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Abstract

This study develops a symmetric two-country New-Keynesian general equilibrium model with endogenous growth, Calvo-style price and wage rigidities, and international trade of final consumption goods and intermediate goods. The equilibrium implications of two financial market structures are compared: financial autarky and complete markets. In the case of financial autarky, no international bond is traded. In the case of complete markets, the households have access to a full set of international nominal state-contingent bonds. We find that assuming complete markets instead of financial autarky leads to higher co-movement of most macroeconomic growth rates across countries, higher co-movement of inflation rates across countries, lower uncovered interest rate parity regression coefficients, and a lower correlation between exchange rate growth and consumption growth differentials. These results are mostly in line with US and UK data from 1950–2015, which are split into two samples, 1950–1970 and 1971–2015, in order to be compared to the model with financial autarky and the model with complete markets, respectively.

Keywords: International financial markets; Monetary policy; Nominal rigidities; Endogenous growth

JEL: E30; E44; F44; G12; O30

1 Introduction

Financial markets have become increasingly integrated in the recent decades among developed economies. In fact, risk sharing possibilities using domestic and international financial markets seem close to be perfect as the empirical evidence by Fitzgerald (2012) suggests. This is not without consequences for the dynamics of macroeconomic quantities and asset prices. Colacito and Croce (2013) demonstrate that accounting for complete international financial markets in a symmetric two-country real business cycle model can help explaining the dynamics of uncovered interest parity violations and the decrease in the correlation between exchange rate growth and consumption growth differentials over time for the country pair United States and United Kingdom. However, their model does not incorporate endogenous (or exogenous) inflation. Hence, relatively little is known on the impact of the international financial markets structure on equilibrium dynamics in a model that accounts for inflation. With this paper, we attempt bridging a part of this gap and develop a symmetric two-country New-Keynesian general equilibrium model in order to analyze the equilibrium effects of the aforementioned stylized fact that financial markets have become highly integrated in the recent past.

Specifically, we compare the implications of a model with complete financial markets to the results of an equivalent model in which households live in financial autarky for macro quantities, inflation, and financial variables. Complete financial markets are introduced by giving households access to a complete set of nominal state-contingent bonds. In financial autarky, no international bond is traded between the countries.

Regarding the more standard model ingredients, the households display Epstein and Zin (1989) preferences and consume both countries' final goods. Hence, additionally to the possibility that international financial markets are present in the model there is a channel for real final goods trade and thus for sharing risks using goods markets. Moreover, intermediate goods are also traded across countries. Additionally, there are demand shocks in our model by assuming that the home bias parameter in the consumption bundle is stochastic. The households provide a continuum of labor services to domestic firms. Labor is not mobile across countries. The intermediate goods are produced using labor, physical capital, and intangible capital by monopolistically competitive firms. Intermediate goods are then bundled together by a perfectly competitive final goods firm. Both physical and intangible capital are subject to convex adjustment costs in the spirit of Jermann (1998). The presence of intangible capital and investment in research and development (R&D) gives rise to sustainable endogenous growth, as in the model of Kung (2015). Wages and prices are subject to nominal rigidities following Schmitt-Grohé and Uribe (2006) in the spirit of Calvo (1983). Hence, only a fraction of wages and prices are allowed to adjust optimally in a given period. The monetary authorities in our model set the nominal interest rate separately in each country by accounting for interest rate smoothing, deviations of the inflation rate from target, and the output gap in its economy.

To discipline the model, we calibrate it using US data. UK data are used as a foreign country representative for cross-country comparisons. The data span the period from 1950 to 2015. We split the sample into an early period from 1950 to 1970 which is characterized by weak financial integration (a counterpart of financial autarky in our theoretical model) and a late sample from 1971 to 2015 which is characterized by high financial integration (an analogue to a complete markets case in our model). The theoretical model is calibrated to match the key moments of the early sample 1950–1970. We then use the same calibration and assume complete financial markets to investigate which moments change with this assumption, and if the change in the structure of financial markets can partly account for the data moments in the late sample 1971–2015.

The financial autarky model is relatively well in line with the major macroeconomic moments in the early sample. Notably, investments are much more volatile than output growth, as in the data. The volatility of employment is higher than volatility of real wages both in the data and in the model. Moreover, consumption growth is more volatile than output growth, as in our data sample. When complete financial markets are introduced, average output growth significantly increases and average inflation rates go up. The first observation is contrary to the data, but the second one is aligned with the moments in the data. The levels and dynamics of risk-free rates follow data patterns closely. Even though risk-premia fall short of the levels seen in the data, their contraction with increasing integration of financial markets stands in line with the data. Also in line with the data, the model produces considerable co-movement of consumption growth and output growth across countries, a part of it is due to the presence of common productivity shocks but a part of it is also endogenous. Additionally, the cross-country correlation of output growth endogenously increases considerably replicating the shift present in the data. The simulated increase in cross-country co-movements of capital investment, labor, and inflation rates when moving from financial autarky to complete markets closely resembles movements in the data. Similarly, the correlation of risk-free rates across countries increases, tracking the data. One of the financial market puzzles, the forward premium anomaly associated with the uncovered real interest rate parity regression coefficient in our model is well in line with its data counterpart. Moreover, it drops considerably once financial markets become more integrated following the shift in the data. Last but not least, when financial markets are introduced the correlation between exchange rate growth and the consumption growth differential shrinks dramatically, as in the data.

Admittedly, the model faces difficulties in creating high equity premia and their volatilities and high exchange rate volatility. Moreover, labor growth is too volatile in the model. When the economy moves from financial autarky to complete markets, consumption and output also become too volatile, possibly compensating for too low inflation and its volatility in the complete markets case.

Our paper belongs to the strand of literature analyzing different forms of economic integration in a multi-country model set-up. Specifically, we ask the question about the effects of financial integration (financial autarky vs. complete markets) on the joint dynamics of macroeconomic and financial variables. In terms of our objective we are closest to Colacito and Croce (2010), Colacito and Croce (2013), or Coeurdacier, Rey, and Winant (2015) in asking similar questions in a related (yet, not identical) model set-up. Regarding the model structure, ours resembles most the macro-financial frameworks used in Kogan (2001), Evers (2015), and Colacito, Croce, Ho, and Howard (2018).

The results of our model contain a mix of findings. Most macro quantities and their correlations are well in line with the data and some other studies (see, e.g., Kogan, 2001; Tretvoll, 2018; Colacito, Croce, Ho, and Howard, 2018). We also find cross-country correlations close to actual data, which has also been documented by Colacito and Croce (2010), Colacito and Croce (2011), and Colacito and Croce (2013). Finally, our model resolves certain asset pricing puzzles and repeats some of the results by, e.g., Colacito and Croce (2013) and Colacito, Croce, Ho, and Howard (2018).

The novelty of our results comes from the additional features of the model, such as the inclusion of labor markets, wage and price setting frictions, and inflation dynamics, where we document some plausible results, complementing the studies by Kogan (2001), Favilukis and Lin (2016), and Colacito, Croce, Ho, and Howard (2018).

The most important related literature is reviewed in Section 2. Section 3 presents the model, its calibration is discussed in Section 4, and the results are presented in Section 5. Finally, Section 6 summarizes and concludes this study.

2 Related Literature

The literature that we most relate ourselves to is dealing with different forms of economic integration in a multi-country model set-up. The different economic integration forms may capture a range of financial integration (financial autarky, partially integrated markets, complete markets), monetary policy integration regimes (independent monetary policies, monetary union), or fiscal policy integration regimes (independent fiscal policies, partial and complete fiscal unions). The research questions targeted in this strand of literature typically include the explanation of a number of stylized facts in finance and economics, the analysis of shock transmission channel differences, and the welfare analysis of financial, monetary, or fiscal integration.

Our aim is to construct a model that is a good representation of the macro-financial state in the countries and to illustrate the changes in the economies when moving from financial autarky to complete markets (i.e. different forms of financial integration). A particular question at hand is to understand the impact of the structure of international financial markets on the equilibrium dynamics of macroeconomic and financial quantities.

A similar question in a quite similar set-up to ours is raised in the study of Colacito and Croce (2013). They develop a two-country endowment economy where the households consume both countries' final goods and the consumption growth processes in both countries are subject to cross-country correlated short- and long-run risk shocks. With their model at hand, Colacito and Croce (2013) compare the equilibrium when households live in financial autarky to the equilibrium when households have a complete set of international state-contingent bonds available for trade. In particular, the move from financial autarky to complete markets can explain two anomalies observed in US and UK data. First, the correlation between exchange rate growth and consumption growth differentials has decreased over time (Backus and Smith, 1993). Second, the tendency of currencies in high real interest rate countries to appreciate has become more severe over time (Fama, 1984), leading to lower coefficients in uncovered interest rate parity regressions. We go a step further and extend their model set-up to a production economy by introducing intermediate and final goods, as well as labor, wage, and price setting decisions. Our model thus not only (partially) replicates the main results of Colacito and Croce (2013) but also provides some insight into the bahavior of labor, wages, prices, and other macro variables.

Relatively tightly connected to our research question are also the studies by Colacito and Croce (2010) and Coeurdacier, Rey, and Winant (2015). Colacito and Croce (2010) include long-run risks in a two-country endowment economy with international trade in consumption goods and study the model under both financial autarky and complete markets regimes. The authors find sizable welfare losses of the order of around ten percent of lifetime consumption when international financial markets are shut down in the model (i.e. when moving from complete markets to financial autarky). Our model improves on Colacito and Croce (2010) results by explaining a higher and more correlated risk-free rate in complete markets. An even more similar set-up to ours is developed in Coeurdacier, Rey, and Winant (2015) where a two-country neoclassical growth model is employed. The countries are allowed to differ in their size, capital scarcity, and risk. Three different financial market structures are considered: financial autarky, incomplete markets, in which only a risk-free bond is traded between countries, and complete markets. The model is used to derive welfare gains of financial integration for developed countries on the one hand and emerging economies on the other hand. The effects of different risk parameters on consumption and investment volatilities, risk-free rate, risk premium, and market price of risk are measured. However, the resulting counteracting nature of these effects produces rather small welfare gains (at most a few percentage points of lifetime consumption) even if one considers the most favorable case where risk premia are high and international financial markets are complete, in contrast to the results of Colacito and Croce (2010). The study by Coeurdacier, Rey, and Winant (2015) relates to our analysis in its turn to production economies and implications for macro and asset pricing moments under a varying degree of financial integration.

A study that is very close to ours in terms of model set-up, yet posing different questions, is the study by Evers (2015). His main focus is on the impact of fiscal authority arrangements on regional consumption, output, and employment stability over the business cycle. The author assumes a monetary union economy under three different forms of fiscal federalism which are compared in terms of their welfare effects. While welfare gains are found under the central fiscal authority regime, welfare losses are generated in the fiscal equalization arrangement. Both effects stem from different magnitudes of consumption fluctuations. Overall, the model's macro moments are remarkably close to data moments but highly resistant to changes in the fiscal authority regime. A particular feature that we borrow from the model in Evers (2015) is the engagement of the two economies in the production and trade of intermediate goods, which are used in the production of the final good.

Our model composition also resembles a lot the one by Kogan (2001). The author introduces a two-country production economy with sticky nominal prices and wages that help generating cross-country correlations of output and returns that are much higher and closer to the data. Kogan (2001) demonstrates that despite output and asset returns being highly positively correlated across many industrialized countries, the widely used standard business cycle models (RBS type) with flexible prices and wages cannot not easily explain this stylized fact. He shows that introduction of sticky nominal prices and wages helps bringing the predictions of the theoretical model closer to the actual data moments. While Kogan (2001) does not engage into analysis of different financial integration regimes, we show that in a model with sticky prices and wages the move from financial autarky to complete markets generates higher cross-country correlations that go in the same direction as in Kogan (2001).

