policies. Variables associated with the domestic economy, where necessary, are represented using the index n . Variables associated with a representative foreign economy are denoted with the index m .

The optimization problems included in [Appendix C.1](#) correspond to the two-country model with financial frictions as in [Karadi and Nakov \(2021\)](#) but no supply chains or financial linkages; [Appendix C.2](#) presents the optimization problems associated with the model with supply chains; [Appendix C.3](#) introduces derivations given the two-country version of the model with financial linkages in the form of a share of domestic capital backed by foreign loans. Provided that the derivations in each model extension are unchanged relative to the closed-economy specification or any previous extension, they are not repeated in each section of this appendix take their previous form.

Additionally, [Appendix C.4](#) displays the responses to shocks under alternative values of a number of parameters: the investment adjustment cost (η_i); the survival rate of banks (σ); the proportional advantage in absconding rate (Γ); the fraction of divertable funds (θ); and the elasticity of substitution between local and export capital (η_k).

C.1 Optimization problems of the two-country model with financial frictions

C.1.1 The households' problem

Households maximize their lifetime utility over consumption C_t , hours worked H_t , short-term assets D_t , and long-term bonds $B_{h,t}$ to maximize their discounted lifetime utility:

$$\max_{C_t, H_t, B_t, K_t} \mathbb{E}_t \sum_{k=0}^{\infty} \beta^k U_{t+k} \quad (\text{C.1})$$

subject to the budget constraint of the form:

$$C_t + D_t + B_{h,t} = W_t H_t + R_{b,t} B_{h,t-1} - \frac{1}{2} \kappa (B_{h,t} - \bar{B}_h)^2 + R_t D_{t-1} + \Pi_t \quad (\text{C.2})$$

A Lagrangian associated with the households' lifetime utility maximization problem is:

$$\begin{aligned} \mathcal{L}(C_t, H_t, D_t, B_{h,t}) = & \mathbb{E}_t \sum_{t=1}^{\infty} \beta^{t+k} \left[\frac{(C_{t+k} - h\bar{C}_{t+k-1})^{1-\sigma_c}}{1-\sigma_c} - \vartheta \frac{H_{t+k}^{1+\varphi_h}}{1+\varphi_h} \right] \\ & - \mathbb{E}_t \sum_{t=1}^{\infty} \beta^t q_t \left[C_{t+k} + D_{t+k} + B_{h,t+k} - W_{t+k} H_{t+k} - R_{b,t+k} B_{h,t+k-1} \right. \\ & \left. + \frac{1}{2} \kappa (B_{h,t+k} - \bar{B}_h)^2 - R_{t+k} D_{t+k-1} - \Pi_{t+k} \right] \end{aligned} \quad (\text{C.3})$$

FOCs:

$$\frac{\partial \mathcal{L}(C_t, H_t, D_t, B_{h,t})}{\partial C_t} = \beta^t (C_t - hC_{t-1})^{-\sigma_c} - \beta^{t+1} h (C_{t+1} - hC_t)^{-\sigma_c} - \beta^t q_t = 0 \quad (\text{C.4})$$

$$\frac{\partial \mathcal{L}(C_t, H_t, D_t, B_{h,t})}{\partial H_t} = -\beta^t \chi H_t^\varphi + \mu_t \beta^t W_t = 0 \quad (\text{C.5})$$

$$\frac{\partial \mathcal{L}(C_t, H_t, D_t, B_{h,t})}{\partial D_t} = -q_t \beta^t + \mu_{t+1} \beta^{t+1} R_{t+1} = 0 \quad (\text{C.6})$$

$$\frac{\partial \mathcal{L}(C_t, H_t, D_t, B_{h,t})}{\partial B_{h,t}} = -q_t \beta^t + q_{t+1} \beta^{t+1} R_{b,t+1} - q_t \beta^t \kappa (B_{h,t} - \bar{B}_h) = 0 \quad (\text{C.7})$$

From equation (C.4):

$$q_t = (C_t - hC_{t-1})^{-\sigma_c} - \beta h \mathbb{E}_t (C_{t+1} - hC_t)^{-\sigma_c} \quad (\text{C.8})$$

From equation (C.5):

$$\chi H_t^\varphi = q_t W_t \quad (\text{C.9})$$

From equation (C.6):

$$q_t \beta^t = q_{t+1} \beta^{t+1} R_{t+1} = 0 \quad (\text{C.10})$$

$$\frac{q_t}{q_{t+1}} = \beta R_{t+1} \quad (\text{C.11})$$

$$1 = \beta \frac{q_{t+1}}{q_t} R_{t+1} \quad (\text{C.12})$$

From equation (C.7):

$$1 = \beta \frac{q_{t+1}}{q_t} R_{b,t+1} - \kappa (B_{h,t} - \bar{B}_h) \quad (\text{C.13})$$

Using equation (C.12):

$$\beta \frac{q_{t+1}}{q_t} R_{t+1} = \beta \frac{q_{t+1}}{q_t} R_{b,t+1} - \kappa (B_{h,t} - \bar{B}_h) \quad (\text{C.14})$$

$$B_{h,t} = \bar{B}_h + \frac{\mathbb{E}_t \beta \frac{q_{t+1}}{q_t} (R_{b,t+1} - R_{t+1})}{\kappa} \quad (\text{C.15})$$

The aggregate consumption of households C_t consists of consumption of domestic and imported goods aggregated in the following manner:

$$C_t = \left[\sum_{m=1}^M \gamma_m^{\frac{1}{\varepsilon_c}} (C_{m,t})^{\frac{\varepsilon_c-1}{\varepsilon_c}} \right]^{\frac{\varepsilon_c}{\varepsilon_c-1}} \quad (\text{C.16})$$

Households optimize their consumption basket of domestic and imported goods subject to the following aggregate expenditure on consumer goods:

$$P_t C_t = P_{n,t} C_{n,t} + \sum_{\substack{m=1 \\ m \neq n}}^M (1 + \varepsilon_{\tau,t}) s_t^{nm} P_{m,t} C_{m,t} \quad (\text{C.17})$$

where P_t is the consumer price index composed of the prices of goods consumed by the local households and weighted by their corresponding shares in the aggregate consumption basket:

$$P_t = \left[\sum_{m=1}^M \gamma_m (P_{m,t})^{1-\varepsilon_c} \right]^{\frac{1}{1-\varepsilon_c}} \quad (\text{C.18})$$

The Lagrangian associated with household's optimization of expenditures on domestically-

produced versus imported goods is given by:

$$\mathcal{L}(C_{n,t}, C_{m,t}) = \left[\sum_{m=1}^M \gamma_m^{\frac{1}{\varepsilon_c}} (C_{m,t})^{\frac{\varepsilon_c-1}{\varepsilon_c}} \right]^{\frac{\varepsilon_c}{\varepsilon_c-1}} - q_t^c \left[P_{n,t} C_{n,t} + \sum_{\substack{m=1 \\ m \neq n}}^M (1 + \varepsilon_{\tau,t}) s_t^{nm} P_{m,t} C_{m,t} - P_t C_t \right] \quad (\text{C.19})$$

The first-order conditions of the optimization problem w.r.t. $C_{n,t}$ and $C_{m,t}$ (for $m \neq n$) are as follows:

$$\frac{\partial \mathcal{L}(C_{n,t}, C_{m,t})}{\partial C_{n,t}} = \gamma_n^{\frac{1}{\varepsilon_c}} (C_{n,t})^{-\frac{1}{\varepsilon_c}} \left[\sum_{m=1}^M \gamma_m^{\frac{1}{\varepsilon_c}} (C_{m,t})^{\frac{\varepsilon_c-1}{\varepsilon_c}} \right]^{\frac{1}{\varepsilon_c-1}} - q_t^c P_{n,t} = 0 \quad (\text{C.20})$$

$$\frac{\partial \mathcal{L}(C_{n,t}, C_{m,t})}{\partial C_{m,t}} = \gamma_m^{\frac{1}{\varepsilon_c}} (C_{m,t})^{-\frac{1}{\varepsilon_c}} \left[\sum_{m=1}^M \gamma_m^{\frac{1}{\varepsilon_c}} (C_{m,t})^{\frac{\varepsilon_c-1}{\varepsilon_c}} \right]^{\frac{1}{\varepsilon_c-1}} - q_t^c (1 + \varepsilon_{\tau,t}) s_t^{nm} P_{m,t} = 0 \quad (\text{C.21})$$

Combining and simplifying the first-order conditions - (C.20) and (C.21) - yields:

$$C_{m,t} = \frac{\gamma_m}{\gamma_n} \left[\frac{(1 + \varepsilon_{\tau,t}) s_t^{nm} P_{m,t}}{P_{n,t}} \right]^{-\varepsilon_c} C_{n,t} \quad (\text{C.22})$$

I substitute (C.22) into (C.18), which results in:

$$P_t C_t = P_{n,t} C_{n,t} + \sum_{\substack{m=1 \\ m \neq n}}^M (1 + \varepsilon_{\tau,t}) s_t^{nm} P_{m,t} \frac{\gamma_m}{\gamma_n} \left[\frac{(1 + \varepsilon_{\tau,t}) s_t^{nm} P_{m,t}}{P_{n,t}} \right]^{-\varepsilon_c} C_{n,t} \quad (\text{C.23})$$

Assuming the definition of the price index given by equation (C.18), equation (C.23) simplifies into the following optimal allocation of the households' budget to locally produced goods:

$$C_{n,t} = \gamma_n \left[\frac{P_{n,t}}{P_t} \right]^{-\varepsilon_c} C_t \quad (\text{C.24})$$

Equation (C.24) is substituted back into (C.22) to obtain the optimal demand conditions for imported goods:

$$C_{m,t} = \frac{\gamma_m}{\gamma_n} \left[\frac{(1 + \varepsilon_{\tau,t}) s_t^{nm} P_{m,t}}{P_{n,t}} \right]^{-\varepsilon_c} \gamma_n \left[\frac{P_{n,t}}{P_t} \right]^{-\varepsilon_c} C_t \quad (\text{C.25})$$

Simplifying further yields the following optimal demand condition for imported consumer goods:

$$C_{m,t} = \gamma_m \left[\frac{(1 + \varepsilon_{\tau,t}) s_t^{nm} P_{m,t}}{P_t} \right]^{-\varepsilon_c} C_t \quad (\text{C.26})$$

C.1.2 The firms' problem

Retailers

Competitive retailers purchase differentiated goods from intermediate goods producers and combine them into a homogeneous final good. Aggregate output of retailers XR_t is given by the following CES aggregate of a continuum differentiated intermediate goods:

$$XR_t = \left[\int_0^1 XR_t(v)^{\frac{\mu-1}{\mu}} dv \right]^{\frac{\mu}{\mu-1}} \quad (\text{C.27})$$

The profit maximization problem of the representative retailer v is given by the difference between the revenues from the sales of the final good and the expenditures on intermediate goods:

$$\max_{XR_t(v)} \left[P_t XR_t - \int_0^1 P_t(v) XR_t(v) dv \right] \quad (\text{C.28})$$

which given the definition of the final good from (C.27) yields:

$$\max_{XR_t(v)} \left[P_t \left[\int_0^1 XR_t(v)^{\frac{\mu-1}{\mu}} dv \right]^{\frac{\mu}{\mu-1}} - \int_0^1 P_t(v) XR_t(v) dv \right] \quad (\text{C.29})$$

The first-order condition of the retailers' profit maximization problem is:

$$P_t \left[\int_0^1 XR_t(v)^{\frac{\mu-1}{\mu}} dv \right]^{\frac{1}{\mu-1}} XR_t(v)^{-\frac{1}{\mu}} - P_t(v) = 0 \quad (\text{C.30})$$

which can be simplified into the following retailers' demand for a typical variety of the intermediate good produced by the representative firm v :

$$XR_t(v) = \left[\frac{P_t(v)}{P_t} \right]^{-\mu} XR_t \quad (\text{C.31})$$

Using the production function for each intermediate good, (C.31) becomes:

$$\varepsilon_{a,t} \int_0^1 K_t(v)^\alpha H_t(v)^{1-\alpha} dv = \left[\frac{P_t(v)}{P_t} \right]^{-\mu} XR_t \quad (\text{C.32})$$

Now define a measure of price dispersion v_t^p :

$$v_t^p = \int_0^1 \left[\frac{P_t(v)}{P_t} \right]^{-\mu} dv \quad (\text{C.33})$$

Using the definition of aggregate labor input, we can define retail output XR_t as:

$$XR_t = \frac{X_t}{v_t^p} \quad (\text{C.34})$$

Finally, following the zero-profit condition, the price of the final good can be defined by:

$$P_t = \left[\int_0^1 P_t(v)^{1-\mu} dv \right]^{\frac{1}{1-\mu}} \quad (\text{C.35})$$

Intermediate goods producers

Intermediate goods producers combine labor inputs and transform labor into a distinctive good:

$$X_t(v) = \varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \quad (\text{C.36})$$

Intermediate goods producers face the common wage rate W_t and plan their future production with a goal to minimize cost. Their optimization problem can be formalized as:

$$\min_{K_t(v), H_t(v)} Z_{k,t} K_t(v) + W_t H_t(v) \quad (\text{C.37})$$

s.t.

$$\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \geq \left[\frac{P_{n,t}(v)}{P_{n,t}} \right]^{-\mu} XR_t \quad (\text{C.38})$$

