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TECHNOLOGY TRADE WITH ASYMMETRIC TAX REGIMES AND HETEROGENEOUS LABOR MARKETS: IMPLICATIONS FOR MACRO QUANTITIES AND ASSET PRICES[*]

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Abstract

The international diffusion of technology plays a key role in stimulating global growth and explaining co-movements of international equity returns. Existing empirical evidence suggests that countries are heterogeneous in their attitude toward innovation: Some countries rely more on technology adoption while other countries rely more on internal technology production. European countries that rely more on adoption are also typically characterized by lower fiscal policy flexibility and higher labor market rigidity. We develop a two-country model, in which both countries rely on R&D and adoption, to study the short- and long-run effects of aggregate technology and adoption probability shocks on economic growth in the presence of the aforementioned asymmetries. Our framework suggests that an increase in the ability to adopt technology from abroad stimulates future economic growth in the country that benefits from higher adoption rates but the beneficial effects also spread to the foreign country. Moreover, it helps to explain the differences in macro quantities and equity returns observed in the international data.

Keywords: Technology Adoption, R&D Investment, Asymmetric Tax Regimes, Asset Prices

JEL: E3, F3, F4, G12

1 Introduction

The seminal work of Romer (1990) illustrates the fundamental role of technological innovation for economic growth. Building on the argument that asset prices reflect changes in the growth opportunities of the economy, the recent asset pricing literature has analyzed the link between technological innovation and stock returns (Garleanu, Panageas, and Yu, 2012; Kung and Schmid, 2015; Bena, Garlappi, and Grüning, 2016). Given that technological innovation is not only based on internal production but can also be imported from abroad, Gavazzoni and Santacreu (2015) and Croce, Nguyen, and Schmid (2015) argue that technological adoption can help to explain the correlation across international stock markets and the co-movement of macroeconomic quantities across different countries.

Traditional models that aim at explaining the link between technological innovation and the co-movement of international capital markets and macro quantities typically assume that countries are homogeneous, that is, they feature identical fundamentals. However, countries tend to exhibit structural differences. Importantly, such differences show up also across countries belonging to the same region. Moreover, the relative contribution of technology adoption as compared to the internal technology production differs across countries. For instance, Choi, González, and Gray (2013) show that fiscally weak European countries and Eastern European countries exhibit low level of investment in research and development (R&D) and thus rely more on technology adoption from abroad to sustain economic growth. Differently, fiscally strong countries are closer to the technology frontier and sustain economic growth with a sizable amount of R&D investments. In addition, fiscally weak and fiscally strong European countries typically differ in their economic fundamentals. For instance, fiscally weak countries tend to have less flexible labor markets (Nickell, 1997). This suggests that the country's characteristics may affect the link between the diffusion of technology and international stock returns. In this respect, Jahan-Parvar, Liu, and Rothman (2013) suggest that cross-country heterogeneity helps to match the observed differences in the equity risk premium between developed and emerging markets.

Motivated by these observations, we develop a two-country general equilibrium model where economic growth is driven by internal production of new technology (via R&D) and international technology trade (via adoption). Most importantly, the two countries are heterogeneous in their fiscal policy, in their long-run mean of the adoption probability, and in the flexibility of their labor market. To be close to the current European scenario, we assume that the fiscally weak country employs a zero-deficit fiscal rule, has a rigid labor market, and relies more on adoption than the fiscally strong country (i.e. higher adoption probabilities). Contrarily, the fiscally strong country is allowed to temporarily run a small fiscal deficit when macroeconomic conditions deteriorate, has a less rigid labor market, and relies less on adoption.