Colacito, Croce, Ho, and Howard (2018) present one more study that resembles closely our model structure, yet targeting different objectives in their analysis. The authors suggest an international production economy model with short- and long-run productivity shocks. Colacito, Croce, Ho, and Howard (2018) analyze the importance of various economic elements (assumptions) for the model's ability to represent real-economy data. The most successful benchmark model incorporates high relative risk aversion and high intertemporal elasticity of substitution, milder investment home bias (relative to consumption home bias), and heterogeneous productivity capital. It is able to partially explain the Backus-Smith puzzle, replicate volatilities of consumption and output, produce realistic average risk-free rates and excess returns, and high volatility of the exchange rate.

Our model is also distantly related to a number of empirical studies (mostly from central banks) using two-country New-Keynesian DSGE frameworks with price and wage setting frictions to explore the effects of shocks and regimes or policy changes on the economies. One of the first examples of such a model is provided by Laxton and Pesenti (2003), which is used to explore the effectiveness of rules in stabilizing output and inflation variability. Other examples include the models by, e.g., Silveira (2006), Alves, Gomes, and Sousa (2007), and Breuss and Rabitsch (2009). While the focus of these studies is mostly on the replication of macroeconomic moments and output variance decomposition, the macroeconomic framework used is relatively similar to ours.

Our model features price and wage rigidities as in Schmitt-Grohé and Uribe (2006) in the style of Calvo (1983). Weber (2015) provides additional support to the presence of price stickiness by developing a multi-sector New Keynesian model with Calvo price rigidities differing in sector's frequency of price adjustment. The author is able to replicate excess return for firms that adjust their prices infrequently over firms that adjust more frequently, compatible with their empirical counterparts, thus explicitly showing the importance of price rigidities. Uhlig (2007) and Favilukis and Lin (2016) demonstrate the usefulness of wage rigidities in helping to match asset pricing moments. In addition, we build a model in which long-run inflation is not nil and there is no subsidy to factor inputs, as advocated by Schmitt-Grohé and Uribe (2007) using a related model framework.

Exogenous long-run risk shocks are small, persistent shocks to the expected growth rate of consumption or productivity that have been proven to be effective in explaining a number of asset pricing puzzles (see, e.g., Bansal and Yaron, 2004; Colacito and Croce, 2011; Croce, 2014). Kung and Schmid (2015) go a step further exploring how these shocks can be micro-founded and find that endogenous long-run risk shocks originate from investments in research and development (R&D) that sustain endogenous economic growth driven by growth in the number of intermediate goods in the economy as in Romer (1990). Coupled with Epstein and Zin (1989) preferences and convex adjustment costs as in Jermann (1998), they show how to obtain an endogenous consumption process similar to the one in the economies with exogenous long-run risk shocks. These endogenous long-run risks also prove successful in explaining the term structure of nominal and real interest rates by accounting for endogenous growth in a New-Keynesian model developed by Kung (2015) with menu costs as in Rotemberg (1982). Moreover, he incorporates convex adjustment costs for both physical and intangible capital. The reason behind this success is a negative endogenous co-movement of the low-frequency components in growth and inflation rates originating from the endogenous growth channel. We follow the approach by Kung (2015) and also account for endogenous economic growth by having both physical and intangible capital subject to adjustment costs in our model. Differently from him, we model price rigidities in the style of Calvo (1983) and add endogenous labor supply to the picture. The importance of recursive Epstein-Zin preferences is also documented by Tretvoll (2018) in analyzing and concluding that recursive preferences are essential for the replication of the high exchange rate volatility seen in the data. The author builds a two-country production economy model with international trade in intermediate goods and recursive preferences to highlight the importance of the latter. In addition, recursive preferences are also helpful in bringing cross-country correlations of macro variables closer to the data.

We cast the research question about the effects of financial integration into a production economy framework with endogenous inflation dynamics. Hence, to the best of our knowledge we are the first ones to analyze the equilibrium impact of different international financial market structures in a medium-scale two-country New-Keynesian dynamic stochastic general equilibrium model. Similar to some other studies we manage to capture the change in Backus-Smith correlation when moving from financial autarky to complete markets, as in Colacito and Croce (2013) or Colacito, Croce, Ho, and Howard (2018). Moreover, our model produces a non-unitary regression coefficient in the uncovered real interest rate parity equation and its sharp fall when moving to complete financial markets setup, as in Colacito and Croce (2013) but unaccounted for by Colacito, Croce, Ho, and Howard (2018).

We are also more successful in capturing realistic correlations of main macro aggregates, as compared to Colacito and Croce (2010) or Colacito, Croce, Ho, and Howard (2018). Moreover, we go a step further by introducing labor into the model and achieve reasonable consumption-labor and output-labor correlations.

Our model contains a rare feature of nominal price setting frictions and thus capturing the behavior of inflation in a macro-financial model framework. The model is able to produce a positive (though, not as high) correlation of inflation across countries seen in the actual data.

We fail to produce a high exchange rate volatility, achieved by Colacito and Croce (2010), Colacito and Croce (2011), Colacito and Croce (2013), Tretvoll (2018), among others. However, this comes at the success of replicating cross-country correlations of certain macro variables observed in the data, unlike in Colacito and Croce (2010), Colacito, Croce, Ho, and Howard (2018).

The risk-free rate in our model and its increase in complete markets is also relatively close to its data counterparts, contrary to the attempts by Colacito and Croce (2010) or Colacito, Croce, Ho, and Howard (2018). The same move has been successfully documented in Colacito and Croce (2013) and Coeurdacier, Rey, and Winant (2015). On the contrary, we do not do well in replicating excess returns and obtaining annual equity premia as large as in the data, which has been shown in Colacito and Croce (2011), Croce (2014), and Colacito, Croce, Ho, and Howard (2018).

Overall, our model features quite an informative illustration of what happens to macro and, to a lesser extent, financial moments when the economies move from financial autarky to complete financial markets.

3 Model

This section develops a symmetric two-country New-Keynesian general equilibrium model with Calvo-style price and wage rigidities, in which households invest in physical capital and research and development (R&D) to induce sustainable and balanced endogenous economic growth. Both physical capital and R&D investments are subject to convex adjustment costs.

Households consume an aggregate of both countries' final goods implying the existence of a channel for real international trade in the economy. This international trade channel is assumed to be frictionless, i.e. there are no transportation costs or other frictions impeding the trade of final goods for consumption across countries. We introduce a home bias parameter evolving stochastically to feature a form of demand shocks in the model. The production side of the economy consists of intermediate and final consumption goods producers. Intermediate goods producers use domestic labor and capital as production inputs and are subject to productivity shocks. The intermediate goods produced in the country are bundled together and are used in the production of final goods, both home and abroad. Thus, final goods are produced by using both domestic and foreign bundles of intermediate goods, which are imperfect substitutes of each other. This opens the second channel for real international trade in the model, namely trade in intermediate goods.

International financial markets are either assumed to be complete or completely absent. This implies that we later on analyze two variants of the model, one in which households live in financial autarky and another in which households have access to a complete set of international nominal state-contingent bonds. Finally, the monetary authority of each country, i.e. the home and the foreign country, sets the country-specific nominal interest rate according to a Taylor rule that accounts for interest rate smoothing, inflation targeting, and output gap reduction. The following sections describe the model in detail. In most of the cases, we only give the details and definition for the domestic economy. Whenever needed, quantities with an asterisk as a superscript denote foreign country's quantities.

3.1 Households and the structure of financial markets

Households' preferences in both countries are described by the following utility function as in Epstein and Zin (1989):

$$U_t = \left\{ (1-\beta) v_t^{1-\frac{1}{\psi}} + \beta \left(\mathbb{E}_t [U_{t+1}^{1-\gamma}] \right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}} \right\}^{\frac{1}{1-\frac{1}{\psi}}}, \tag{1}$$

$$U_t^* = \left\{ (1-\beta) (v_t^*)^{1-\frac{1}{\psi}} + \beta \left(\mathbb{E}_t [(U_{t+1}^*)^{1-\gamma}] \right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}} \right\}^{\frac{1}{1-\frac{1}{\psi}}}, \tag{2}$$

where the parameter β is the time discount factor, the parameter γ determines the relative risk aversion (RRA), and the parameter ψ is the elasticity of intertemporal substitution (EIS). This utility specification allows RRA and EIS to be independently chosen. If $\gamma > 1/\psi$, the households display a preference for the early resolution of uncertainty. The quantity v_t (v_t^*) is the utility bundle of the home (foreign) household. It is defined over a bundle of both countries' final goods and leisure in the following way:

$$v_t = \widetilde{C}_t(\bar{L} - L_t)^\tau, \qquad v_t = \widetilde{C}_t^*(\bar{L} - L_t^*)^\tau, \tag{3}$$

$$\widetilde{C}_t = (C_{h,t})^{\phi_t} (C_{f,t})^{1-\phi_t}, \quad \widetilde{C}_t^* = \left(C_{f,t}^*\right)^{\phi_t^*} \left(C_{h,t}^*\right)^{1-\phi_t^*}, \tag{4}$$

where the process ϕ_t determines the home bias, and τ controls the elasticity of the labor supply. The home bias is stochastic in our model to include demand shocks. We assume that the home bias processes follow mean-reverting AR(1) processes defined as follows:

$$\phi_t = \bar{\phi} + \varphi_\phi \cdot (\phi_{t-1} - \bar{\phi}) + \varepsilon_{\phi,t}, \quad \phi_t^* = \bar{\phi} + \varphi_\phi \cdot (\phi_{t-1}^* - \bar{\phi}) + \varepsilon_{\phi,t}^*, \tag{5}$$

where $\bar{\phi}$ denotes the long-run mean of the processes ϕ_t and ϕ_t^*, and φ_ϕ controls the persistence of the shocks induced by the normally distributed shocks $\varepsilon_{\phi,t}$ and $\varepsilon_{\phi,t}^*$ which have mean zero and standard deviation σ_ϕ. The home (foreign) final goods contribution to the home consumption bundle $\widetilde{C}_t$ is denoted by $C_{h,t}$ ($C_{f,t}$). Hence, the home country imports $C_{f,t}$ final goods from abroad. Equivalently, $C_{f,t}^*$ ($C_{h,t}^*$) denote the foreign (home) final goods contribution to the foreign consumption bundle $\widetilde{C}_t^*$.

The households provide a continuum of differentiated labor services $L_{j,t}$ where $j \in [0,1]$. Thus, $L_t = \int_0^1 L_{j,t}dj$ and $L_t^* = \int_0^1 L_{j,t}^*dj$ define the total labor supply of the home and the foreign household, respectively, and $\bar{L}$ is the total time endowment of each household. Labor decisions are made by a central authority within the household sector, i.e. a labor union. This gives rise to monopoly power for the households in supplying labor services. The households' total real wage bills are given by $\int_0^1 w_{j,t}L_{j,t}dj$ and $\int_0^1 w_{j,t}^*L_{j,t}^*dj$, where $w_{j,t}$ and $w_{j,t}^*$ are the real wage rates paid for providing labor service j in the home and the foreign country, respectively. Labor is immobile across countries and thus only provided to local firms.