The corresponding Lagrangian is given by:

$$\begin{aligned} \mathcal{L}(K_t(v), H_t(v)) &= Z_{k,t} K_t(v) + W_t H_t(v) \\ &- mc_t(v) \left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} - \left[\frac{P_{n,t}(v)}{P_{n,t}} \right]^{\frac{\mu}{1-\mu}} XR_t \right] \end{aligned} \quad (\text{C.39})$$

The first-order conditions of the cost minimization problem w.r.t. $K_t(v)$ and $H_t(v)$ are:

$$\frac{\partial \mathcal{L}(K_t(v), H_t(v))}{\partial K_t(v)} = Z_{k,t} - mc_t(v) \alpha K_t(v)^{\alpha-1} H_t(v)^{1-\alpha} = 0 \quad (\text{C.40})$$

$$\frac{\partial \mathcal{L}(K_t(v), H_t(v))}{\partial H_t(v)} = W_t - mc_t(v) (1-\alpha) K_t(v)^\alpha H_t(v)^{-\alpha} = 0 \quad (\text{C.41})$$

Given that all intermediate goods producers are identical, the first-order conditions in real

terms are given by:

$$Z_{k,t} = mc_t \alpha \frac{X_t}{K_t} \quad (\text{C.42})$$

$$W_t = mc_t (1 - \alpha) \frac{X_t}{H_t} \quad (\text{C.43})$$

In optimum, the condition given by equation (C.38) hold with equality:

$$\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} = \left[\frac{P_t(v)}{P_t} \right]^{-\mu} X R_t \quad (\text{C.44})$$

Integrating (C.44) over all intermediate goods producers v yields:

$$\varepsilon_{a,t} \int_0^1 K_t(v)^\alpha H_t(v)^{1-\alpha} dv = X R_t \int_0^1 \left[\frac{P_t(v)}{P_t} \right]^{-\mu} dv \quad (\text{C.45})$$

Now, define the price dispersion index $v_{p,t}$ as:

$$v_{p,t} \equiv \int_0^1 \left[\frac{P_t(v)}{P_t} \right]^{-\mu} dv \quad (\text{C.46})$$

This results in the following relation between retail output $X R_t$ and aggregate production of all intermediate goods producers X_t :

$$X R_t = \frac{\varepsilon_{a,t} K_t^\alpha H_t^{1-\alpha}}{v_{p,t}} = \frac{X_t}{v_{p,t}} \quad (\text{C.47})$$

Define the real (flow) profit of the representative producer is given by:

$$\Pi_t(v) = \frac{P_t(v)}{P_t} X R_t(v) - Z_{k,t} K_t(v) - W_t H_t(v) \quad (\text{C.48})$$

which after substituting for $Z_{k,t}$ and W_t using equations (C.42) and (C.43), respectively, takes the form:

$$\Pi_t(v) = \frac{P_t(v)}{P_t} X R_t(v) - mc_t X_t(v) \quad (\text{C.49})$$

We can rewrite (C.44) as:

$$X_t(v) = \left[\frac{P_t(v)}{P_t} \right]^{-\mu} X R_t \quad (\text{C.50})$$

Therefore, the definition of profits from (C.49) becomes:

$$\Pi_t(v) = \frac{P_t(v)}{P_t} X R_t(v) - mc_t \left[\frac{P_t(v)}{P_t} \right]^{-\mu} X R_t \quad (\text{C.51})$$

The profit maximization problem of a firm that is able to reset its price can be written as:

$$\max_{P_t(v)} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta \theta_p)^k q_{t+k} \left[\frac{P_t(v)}{P_t} X R_{t+k}(v) - m c_{t+k} \left[\frac{P_t(v)}{P_{t+k}} \right]^{-\mu} X R_{t+k} \right] \quad (\text{C.52})$$

$$\max_{P_t(v)} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta \theta_p)^k q_{t+k} \left[\frac{P_t(v)}{P_{t+k}} \left[\frac{P_{t+k}(v)}{P_{t+k}} \right]^{-\mu} X R_{t+k} - m c_{t+k}(v) \left[\frac{P_t(v)}{P_{t+k}} \right]^{-\mu} X R_{t+k} \right] \quad (\text{C.53})$$

The first-order condition can be written as:

$$(1 - \mu) P_t(v)^{-\mu} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta \theta_p)^k q_{t+k} P_{t+k}^{\mu-1} X R_{t+k} + \mu P_t(v)^{-\mu-1} \mathbb{E}_t \sum_{k=0}^{\infty} (\beta \theta_p)^k q_{t+k} m c_{i,t+k} P_{t+k}^{\mu} X R_{t+k} = 0 \quad (\text{C.54})$$

$$\tilde{P}_t(v) = \frac{\mu}{\mu - 1} \frac{\mathbb{E}_t \sum_{k=0}^{\infty} (\beta \theta_p)^k q_{t+k} m c_{i,t+k} P_{t+k}^{\mu-1} X R_{t+k}}{\mathbb{E}_t \sum_{k=0}^{\infty} (\beta \theta_p)^k q_{t+k} P_{t+k}^{\mu} X R_{t+k}} \quad (\text{C.55})$$

which can be written as:

$$\tilde{P}_t(v) = \frac{\mu}{\mu - 1} \frac{e_t}{f_t} \quad (\text{C.56})$$

where

$$e_t = q_t m c_t P_{n,t}^{\mu} X R_t + \theta_p \beta \mathbb{E}_t e_{t+1} \quad (\text{C.57})$$

$$f_t = q_t P_{n,t}^{\mu-1} X R_t + \theta_p \beta \mathbb{E}_t f_{t+1} \quad (\text{C.58})$$

C.1.3 The banks' problem

The financial intermediaries' balance sheet is given by:

$$Q_t S_t + q_t B_{b,t} = N_t + D_t \quad (\text{C.59})$$

where the net worth evolves according to the following rule:

$$N_t = R_{k,t} Q_{t-1} S_{t-1} + R_{b,t} q_{t-1} B_{b,t-1} - R_t D_{t-1} + J_{t-1} \quad (\text{C.60})$$

From (C.59) deposits are given by:

$$D_t = Q_t S_t + q_t B_{b,t} - N_t \quad (\text{C.61})$$

So, by substituting the definition of deposits from (C.61) in $t - 1$ to (C.60), the net worth becomes:

$$\begin{aligned} N_t = & R_{k,t} Q_{t-1} S_{t-1} + R_{b,t} q_{t-1} B_{b,t-1} \\ & - R_t (Q_{t-1} S_{t-1} + q_{t-1} B_{b,t-1} - N_{t-1}) + J_{t-1} \end{aligned} \quad (\text{C.62})$$

which is equivalent to:

$$N_t = (R_{k,t} - R_t) Q_{t-1} S_{t-1} + (R_{b,t} - R_t) q_{t-1} B_{b,t-1} + R_t N_{t-1} + J_{t-1} \quad (\text{C.63})$$

The end-of-period value function with equity issuance conditional on the survival of the bank is:

$$\mathcal{V}_t(N_t) = \max_{S_t, J_t, D_t} \mathbb{E}_t \left\{ \beta \frac{q_{t+1}}{q_t} \left[\begin{aligned} & (1 - \sigma) N_{t+1} \\ & + \sigma (W_{t+1}(N_{t+1}) - J_t - C(J_t, N_t)) \end{aligned} \right] \right\} \quad (\text{C.64})$$

The bankers' maximization problem is to choose their portfolio of S_t and $B_{b,t}$ to maximize $\mathcal{V}_t(N_t)$ subject to the following incentive constraint:

$$\mathcal{V}_t(N_t) \geq \theta Q_t S_t + \Gamma \theta q_t B_{b,t} \quad (\text{C.65})$$

and to choose their equity issuance J_t to maximize $\mathcal{W}_{t+1}(N_{t+1})$ subject to the definition of net worth given by (C.63); assuming at the same time the existence a linear solution of the form $\mathcal{V}_t = \mu_{s,t} Q_t S_t + \mu_{b,t} q_t B_{b,t} + v_t N_t$ and $\mathcal{W}_t = \eta_t N_t$.

Let v_t be the Lagrange multiplier associated with the incentive constraint (C.65), $\lambda_t = v_t / (1 + v_t)$ and Ω_{t+1} a term that augments the banks' discount factor relative to the household's discount factor.

The bank's optimization problem is solved by guessing a linear value function on assets and deposits:

$$\mathcal{V}_t(S_t, B_{b,t}, N_t) = \mu_{s,t} Q_t S_t + \mu_{b,t} q_t B_{b,t} + v_t N_t \quad (\text{C.66})$$

The Lagrangian is formalized as:

$$\begin{aligned} \mathcal{L}_t(S_t, B_{b,t}) = & \mu_{s,t} Q_t S_t + \mu_{b,t} q_t B_{b,t} + v_t N_t \\ & - v_t \left(\theta Q_t S_t + \Gamma \theta q_t B_{b,t} - \mu_{s,t} Q_t S_t - \mu_{b,t} q_t B_{b,t} - v_t N_t \right) \end{aligned} \quad (\text{C.67})$$

The first-order conditions with respect to S_t , $B_{b,t}$, v_t and are expressed as follows:

$$\mu_{s,t} Q_t - v_t \theta Q_t + v_t \mu_{s,t} Q_t = 0 \Rightarrow \mu_{s,t} = \theta \frac{v_t}{1 + v_t} \quad (\text{C.68})$$

$$\mu_{b,t} q_t - v_t \Gamma \theta q_t + v_t \mu_{b,t} q_t = 0 \Rightarrow \mu_{b,t} = \Gamma \frac{v_t}{1 + v_t} \quad (\text{C.69})$$

$$\theta Q_t S_t + \Gamma \theta q_t B_{b,t} - \mu_{s,t} Q_t S_t - \mu_{b,t} q_t B_{b,t} - v_t N_t = 0 \quad (\text{C.70})$$

where v_t is the value of banks' net worth defined as (see equation C.92):

$$v_t = \mathbb{E}_t \left[\beta \frac{Q_{t+1}}{Q_t} Q_{t+1} R_{t+1} + \left(\beta \frac{Q_{t+1}}{Q_t} Q_{t+1} - 1 \right)^2 / (2\zeta) \right] \quad (\text{C.71})$$

Then the solution can be characterized as follows: at the end of each period, an individual bank maximizes the present value of its future dividends given the quadratic cost of equity issuance:

$$\begin{aligned} \mathcal{V}_t(N_t) = & \max_{S_t, J_t, D_t} \mathbb{E}_t \left\{ \beta \frac{Q_{t+1}}{Q_t} \left[(1 - \theta_b) N_{t+1} + \theta_b \left(\mathcal{W}_{t+1}(N_{t+1}) - J_t - \frac{\zeta}{2} \frac{J_t^2}{N_t} \right) \right] \right\} \\ & \text{s.t. } \mathcal{V}_t(S_t, B_{b,t}, N_t) \geq \theta Q_t S_t + \Gamma \theta q_t B_{b,t} \\ & \text{for } N_{t+1} = (R_{k,t+1} - R_{t+1}) Q_t S_t + (R_{b,t+1} - R_{t+1}) q_t B_{b,t} + R_{t+1} N_t + J_t \end{aligned} \quad (\text{C.72})$$

The Lagrangian is formalized as:

$$\begin{aligned} \mathcal{L}_t(S_t, J_t, D_t) = & \mathbb{E}_t \left\{ \beta \frac{Q_{t+1}}{Q_t} \left[(1 - \theta_b) N_{t+1} + \theta_b \left(\eta_{t+1} N_{t+1} - J_t - \frac{\zeta}{2} \frac{J_t^2}{N_t} \right) \right] \right\} \\ & - v_t [\theta Q_t S_t + \Gamma \theta q_t B_{b,t} - \mathcal{V}_t(S_t, B_{b,t}, N_t)] \end{aligned} \quad (\text{C.73})$$

Definitions:

$$\eta_t \equiv \frac{\partial \mathcal{V}_t}{\partial N_t}, \quad \zeta_t \equiv \frac{J_t}{N_t}, \quad \lambda_t \equiv \eta_t (1 - \lambda_t), \quad \Omega_t \equiv (1 - \theta_b) + \theta_b \eta_t \quad (\text{C.74})$$

Given the definition of Ω_t in $t + 1$, the Lagrangian can be rewritten as:

$$\begin{aligned} \mathcal{L}_t(S_t, J_t, D_t) = \mathbb{E}_t \left\{ \beta \frac{\varrho_{t+1}}{\varrho_t} \left[\Omega_{t+1} N_{t+1} - \theta_b J_t - \theta_b \frac{\zeta}{2} \frac{J_t^2}{N_t} \right] \right\} \\ - v_t [\theta Q_t S_t + \Gamma \theta q_t B_{b,t} - \mathcal{V}_t(S_t, B_{b,t}, N_t)] \end{aligned} \quad (\text{C.75})$$

which given the formula for N_{t+1} yields:

$$\begin{aligned} \mathcal{L}_t(S_t, B_{b,t}, N_t) = \mathbb{E}_t \beta_R \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \left\{ \Omega_{t+1} \left[\begin{array}{l} (R_{k,t+1} - R_{t+1}) Q_t S_t \\ + (R_{b,t+1} - R_{t+1}) q_t B_{b,t} \\ + R_{t+1} N_t + J_t \\ - \theta_b J_t - \theta_b \frac{\zeta}{2} \frac{J_t^2}{N_t} \end{array} \right] \right\} \\ - v_t (\theta Q_t S_t + \Gamma \theta q_t B_{b,t} - \mu_{s,t} Q_t S_t - \mu_{b,t} q_t B_{b,t} - v_t N_t) \end{aligned} \quad (\text{C.76})$$