In this framework, a positive macroeconomic shock in one country (both in terms of productivity and in terms of adoption possibilities) increases the availability of new technology and stimulates economic growth in both countries. The impact and the duration of the shock are shaped by the country's structural characteristics. Positive macroeconomic shocks in the rigid country rise macro aggregates both today and in the future. Thanks to the trading channel, output also rises in the flexible country. At the same time, the increase in output activates the tax-smoothing fiscal policy in the flexible country which induces a current decline in consumption. Although current consumption decreases, future consumption is expected to increase in the flexible country and, due to the tax-smoothing policy, the future increase is more persistent but smaller than the one in the rigid country. The structural differences among countries have clear implications for macroeconomic quantities and asset prices. Labor market rigidities and the zero-deficit policy impair a country's ability to counteract the effects of macroeconomic shocks. Therefore, a country characterized by rigid labor market or by a zero-deficit fiscal policy is more exposed to macroeconomic shocks than a frictionless market. However, if only adoption probabilities are heterogeneous, the country with the higher adoption probability features lower volatility of macroeconomic growth rates. These structural differences affect the future growth prospects of the two countries and are reflected in asset returns: macroeconomic fundamentals are more volatile in the rigid country than in the flexible country, and investors command a return premium to invest in the rigid market. In summary, our analysis suggests that structural differences help to accounnt for the properties of international capital markets and, at the same time, affect the international transmission of macroeconomic shocks.

Our benchmark model features endogenous capital accumulation and capital investment subject to capital adjustment costs. For reasons of robustness, we also solve an equivalent model without endogenous capital accumulation. We find that our main results remain intact in this case.

The remainder of the paper is organized as follows. Section 2 discusses the most relevant literature focusing on international endogenous growth models and their implications for business cycles and asset prices. Section 3 presents our international endogenous growth model featuring asymmetric tax regimes and heterogeneous labor market rigidities. The calibration and quantitative implications of our model are discussed in Section 4. To shed light on the robustness of the quantitative implications of the benchmark model, we solve and analyze an equivalent model without endogenous capital accumulation in Section 5. Finally, Section 6 concludes.

2 Background and Motivation

The goal of this paper is to study the link between international asset returns and technological innovation in a world where countries exhibit structural differences. In our model, economic growth is induced by (i) internal production of newly developed intermediate goods and (ii) adoption of new technology from abroad. The production function depends on four elements: a stochastic productivity process (i.e. disembodied technology), the endogenous amount of capital, the endogenous supply of labor, as well as domestically developed and internationally adopted intermediate goods.

Our theoretical framework is closely related to that of Croce, Nguyen, and Schmid (2015) and Gavazzoni and Santacreu (2015). However, we differ from them in several important aspects. Croce, Nguyen, and Schmid (2015) focus on the uncertainty (in the sense of entropy) about economic shocks and its effect on the international technology diffusion. Our utility function does not account for investors' aversion to model uncertainty. Moreover, in our model the total production of final goods depends on both labor and capital while in Croce, Nguyen, and Schmid (2015) it depends on labor only. As we will see later, capital accumulation is important because, via the investment channel, it makes the total output and consumption of one country more sensitive to productivity shocks of the other country. Note also that the inclusion of both R&D and physical capital allows firms to choose between two different investment opportunities, a trade-off absent in Croce, Nguyen, and Schmid (2015). In addition, we assume that the probability of adopting technologies from the foreign quantities is a stochastic process while in Croce, Nguyen, and Schmid (2015) this probability is modeled as a function of the country's total output. These differences enable us to study the short-run and long-run effects of shocks to the adoption probability and their welfare implications.

The main focus of Gavazzoni and Santacreu (2015) is to analyze the effects of endogenous technology adoption on international asset prices. Their international endogenous growth model produces a high correlation of equity returns while fundamentals are moderately correlated, as in the data. Moreover, they provide empirical evidence that countries that trade more (goods and technologies) with each other display higher cross-country correlations of equity returns. As in their study, we concentrate on international trade of technology to explain the co-movement of macroeconomic quantities and stock returns. Moreover, as they do we allow households to fully share risks by imposing a complete international capital markets structure. Differently from our economy and Croce, Nguyen, and Schmid (2015), the model developed by Gavazzoni and Santacreu (2015) does not have a government sector. Therefore, international differences in fiscal policy and potential spillover effects from those are not studied. Moreover, Gavazzoni and Santacreu (2015) include iceberg transaction costs in the international trade of intermediate goods, whereas we allow for frictionless trade. Finally, we differ from both Croce, Nguyen, and Schmid (2015) and Gavazzoni and Santacreu (2015) in that we account for labor market frictions and, most importantly, we allow the two countries to differ in terms of labor market frictions, fiscal policies, and the ability to adopt foreign technologies. Country heterogeneity is important in our framework because it implies that, in equilibrium, the unconditional moments of stock returns and macroeconomic quantities differ across the two countries. Therefore, heterogeneity in international business cycle moments and equity returns' characteristics arises endogenously in our model.