The households earn these wages and the returns on the physical and intangible capital they rent to the intermediate goods firms, i.e. the home (foreign) household earns $R_{K,t}$ ($R_{K,t}^*$) and $R_{N,t}$ ($R_{N,t}^*$) for renting out physical capital K_t (K_t^*) and intangible capital N_t (N_t^*) to the productive sector of the home (foreign) country. The home (foreign) households invest an amount I_t (I_t^*) in physical capital and an amount S_t (S_t^*) in intangible capital. Furthermore, they decide on how much of their own domestic good they consume and how much they import of the foreign country's good for consumption. Additionally, households own all firms in the economy and thus obtain the aggregate dividend D_t (D_t^*). Hence, the budget constraints of the home and foreign household in the financial autarky case (both denoted in units of the home country's good) are given by:

$$C_{h,t} + P_t^{(h)} C_{f,t} + I_t + S_t = \int_0^1 w_{j,t} L_{j,t} dj + R_{K,t} K_t + R_{N,t} N_t + D_t, \tag{6}$$

$$P_t^{(h)} C_{f,t}^* + C_{h,t}^* + P_t^{(h)} (I_t^* + S_t^*) = P_t^{(h)} \left(\int_0^1 w_{j,t}^* L_{j,t}^* dj + R_{K,t}^* K_t^* + R_{N,t}^* N_t^* + D_t^* \right). \tag{7}$$

When international financial markets are complete, the households have access to a full set of international nominal state-contingent bonds. The time t price of such a bond that pays one unit of the home final good at time $t+1$ in state χ_{t+1} is denoted by $Q_{t+1}(\chi_{t+1})$. The portfolio holdings for these bonds of the home and foreign households are denoted by $A_{t+1}(\chi_{t+1})$ and $A_{t+1}^*(\chi_{t+1})$, respectively. Hence, the budget constraint of the home household becomes:

$$C_{h,t} + P_t^{(h)} C_{f,t} + I_t + S_t + \int_{\chi_{t+1}} A_{t+1}(\chi_{t+1}) \frac{Q_{t+1}(\chi_{t+1})}{\mathcal{P}_t} = \int_0^1 w_{j,t} L_{j,t} dj + R_{K,t} K_t + R_{N,t} N_t + D_t + \frac{A_t}{\mathcal{P}_t}. \tag{8}$$

In those budget constraints, $P_t^{(h)}$ denotes the terms of trade or the price of the foreign final good in home final good units. This price is given by:

$$P_t^{(h)} = \frac{1 - \phi_t}{\phi_t} \frac{C_{h,t}}{C_{f,t}}. \tag{9}$$

Moreover, $\mathcal{P}_t$ denotes the average nominal price index whose dynamics are derived later. The foreign household's budget constraint in the case of complete international financial markets is straightforwardly derived and thus not spelled out here in order to conserve space.

The accumulation of physical and intangible capital obeys:

$$K_{t+1} = (1 - \delta_k) K_t + G_k(I_t / K_t) K_t, \tag{10}$$

$$N_{t+1} = (1 - \delta_n) N_t + G_n(S_t / N_t) N_t, \tag{11}$$

where δ_k (δ_n) is the depreciation rate of physical (intangible) capital, and adjustments costs are captured by the functions $G_k(x) = \alpha_{1,k}/(1-1/\zeta_k)x^{1-1/\zeta_k} + \alpha_{2,k}$ and $G_n(x) = \alpha_{1,n}/(1-1/\zeta_n)x^{1-1/\zeta_n} + \alpha_{2,n}$ following Jermann (1998) and Kung (2015). The constants $\alpha_{1,k}$, $\alpha_{2,k}$, $\alpha_{1,n}$, and $\alpha_{2,n}$ are set so that there are no adjustment costs in the deterministic steady state, and ζ_k (ζ_n) determines the investment elasticity.

Solving the households' optimization problems gives the following equilibrium conditions. First, the home country's real stochastic discount factor used to price quantities denoted in utility bundle units is given by (the foreign country's one is defined similarly):

$$\mathbb{M}_{t,t+1} = \beta \left(\frac{v_{t+1}}{v_t}\right)^{-\frac{1}{\psi}} \left(\frac{U_{t+1}}{\mathbb{E}_t[U_{t+1}^{1-\gamma}]^{\frac{1}{1-\gamma}}}\right)^{\frac{1}{\psi}-\gamma}. \tag{12}$$

Second, the real stochastic discount factors used to price quantities denoted in local good units are determined as follows:

$$\mathbb{M}^{loc}_{t,t+1} = \mathbb{M}_{t,t+1}\frac{v_{t+1}}{v_t}\frac{C_{h,t}}{C_{h,t+1}}, \qquad \mathbb{M}^{loc,*}_{t,t+1} = \mathbb{M}^*_{t,t+1}\frac{v^*_{t+1}}{v^*_t}\frac{C^*_{f,t}}{C^*_{f,t+1}}. \tag{13}$$

Consequently, the nominal pricing kernels of the home household are defined by $\mathbb{M}^{\$}_{t,t+1} = \mathbb{M}_{t,t+1}\mathcal{P}_t/\mathcal{P}_{t+1}$ and $\mathbb{M}^{\$,loc}_{t,t+1} = \mathbb{M}^{loc}_{t,t+1}\mathcal{P}_t/\mathcal{P}_{t+1}$. Equivalent expressions hold for the foreign household. Third, the consumption-leisure trade-off conditions are given by:

$$\frac{\tau C_{h,t}}{\phi(\bar{L}-L_t)} = \frac{w_t}{\lambda_{L,t}}, \qquad \frac{\tau C^*_{f,t}}{\phi(\bar{L}-L_t)} = \frac{w^*_t}{\lambda^*_{L,t}}, \tag{14}$$

where w_t and w^*_t are the average real wages prevailing in the home and the foreign country, and $\lambda_{L,t}$ and $\lambda^*_{L,t}$ are the shadow prices of alleviating the labor demand constraint, given in Equation (43). Fourth, optimal capital investment in the home country is determined by the following Euler equation:

$$1 = \mathbb{E}_t\left[\mathbb{M}^{loc}_{t,t+1}G'_{k,t}\left\{R_{K,t+1} - \frac{I_{t+1}}{K_{t+1}} + \left(\frac{1-\delta_k+G_{k,t+1}}{G'_{k,t+1}}\right)\right\}\right]. \tag{15}$$

Fifth, optimal home country's R&D investment satisfies:

$$1 = \mathbb{E}_t\left[\mathbb{M}^{loc}_{t,t+1}G'_{n,t}\left\{R_{N,t+1} - \frac{S_{t+1}}{N_{t+1}} + \left(\frac{1-\delta_n+G_{n,t+1}}{G'_{n,t+1}}\right)\right\}\right]. \tag{16}$$

The two former conditions are straightforwardly adapted to the foreign country. Solving for the optimal amounts of consumption of the domestic and the foreign good of both households in the case of complete international financial markets gives the following three equilibrium conditions:

$$Z_t \phi_t^* C_{h,t}^* = (1 - \phi_t^*) C_{h,t}, \tag{17}$$

$$Z_t (1 - \phi_t) C_{f,t}^* = \phi_t C_{f,t}, \tag{18}$$

$$Z_t = Z_{t-1} \frac{\mathbb{M}_{t-1,t}}{\mathbb{M}_{t-1,t}^*} \frac{v_t / v_{t-1}}{v_t^* / v_{t-1}^*} \frac{\mathcal{P}_{t-1} / \mathcal{P}_t}{\mathcal{P}_{t-1}^* / \mathcal{P}_{t^*}}, \tag{19}$$

where the quantity $Z_t = \frac{1}{P_t^{(h)}} \frac{C_{h,t}}{C_{f,t}^*}$ constitutes a common factor in the international consumption good allocation. The equations above are structurally similar to the ones derived in Colacito and Croce (2013) for the case of an endowment economy with complete international financial markets. However, an important difference is that we assume that households can trade a complete set of international nominal state-contingent bonds and not a complete set of international real state-contingent bonds. Hence, the definition of Z_t also accounts for inflation rates as visible by the presence of the term $(\mathcal{P}_{t-1}/\mathcal{P}_t)/(\mathcal{P}_{t-1}^*/\mathcal{P}_t^*)$ in Equation (19). Colacito and Croce (2013) call Z_t the "pseudo" Pareto share. We prefer to call it the international consumption allocation factor since we are not solving for the social planner equilibrium here unlike Colacito and Croce (2013). The conditions for the financial autarky case are given by restricting the definition of the international consumption allocation factor to $Z_t \equiv 1$.

3.2 Wage rigidities and labor markets

The household has monopoly power in supplying labor but faces nominal wage rigidities as a fraction of wages cannot be re-set optimally in any given period in the spirit of Calvo (1983) and Schmitt-Grohé and Uribe (2006). The labor union supplies enough labor to satisfy demand for each labor variety j, i.e. $L_{j,t} = L_{j,t}^d = \left(\frac{w_{j,t}}{w_t}\right)^{-\tilde{\eta}} L_t^d = \left(\frac{W_{j,t}}{W_t}\right)^{-\tilde{\eta}} L_t^d$. Hence, the total labor supply satisfies $L_t = L_t^d \int_0^1 \left(\frac{w_{j,t}}{w_t}\right) dj$, where L_t^d denotes the total amount of labor demanded by the intermediate goods firms. The derivation of the intermediate goods firms' demand for each labor variety is relegated to Section 3.4. The nominal wage for variety labor variety j is denoted by $W_{j,t}$ and the corresponding real wage by $w_{j,t}$. Hence, one has $W_{j,t} \equiv w_{j,t} \mathcal{P}_t$ and $W_t \equiv w_t \mathcal{P}_t$. The nominal wage index W_t

is defined by the following equation:

$$W_t := \left[\int_0^1 W_{j,t}^{1-\tilde{\eta}} dj\right]^{\frac{1}{1-\tilde{\eta}}}. \tag{20}$$

The wages are subject to Calvo-style nominal wage rigidities. Specifically, we assume that only a fraction $1-\mu$ of labor markets can set the nominal wage optimally at any time t. Hence, the nominal wage $W_{j,t}$ for labor variety j obeys the following dynamics:

$$W_{j,t} = \begin{cases} \tilde{W}_t & \text{if } W_{j,t} \text{ is set optimally at time } t, \\ W_{j,t-1} & \text{otherwise,} \end{cases} \tag{21}$$

This implies that the real wage $w_{j,t}$ is subject to the following dynamics:

$$w_{j,t} = \begin{cases} \tilde{w}_t & \text{if } w_{j,t} \text{ is set optimally at time } t, \\ \frac{1}{\pi_t} w_{j,t-1} & \text{otherwise.} \end{cases} \tag{22}$$

Due to the labor demand curve faced by the union being identical and the labor supply cost being the same across all labor markets, the real wage $\tilde{w}_t$ and the labor supply $\tilde{L}_t$ are identical across all labor markets updating wages optimally in a given period. Hence, this implies that $\tilde{w}_t^{\tilde{\eta}} \tilde{L}_t = w_{j,t}^{\tilde{\eta}} L_t^d$. Given the consumption-leisure trade-off condition (14), we solve for the optimal wage $\tilde{w}_t$ by maximizing the following expression:

$$\max_{\{\tilde{w}_t\}} \left\{ \mathbb{E}_t \left[\sum_{s=0}^{\infty} (\mu\beta)^s \lambda_{C,t+s} w_{t+s}^{\tilde{\eta}} L_{t+s}^d \prod_{k=1}^{s} \bar{\pi}_{t+k}^{\tilde{\eta}} \left(\tilde{w}_t^{1-\tilde{\eta}} \prod_{k=1}^{s} \frac{1}{\bar{\pi}_{t+k}} - \frac{w_{t+s}}{\lambda_{L,t+s}} \tilde{w}_t^{-\tilde{\eta}} \right) \right] \right\}, \tag{23}$$

which implies the following recursive specification for the resulting equilibrium conditions:

$$f_t^1 = f_t^2, \tag{24}$$

$$f_t^1 = \frac{\tilde{\eta}-1}{\tilde{\eta}} \lambda_{C,t} \left(\frac{w_t}{\tilde{w}_t}\right)^{\tilde{\eta}} \tilde{w}_t L_t^d + \beta\mu \mathbb{E}_t \left[\pi_{t+1}^{\tilde{\eta}-1} \left(\frac{\tilde{w}_{t+1}}{\tilde{w}_t}\right)^{\tilde{\eta}-1} f_{t+1}^1 \right], \tag{25}$$

$$f_t^2 = \frac{\varphi C_{h,t}}{\phi(\bar{L}-L_t)} \lambda_{C,t} \left(\frac{w_t}{\tilde{w}_t}\right)^{\tilde{\eta}} L_t^d + \beta\mu \mathbb{E}_t \left[\pi_{t+1}^{\tilde{\eta}} \left(\frac{\tilde{w}_{t+1}}{\tilde{w}_t}\right)^{\tilde{\eta}} f_{t+1}^2 \right], \tag{26}$$

where $\lambda_{C,t} = \partial U_t / \partial C_{h,t} = (1-\beta)\phi_t U_t^{1/\psi} v_t^{-1/\psi} v_t / C_{h,t}$. Combining the aggregate labor supply definition $L_t = \int_0^1 L_{j,t}\, dj$ with the optimal labor demand condition (43), with the similar condition for labor markets, in which the wage rate is set optimally, i.e. $\tilde{L}_t =$