The first-order condition with respect to S_t is:

$$\mathbb{E}_t \beta_R \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \Omega_{t+1} (R_{k,t+1} - R_{t+1}) Q_t - v_t \theta Q_t + v_t \mu_{s,t} Q_t = 0 \quad (\text{C.77})$$

Substituting for $\mu_{s,t}$ yields:

$$\mathbb{E}_t \beta \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \Omega_{t+1} (R_{k,t+1} - R_{t+1}) - v_t \theta + v_t \theta \frac{v_t}{1 + v_t} = 0 \quad (\text{C.78})$$

$$\mathbb{E}_t \beta \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \Omega_{t+1} (R_{k,t+1} - R_{t+1}) - \frac{v_t \theta (1 + v_t)}{1 + v_t} + \frac{v_t^2 \theta}{1 + v_t} = 0 \quad (\text{C.79})$$

Given that $\lambda_t = v_t / (1 + v_t)$:

$$\mathbb{E}_t \beta_R \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \Omega_{t+1} (R_{k,t+1} - R_{t+1}) = \theta \lambda_t \quad (\text{C.80})$$

The first-order condition of the optimization problem of banks with respect to $B_{b,t}$ is:

$$\mathbb{E}_t \beta_R \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \Omega_{t+1} (R_{b,t+1} - R_{t+1}) - v_t \Gamma \theta + v_t \mu_{b,t} = 0 \quad (\text{C.81})$$

Substituting for $\mu_{b,t}$ yields:

$$\mathbb{E}_t \beta_R \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \Omega_{t+1} (R_{b,t+1} - R_{t+1}) - v_t \Gamma \theta + v_t \Gamma \frac{v_t}{1 + v_t} = 0 \quad (\text{C.82})$$

$$\mathbb{E}_t \beta_R \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \Omega_{t+1} (R_{b,t+1} - R_{t+1}) + \frac{-v_t \Gamma \theta (1 + v_t)}{1 + v_t} + \frac{v_t \Gamma v_t}{1 + v_t} = 0 \quad (\text{C.83})$$

$$\mathbb{E}_t \beta_R \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \Omega_{t+1} (R_{b,t+1} - R_{t+1}) + \frac{-v_t \Gamma \theta - v_t^2 \Gamma \theta + v_t^2 \Gamma \theta}{1 + v_t} = 0 \quad (\text{C.84})$$

$$\mathbb{E}_t \beta_R \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \Omega_{t+1} (R_{b,t+1} - R_{t+1}) + \frac{-v_t \Gamma \theta}{1 + v_t} = 0 \quad (\text{C.85})$$

Given that $\lambda_t = v_t / (1 + v_t)$:

$$\mathbb{E}_t \beta \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \Omega_{t+1} (R_{b,t+1} - R_{t+1}) = \theta \Gamma \lambda_t \quad (\text{C.86})$$

The objective of the banker is to issue equity in order to maximize $\mathcal{W}_{t+1}(N_{t+1})$ subject to (C.63):

$$\max_{J_t} \mathbb{E}_t \left\{ \beta_R \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \left[\Omega_{t+1} \begin{bmatrix} (R_{k,t+1} - R_{t+1}) Q_t S_t \\ + (R_{b,t+1} - R_{t+1}) q_t B_{b,t} \\ + R_{t+1} N_t + J_t \end{bmatrix} - J_t - \frac{\zeta}{2} \frac{J_t^2}{N_t} \right] \right\} \quad (\text{C.87})$$

It is, therefore assumed that the equity is issued and the cost of equity is paid only by the surviving banks. So, conditional the bank has survived to $t + 1$ the amount of equity it issues in t is such that the bank maximizes $\mathcal{W}_{t+1}(N_{t+1}) = \eta_{t+1} N_{t+1}$ subject to the cost of equity issuance.

The Lagrangian is formalized as:

$$\mathcal{L}_t(J_t, N_t) = \mathbb{E}_t \left\{ \begin{array}{l} \beta_R \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \left[\Omega_{t+1} \begin{bmatrix} (R_{k,t+1} - R_{t+1}) Q_t S_t \\ + (R_{b,t+1} - R_{t+1}) q_t B_{L,t}^n \\ + R_{t+1} N_t + J_t \end{bmatrix} - J_t - \frac{\zeta}{2} \frac{J_t^2}{N_t} \right] \\ - \lambda_t (\eta_t N_t - \mathcal{W}_t) \end{array} \right\} \quad (\text{C.88})$$

The first-order condition with respect to the cost of equity issuance J_t is:

$$\mathbb{E}_t \beta_R \frac{\lambda_{R,t+1}}{\lambda_{R,t}} (\Omega_{t+1} - 1) - \zeta \tilde{\zeta}_t = 0 \quad (\text{C.89})$$

which implies:

$$\tilde{\zeta}_t = \frac{\mathbb{E}_t \beta \frac{\lambda_{R,t+1}}{\lambda_{R,t}} (\Omega_{t+1} - 1)}{\zeta} \quad (\text{C.90})$$

$$\eta_t \equiv \frac{\partial \mathcal{V}_t}{\partial N_t} \Rightarrow \eta_t = \mathbb{E}_t \beta_R \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \Omega_{t+1} R_{t+1} + \frac{\zeta}{2} \tilde{\zeta}_t^2 + \lambda_t \eta_t \quad (\text{C.91})$$

$$v_t = \mathbb{E}_t \beta \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \Omega_{t+1} R_{t+1} + \frac{\mathbb{E}_t \left[\beta_R \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \Omega_{t+1} - 1 \right]^2}{2\zeta} \quad (\text{C.92})$$

I also need to characterize the behavior of the multiplier λ_t . In this case, since $V_t = \eta_t n_t$ and (C.65) holds with equality, it follows that:

$$\eta_t n_t = \theta(Q_t K_t + q_t B_{b,t}) \quad (\text{C.93})$$

From (C.91) it follows that:

$$\eta_t(1 - \lambda_t) = v_t \quad (\text{C.94})$$

and substituting in (C.93), I get the following expression for λ_t

$$\lambda_t = 1 - \frac{v_t}{\theta \phi_t} \quad (\text{C.95})$$

C.1.4 Capital goods producers

Capital goods producers incur a quadratic investment adjustment cost per unit of investment defined as:

$$f\left(\frac{I_t}{I_{t-1}}\right) \equiv \frac{\eta_i}{2} \left[\frac{I_t}{I_{t-1}} - 1\right]^2 \quad (\text{C.96})$$

where $\eta_i > 0$ is the adjustment cost parameter.

Capital goods producers maximize their present discounted profits by choosing the optimal quantity of investment by solving the following problem:

$$\max_{I_t} \mathbb{E}_t \sum_{t=0}^{\infty} \Lambda_{t,t+1} \left[Q_t I_t - \left[1 + f\left(\frac{I_t}{I_{t-1}}\right) \right] I_t \right] \quad (\text{C.97})$$

where Q_t is the price of a security that finances the purchase of a unit of physical capital.

The optimality condition yields the following Q -investment relation for capital goods:

$$Q_t = 1 + f\left(\frac{I_t}{I_{t-1}}\right) + \frac{I_t}{I_{t-1}} f'\left(\frac{I_t}{I_{t-1}}\right) - \mathbb{E}_t \left[\Lambda_{t,t+1} \left(\frac{I_{t+1}}{I_t}\right)^2 f'\left(\frac{I_{t+1}}{I_t}\right) \right] \quad (\text{C.98})$$

which corresponds to:

$$Q_t = 1 + \frac{\eta_i}{2} \left[\left(\frac{I_t}{I_{t-1}}\right) - 1 \right]^2 + \eta_i \left[\frac{I_t}{I_{t-1}} - 1 \right] \frac{I_t}{I_{t-1}} - \mathbb{E}_t \left[\Lambda_{t,t+1} \eta_i \left[\frac{I_{t+1}}{I_t} - 1 \right] \left(\frac{I_{t+1}}{I_t}\right)^2 \right] \quad (\text{C.99})$$

The aggregate capital stock in period t is given by the following law of motion of capital:

$$K_t = I_t \left[1 - f\left(\frac{I_t}{I_{t-1}}\right) \right] + (1 - \delta) K_{t-1} \quad (\text{C.100})$$

where $0 < \delta < 1$ is the depreciation rate of capital.

C.2 Optimization problems of the model with supply chains

In this section, I present the derivations of the firm's problem with supply chains given three specifications of a production function with value-added on the one hand and intermediate inputs on the other: Leontief technology, CES technology, and Cobb-Douglas technology. In [Chapter 1](#), I utilize the Leontief specification of technology to feature supply chains.

C.2.1 The firms' problem

Leontief technology

Take the Leontief technology with capital, labor, and intermediate inputs combined as follows:

$$X_t(v) = \varepsilon_{a,t} \left[\frac{K_t(v)^\alpha H_t(v)^{1-\alpha}}{1 - \varphi_i}, \frac{X_t^s(v)}{\varphi_i} \right] \quad (\text{C.101})$$

Given the properties of the Leontief specification, cost minimization requires that output is produced using equal shares of each input at all times. That is:

$$X_t(v) = \frac{\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha}}{1 - \varphi_i} = \frac{\varepsilon_{a,t} X_t^s(v)}{\varphi_i} \quad (\text{C.102})$$

It, therefore, implies that the value added explains a fixed share $(1 - \varphi_i)$ of output:

$$\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} = (1 - \varphi_i) X_t(v) \quad (\text{C.103})$$

and the share of intermediate inputs in output equals φ_i at all times:

$$\varepsilon_{a,t} X_t^s(v) = \varphi_i X_t(v) \quad (\text{C.104})$$

The cost function is the sum of inputs multiplied by their corresponding unit prices:

$$\mathcal{C}_t(v) = Z_t K_t(v) + W_t H_t(v) + P_t^s X_t^s(v) \quad (\text{C.105})$$

Solving the first-order condition of the cost-minimization problem for capital $K_t(v)$ yields:

$$K_t(v) = \left[(1 - \varphi_i) \frac{X_t(v)}{\varepsilon_{a,t} H_t(v)^{1-\alpha}} \right]^{\frac{1}{\alpha}} \quad (\text{C.106})$$

so that the cost function becomes:

$$C_t(v) = Z_t \left[(1 - \varphi_i) \frac{X_t(v)}{\varepsilon_{a,t} H_t(v)^{1-\alpha}} \right]^{\frac{1}{\alpha}} + W_t H_t(v) + P_t^s X_t^s(v) \quad (\text{C.107})$$

The first-order condition of the cost-minimization problem with respect to labor is:

$$W_t = Z_t \frac{1-\alpha}{\alpha} \left[(1 - \varphi_i) \frac{X_t(v)}{\varepsilon_{a,t} H_t(v)^{1-\alpha}} \right]^{\frac{1}{\alpha}} \quad (\text{C.108})$$

So, the optimal use of labor in technology $\tilde{H}_t(v)$ by a representative producer is given by:

$$\tilde{H}_t(v) = (1 - \varphi_i) \left[\frac{1-\alpha}{\alpha} \frac{Z_t}{W_t} \right]^{\alpha} \frac{X_t(v)}{\varepsilon_{a,t}} \quad (\text{C.109})$$

Substituting for $H_t(v)$ in equation (C.106) the optimal demand for labor $\tilde{H}_t(v)$ yields the optimal use of capital $\tilde{K}_t(v)$ in technology:

$$\tilde{K}_t(v) = (1 - \varphi_i) \left[\frac{\alpha}{1-\alpha} \frac{W_t}{Z_t} \right]^{1-\alpha} \frac{X_t(v)}{\varepsilon_{a,t}} \quad (\text{C.110})$$

Substituting for $H_t(v)$ and $K_t(v)$ in the cost function their optimal quantities - $\tilde{H}_t(v)$ and $\tilde{K}_t(v)$ - and using condition (C.104) yields:

$$\begin{aligned} C_t(v) = & Z_t (1 - \varphi_i) \left[\frac{W_t}{Z_t} \frac{\alpha}{1-\alpha} \right]^{1-\alpha} \frac{X_t(v)}{\varepsilon_{a,t}} \\ & + W_t (1 - \varphi_i) \left[\frac{Z_t}{W_t} \frac{1-\alpha}{\alpha} \right]^{\alpha} \frac{X_t(v)}{\varepsilon_{a,t}} + P_t^s \frac{\varphi_i X_t(v)}{\varepsilon_{a,t}} \end{aligned} \quad (\text{C.111})$$