More broadly, our paper also expands on the growing literature on international technology diffusion and its effect on productivity, growth, and cross-country income differences. Using a novel dataset on technology trade, Choi, González, and Gray (2013) find evidence of a positive association between technology adoption and productivity growth. Comin and Hobijn (2004) observe that the ability of countries to adopt technologies depends on human capital, government characteristics, degree of trade openness, and the former adoption process. In this respect, cross-country macroeconomic heterogeneity matters a great deal for the international diffusion of technologies. Moreover, they show that the adoption of foreign technologies impacts more strongly on countries' productivity than it does on its domestic investment in R&D. Therefore, technology adoption is key for stimulating growth and should be publicly subsidized. Using data on international patents, Peri (2005) shows that knowledge flows within and across countries tend to have positive effects on productivity and innovation. Eaton and Kortum (1996) observe that international trade in ideas is a major factor in world growth. Specifically, they find that most OECD members—the United States being a prominent exception— obtain more than 50% of their productivity growth from ideas that originated abroad. It turns out that positive (negative) shocks to the adoption process may boost (undermine) global growth.[1] We contribute to

[1] Other studies aimed at quantifying the benefits of international technology diffusion to productivity growth include Benhabib and Spiegel (1994), Parente and Prescott (1994), Coe and Helpman (1995), and Eaton and Kortum (1999).

this literature by showing that the benefits of the economic expansion in the home country caused by an increase in the probability of adoption are transmitted to the foreign country through the channel of trade in intermediate goods. Specifically, our international endogenous growth framework suggests that these benefits are long-lasting, and that countries' structural heterogeneity determines to what extent macroeconomic shocks spill over to the other country. Thus, we confirm that adoption is a key channel in short-run and (more importantly) long-run global growth.

3 Model

In this section, we introduce a model of technology trade between two economies—a domestic and a foreign economy—that differ from each other with respect to the severity of the labor market friction, the amount of technology adopted from abroad, and the tax regime. In what follows, we first introduce the household behavior, after which we present the production sector, and the government policy regimes. Households and production technology are fairly standard in this literature. As such, we put more emphasis on the description of the innovation process, on the country-specific fiscal policy, and on the labor market specifications. Unless specified differently, in the sections below all equations labeled by index $j \in \{H, F\}$ refer to both countries. We use H to refer to the home country and F to refer to the foreign country. When needed, to denote the country different from country j we use the symbol $-j$. Hence, $-j = H$ if $j = F$ and $-j = F$ if $j = H$.

3.1 Households

Preferences. In each country, there is a representative household that has recursive preferences in the spirit of Epstein and Zin (1989):

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

The household obtains utility from consumption $C_{j,t}$ and leisure $\bar{L}_j - L_{j,t}$. Consumption and leisure enter the utility function by means of the CES aggregator $u_{j,t}$ defined as:

$$u_{j,t} = \left[\kappa_j C_{j,t}^{1-\frac{1}{\sigma}} + (1-\kappa_j)[N_{j,t}(\bar{L}_j - L_{j,t})]^{1-\frac{1}{\sigma}} \right]^{\frac{1}{1-\frac{1}{\sigma}}}.$$

The parameter γ denotes the relative risk aversion, ψ determines the elasticity of intertemporal substitution, and σ is the degree of complementarity between leisure and consumption. $\bar{L}_j$ is the total time endowment, $L_{j,t}$ is the labor supply, while the parameter κ_j measures the weight on consumption in the utility bundle $u_{j,t}$. Finally, $N_{j,t}$ is the available technology in the economy, i.e. the total number of patents either developed domestically or adopted from abroad up to period t.

Financial markets. In each country $j \in \{H, F\}$, there are two domestic financial markets: the stock market and the bond market. Moreover, there is an international financial market allowing the households to perfectly share risks. The representative household maximizes lifetime utility subject to its budget constraint:

$$C_{j,t} + S_{j,t} + \mathbb{E}_t[\mathbb{M}_{j,t+1} Z_{j,t+1}] = (1 - \tau_{j,t}) W^u_{j,t} L_{j,t} + D^a_{j,t} + Z_{j,t},$$

where $D^a_{j,t}$ is the aggregate dividend, while $W^u_{j,t}$ represents the frictionless wage, which is taxed at the rate $\tau_{j,t}$. Finally, the total R&D expenditure in country j is given by $S_{j,t}$, and $Z_{j,t}$ is the value of households' financial wealth, as in Gavazzoni and Santacreu (2015), accounting for complete international financial markets.