$L_t^d \int_0^1 \left(\frac{\tilde{w}_t}{w_t}\right)^{-\tilde{\eta}} dj$, and with the aforementioned wage stickiness dynamics, one obtains:

$$L_t = (1-\mu) L_t^d \sum_{s=0}^{\infty} \mu^s \left(\frac{\tilde{W}_{t-s}}{W_t}\right)^{-\tilde{\eta}}. \tag{27}$$

Let $\tilde{s}_t := (1-\mu) \sum_{s=0}^{\infty} \mu^s \left(\frac{\tilde{W}_{t-s}}{W_t}\right)^{-\tilde{\eta}}$. The variable $\tilde{s}_t$ measures the degree of wage dispersion across differentiated labor varieties. Hence, we have:

$$L_t = \tilde{s}_t L_t^d, \tag{28}$$

and $\tilde{s}_t$ can be recursively defined as follows:

$$\tilde{s}_t = (1-\mu) \left(\frac{\tilde{w}_t}{w_t}\right)^{-\tilde{\eta}} + \mu \left(\frac{w_{t-1}}{w_t}\right)^{-\tilde{\eta}} \pi_t^{\tilde{\eta}} \tilde{s}_{t-1}. \tag{29}$$

Note that $\tilde{s}_t \geq 1$, i.e. there is always at least as much labor supply as there is labor demand. Finally, from the wage dynamics and the average wage index definition it follows that the dynamics of the average real wage rate obey:

$$w_t^{1-\tilde{\eta}} = (1-\mu) \tilde{w}_t^{1-\tilde{\eta}} + \mu w_{t-1}^{1-\tilde{\eta}} \left(\frac{1}{\pi_t}\right)^{1-\tilde{\eta}}. \tag{30}$$

3.3 Final goods sector

The perfectly competitive final goods firm in the home country combines the bundles of domestic and foreign intermediate goods according to the following production function:

$$Y_t = \left(\tilde{\gamma}^{\frac{1}{\tilde{\theta}}} y_{h,t}^{\frac{\tilde{\theta}-1}{\tilde{\theta}}} + (1-\tilde{\gamma})^{\frac{1}{\tilde{\theta}}} y_{f,t}^{\frac{\tilde{\theta}-1}{\tilde{\theta}}}\right)^{\frac{\tilde{\theta}}{\tilde{\theta}-1}}, \tag{31}$$

where $\tilde{\theta}$ denotes the elasticity of substitution between the domestic bundle $y_{h,t} = x_{h,t}/s_t$ and foreign bundle $y_{f,t} = x_{f,t}/s_t$ of intermediate goods, and $\tilde{\gamma}$ denotes the share of the home-produced intermediate goods bundle in the domestic final goods production function. The process s_t determines the efficiency distortion due to price stickiness (see Section 3.5 for details). Since $\tilde{\gamma} > 0.5$, it reflects the home bias in final goods production. Intermediate goods varieties are bundled according to the following CES function:

$$x_{h,t} = \left(\int_0^1 X_{h,t}(i)^{\frac{\nu-1}{\nu}} \, di \right)^{\frac{\nu}{\nu-1}}, \tag{32}$$

where $X_{h,t}(i)$ is the quantity of intermediate good $i \in [0, 1]$ produced at home used for bundling the input to the production of the home country's final good. Symmetrically, the bundle of foreign intermediate goods to be used in domestic country's final goods production is:

$$x_{f,t} = \left(\int_0^1 X_{f,t}(i)^{\frac{\nu-1}{\nu}} \, di \right)^{\frac{\nu}{\nu-1}}, \tag{33}$$

where $X_{f,t}(i)$ is the quantity of intermediate good $i \in [0, 1]$ produced abroad and imported by the home country for final goods production.

Solving the first stage of the two-stage optimization problem of the domestic final goods firm gives the demand functions for intermediate goods bundles from home and abroad in the domestic market:

$$x_{h,t} = \tilde{\gamma} Y_t \left(\frac{P_{h,t}}{\mathcal{P}_t} \right)^{-\tilde{\theta}}, \qquad x_{f,t} = (1 - \tilde{\gamma}) Y_t \left(\frac{P_{f,t}}{\mathcal{P}_t} \right)^{-\tilde{\theta}}, \tag{34}$$

where $P_{h,t}$ is the price of the domestic intermediate goods bundle used for final goods production in the domestic economy, $P_{f,t}$ is the price of foreign intermediate goods used for final goods production in the domestic economy, and $\mathcal{P}_t$ is the price of domestically produced final goods. The prices of bundles are defined as:

$$P_{h,t} = \left(\int_0^1 P_{h,t}(i)^{1-\nu} \, di \right)^{\frac{1}{1-\nu}}, \qquad P_{f,t} = \left(\int_0^1 P_{f,t}(i)^{1-\nu} \, di \right)^{\frac{1}{1-\nu}}. \tag{35}$$

The second stage of the domestic final goods producer optimization task gives the demand for intermediate good variety i from home and abroad, respectively, which is used in the home country:

$$X_{h,t}(i) = x_{h,t} \left(\frac{P_{h,t}(i)}{P_{h,t}} \right)^{-\nu}, \qquad X_{f,t}(i) = x_{f,t} \left(\frac{P_{f,t}(i)}{P_{h,t}} \right)^{-\nu}, \tag{36}$$

where $P_{h,t}(i)$ is the price of domestic intermediate good i to be bundled and used for final goods production in the domestic economy and $P_{f,t}(i)$ is the price of foreign intermediate good i to be bundled and used for final goods production in the domestic economy. The demand for home and foreign goods bundles and intermediate goods required to produce the foreign final good are symmetric. Therefore, we omit them from this description.

3.4 Intermediate goods sector

The optimization problem of intermediate goods producers can also be split into two sub-tasks. First, they choose the amount of production inputs to maximize the firm value given the definition of profits. Second, they maximize their profits by setting the prices optimally given the production demand from the final goods firm as well as the associated costs and price setting frictions that they face. In this section, we deal with the first task only, the second task is dealt with in the next section.

The intermediate goods firm charges the same price for its production in all the markets. Thus, the law of one price holds: $P_{h,t}(i) = P^*_{h,t}(i)$. Moreover, they maximize their nominal firm value by choosing the production inputs $K_t(i)$, $L^d_t(i)$, and $N_t(i)$:

$$\max_{\{L^d_t(i),K_t(i),N_t(i)\}} \left\{ \mathbb{E}_t \left[\sum_{t=0}^{\infty} \mathbb{M}^{\$}_{0,t} \mathcal{P}_t D_t(i) \right] \right\}, \tag{37}$$

where real dividends are given by:

$$\begin{aligned} D_t(i) &= \frac{P_{h,t}(i)X_{h,t}(i) + P^*_{h,t}(i)X^*_{h,t}(i)}{\mathcal{P}_t} - R_{K,t}K_t(i) - R_{N,t}N_t(i) - w_t L^d_t(i) \qquad (38) \\ &= \frac{P_{h,t}(i)}{\mathcal{P}_t}\left[x_{h,t}\left(\frac{P_{h,t}(i)}{P_{h,t}}\right)^{-\nu} + x^*_{h,t}\left(\frac{P^*_{h,t}(i)}{P_{f,t}}\right)^{-\nu}\right] - R_{K,t}K_t(i) - R_{N,t}N_t(i) - w_t L^d_t(i), \end{aligned}$$

subject to producing at least as much output as demanded in home and foreign markets:

$$X_{h,t}(i) \geq x_{h,t}\left(\frac{P_{h,t}(i)}{P_{h,t}}\right)^{-\nu}, \qquad X^*_{h,t}(i) \geq x^*_{h,t}\left(\frac{P^*_{h,t}(i)}{P^*_{h,t}}\right)^{-\nu}, \tag{39}$$

subject to the demand for home and foreign intermediate goods bundles (34) as well as subject to the specification of the production output function:

$$\begin{aligned} X_t(i) &= X_{h,t}(i) + X^*_{h,t}(i) \qquad (40) \\ &= F(K_t(i), N_t(i), N_t, L^d_t(i), a_t) \\ &= (K_t(i))^{\alpha}(e^{a_t}N_t(i)^{\eta}N_t^{1-\eta}L^d_t(i))^{1-\alpha}. \end{aligned}$$

Here, N_t is the economy-wide number of patents and $N_t(i)$ the number of firm-specific patents. The parameter η specifies the degree of technological appropriability. This specification ensures sustainable endogenous economic growth in the intangible capital input N_t. Stochastic productivity shocks are induced by the process a_t, whose dynamics are specified as follows:

$$a_t = \varpi_t + z_t, \quad \varpi_t = \varphi_\varpi \varpi_{t-1} + \varepsilon_{\varpi,t}, \quad \varepsilon_{\varpi,t} \sim \mathcal{N}(0, \sigma_\varpi), \quad z_t = \varphi_z z_{t-1} + \varepsilon_{z,t}, \quad \varepsilon_{z,t} \sim \mathcal{N}(0, \sigma_z), \tag{41}$$

where ϖ_t is the home country's country-specific productivity (in the foreign country an independent shock process denoted by ϖ_t^* will drive country-specific productivity shocks) and z_t is common productivity (therefore the same process is also present in the foreign country). The parameters φ_a and φ_z control the persistence of productivity shocks.