The marginal cost is the derivative of the cost function with respect to output $X_t(v)$:

$$\begin{aligned} \frac{\partial C_t(v)}{\partial X_t(v)} = mc_t(v) = & \frac{Z_t}{\varepsilon_{a,t}} (1 - \varphi_i) \left[\frac{W_t}{Z_t} \frac{\alpha}{1-\alpha} \right]^{1-\alpha} \\ & + \frac{W_t}{\varepsilon_{a,t}} (1 - \varphi_i) \left[\frac{Z_t}{W_t} \frac{1-\alpha}{\alpha} \right]^{\alpha} + \varphi_i \frac{P_t^s}{\varepsilon_{a,t}} \end{aligned} \quad (\text{C.112})$$

which can be simplified into the following formula with the weighted unit cost of value added

and intermediate inputs:

$$mc_t(v) = (1 - \varphi_i) \frac{Z_t^\alpha W_t^{1-\alpha}}{\alpha^\alpha (1 - \alpha)^{1-\alpha} \varepsilon_{a,t}} + \varphi_i \frac{P_t^s}{\varepsilon_{a,t}} \quad (\text{C.113})$$

Assume that physical capital K_t is divided into local and export capital - $K_{h,t}$ and $K_{f,t}$, respectively - according to the following rule:

$$K_t(v) = \left[\varphi_k K_{h,t-1}(v)^{\frac{\eta_k-1}{\eta_k}} + (1 - \varphi_k) K_{f,t-1}(v)^{\frac{\eta_k-1}{\eta_k}} \right]^{\frac{\eta_k}{\eta_k-1}} \quad (\text{C.114})$$

Given the properties of the Leontief specification, cost minimization requires that output is produced using equal shares of each input at all times. That is:

$$X_t(v) = \frac{K_t(v)^\alpha H_t(v)^{1-\alpha}}{1 - \varphi_i} = \frac{X_t^s(v)}{\varphi_i} \quad (\text{C.115})$$

It, therefore, implies that the value added explains a fixed share $(1 - \varphi_i)$ of output:

$$K_t(v)^\alpha H_t(v)^{1-\alpha} = (1 - \varphi_i) X_t(v) \quad (\text{C.116})$$

and the share of intermediate inputs in output equals φ_i at all times:

$$X_t^s(v) = \varphi_i X_t(v) \quad (\text{C.117})$$

The cost function is the sum of inputs multiplied by their corresponding unit prices:

$$C_t(v) = Z_{k,t} K_{h,t}(v) + Z_{k,t} K_{f,t}(v) + W_t H_t(v) + P_t^s X_t^s(v) \quad (\text{C.118})$$

Solving the first-order condition of the cost minimization problem for capital $K_t(v)$ yields:

$$K_t(v) = \left[(1 - \varphi_i) \frac{X_t(v)}{\varepsilon_{a,t} H_t(v)^{1-\alpha}} \right]^{\frac{1}{\alpha}} \quad (\text{C.119})$$

The first-order condition of the cost-minimization problem with respect to labor is:

$$W_t = Z_t \frac{1 - \alpha}{\alpha} \left[(1 - \varphi_i) \frac{X_t(v)}{\varepsilon_{a,t} H_t(v)} \right]^{\frac{1}{\alpha}} \quad (\text{C.120})$$

So, the optimal use of labor in technology $\tilde{H}_t(v)$ by a representative producer is given by:

$$\tilde{H}_t(v) = (1 - \varphi_i) \left[\frac{1 - \alpha}{\alpha} \frac{Z_t}{W_t} \right]^\alpha X_t(v) \quad (\text{C.121})$$

Substituting for $H_t(v)$ in equation (C.119) the optimal demand for labor $\tilde{H}_t(v)$ yields the optimal use of capital $\tilde{K}_t(v)$ in technology:

$$\tilde{K}_t(v) = (1 - \varphi_i) \left[\frac{\alpha}{1 - \alpha} \frac{W_t}{Z_t} \right]^{1-\alpha} X_t(v) \quad (\text{C.122})$$

Under the assumption of a CES function which aggregates local and export capital into $K_t(v)$, we have the following optimal demands for local and export capital:

$$\tilde{K}_{h,t}(v) = \varphi_k Z_{k,t}^{-\eta_k} \tilde{K}_t(v) \quad (\text{C.123})$$

$$\tilde{K}_{f,t}(v) = (1 - \varphi_k) Z_{k,t}^{-\eta_k} \tilde{K}_t(v) \quad (\text{C.124})$$

Substituting for $H_t(v)$ and $K_t(v)$ in the cost function their optimal quantities - $\tilde{H}_t(v)$ and $\tilde{K}_t(v)$ - and using condition (C.117) yields:

$$\begin{aligned} \mathcal{C}_t(v) &= Z_{k,t}^{1-\eta_k} (1 - \varphi_i) \left[\frac{W_t}{Z_t} \frac{\alpha}{1 - \alpha} \right]^{1-\alpha} X_t(v) \\ &+ W_t (1 - \varphi_i) \left[\frac{Z_{k,t}}{W_t} \frac{1 - \alpha}{\alpha} \right]^\alpha X_t(v) + P_t^s \varphi_i X_t(v) \end{aligned} \quad (\text{C.125})$$

The marginal cost is the derivative of the cost function with respect to output $X_t(v)$:

$$\begin{aligned} \frac{\partial \mathcal{C}_t(v)}{\partial X_t(v)} &= mc_t(v) = Z_{k,t}^{1-\eta_k} (1 - \varphi_i) \left[\frac{W_t}{Z_t} \frac{\alpha}{1 - \alpha} \right]^{1-\alpha} \\ &+ W_t (1 - \varphi_i) \left[\frac{Z_{k,t}}{W_t} \frac{1 - \alpha}{\alpha} \right]^\alpha + \varphi_i P_t^s \end{aligned} \quad (\text{C.126})$$

which can be simplified into the following formula with the weighted unit cost of value added and intermediate inputs:

$$mc_t(v) = (1 - \varphi_i) \frac{Z_{k,t}^\alpha W_t^{1-\alpha} (1 - \alpha + \alpha Z_{k,t}^{-\eta_k})}{\alpha^\alpha (1 - \alpha)^{1-\alpha}} + \varphi_i P_t^s \quad (\text{C.127})$$

CES technology

Take the following CES technology with labor, capital, and intermediate inputs:

$$X_t(v) = \left[(1 - \varphi_i) \left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{\frac{\eta-1}{\eta}} + \varphi_i X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \quad (\text{C.128})$$

A Lagrangian corresponding the cost minimization problem is given by:

$$\begin{aligned} \mathcal{L}(H_t(v), K_t(v), X_t^s(v)) &= W_t H_t(v) + Z_t K_t(v) + P_t^s X_t^s(v) \\ - mc_t(v) &\left(\left[(1 - \varphi_i) \left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{\frac{\eta-1}{\eta}} + \varphi_i X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} - \left[\frac{P_t(v)}{P_t} \right]^{-\mu} X R_t \right) \end{aligned} \quad (\text{C.129})$$

The first-order conditions with respect to $H_t(v)$, $K_t(v)$, and $X_t^s(v)$ are:

$$\begin{aligned} \frac{\partial \mathcal{L}(H_t(v), K_t(v), X_t^s(v))}{\partial H_t(v)} &= W_t - mc_t(v) \\ &\times \left[(1 - \varphi_i) \left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{\frac{\eta-1}{\eta}} + \varphi_i X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{1}{\eta-1}} \\ &\times (1 - \varphi_i) \left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{-\frac{1}{\eta}} (1 - \alpha) \varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{-\alpha} \\ &= W_t - mc_t(v) (1 - \varphi_i) (1 - \alpha) X_t(v)^{\frac{1}{\eta}} \frac{\left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{\frac{\eta-1}{\eta}}}{H_t(v)} = 0 \end{aligned} \quad (\text{C.130})$$

$$\begin{aligned} \frac{\partial \mathcal{L}(H_t(v), K_t(v), X_t^s(v))}{\partial K_t(v)} &= Z_t - mc_t(v) \\ &\times \left[(1 - \varphi_i) \left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{\frac{\eta-1}{\eta}} + \varphi_i X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{1}{\eta-1}} \\ &\times (1 - \varphi_i) \left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{-\frac{1}{\eta}} \alpha \varepsilon_{a,t} K_t(v)^{\alpha-1} H_t(v)^{1-\alpha} \\ &= Z_t - mc_t(v) (1 - \varphi_i) \alpha X_t(v)^{\frac{1}{\eta}} \frac{\left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{\frac{\eta-1}{\eta}}}{K_t(v)} = 0 \end{aligned} \quad (\text{C.131})$$

$$\begin{aligned} \frac{\partial \mathcal{L}(H_t(v), K_t(v), X_t^s(v))}{\partial X_t^s(v)} &= P_t^s - mc_t(v) \\ &\times \left[(1 - \varphi_i) \left[\varepsilon_{a,t} K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{\frac{\eta-1}{\eta}} + \varphi_i X_t^s(v)^{\frac{\eta-1}{\eta}} \right]^{\frac{1}{\eta-1}} \varphi_i X_t^s(v)^{-\frac{1}{\eta}} \\ &= P_t^s - mc_t(v) \varphi_i \left[\frac{X_t(v)}{X_t^s(v)} \right]^{\frac{1}{\eta}} = 0 \end{aligned} \quad (\text{C.132})$$

All intermediate goods producers are identical. Therefore, the first-order conditions of the cost-minimization problem of all intermediate goods producers with respect to labor, capital,

and intermediate inputs given the CES specification of technology are, respectively:

$$W_t = mc_t(1 - \varphi_i)(1 - \alpha)X_t^{\frac{1}{\eta}} \frac{\left[\varepsilon_{a,t} K_t^\alpha H_t^{1-\alpha} \right]^{\frac{\eta-1}{\eta}}}{H_t} \quad (\text{C.133})$$

$$Z_t = mc_t(1 - \varphi_i)\alpha X_t^{\frac{1}{\eta}} \frac{\left[\varepsilon_{a,t} K_t^\alpha H_t^{1-\alpha} \right]^{\frac{\eta-1}{\eta}}}{K_t} \quad (\text{C.134})$$

$$P_t^s = mc_t \varphi_i \left[\frac{X_t}{X_t^s} \right]^{\frac{1}{\eta}} \quad (\text{C.135})$$

Cobb-Douglas technology

Take the following Cobb-Douglas technology with labor, capital, and intermediate inputs:

$$X_t(v) = \varepsilon_{a,t} \left[K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{(1-\varphi_i)} X_t^s(v)^{\varphi_i} \quad (\text{C.136})$$

A Lagrangian corresponding the cost minimization problem is given by:

$$\begin{aligned} \mathcal{L}(H_t(v), K_t(v), X_t^s(v)) &= W_t H_t(v) + Z_t K_t(v) + P_t^s X_t^s(v) \\ &- mc_t(v) \left(\varepsilon_{a,t} \left[K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{(1-\varphi_i)} X_t^s(v)^{\varphi_i} - \left[\frac{P_t(v)}{P_t} \right]^{-\mu} X R_t \right) \end{aligned} \quad (\text{C.137})$$

The first-order conditions with respect to $H_t(v)$, $K_t(v)$, and $X_t^s(v)$ are:

$$\begin{aligned} \frac{\partial \mathcal{L}(H_t(v), K_t(v), X_t^s(v))}{\partial H_t(v)} &= W_t - mc_t(v) \varepsilon_{a,t} (1 - \varphi_i)(1 - \alpha) \left[K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{-\varphi_i} \\ &\times X_t^s(v)^{\varphi_i} K_t(v)^\alpha H_t(v)^{-\alpha} = W_t - mc_t(v)(1 - \varphi_i)(1 - \alpha) \frac{X_t(v)}{K_t(v)^\alpha H_t(v)^{1-\alpha}} \\ &\times K_t(v)^\alpha H_t(v)^{-\alpha} = W_t - mc_t(v)(1 - \varphi_i)(1 - \alpha) \frac{X_t(v)}{H_t(v)} = 0 \end{aligned} \quad (\text{C.138})$$

$$\begin{aligned} \frac{\partial \mathcal{L}(H_t(v), K_t(v), X_t^s(v))}{\partial K_t(v)} &= Z_t - mc_t(v) \varepsilon_{a,t} (1 - \varphi_i) \alpha \left[K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{-\varphi_i} \\ &\times X_t^s(v)^{\varphi_i} K_t(v)^{\alpha-1} H_t(v)^{1-\alpha} = Z_t - mc_t(v)(1 - \varphi_i) \alpha \frac{X_t(v)}{K_t(v)^\alpha H_t(v)^{1-\alpha}} \\ &\times K_t(v)^{\alpha-1} H_t(v)^{1-\alpha} = Z_t - mc_t(v)(1 - \varphi_i) \alpha \frac{X_t(v)}{K_t(v)} = 0 \end{aligned} \quad (\text{C.139})$$

$$\begin{aligned} \frac{\partial \mathcal{L}(H_t(v), K_t(v), X_t^s(v))}{\partial X_t^s(v)} &= P_t^s - mc_t(v) \varphi_i \varepsilon_{a,t} \left[K_t(v)^\alpha H_t(v)^{1-\alpha} \right]^{(1-\varphi_i)} \\ &\times X_t^s(v)^{\varphi_i-1} = P_t^s - mc_t(v) \varphi_i \frac{X_t(v)}{X_t^s(v)} = 0 \end{aligned} \quad (\text{C.140})$$