Optimality conditions. In the spirit of Uhlig (2007), we assume that wages are sticky and only a fraction of them is determined by the intratemporal optimality condition:

$$\frac{1-\kappa_j}{\kappa_j} N_{j,t}^{(1-1/\sigma)} \left(\frac{C_{j,t}}{\bar{L}_j - L_{j,t}} \right)^{1/\sigma} = (1 - \tau_{j,t}) W^u_{j,t}. \tag{1}$$

The remaining part of the wage just grows with aggregate productivity:

$$W_{j,t} = \left(e^{\Delta a_{j,t}} W_{j,t-1} \right)^{\mu_j} \left(W^u_{j,t} \right)^{1-\mu_j}, \tag{2}$$

where the country-specific parameter $\mu_j > 0$ determines the fraction of the wage that is sticky, while $\Delta a_{j,t}$ captures the domestic technology growth rate, as defined in Equation (25), and the assumption that the wage is indexed to aggregate productivity growth when it cannot be chosen optimally.[2] In this setting, the stochastic discount factor in economy j is given by:

$$\mathbb{M}_{j,t+1} = \beta \left(\frac{u_{j,t+1}}{u_{j,t}} \right)^{\frac{1}{\sigma} - \frac{1}{\psi}} \left(\frac{C_{j,t+1}}{C_{j,t}} \right)^{-\frac{1}{\sigma}} \left(\frac{U^{1-\gamma}_{j,t+1}}{E_t[U^{1-\gamma}_{j,t+1}]} \right)^{\frac{\frac{1}{\psi} - \gamma}{1-\gamma}}, \tag{3}$$

where the last factor captures aversion to continuation utility risk (i.e. long-run risk). The usual Euler conditions for domestic asset prices (i.e. equity and risk-free one-period bond) are given by:

$$\begin{aligned} V^a_{j,t} &= D^a_{j,t+1} + \mathbb{E}_t[\mathbb{M}_{j,t+1} V^a_{j,t+1}], \\ 1 &= \mathbb{E}_t[\mathbb{M}_{j,t+1} R^f_{j,t}]. \end{aligned} \tag{4}$$

We denote by $r^f_{j,t} = \ln(R^f_{j,t})$ the risk-free rate.

3.2 Production

Final goods. In each country $j \in \{H, F\}$ a non-traded final good, whose total output is denoted by $Y_{j,t}$, is produced by a representative perfectly competitive firm. Production of the final output takes place by employing capital $K_{j,t}$, labor $L_{j,t}$, and a basket of intermediate goods $\Sigma_{j,t}$, whose technology (i.e. patent) has been either developed domestically or adopted from abroad. As will be explained

[2] Donadelli and Grüning (2016) show, using a one-country endogenous growth model, that this simple form of modeling wage rigidities performs quantitatively very similarly to a more complex setting, in which wage rigidities arise from a Calvo-type of wage stickiness.

later, we assume that the foreign adopted intermediate goods employed by the representative firm in country j are bought from country $-j$, whereas the domestically developed intermediate goods are purchased from the local firm. Therefore, we denote by $X_{j,i,t}$ the time-t units of intermediate good i, employed in country j, whose patent is domestically developed (i.e. domestic intermediate goods). Similarly, we denote by $X^*_{j,l,t}$ the time-t units of good l used by the firm of country j, whose patent is developed abroad (i.e. adopted intermediate goods).[3] As we will demonstrate in Section 5, for our main results concerning the equilibrium implications of the assumed structural heterogeneities across the two countries it is not important to have endogenous capital accumulation in the model. Some moments, like the equity premium and the cross-country consumption growth correlation, are also more realistic without endogenous capital accumulation. However, we think physical capital is an important and standard ingredient in such a model as ours, and it induces important trade-off decisions to be made by the final goods firm, i.e. the decision how much to invest in capital and how much labor to supply. The representative firm of country j is endowed with the following technology:

$$Y_{j,t} = \left(K_{j,t}^{\alpha} \left(\Omega_{j,t} L_{j,t} \right)^{1-\alpha} \right)^{1-\xi} \Sigma_{j,t}^{\xi}, \tag{5}$$

where $\Omega_{j,t}$ is an exogenous stochastic productivity process given by:

$$\ln(\Omega_{j,t}) = \rho_{\Omega} \ln(\Omega_{j,t-1}) + \epsilon_{j,t}^{\Omega}, \quad \epsilon_{j,t}^{\Omega} \sim N(0, \sigma_{\Omega}^2), \tag{6}$$

while

$$\Sigma_{j,t} = \left[\int_0^{A_{j,t}} \left(X_{j,i,t} \right)^{\frac{1}{\nu}} di + \int_0^{A^*_{j,t}} \left(X^*_{j,l,t} \right)^{\frac{1}{\nu}} dl \right]^{\nu}$$

denotes an aggregate composite of intermediate goods. Here, we use $A_{j,t}$ and $A^*_{j,t}$ to label the number of intermediate goods available at date t, whose patents have been domestically developed and adopted from abroad, respectively. Furthermore, the parameter $\nu > 1$ determines the elasticity of substitution between domestic intermediate goods and adopted intermediate goods. Capital evolves according to the following dynamics:

$$K_{j,t+1} = (1-\delta) K_{j,t} + \Lambda(I_{j,t}/K_{j,t}) K_{j,t}, \tag{7}$$

and it is subject to convex adjustment costs specified as in Jermann (1998) by means of the following adjustment cost function:

$$\Lambda_{j,t} := \Lambda \left(\frac{I_{j,t}}{K_{j,t}} \right) = \frac{\alpha_1}{1-\frac{1}{\zeta}} \left(\frac{I_{j,t}}{K_{j,t}} \right)^{1-\frac{1}{\zeta}} + \alpha_2, \text{ where } \alpha_1 = (\overline{\alpha} + \delta - 1)^{\frac{1}{\zeta}}, \ \alpha_2 = \frac{1}{1-\zeta} (\overline{\alpha} + \delta - 1).$$

The constant $\overline{\alpha}$ is chosen such that there are no adjustment costs in the deterministic steady state, while the parameter ζ determines the elasticity of investment.

The final goods firm takes prices as given and chooses the demand for domestic and adopted intermediate goods, capital, investment, and labor in order to maximize the present value of its future

[3] In other words, we are assuming that any patent may give rise to two different goods, of which both are used in the production of the final good: When we consider production in country j, then $X_{j,i,t}$ represents the units of good i whose patent is developed in country j, while $X^*_{j,i,t}$ represents the units of good i whose patent is adopted from country $-j$. In the sense specified above, the superscript * refers to adopted goods.

dividends, subject to the definition of dividends:

$$D_{j,t} = Y_{j,t} - W_{j,t}L_{j,t} - I_{j,t} - \int_0^{A_{j,t}} P_{j,i,t}X_{j,i,t}di - \int_0^{A^*_{j,t}} P^*_{j,l,t}X^*_{j,l,t}dl,$$

and the capital accumulation equation (7). We use $P_{j,i,t}$ and $P^*_{j,l,t}$ to denote the prices of the domestic and the adopted intermediate goods at time t, respectively. Taking these prices as given, the optimal demands for the domestic intermediate goods i and for the adopted intermediate good l are given by:

$$X_{j,i,t} = \left(\frac{\xi \left(K^\alpha_{j,t} \left(\Omega_{j,t}L_{j,t}\right)^{1-\alpha} \right)^{1-\xi} \left(\Sigma_{j,t}\right)^{\xi - \frac{1}{\nu}}}{P_{j,i,t}} \right)^{\frac{\nu}{\nu-1}}, \tag{8}$$

$$X^*_{j,l,t} = \left(\frac{\xi \left(K^\alpha_{j,t} \left(\Omega_{j,t}L_{j,t}\right)^{1-\alpha} \right)^{1-\xi} \left(\Sigma_{j,t}\right)^{\xi - \frac{1}{\nu}}}{P^*_{j,l,t}} \right)^{\frac{\nu}{\nu-1}}. \tag{9}$$