We assume that the labor input $L_t^d(i)$ used by firm $i \in [0,1]$ is composed of a continuum of differentiated labor services $L_{j,t}^d(i)$ where $j \in [0,1]$ is the labor service index. Hence, we define $L_t^d(i)$ formally as:

$$L_t^d(i) = \left[\int_0^1 (L_{j,t}^d(i))^{1-\frac{1}{\tilde{\eta}}} dj\right]^{\frac{1}{1-\frac{1}{\tilde{\eta}}}}. \tag{42}$$

For any given demand of the intermediate good firm $L_t^d(i)$, the demand $L_{j,t}^d(i)$ for the variety of labor $j \in [0,1]$ solves the dual problem of minimizing the total labor cost, i.e. $\int_0^1 W_{j,t} L_{j,t}^d(i) dj$, subject to condition (42) above. Hence, the optimal demand for type j labor is given by:

$$L_{j,t}^d(i) = \left(\frac{W_{j,t}}{W_t}\right)^{-\tilde{\eta}} L_t^d(i) = \left(\frac{w_{j,t}}{w_t}\right)^{-\tilde{\eta}} L_t^d(i), \tag{43}$$

where the nominal wage index W_t has been defined in Equation (20). Finally, the aggregate labor demand is defined as follows:

$$L_t^d = \int_0^1 L_t^d(i) di. \tag{44}$$

Hence, the total demand for labor variety j satisfies:

$$L_{j,t}^d = \int_0^1 L_{j,t}^d(i) di = \left(\frac{W_{j,t}}{W_t}\right)^{-\tilde{\eta}} L_t^d = \left(\frac{w_{j,t}}{w_t}\right)^{-\tilde{\eta}} L_t^d. \tag{45}$$

The first-order conditions of the optimization problem (37)–(40) are given by:

$$\frac{w_t}{MC_t(i)} = \frac{(1-\alpha)F(K_t(i), N_t(i), N_t, L_t^d(i), a_t)}{L_t^d(i)}, \tag{46}$$

$$\frac{R_{K,t}}{MC_t(i)} = \frac{\alpha F(K_t(i), N_t(i), N_t, L_t^d(i), a_t)}{K_t(i)}, \tag{47}$$

$$\frac{R_{N,t}}{MC_t(i)} = \frac{\eta(1-\alpha)F(K_t(i), N_t(i), N_t, L_t^d(i), a_t)}{N_t(i)}, \tag{48}$$

where $MC_t(i)$ denotes marginal costs of firm i. The intermediate goods firm's problem is symmetric. Therefore, all firms make identical decisions. Thus, one obtains a symmetric equilibrium: $X_t(i) \equiv X_t$, $K_t(i) \equiv K_t$, $N_t(i) \equiv N_t$, $L_t^d(i) \equiv L_t^d$, $MC_t(i) \equiv MC_t$, and $P_t(i) \equiv P_t$.

3.5 Price setting rigidities

To derive the optimal price $\tilde{P}_{h,t}(i)$, the intermediate goods firms have to take into account that with some exogenous probability θ they are not allowed to re-set their price. In such a case, the price remains at the level it was last set optimally. Hence, the price is not indexed, neither to inflation nor economic growth, similar to the specification of wage rigidities. If a firm is allowed to set the price in a given period, this price solves:

$$\max_{\{\tilde{P}_{t+j}(i)\}} \left\{ \mathbb{E}_t \left[\sum_{j=0}^{\infty} \mathrm{M}_{t,t+j}^{loc} / \mathcal{P}_{t+j} \theta^j \left(\tilde{P}_t(i) X_{t+j}(i) - \mathcal{P}_{t+j}(1+\eta(1-\alpha)) MC_{t+j}(i) X_{t+j}(i) \right) \right] \right\}. \tag{49}$$

Solving for the optimal price and later on taking symmetry into account (i.e. also $\tilde{P}_t(i) \equiv \tilde{P}_t$) gives rise to the following three equilibrium conditions:

$$F_{1,t} = X_t + \theta \mathbb{E}_t \left[\mathrm{M}_{t,t+1}^{loc} \left(\frac{1}{\bar{\pi}_{t+1}} \right)^{1-\nu} F_{1,t+1} \right], \tag{50}$$

$$F_{2,t} = \frac{\nu}{\nu - 1}(1+\eta(1-\alpha)) MC_t(i) X_t + \theta \mathbb{E}_t \left[\mathrm{M}_{t,t+1}^{loc} \left(\frac{1}{\bar{\pi}_{t+1}} \right)^{-\nu} F_{2,t+1} \right], \tag{51}$$

$$\tilde{p}_t = \left[\frac{1-\theta \bar{\pi}_t^{\nu-1}}{1-\theta} \right]^{\frac{1}{1-\nu}} = \frac{F_{2,t}}{F_{1,t}}, \tag{52}$$

where $\bar{\pi}_{t+1} = \mathcal{P}_{t+1}/\mathcal{P}_t$ is gross inflation between time t and $t+1$, and $\tilde{p}_t = \tilde{P}_t/\mathcal{P}_t$ is the normalized optimal price. The aggregate price level or average nominal price index is obtained by using the following aggregation rule:

$$\mathcal{P}_t = \left[\tilde{\gamma} P_{h,t}^{1-\tilde{\theta}} + (1-\tilde{\gamma}) P_{f,t}^{1-\tilde{\theta}}\right]^{\frac{1}{1-\tilde{\theta}}} . \tag{53}$$

Due to prices being sticky, there is an efficiency distortion. Hence, the final real output quantities not given by $y_{h,t} = x_{h,t}$ and $y_{f,t} = x_{f,t}$, but instead by $y_{h,t} = x_{h,t}/s_t$ and $y_{f,t} = x_{f,t}/s_t$, where s_t is governed by the following dynamics:

$$s_t = (1-\theta)(\tilde{p}_t)^{-\nu} + \theta \bar{\pi}_t^{\nu} s_{t-1}, \tag{54}$$

In particular, $s_t > 1$ if $\theta > 0$. Hence, there is a real output loss if prices are sticky.

3.6 Monetary authorities

The central bank in the home country sets the nominal interest rate according to the following Taylor rule:

$$\mathcal{R}_t = (1-\phi_R)\bar{\mathcal{R}}_{ss} + \phi_R \mathcal{R}_{t-1} + (1-\phi_R)\left[\phi_\pi \ln\left(\frac{\bar{\pi}_t}{\bar{\pi}_{ss}}\right) + \phi_x \ln\left(\frac{Y_t}{Y_{ss}}\right)\right] + \varepsilon_{u,t}. \tag{55}$$

Hence, the central bank applies interest rate smoothing and reacts to inflation deviations from target and the output gap. The interest rate smoothing parameter is denoted by ϕ_R and the magnitude of reactions to inflation rate deviations is controlled by the parameter ϕ_π. Furthermore, the magnitude of reactions to the output gap is determined by the parameter ϕ_x. The variables $\bar{\mathcal{R}}_{ss}$, $\bar{\pi}_{ss}$, and Y_{ss} denote the deterministic steady state of the nominal interest rate, the inflation rate, and the final real output, respectively. Unanticipated and unexpected monetary policy shocks are induced by the normally distributed random variable $\varepsilon_{u,t}$ which has mean zero and standard deviation σ_u. The foreign country's central bank applies an equivalent Taylor rule to determine the foreign nominal interest rate.

3.7 Aggregation

In the case of complete international financial markets, the bonds are assumed to be in zero-net supply and thus the following market clearing condition applies:

$$A_{t+1}(\chi_{t+1}) + A^*_{t+1}(\chi_{t+1}) = 0. \tag{56}$$

The aggregate resource constraints for both countries are given by:

$$Y_t = C_{h,t} + C^*_{h,t} + I_t + S_t, \qquad Y^*_t = C^*_{f,t} + C_{f,t} + I^*_t + S^*_t. \tag{57}$$

3.8 Asset prices

The real exchange rate is equal to the real terms of trade. In particular, we define the real exchange rate as the price of the foreign good in home good units as follows:

$$E_t = P^{(h)}_t = \frac{1-\phi_t}{\phi_t}\frac{C_{h,t}}{C_{f,t}}. \tag{58}$$

Hence, real exchange rate growth is given by:

$$\Delta e_t = \ln\left(\frac{E_t}{E_{t-1}}\right). \tag{59}$$

The nominal and real interest rates are defined as follows:

$$r^{\$}_{f,t} = \ln(\mathcal{R}_t), \qquad r_{f,t} = r^{\$}_{f,t-1} - \pi_t. \tag{60}$$

From the household's intertemporal optimization, the real interest rate also has to satisfy:

$$1 = \mathbb{E}_t\left[\mathbb{M}^{loc}_{t,t+1} e^{r_{f,t+1}}\right] = \mathbb{E}_t\left[\mathbb{M}^{loc}_{t,t+1}\frac{\mathcal{R}_t}{\bar{\pi}_{t+1}}\right]. \tag{61}$$

The two equity returns in the model are given by the (real) return on physical capital $r_{I,t}$ and the (real) return on intangible capital $r_{S,t}$, which are defined by the following expressions:

$$r_{I,t} = \ln\left(G'_{k,t}\left[R_{K,t+1} - \frac{I_{t+1}}{K_{t+1}} + \frac{1-\delta_k + G_{k,t+1}}{G'_{k,t+1}}\right]\right), \tag{62}$$

$$r_{S,t} = \ln\left(G'_{n,t}\left[R_{N,t+1} - \frac{S_{t+1}}{N_{t+1}} + \frac{1-\delta_n + G_{n,t+1}}{G'_{n,t+1}}\right]\right). \tag{63}$$

The corresponding levered excess returns are given by:

$$r^{exc}_{I,t} = (1+\bar{\ell})(r_{I,t} - r_{f,t}), \qquad r^{exc}_{S,t} = (1+\bar{\ell})(r_{S,t} - r_{f,t}), \tag{64}$$

where excess returns are levered as in Boldrin, Christiano, and Fisher (2001). In particular, we set $\bar{\ell} = 2/3$.

4 Calibration

For the calibration of our model we rely on data for the United States (US) and the United Kingdom (UK). These two countries have a long and reliable sample of annual data ranging from 1950 until 2015 available. As in Colacito and Croce (2013), we split the data into two sub-periods to have a sample of data, characterized by financial autarky, and a sample of data, characterized by intense financial integration. The first sample covers the period 1950–1970 and the second sample the period 1971–2015. For country-specific moments, we use US data as the empirical counterpart for our calibration exercise so that the US represents the home economy in the model. For international moments, we also use UK data so that the UK represents the foreign economy in the model.

We choose our calibration to match as well as possible key moments of the first sub-period, i.e. the financial autarky period from 1950 to 1970. Specifically, we would like to match as closely as possible the following moments: average US output growth, average US inflation, US output growth volatility, and the cross-country correlation between US and UK output growth. With the resulting calibration, we solve two versions of the model: the first one assumes households living in financial autarky and the second one features complete international financial markets. The calibration is quarterly, and all parameters, which we discuss in what follows, are summarized in Table 1. Since the model is symmetric, the parameters are identical across countries.

Table 1: Quarterly calibration

Parameter	Description	Value
β	Time discount factor	$0.984^{1/4}$
γ	Risk aversion parameter	10
ψ	Elasticity of intertemporal substitution	1.4
ν	Substitution elasticity of intermediate goods	10
$\tilde{\theta}$	Price elasticity of traded intermediate goods	0.9
$\tilde{\gamma}$	Intermediate goods trade share	0.85
τ	Labor supply elasticity parameter	1.5702
μ	Calvo optimal wage setting probability	0.35
$\tilde{\eta}$	Labor variety substitution elasticity	21
η	Degree of technological appropriability	0.0214
ζ_k	Physical capital adjustment cost elasticity	4.8
δ_k	Physical capital depreciation rate	0.02
ζ_n	Technology capital adjustment cost elasticity	3.3
δ_n	Technology capital depreciation rate	0.0375
α	Physical capital share	0.35
θ	Calvo optimal price setting probability	0.75
ϕ_R	Degree of monetary policy inertia	0.7
ϕ_π	Inflation parameter in Taylor rule	1.5
ϕ_x	Output gap parameter in Taylor rule	0.1
$\bar{\pi}_{ss}$	Inflation target / steady-state inflation	0.0065
$\bar{\phi}$	Average Home bias in consumption	0.95
σ_ϖ	Country-specific productivity shock volatility	0.018
σ_z	Common productivity shock volatility	0.0085
σ_u	Monetary policy shock volatility	0.0015
σ_ϕ	Demand shock volatility	0.0025
φ_ϖ	Country-specific productivity shock persistence	$0.85^{1/4}$
φ_z	Common productivity shock persistence	$0.85^{1/4}$
φ_ϕ	Demand shock persistence	$0.85^{1/4}$
$\rho_{\varpi\varpi^*}$	Cross-country country-specific productivity shock correlation	0
ρ_{zz^*}	Cross-country common productivity shock correlation	0
ρ_{uu^*}	Cross-country monetary policy shock correlation	0
$\rho_{\phi\phi^*}$	Cross-country demand shock correlation	0
$\rho_{\varpi n}, \rho_{\varpi^* n^*}$	Within-country country-specific productivity and common productivity shock correlation	0
$\rho_{\varpi u}, \rho_{\varpi^* u^*}$	Within-country country-specific productivity and monetary policy shock correlation	0
$\rho_{\varpi\phi}, \rho_{\varpi^*\phi^*}$	Within-country country-specific productivity and demand shock correlation	0
ρ_{zu}, ρ_{zu^*}	Within-country common productivity and monetary policy shock correlation	0
$\rho_{z\phi}, \rho_{z\phi^*}$	Within-country common productivity and demand shock correlation	0
$\rho_{u\phi}, \rho_{u^*\phi^*}$	Within-country monetary policy and demand shock correlation	0

This table reports the parameters used in the quarterly calibration of our model.