All intermediate goods producers are identical. Therefore, the first-order conditions of the

cost-minimization problem of all intermediate goods producers with respect to labor, capital, and intermediate inputs given the Cobb-Douglas specification of technology are, respectively:

$$W_t = mc_t(1 - \varphi_i)(1 - \alpha) \frac{X_t}{H_t} \quad (\text{C.141})$$

$$Z_t = mc_t(1 - \varphi_i)\alpha \frac{X_t}{K_t} \quad (\text{C.142})$$

$$P_t^s = mc_t \varphi_i \frac{X_t}{X_t^s} \quad (\text{C.143})$$

C.3 Optimization problems of the two-country model with financial linkages

Assume that physical capital K_t is divided into local and export capital - $K_{h,t}$ and $K_{f,t}$, respectively - according to:

$$K_t(v) = \left[\varphi_k K_{h,t-1}(v)^{\frac{\eta_k-1}{\eta_k}} + (1 - \varphi_k) K_{f,t-1}(v)^{\frac{\eta_k-1}{\eta_k}} \right]^{\frac{\eta_k}{\eta_k-1}} \quad (\text{C.144})$$

Under the assumption of a CES function, which aggregates local and export capital into $K_t(v)$, I get the following optimal demands for local and export capital:

$$K_{h,t}(v) = \varphi_k \left[\frac{Z_{h,t}}{Z_{k,t}} \right]^{-\eta_k} K_t(v) \quad (\text{C.145})$$

$$K_{f,t}(v) = (1 - \varphi_k) \left[\frac{Z_{f,t}}{Z_{k,t}} \right]^{-\eta_k} K_t(v) \quad (\text{C.146})$$

The cost function is the sum of inputs multiplied by their corresponding unit prices:

$$C_t(v) = Z_{k,t} K_{h,t}(v) + Z_{k,t} K_{f,t}(v) + W_t H_t(v) + P_t^s X_t^s(v) \quad (\text{C.147})$$

Substituting for $K_{h,t}$ and $K_{f,t}$ the optimal demands for local and export capital (equations C.144 and C.144) and assuming $Z_{h,t} = Z_{f,t}$ results in the following cost function:

$$C_t(v) = Z_{k,t}^{1-\eta_k} K_t(v) + W_t H_t(v) + P_t^s X_t^s(v) \quad (\text{C.148})$$

Solving the first-order condition of the cost minimization problem for capital $K_t(v)$ given

the Leontief specification of technology yields:

$$K_t(v) = \left[(1 - \varphi_i) \frac{X_t(v)}{H_t(v)^{1-\alpha}} \right]^{\frac{1}{\alpha}} \quad (\text{C.149})$$

The first-order condition of the cost-minimization problem with respect to labor $H_t(v)$ gives the following optimal use of labor in technology $\tilde{H}_t(v)$:

$$\tilde{H}_t(v) = (1 - \varphi_i) \left[\frac{1 - \alpha}{\alpha} \frac{Z_{k,t}}{W_t} \right]^{\alpha} X_t(v) \quad (\text{C.150})$$

Substituting for $H_t(v)$ in equation (C.149) the optimal demand for labor $\tilde{H}_t(v)$ yields the optimal use of capital $\tilde{K}_t(v)$ in technology:

$$\tilde{K}_t(v) = (1 - \varphi_i) \left[\frac{\alpha}{1 - \alpha} \frac{W_t}{Z_{k,t}} \right]^{1-\alpha} X_t(v) \quad (\text{C.151})$$

Substituting for $H_t(v)$ and $K_t(v)$ in the cost function their optimal quantities - $\tilde{H}_t(v)$ and $\tilde{K}_t(v)$ - and using $X_t^s = \varphi_i X_t$ yields:

$$\begin{aligned} \mathcal{C}_t(v) &= Z_{k,t}^{1-\eta_k} (1 - \varphi_i) \left[\frac{W_t}{Z_t} \frac{\alpha}{1 - \alpha} \right]^{1-\alpha} X_t(v) \\ &+ W_t (1 - \varphi_i) \left[\frac{Z_{k,t}}{W_t} \frac{1 - \alpha}{\alpha} \right]^{\alpha} X_t(v) + P_t^s \varphi_i X_t(v) \end{aligned} \quad (\text{C.152})$$

The marginal cost is the derivative of the cost function with respect to output $X_t(v)$:

$$\begin{aligned} \frac{\partial \mathcal{C}_t(v)}{\partial X_t(v)} &= mc_t(v) = Z_{k,t}^{1-\eta_k} (1 - \varphi_i) \left[\frac{W_t}{Z_t} \frac{\alpha}{1 - \alpha} \right]^{1-\alpha} \\ &+ W_t (1 - \varphi_i) \left[\frac{Z_{k,t}}{W_t} \frac{1 - \alpha}{\alpha} \right]^{\alpha} + \varphi_i P_t^s \end{aligned} \quad (\text{C.153})$$

which can be simplified into the following formula with the weighted unit cost of value-added and intermediate inputs:

$$mc_t(v) = (1 - \varphi_i) \frac{Z_{k,t}^{\alpha} W_t^{1-\alpha} (1 - \alpha + \alpha Z_{k,t}^{-\eta_k})}{\alpha^{\alpha} (1 - \alpha)^{1-\alpha}} + \varphi_i P_t^s \quad (\text{C.154})$$

Domestic banks extend their lending to both domestic and foreign intermediate goods producers. They now hold two types of financial assets as part of their portfolio: (i) assets backed by local domestic capital and (ii) assets backed by foreign export capital:

$$S_{h,t-1} = K_{h,t} \quad (\text{C.155})$$

$$S_{f,t-1} = K_{h,t}^* \quad (\text{C.156})$$

The liabilities part of domestic banks' balance sheet is composed of deposits collected from households in both countries and the net worth N_t :

$$Q_t S_{h,t} + s_t Q_t^* S_{f,t} + q_t B_{b,t} = N_t + D_t \quad (\text{C.157})$$

where the net worth evolves according to the following rule:

$$N_t = R_{k,t} Q_{t-1} S_{h,t-1} + R_{k,t}^* s_t Q_{t-1}^* S_{f,t-1} + R_{b,t} q_{t-1} B_{b,t-1} - R_t D_{t-1} + J_{t-1} \quad (\text{C.158})$$

From (C.157) deposits are given by:

$$D_t = Q_t S_{h,t} + s_t Q_t^* S_{f,t} + q_t B_{b,t} - N_t \quad (\text{C.159})$$

So, by substituting the definition of deposits from (C.159) in $t - 1$ into (C.158), the net worth becomes:

$$\begin{aligned} N_t = & (R_{k,t} - R_t) Q_{t-1} S_{h,t-1} + (R_{k,t}^* - R_t) s_t Q_{t-1}^* S_{f,t-1} \\ & + (R_{b,t} - R_t) q_{t-1} B_{b,t-1} + R_t N_{t-1} + J_{t-1} \end{aligned} \quad (\text{C.160})$$

The end-of-period value function with the issuance of new equity J_t conditional on the survival of the bank is:

$$\mathcal{V}_t(N_t) = \max_{S_{h,t}, S_{f,t}, J_t, D_t} \mathbb{E}_t \left[\Lambda_{t,t+1} \left[\begin{array}{c} (1 - \sigma) N_{t+1} \\ + \sigma (\mathcal{W}_{t+1}(N_{t+1}) - J_t - C(J_t, N_t)) \end{array} \right] \right] \quad (\text{C.161})$$

The bankers' maximization problem is to choose their portfolio of $S_{h,t}$, $S_{f,t}$, and $B_{b,t}$ to maximize $\mathcal{V}_t(N_t)$ subject to the following incentive constraint:

$$\mathcal{V}_t(N_t) \geq \theta(Q_t S_{h,t} + s_t Q_t^* S_{f,t}) + \Gamma \theta q_t B_{b,t} \quad (\text{C.162})$$

and to choose their equity issuance J_t to maximize $\mathcal{W}_{t+1}(N_{t+1})$ subject to the definition of net worth given by (C.160); assuming at the same time the existence of a linear solution of the form $\mathcal{V}_t = \mu_{s,t}(Q_t S_{h,t} + s_t Q_t^* S_{f,t}) + \mu_{b,t} q_t B_{b,t} + v_t N_t$ and $\mathcal{W}_t = \eta_t N_t$.

The bank's optimization problem is solved by guessing a linear value function on assets

and deposits:

$$\mathcal{V}_t(S_{h,t}, S_{f,t}, B_{b,t}, N_t) = \mu_{s,t}(Q_t S_{h,t} + s_t Q_t^* S_{f,t}) + \mu_{b,t} q_t B_{b,t} + v_t N_t \quad (\text{C.163})$$

The Lagrangian is formalized as:

$$\begin{aligned} \mathcal{L}_t(S_t, B_{b,t}) &= \mu_{s,t} Q_t S_t + \mu_{b,t} q_t B_{b,t} + v_t N_t \\ &- v_t \left(\theta Q_t S_t + \Gamma \theta q_t B_{b,t} - \mu_{s,t} Q_t S_t - \mu_{b,t} q_t B_{b,t} - v_t N_t \right) \end{aligned} \quad (\text{C.164})$$

The first-order conditions with respect to $S_{h,t}$, $S_{f,t}$, $B_{b,t}$, v_t and are expressed as follows:

$$\mu_{s,t} = \theta \frac{v_t}{1 + v_t} \quad (\text{C.165})$$

$$\mu_{b,t} = \Gamma \frac{v_t}{1 + v_t} \quad (\text{C.166})$$

$$\theta(Q_t S_{h,t} + s_t Q_t^* S_{f,t}) + \Gamma \theta q_t B_{b,t} - \mu_{s,t}(Q_t S_{h,t} + s_t Q_t^* S_{f,t}) - \mu_{b,t} q_t B_{b,t} - v_t N_t = 0 \quad (\text{C.167})$$

At the end of each period, an individual bank maximizes the present value of its future dividends given the quadratic cost of equity issuance:

$$\begin{aligned} \mathcal{V}_t(N_t) &= \max_{S_{h,t}, S_{f,t}, J_t, D_t} \mathbb{E}_t \left[\Lambda_{t,t+1} \left[\begin{aligned} &(1 - \theta_b) N_{t+1} \\ &+ \theta_b \left(\mathcal{W}_{t+1}(N_{t+1}) - J_t - \frac{\zeta}{2} \frac{J_t^2}{N_t} \right) \end{aligned} \right] \right] \\ \text{s.t. } &\mathcal{V}_t(S_{h,t}, S_{f,t}, B_{b,t}, N_t) \geq \theta(Q_t S_{h,t} + s_t Q_t^* S_{f,t}) + \Gamma \theta q_t B_{b,t} \\ \text{for } &N_{t+1} = (R_{k,t+1} - R_{t+1}) Q_t S_{h,t} + (R_{k,t+1}^* - R_{t+1}) s_t Q_t^* S_{f,t} \\ &+ (R_{b,t+1} - R_{t+1}) q_t B_{b,t} + R_{t+1} N_t + J_t \end{aligned} \quad (\text{C.168})$$

The first-order condition of the optimization problem of banks with respect to $S_{h,t}$ is:

$$\mathbb{E}_t [\Lambda_{t,t+1} \Omega_{t+1} (R_{k,t+1} - R_{t+1})] = \theta \lambda_t \quad (\text{C.169})$$

The first-order condition of the optimization problem of banks with respect to $S_{f,t}$ is:

$$\mathbb{E}_t [\Lambda_{t,t+1} \Omega_{t+1} s_t (R_{k,t+1}^* - R_{t+1})] = \theta \lambda_t \quad (\text{C.170})$$

The first-order condition with respect to $B_{b,t}$ is:

$$\mathbb{E}_t [\Lambda_{t,t+1} \Omega_{t+1} (R_{b,t+1} - R_{t+1})] = \theta \Gamma \lambda_t \quad (\text{C.171})$$

The conditions given by equations (C.170) and (C.171) result in the following interest rate parity between investment in local and foreign assets:

$$\mathbb{E}_t \left[\hat{s}_t + \hat{R}_{k,t+1}^* \right] = \mathbb{E}_t \hat{R}_{k,t+1} \quad (\text{C.172})$$

where variables in hats denote log deviations from non-stochastic steady-state.

The objective of the banker is to issue equity to maximize $\mathcal{W}_{t+1}(N_{t+1})$ subject to (C.160):

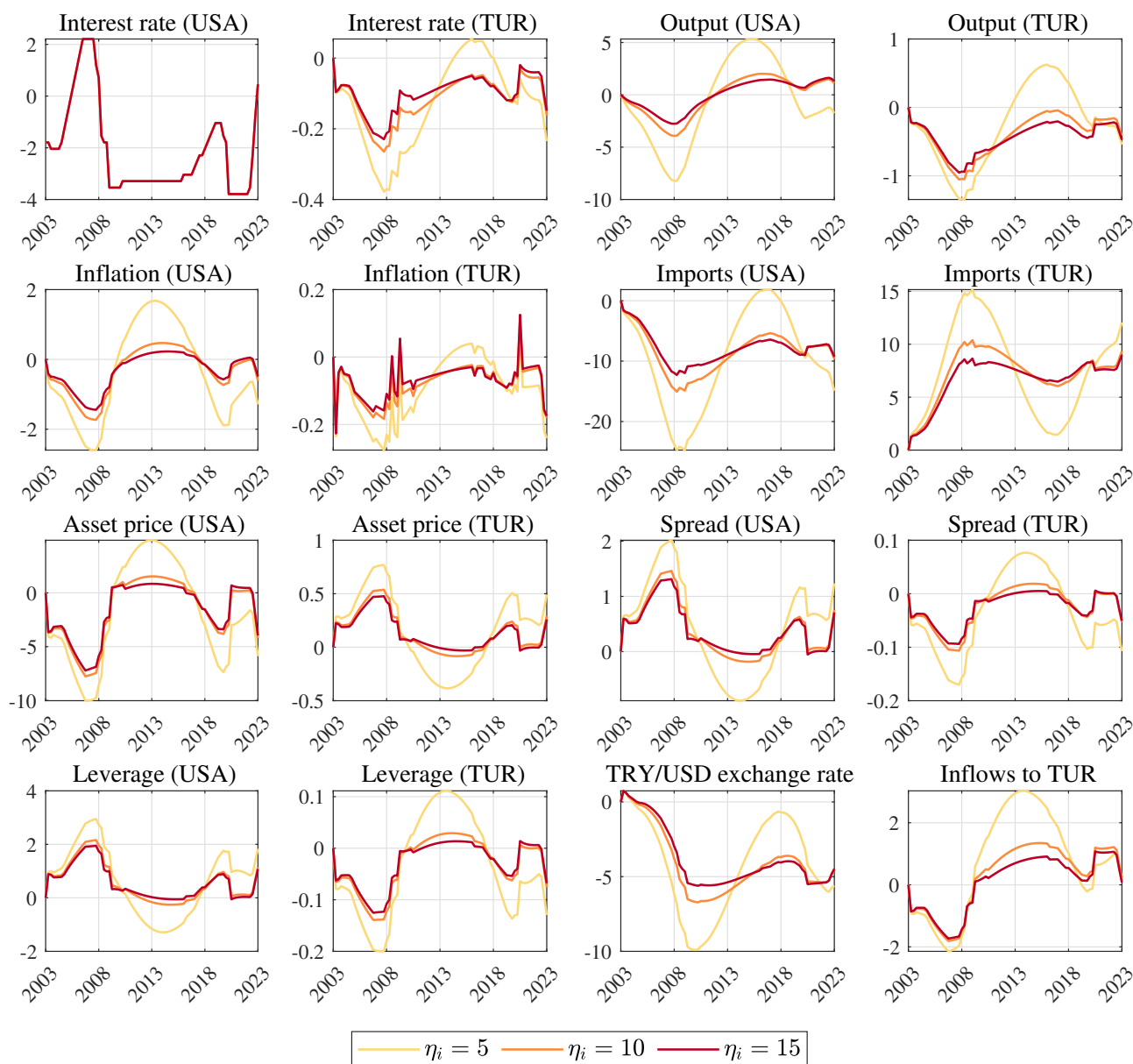
$$\max_{J_t} \mathbb{E}_t \left[\Lambda_{t,t+1} \left[\Omega_{t+1} \left[\begin{array}{c} (R_{k,t+1} - R_{t+1})Q_t S_t \\ + (R_{k,t+1}^* - R_{t+1})s_t Q_t^* S_t^* \\ + (R_{b,t+1} - R_{t+1})q_t B_{b,t} \\ + R_{t+1}N_t + J_t \end{array} \right] - J_t - \frac{\zeta}{2} \frac{J_t^2}{N_t} \right] \right] \quad (\text{C.173})$$

The first-order conditions of which remain unchanged relative to the version of the model without lending to the foreign economy with the exception that now the banks' leverage ϕ_t is defined as:

$$\phi_t \equiv \frac{Q_t S_{h,t} + s_t Q_t^* S_{f,t} + \Gamma q_t B_{b,t}}{N_t} \quad (\text{C.174})$$

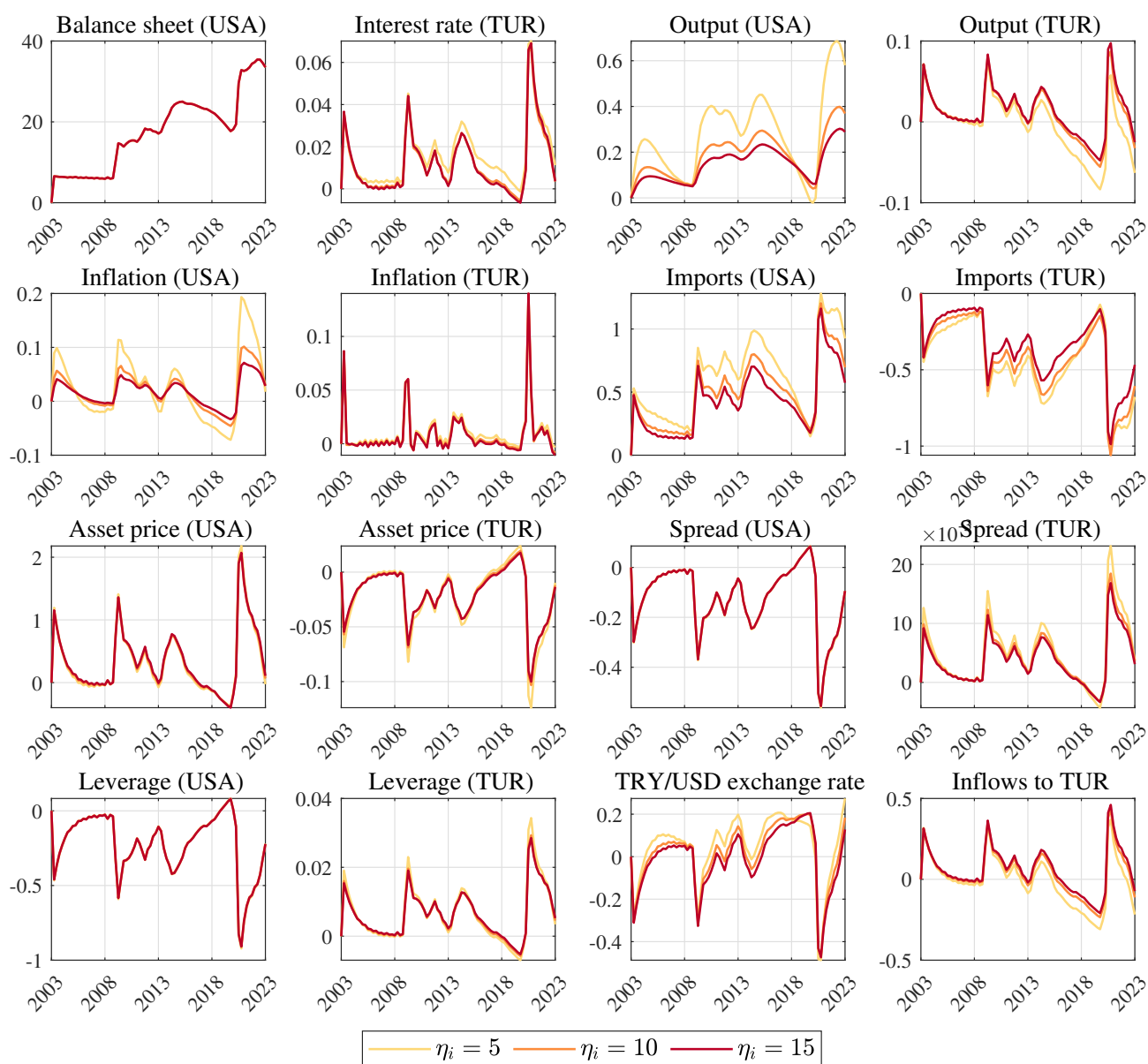
C.4 Sensitivity checks

Figure C.1: Sensitivity analysis: investment adjustment cost. Conditional forecast of the US conventional monetary policy path.



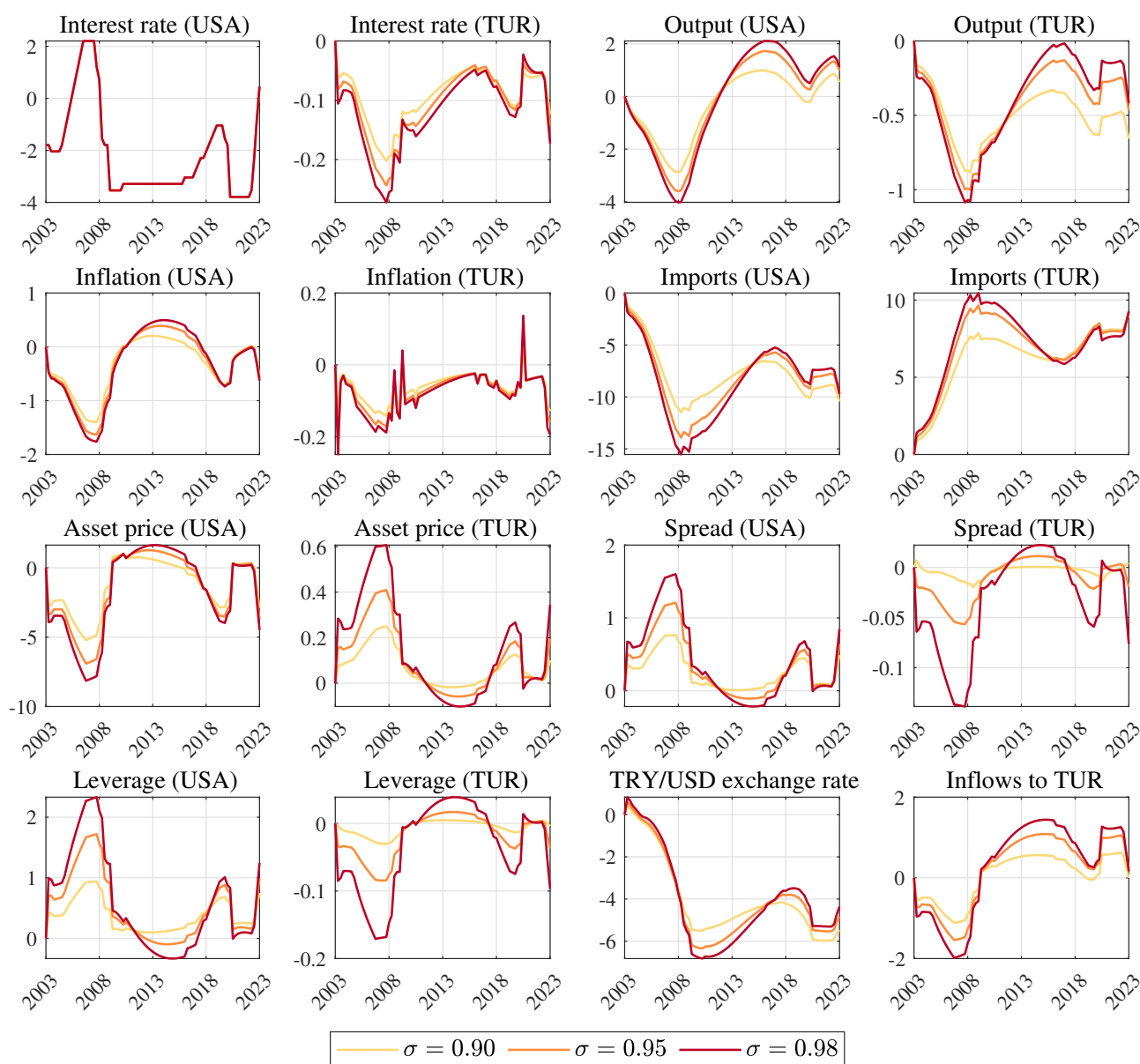
Notes: Simulations based on the model with supply chains and financial linkages.

Figure C.2: Sensitivity analysis: investment adjustment cost. Conditional forecast of asset purchases by the US Fed.