As in the literature on exogenous and endogenous long-run risks (see, for example, Bansal and Yaron, 2004; Kung and Schmid, 2015), the elasticity of intertemporal substitution is chosen to be above 1, i.e. $\psi = 1.4$, and the relative risk aversion is set to $\gamma = 10$. The subjective discount factor is chosen to be $0.984^{1/4}$. Moreover, the elasticity of the labor supply τ is chosen so that the households work one third of their total time endowment in the deterministic steady state, given all the other parameters. In our calibration, this implies $\tau = 1.5702$.

Wage rigidities are assumed to be mild in the current calibration. In this respect, we set the optimal wage setting probability to $\mu = 0.35$, following Uhlig (2007). The labor variety substitution elasticity is set to $\tilde{\eta} = 21$ as in Schmitt-Grohé and Uribe (2006).

Most of the production side parameters are either set identically or very close to the values used by Kung (2015). Hence, we have $\zeta_k = 4.8$ ($\zeta_n = 3.3$) for the physical (intangible) capital adjustment cost elasticity, $\delta_k = 0.02$ ($\delta_n = 0.0375$) for the physical (intangible) capital depreciation rate, and $\alpha = 0.35$ for the capital share. The volatility of monetary policy shocks $\sigma_u = 0.0015$ is half of the value used by Kung (2015). The degree of monetary policy inertia in the Taylor rule is set to $\phi_R = 0.7$, the inflation parameter in the Taylor rule is set to $\phi_\pi = 1.5$, and the output gap parameter in the Taylor rule is set to $\phi_x = 0.1$, as in Kung (2015).

We set $\nu = 10$ for the substitution elasticity of intermediate goods. Regarding the trade of intermediate goods, we follow Evers (2015) and set the price elasticity of traded intermediate goods $\tilde{\theta}$ equal to 0.9 and the intermediate goods trade share $\tilde{\gamma}$ equal to 0.85.

The optimal price setting probability is set to $\theta = 0.75$, as in Galí (2002). The inflation targets are set to $\bar{\pi}_{ss} = \bar{\pi}^*_{ss} = 0.0065$ in order to obtain an annual deterministic steady-state inflation rate of 2.6 percentage points. The country-specific productivity shock volatility σ_ϖ is set to 0.018. The common productivity shock volatility σ_z is set to 0.0085. The relative size of these volatilities is important to match the cross-country output growth correlation in the data. Both productivity shock persistence parameters φ_ϖ and φ_z are equal to $0.85^{1/4}$. The degree of technological appropriability η is determined by having a deterministic steady-state growth rate of 0.02. Therefore, we obtain $\eta = 0.0214$.

Next, as in Colacito and Croce (2013), we set the average consumption home bias parameter to $\bar{\phi} = 0.95$. We include demand shocks in our model by making the home bias in each country stochastic. The volatility of these demand shocks is equal to $\sigma_\phi = 0.0025$, and the persistence is equal to $\varphi_\phi = 0.85^{1/4}$. Finally, all exogenous correlations are set to 0.

5 Results

The model is solved using third-order perturbations around the stochastic steady state implemented in Dynare++, version 4.4.3. In this section, we discuss the simulated moments from the model comparing the results from using two different structures of international financial markets. Moreover, we analyze the main impulse response functions of the model.

The empirical counterparts are computed using US and UK data. The US represents the home economy and thus its empirical country-specific moments are used for comparison with the dynamics of domestic macroeconomic quantities and asset prices. International moments are computed utilizing the UK as empirical counterpart for the foreign economy. The simulated moments alongside these empirical counterparts are reported in Table 2. The moments for country-specific macroeconomic quantities and asset prices are reported in the first two panels of the table. The last panel reports cross-country correlations of macroeconomic growth rates and asset returns, as well as moments related to the dynamics of exchange rate growth. The empirical moments are computed for two time periods, i.e. 1950–1970 and 1971–2015, in the second and third column of the table. Two model variants are solved for, and the corresponding simulated moments are reported in the fourth and fifth column of the table. The first model variant features households living in financial autarky.[1] The second model variant features complete international financial markets. The parameters of the model are identical in both cases (and reported in Table 1). In what follows, we first discuss the simulated moments of the financial autarky model and how it compares with the empirical moments of the early sample. Then, we analyze the effects of introducing complete integration of financial markets into the model.

An inspection of the first panel of Table 2 shows that the average output growth rate is about 40 basis points (bps) lower than the empirical counterpart of the early sample and

[1] This is achieved by using $Z_t \equiv 0$ instead of the expression in Equation (19) in the model.

Table 2: Simulation Results

Moment	Data		Model	
	United States 1950–1970	United States 1971–2015	Financial Autarky	Complete Markets
Country-specific macroeconomic quantities				
$\mathbb{E}[\Delta y]$	1.88	1.42	1.46	1.86
$\mathbb{E}[\pi]$	2.46	3.50	2.16	2.42
$\sigma(\Delta c)$	2.08	1.49	2.80	3.14
$\sigma(\Delta y)$	1.37	1.15	1.36	1.37
$\sigma(\Delta s)$	—	—	6.18	5.95
$\sigma(\Delta i)$	9.22	7.91	5.52	5.30
$\sigma(\Delta l)$	2.19	1.74	7.34	7.79
$\sigma(\Delta w)$	1.51	2.21	1.56	1.58
$\sigma(\pi)$	1.57	2.28	0.66	0.70
Country-specific asset prices				
$\mathbb{E}[r_f]$	3.05	4.96	2.39	2.75
$\mathbb{E}[r_I^{exc}]$	10.71	7.09	0.92	0.62
$\mathbb{E}[r_S^{exc}]$	—	—	1.44	0.96
$\sigma(r_f)$	1.61	3.40	0.99	1.00
$\sigma(r_I^{exc})$	17.86	17.99	3.02	3.00
$\sigma(r_S^{exc})$	—	—	4.59	4.53
International moments (vis-à-vis the United Kingdom)				
$\text{corr}(\Delta c, \Delta c^*)$	0.67	0.41	0.40	0.40
$\text{corr}(\Delta y, \Delta y^*)$	0.22	0.47	0.22	0.38
$\text{corr}(\Delta s, \Delta s^*)$	—	—	0.21	0.32
$\text{corr}(\Delta i, \Delta i^*)$	-0.05	0.54	0.22	0.33
$\text{corr}(\Delta l, \Delta l^*)$	0.18	0.57	0.15	0.21
$\text{corr}(\Delta w, \Delta w^*)$	-0.20	-0.32	0.14	0.11
$\text{corr}(\pi, \pi^*)$	0.75	0.93	0.16	0.34
$\text{corr}(r_f, r_f^*)$	0.85	0.89	0.14	0.23
$\text{corr}(r_I^{exc}, r_I^{exc,*})$	0.92	0.81	0.19	0.29
$\text{corr}(r_S^{exc}, r_S^{exc,*})$	—	—	0.19	0.30
$\sigma(\Delta e)$	6.76	8.72	3.43	0.94
$\sigma(\Delta e)/\sigma(\Delta c)$	3.25	5.87	1.23	0.30
$\text{corr}(\Delta e, \Delta c - \Delta c^*)$	0.07	-0.29	0.91	0.18
$\beta_{UIP}^{nominal}$	0.37	0.40	0.87	-0.06
β_{UIP}^{real}	0.70	-0.15	0.87	0.27

This table reports the empirical and model-implied moments of key macroeconomic quantities and asset prices. Means and volatilities are reported in percentage points. Annual data for the United States and the United Kingdom for the period 1950–2015 are used to compute the empirical moments. The country-specific empirical moments are the moments for the United States. The international moments are computed vis-à-vis the United Kingdom. We report the moments for the period 1950–1970 (to compare them with the financial autarky model) and for the period 1971–2015 (to compare them with the complete markets model). More details on the data are given in Appendix A. The simulated model-implied moments are based on 3,000 simulations, each being 305 quarters long from which the first 80 are not used for computing the moments ("burn-in" period). Two sets of simulated model-implied moments are reported. In the first case, households live in financial autarky. In the second case, households have access to complete international financial markets. The parameters used are summarized in Table 1.

that the average inflation rate is roughly in line with the empirical counterpart of the early sample. The model produces consumption growth to be more volatile than output growth, as in the data. The volatility of output growth is matched exactly due to calibration choices. The model produces a high volatility of capital investment growth, almost as high as in the data, and produces R&D investment growth volatility of roughly the same magnitude. Labor growth volatility is too high in the model, relative to the data, but wage growth volatility is reproduced well, due to the inclusion of wage rigidities. Finally, inflation rate volatility is not sufficient and reaches only slightly more than 40% of the empirical counterpart.

The second panel of Table 2 reports country-specific asset prics. The risk-free rate is 3.05% in the data and 2.39% in the model and thus reasonably reproduced by the model. Both the average excess returns of capital investment and R&D investment are too low in the model. We only have an empirical counterpart for the excess return of capital investment and its average is much higher than in the model. Therefore, the model is not able to explain the equity premium puzzle. Furthermore, the real risk-free rate volatility is slightly lower in the model (0.99 percentage points (pp) in the model vs. 1.61pp in the data, respectively). As expected, due to the failure in explaining the equity premium puzzle, the model does not produce sufficient excess return variability as well.

Due to calibration choices, the model re-produces the value of 0.22 for the cross-country correlation of output growth, as in the early sample. Consumption growth co-moves more than output growth due to the trade channels and demand shocks. Therefore, a correlation of 0.40 is observed. In the data, this correlation is even higher and equal to 0.67. The other correlations of macroeconomic growth rates fall into the same region and are equal to values between 0.14 and 0.22. In the data, capital investment growth and wage growth co-move negatively across the countries, which is in contrast to the model's implications. Labor growth correlation in the data is very similar to the one in the model (0.18 vs. 0.15).

The model does not produce sufficient correlation in inflation rates. The simulated correlation in the model is equal to 0.16. However, in the data inflation rates co-move strongly with a value for the correlation equal to 0.75. Similar observations can be made for the correlations of the risk-free rates and capital investment excess returns.

The last five moments reported in the table are concerned with three famous anomalies in international macroeconomics. The first one is the exchange rate volatility puzzle (see, for example, Tretvoll, 2018). It states that standard international models fail to produce the observed high variability of exchange rates in the data. In our model, exchange rate growth volatility is substantial and reaches about 50% of the empirical counterpart. Therefore, a partial resolution of this puzzle is achieved in the financial autarky model.