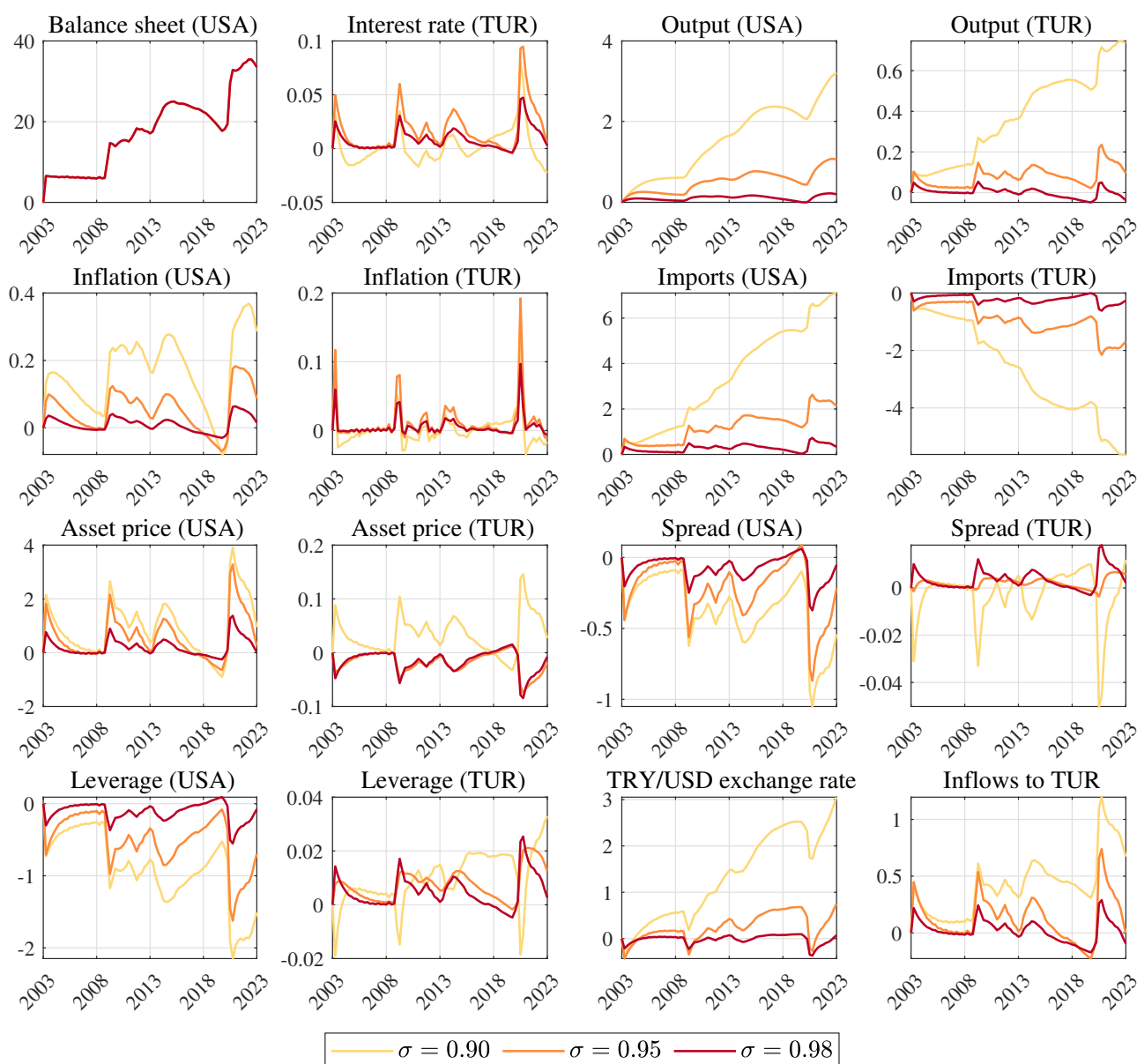
Notes: Simulations based on the model with supply chains and financial linkages.

Figure C.3: Sensitivity analysis: survival rate of banks. Conditional forecast of the US conventional monetary policy path.



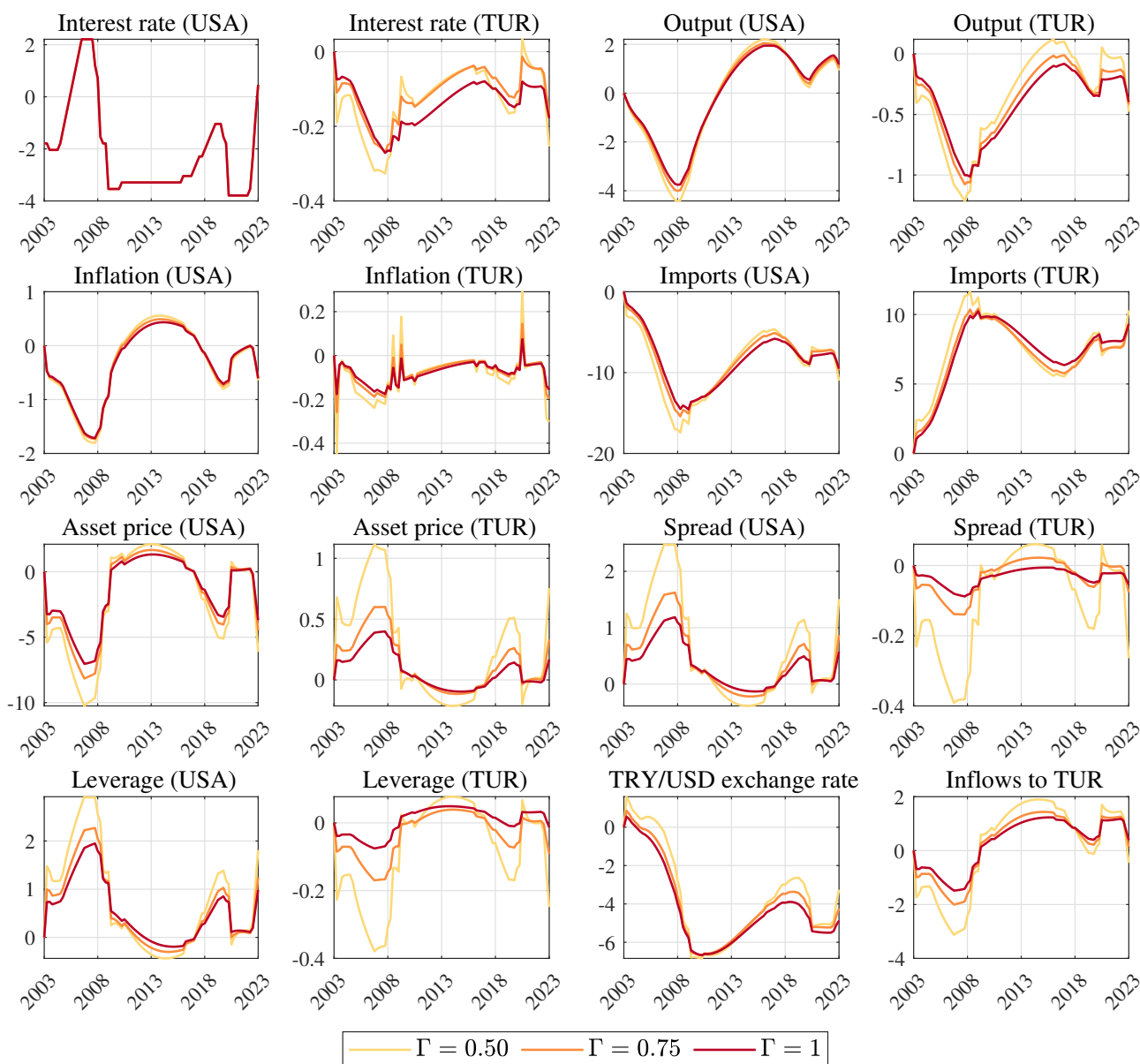
Notes: Simulations based on the model with supply chains and financial linkages.

Figure C.4: Sensitivity analysis: survival rate of banks. Conditional forecast of asset purchases by the US Fed.



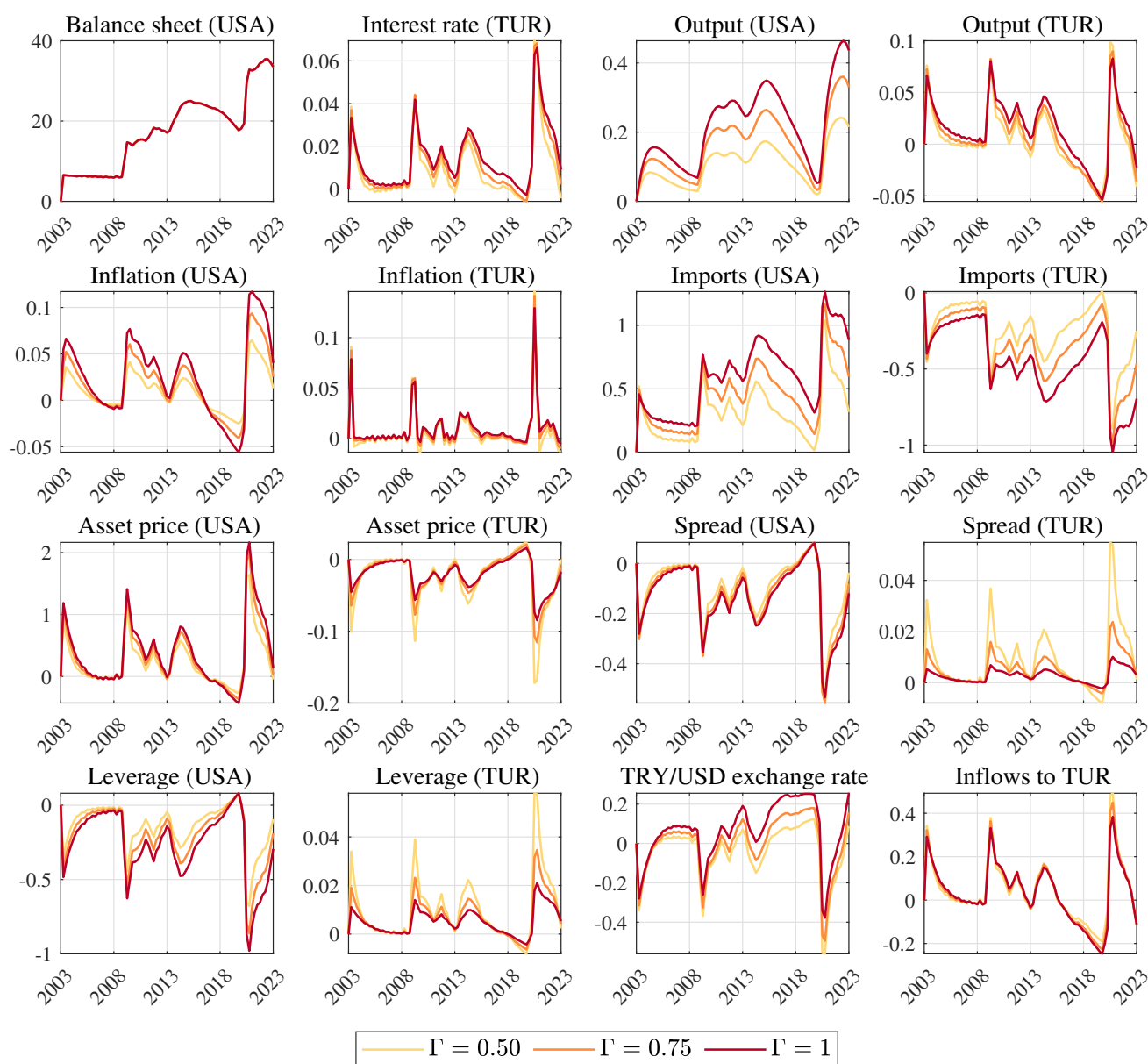
Notes: Simulations based on the model with supply chains and financial linkages.

Figure C.5: Sensitivity analysis: proportional advantage in absconding rate. Conditional forecast of the US conventional monetary policy path.



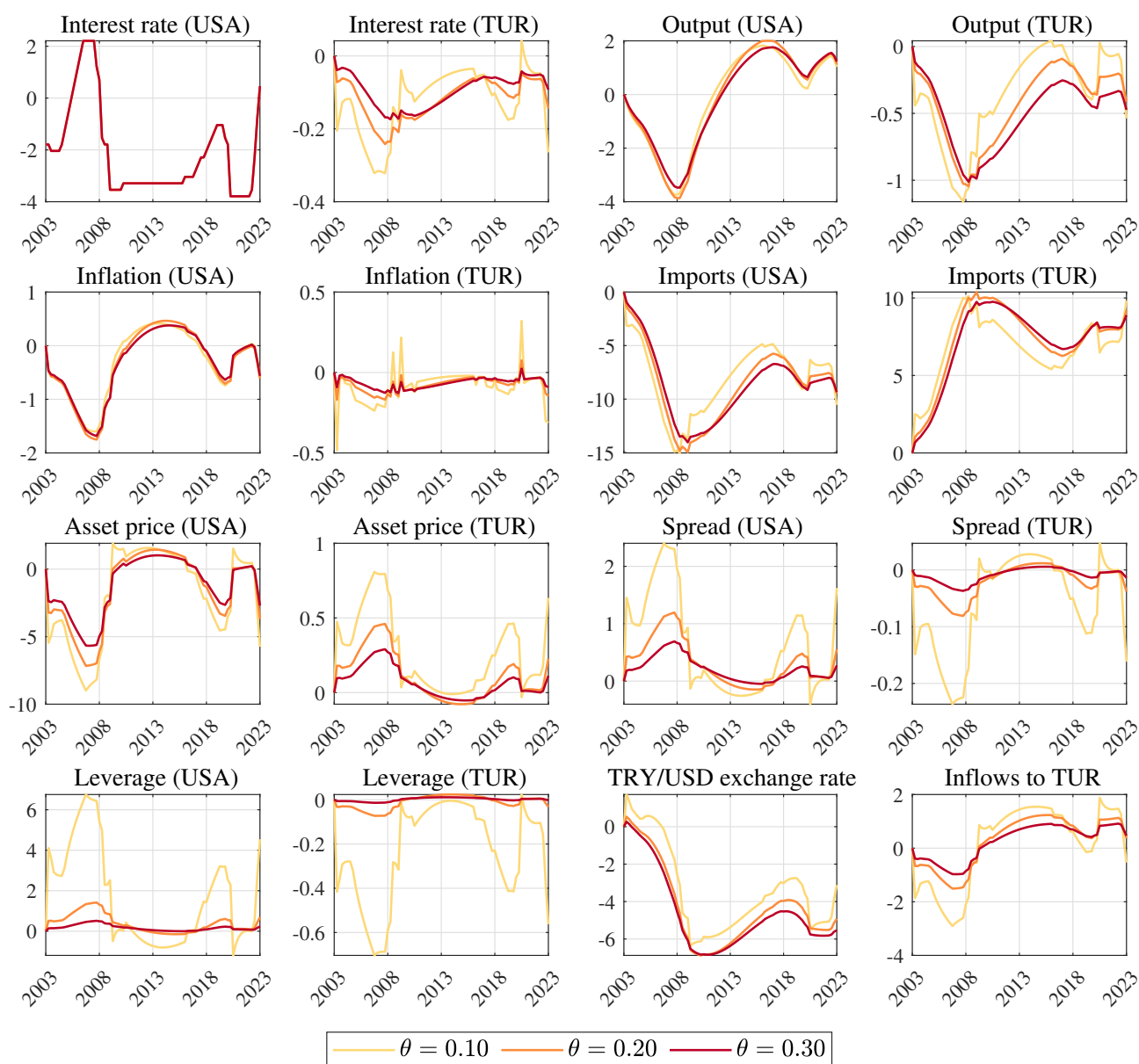
Notes: Simulations based on the model with supply chains and financial linkages.

Figure C.6: Sensitivity analysis: proportional advantage in absconding rate. Conditional forecast of asset purchases by the US Fed.



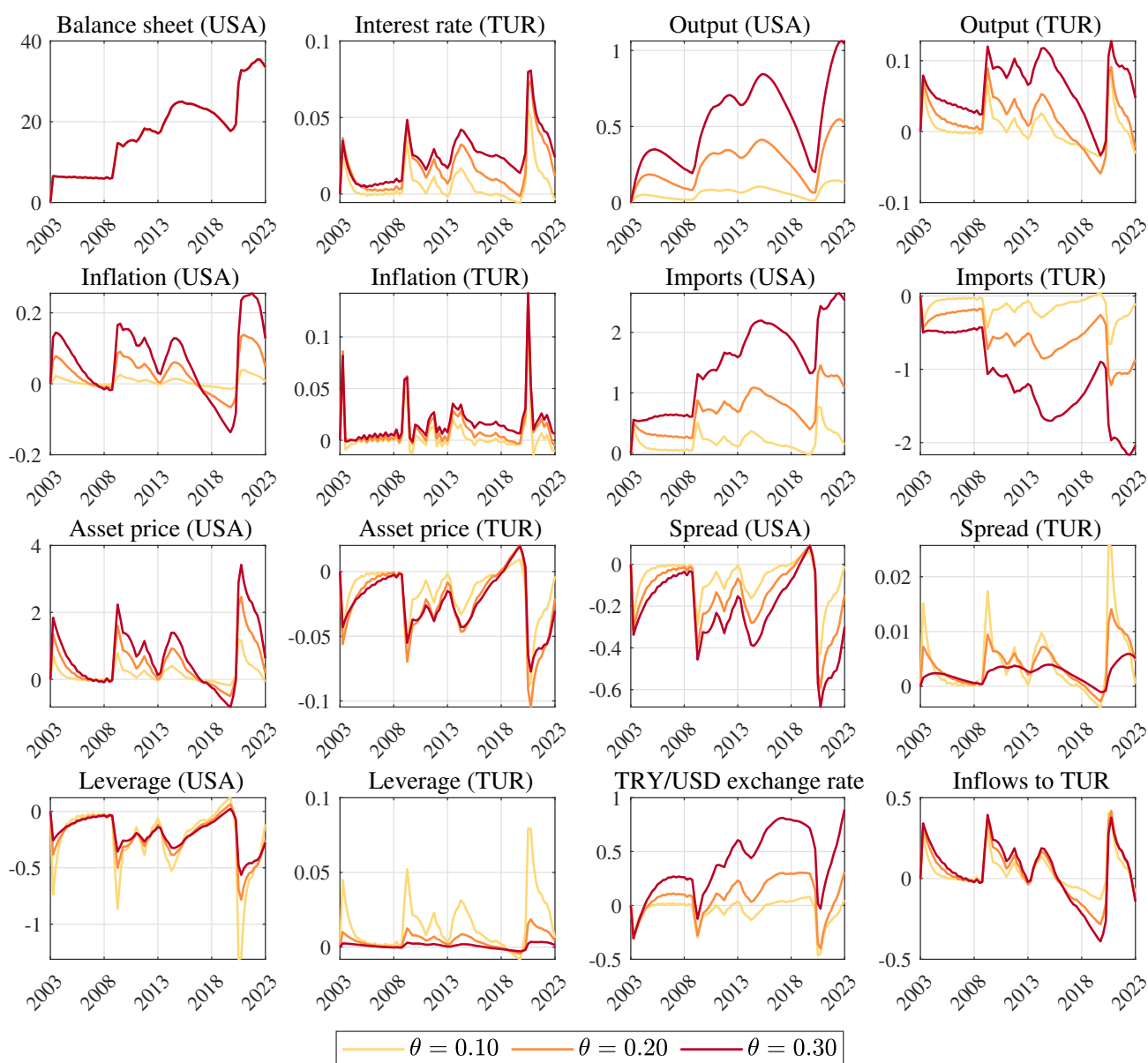
Notes: Simulations based on the model with supply chains and financial linkages.

Figure C.7: Sensitivity analysis: fraction of divertable funds. Conditional forecast of the US conventional monetary policy path.



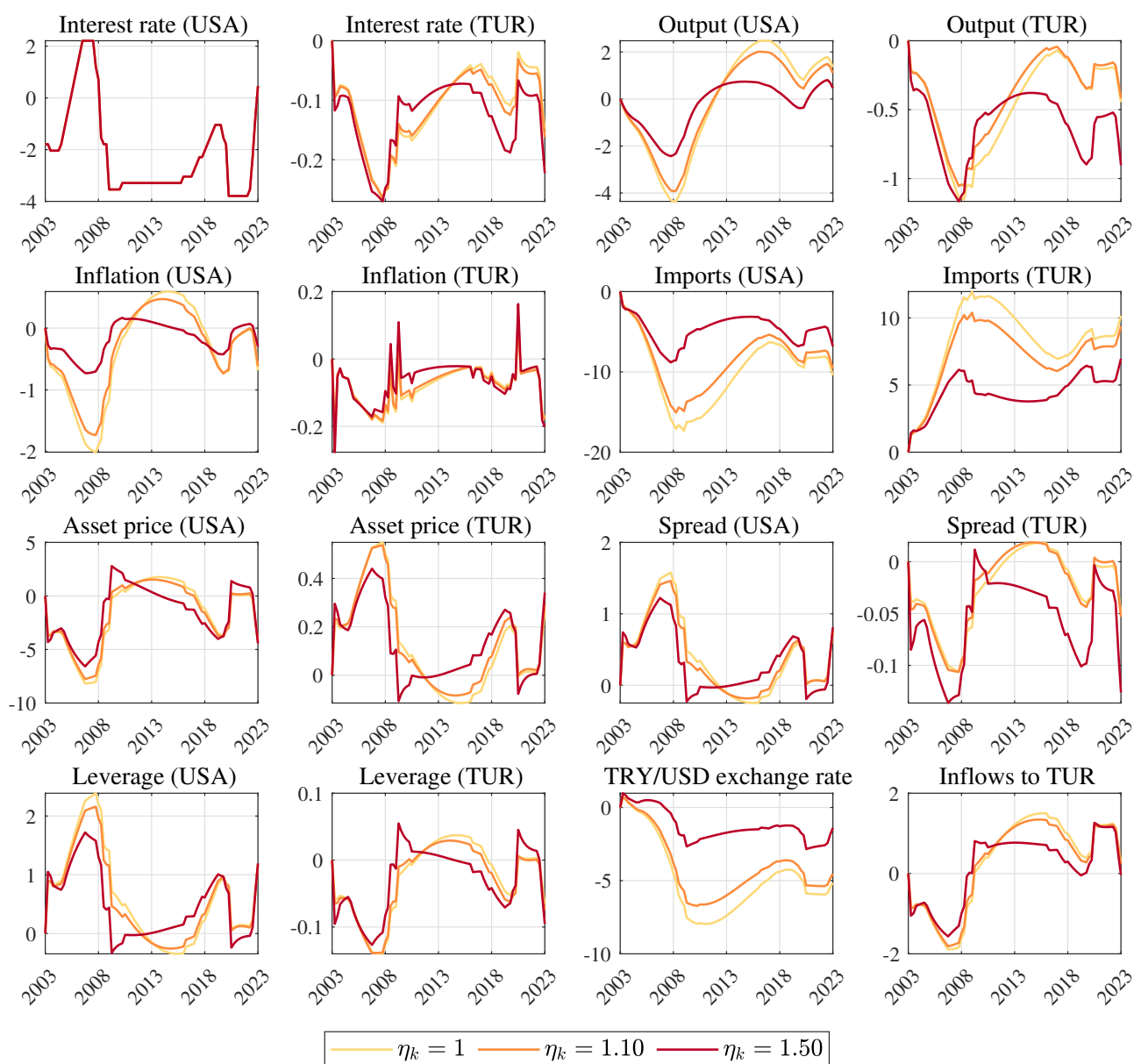
Notes: Simulations based on the model with supply chains and financial linkages.

Figure C.8: Sensitivity analysis: fraction of divertable funds. Conditional forecast of asset purchases by the US Fed.



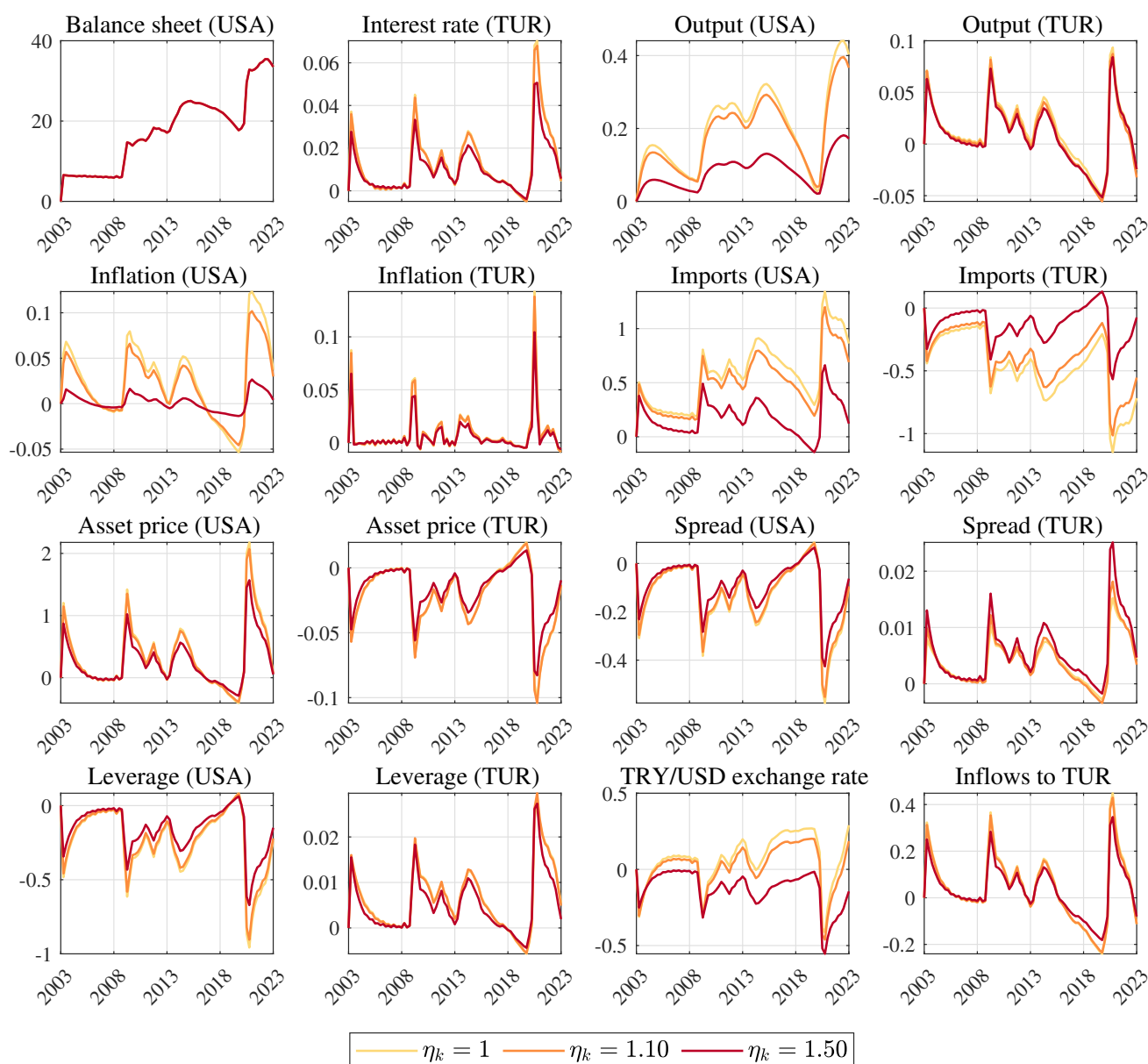
Notes: Simulations based on the model with supply chains and financial linkages.

Figure C.9: Sensitivity analysis: elasticity of substitution between local and export capital. Conditional forecast of the US conventional monetary policy path.



Notes: Simulations based on the model with supply chains and financial linkages.

Figure C.10: Sensitivity analysis: elasticity of substitution between local and export capital. Conditional forecast of asset purchases by the US Fed.



Notes: Simulations based on the model with supply chains and financial linkages.