The second anomaly is the Backus and Smith (1993) correlation puzzle, i.e. the correlation between exchange rate growth and consumption growth differentials being equal to one in the standard international macroeconomics textbook model. However, one usually observes coefficients not far from zero in the data. In our data, indeed, the correlation coefficient is slightly positive and very close to zero in the early sample and slightly negative in the late sample. In our financial autarky model, the correlation between exchange rate growth and the differential of the consumption growth rates in the countries is close to 1. Therefore, the financial autarky model gives rise to this puzzle as well.

The third and final anomaly is the failure of uncovered interest parity (UIP) in the data, as documented by Fama (1984). However, UIP holds in the standard international macroeconomics textbook model. Hence, we report the average real and nominal uncovered interest parity (UIP) coefficients obtained from simulations of the model by using the following regressions applied to annualized model data:

$$\Delta e_{t+1} = \beta_{UIP}^{real}(r_{f,t} - r_{f,t}^{*}) + \varepsilon_{t+1}, \qquad \Delta e_{t+1} + \bar{\pi}_{t+1}^{*} - \bar{\pi}_{t+1} = \beta_{UIP}^{nominal}(r_{f,t}^{\$} - r_{f,t}^{\$,*}) + \varepsilon_{t+1}. \quad (65)$$

Real and nominal UIP holds if $\beta_{UIP}^{real} = 1$ and $\beta_{UIP}^{nominal} = 1$, respectively. In our simulations, the real UIP regression coefficient is equal to 0.87 in the financial autarky model. The nominal UIP coefficient is also 0.87 in the financial autarky model. In the data, the coefficients are 0.70 and 0.37, respectively.

Now, we turn to the analysis of the equilibrium effects of including complete markets into the model. The first observation we can make is that average output growth increases significantly by 40bps to 1.86pp. This goes along an increase in the average inflation rate. Both effects are due to the stochasticity in the model as the deterministic steady states have not changed. Consumption growth becomes slightly more volatile, whereas other macroeconomic volatilities remain basically unchanged relative to the moments of the financial autarky model.

The average risk-free rate slightly increases and, in turn, the average excess returns slightly decrease. Return volatilities do not change with the introduction of complete markets.

Now we turn to the crucial part of the model analysis, i.e. the analysis of changes in international moments when financial markets become fully integrated. Introducing complete markets increases the cross-country output growth correlation in the model considerably, from 0.22 to 0.38. In the data, one also sees a similar increase from 0.22 to 0.47. The increase in the co-movement of output growth is due to the intermediate goods trade channel. When complete markets are introduced, this trade channel can be used to better align output growth across countries. The consumption growth correlation does not change in the model but decreases in the data.

The inclusion of complete markets makes R&D investment and capital investment growth co-move slightly more than in financial autarky, i.e. the correlations increase from 0.21 and 0.22 to 0.32 and 0.33. Moreover, labor growth also co-moves slightly more (an increase from 0.15 to 0.21 is observed), whereas wage growth co-moves slightly less (a decrease from 0.14 to 0.11 is observed). This is qualitatively in line with the data since labor growth becomes more correlated in the late sample and wage growth becomes less correlated.

There is also a significant boost in the correlation between inflation rates, both in the model and in the data. The increase in the model's moments is equal to 18bps (i.e. from 0.16 to 0.34) and the increase in the empirical counterpart is equal to 16bps (i.e. from 0.75 to 0.93). This consequently explains a slight increase in the model's cross-country correlation of the real risk-free rates. Similarly, the correlations of excess returns increase.

With respect to exchange rate growth volatility, there is a huge drop in this moment when complete financial markets are introduced, this is in contrast to other studies that compared the complete markets case to the financial autarky case, such as Colacito and Croce (2013), for example, and the data. In our production economy setting, the trade of goods seems to be more important to share risks than financial markets in the case of complete markets. Too low adjustments (volatilities) of exchange rate and prices are the most likely sources of excessive volatility in consumption growth rates in the case of complete markets. While one would expect more inter-temporal consumption smoothing in complete markets due to the increased availability of financial instruments, insufficient absorption of economic shocks via fluctuations in exchange rate and prices drives consumption volatility up, against the trends in the data. On the other hand, the correlation between exchange rate growth and the consumption growth differential drops significantly, as in the data, and gets closer to the data counterpart in complete markets. This correlation is largely positive in the financial autarky case and only marginally positive in the complete markets case. These findings are in line with Colacito and Croce (2013) who study the same two market structures in a two-country endowment economy. Finally, the uncovered interest parity coefficients also gets closer to zero when complete financial markets are introduced in line with the changes in actual data.

Taken together, the introduction of complete markets implies significant changes in the co-movements of most macroeconomic growth rates. From solving earlier versions of the model that did not feature trade in intermediate goods, we know that the large changes in the correlations of growth rates are due to having this trade channel present. In particular, the increased co-movement in macroeconomic quantities when moving from the early to the late sample are explained in the model very well by changing the financial markets structure. Complete financial markets also affect positively the capacity of the model to explain international macro anomalies to a large extent.

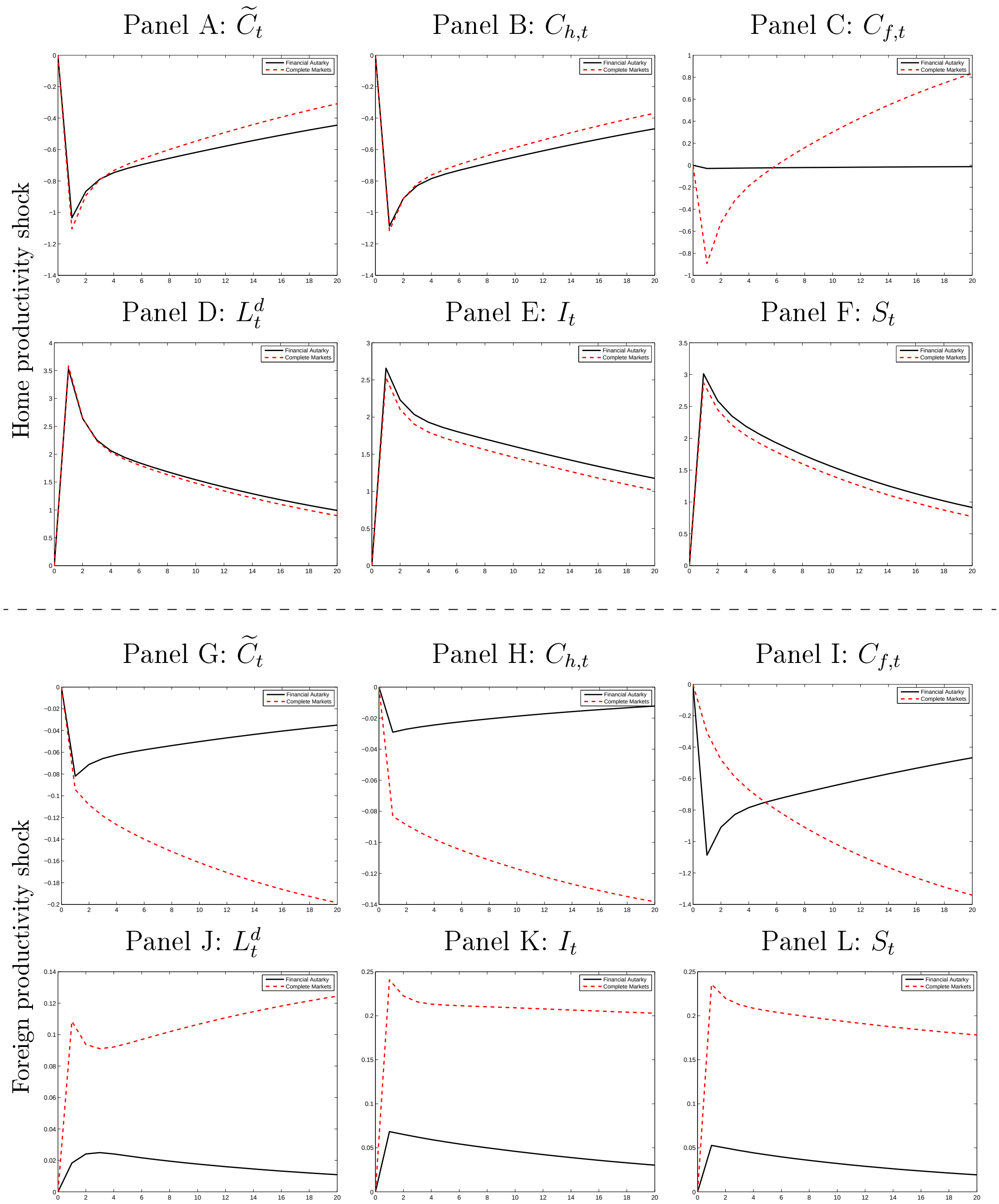
To shed more light on the mechanisms behind these results, we now turn to analyzing the impulse response functions of the model. We contrast the resulting impulse response functions assuming financial autarky with the ones assuming complete markets. We only look at the impulse response functions after productivity shocks here in the main text due to the dominance of these shocks in generating the dynamics in the moments. The impulse response functions of monetary policy and demand shocks and their analysis are relegated to Appendix B to conserve space. Figures 1–3 depict the impulse response functions of macroeconomic quantities and asset prices in response to productivity shocks.

By inspecting Figure 1, one can realize that the consumption bundle decreases in both financial market structures and to both home and foreign productivity shocks. Therefore, the consumption impulse responses look very much alike in response to both home and foreign productivity shocks in the financial autarky case which is the source of the endogenous co-movement. However, in the complete markets case the decrease in response to foreign productivity shocks is significantly more pronounced. Moreover, the foreign good's contribution to the home country's consumption bundle $C_{f,t}$ hardly reacts in the financial autarky case and first reacts negatively and then positively in the complete markets case. The responses are less positive with complete markets for labor, capital investment, and R&D investment for home productivity shocks and more positive for foreign productivity shocks, implying an increase in the co-movement from productivity shocks for these quantities in the complete markets case.

Figure 2 reveals that the reactions of output to productivity shocks are more pronounced with complete markets and that exchange rate growth becomes much less responsive to productivity shocks when financial markets are complete.

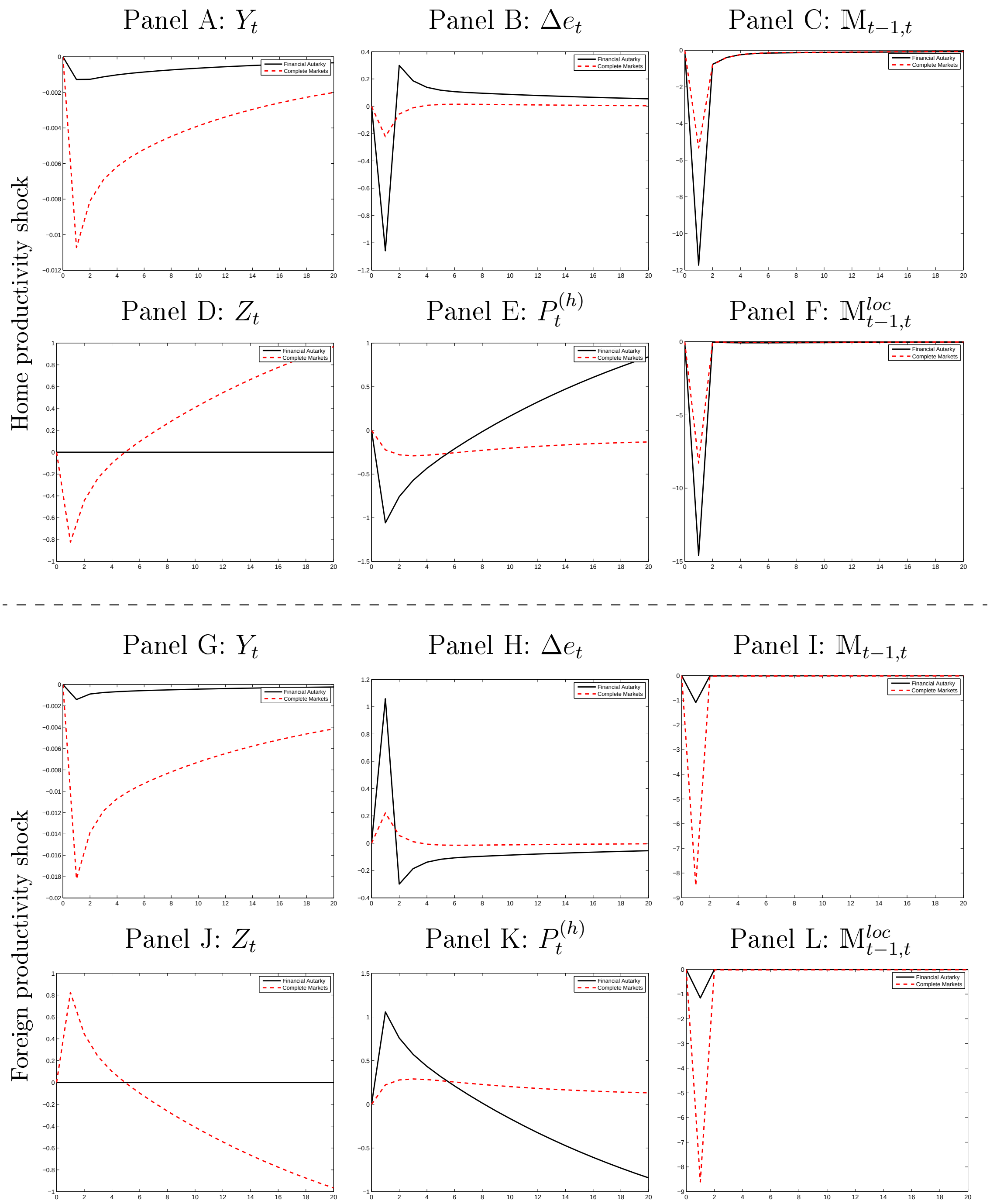
Inflation, as depicted in Figure 3, reacts strongly and persistently to home productivity shocks in the financial autarky case. This positive response is slightly diminished when financial markets are complete. Inflation basically does not react to foreign productivity shocks in the financial autarky case but strongly positive in the complete markets case due to the small increase in the price of imported goods with complete markets. This leads to the observed higher correlation of inflation rates with complete financial markets. Wages react more strongly negatively in response to foreign productivity shocks when complete markets are introduced, as visible in Panel I of Figure 3.

Figure 1: Impulse responses – consumption, labor, and investments (productivity shocks)



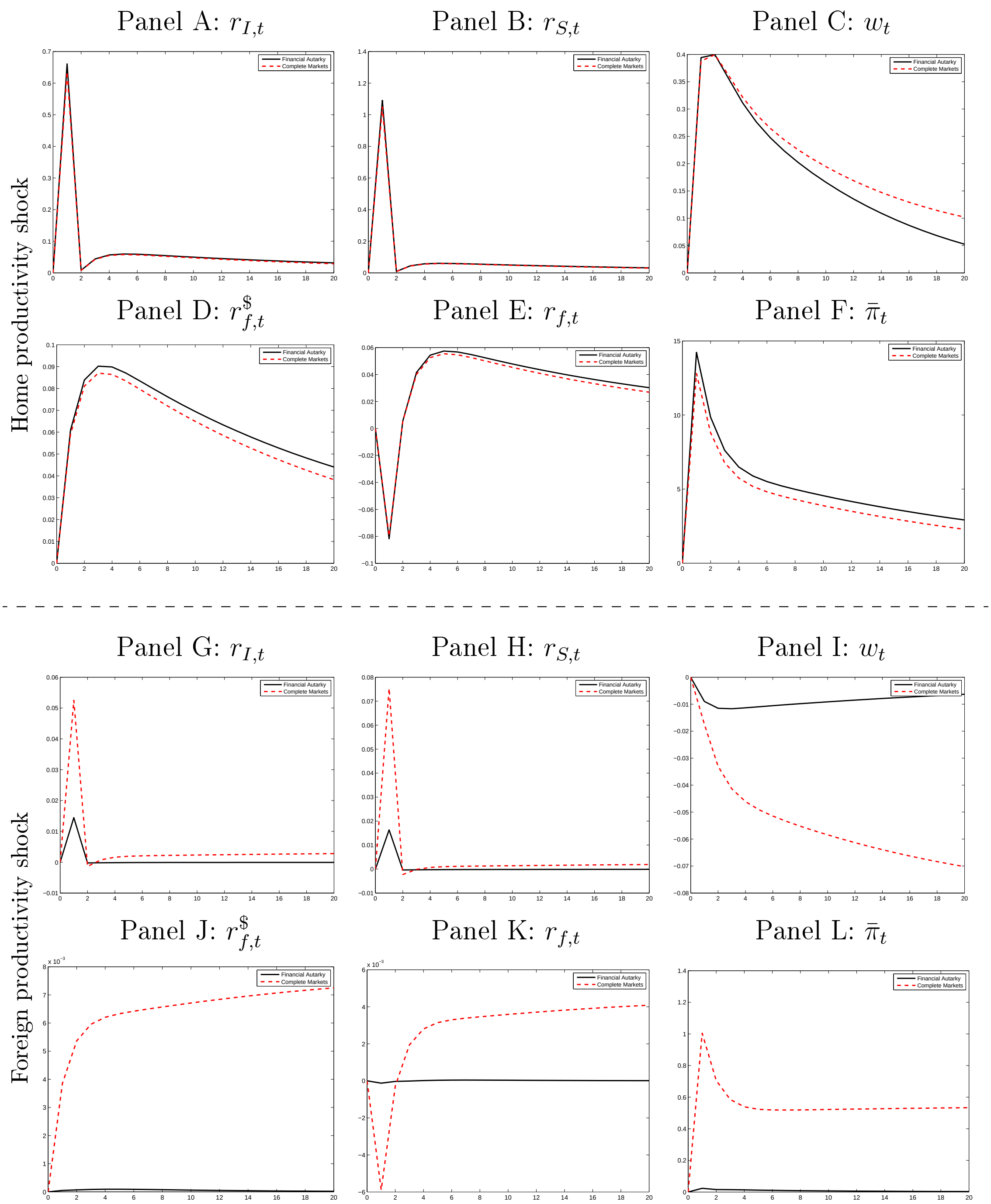
This figure depicts the home consumption bundle C_t, the home good's contribution to home consumption $C_{h,t}$, the foreign good's contribution to home consumption $C_{f,t}$, home labor demand L_t^d, home capital investment I_t, and home R&D investment S_t in response to a positive one-standard-deviation home (foreign) country's productivity shock $\varepsilon_{a,t}$ ($\varepsilon_{a,t}^*$) in the upper (lower) panel for both the financial autarky case (black solid lines) and the complete markets case (red dashed lines). The length of each impulse response function is 20 quarters, where the shock materializes in the first quarter, and the economy is initially in the stochastic steady state. The values reported are log deviations from the steady state in percentage points.

Figure 2: Impulse responses – aggregate quantities and prices (productivity shocks)



This figure depicts aggregate home output Y_t, log real exchange rate growth Δe_t, the home real stochastic discount factor for pricing quantities in utility bundle units $\mathbb{M}_{t-1,t}$, the international consumption allocation factor Z_t, the home real terms of trade $P_t^{(h)}$, and the home real stochastic discount factor for pricing quantities in domestic good units $\mathbb{M}_{t-1,t}^{loc}$ in response to a positive one-standard-deviation home (foreign) country's productivity shock $\varepsilon_{a,t}$ ($\varepsilon_{a,t}^*$) in the upper (lower) panel for both the financial autarky case (black solid lines) and the complete markets case (red dashed lines). The length of each impulse response function is 20 quarters, where the shock materializes in the first quarter, and the economy is initially in the stochastic steady state. The values reported are log deviations from the steady state in percentage points except for exchange rate growth whose impulse response function is reported in absolute deviations from the steady state in percentage points.

Figure 3: Impulse responses – returns, wage, and inflation (productivity shocks)



This figure depicts the log home real return on physical capital $r_{I,t}$, the log home real return on intangible capital $r_{S,t}$, the home real wage rate w_t, the home nominal risk-free rate $r^{\$}_{f,t}$, the home real risk-free rate $r_{f,t}$, and the home inflation rate $\bar{\pi}_t$ in response to a positive one-standard-deviation home (foreign) country's productivity shock $\varepsilon_{a,t}$ $(\varepsilon^*_{a,t})$ in the upper (lower) panel for both the financial autarky case (black solid lines) and the complete markets case (red dashed lines). The length of each impulse response function is 20 quarters, where the shock materializes in the first quarter, and the economy is initially in the stochastic steady state. The values reported are absolute deviations from the steady state in percentage points except for the real wage rate whose impulse response function is reported in log deviations from the steady state in percentage points.

6 Summary and Conclusion

This study deals with the equilibrium implications of financial integration in a symmetric two-country medium-scale New-Keynesian dynamic stochastic general equilibrium model. The model contains households supplying labor and renting out physical and intangible capital to the production sector, intermediate and final goods that are traded internationally, and monetary authorities in each of the countries. Prices and wages are subject to Calvo-style nominal rigidities. Intangible capital and investments in R&D give rise to sustained endogenous economic growth. The model is taken to two financial integration set-ups: financial autarky (represented by US and UK data from 1950 to 1970) and complete markets (cross-referenced with US and UK data from 1971 to 2015).

The financial autarky model is relatively well in line with the major macroeconomic moments in the early sample. Notably, investments are much more volatile than output growth, as in the data. The volatility of employment is higher than volatility of real wages both in the data and in the model. Moreover, consumption growth is more volatile than output growth, as in our data sample. When complete financial markets are introduced, average output growth significantly increases and average inflation rates go up. The first observation is at odds with the data, but the second observation complies with the data. The levels and dynamics of risk-free rates follow data patterns closely. Even though risk premia fall short of the levels seen in the data, their contraction with increasing integration of financial markets stands in line with the data.

Also in line with the data, the model produces considerable co-movement of consumption growth and output growth across countries. Additionally, the cross-country correlation of output growth increases considerably replicating the shift present in the data. The simulated increase in cross-country co-movements of capital investment, labor, and inflation rates when moving from financial autarky to complete markets closely resembles movements in the data. Similarly, correlation of risk-free rates across countries increases, tracking the data. One of the financial market puzzles, the forward premium anomaly associated with the uncovered real interest rate parity regression coefficient in our model is well in line with its data counterpart. Moreover, it drops considerably once financial markets become more integrated following the shift in the data. Last but not least, when financial markets are introduced the correlation between exchange rate growth and the consumption growth differential shrinks dramatically, as in the data.

Going forward, a few additional analyses should be undertaken with our model. Firstly, the comparison of the model's implications in the two financial integration regimes with trade in intermediate and final goods to a model where only trade in final goods is possible should be carried out. Secondly, the impact of price rigidities on inflation dynamics and other macroeconomic quantities should be investigated more thoroughly by solving different calibrations of the model with varying intensities of price rigidities. For a better understanding of the relationships and the effects present in the current version of the model it would also be beneficial to execute a thorough model's sensitivity analysis to the values of model's most important parameters. Since the model represents a rather complicated economic system, there is a number of channels how the parameter value choices affect the equilibrium. Finally, extending the model to feature an even higher degree of integration among countries, i.e. a joint currency and joint monetary policy as it has been established among a large set of European countries with the European Monetary Union, is left for future research.

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