The first-order condition with respect to labor, instead, gives rise to the following equation in the labor market:

$$W_{j,t} = \frac{(1-\alpha)(1-\xi)Y_{j,t}}{L_{j,t}}. \tag{10}$$

Finally, the first-order condition with respect to next period's capital implies:

$$1 = \mathbb{E}_t \left[\mathbb{M}_{j,t+1}\Lambda'_{j,t} \left\{ \frac{\alpha(1-\xi)Y_{j,t+1} - I_{j,t+1}}{K_{j,t+1}} + \left(\frac{1-\delta+\Lambda_{j,t+1}}{\Lambda'_{j,t+1}} \right) \right\} \right]. \tag{11}$$

Intermediate goods. The production of intermediate goods takes place in infinitesimally small and monopolistically competitive firms. Following Gavazzoni and Santacreu (2015), we assume that the foreign adopted intermediate goods used in country j are produced in country $-j$ and sold abroad where the goods' prices are denoted in importer's final goods units. This means that in each country j the representative final goods firm employs the intermediate goods produced by a monopolistically competitive, specialized domestic firm that produces good i, with $i \in [0, A_{j,t}]$, and it employs the goods from a monopolistically competitive, specialized domestic firm in country $-j$ that produces good l, with $l \in [0, A^*_{j,t}]$. In order to produce one unit of each intermediate good, firms must employ one unit of the final good. Hence, profit maximization in the intermediate goods' sector takes the following form:

$$\Pi_{j,i,t} = \max_{\{P_{j,i,t}\}} \left\{ P_{j,i,t}X_{j,i,t}(P_{j,i,t}) - X_{j,i,t}(P_{j,i,t}) \right\}, \qquad i \in [0, A_{j,t}], \tag{12}$$

$$\Pi^*_{j,l,t} = \max_{\{P^*_{j,l,t}\}} \left\{ P^*_{j,l,t}/Q_{j,t}X^*_{j,l,t}(P^*_{j,l,t}/Q_{j,t}) - X^*_{j,l,t}(P^*_{j,l,t}/Q_{j,t}) \right\}, \qquad l \in [0, A^*_{j,t}], \tag{13}$$

where $\Pi_{j,i,t}$ and $\Pi^*_{j,i,t}$ are the profits from producing the domestic intermediate good i and the adopted intermediate good l, respectively. The exchange rate is denoted by $Q_{j,t}$ and defined below in Equation (16). At the optimal demand for intermediate goods, given by Equations (8) and (9), intermediate goods firms charge a constant markup over marginal cost, subject only to exchange rate risk:

$$P_{j,i,t} \equiv P_j = \nu, \tag{14}$$

$$P^*_{j,l,t} \equiv P^*_j = \nu Q_{j,t}, \tag{15}$$

where $Q_{j,t}$ denotes the exchange rate or terms of trade, i.e. the price of country j's goods in units of country $-j$'s goods. Due to the assumption of complete markets, exchange rate growth is determined by the following equation, as in Gavazzoni and Santacreu (2015) and Colacito and Croce (2013):

$$\frac{Q_{j,t+1}}{Q_{j,t}} = \frac{\mathbb{M}_{j,t+1}}{\mathbb{M}_{-j,t+1}}. \tag{16}$$

The exchange rate is pinned down by defining

$$\Upsilon_{j,t} = Q_{j,t} \left(\frac{C_{j,t}}{C_{-j,t}} \right)^{-\frac{1}{\psi}}, \tag{17}$$

which satisfies the following recursion:

$$\Upsilon_{j,t+1} = \Upsilon_{j,t} \frac{\mathbb{M}_{j,t+1}}{\mathbb{M}_{-j,t+1}} \frac{(C_{j,t+1}/C_{j,t})^{-\frac{1}{\psi}}}{(C_{-j,t+1}/C_{-j,t})^{-\frac{1}{\psi}}}. \tag{18}$$

To ensure balanced growth, we impose the following parametric restriction:

$$\frac{(\nu-1)\xi}{1-\xi} = 1-\alpha, \tag{19}$$

which implies the following conditions for the intermediate goods sector:

$$X_{j,i,t} \equiv X_{j,t} = \left(\frac{\xi}{\nu}\right)^{\frac{\nu}{\nu-1}} K^{\alpha}_{j,t} \left(\Omega_{j,t} L_{j,t}\right)^{1-\alpha} \left(\left(\frac{\xi}{\nu}\right)^{\frac{1}{\nu-1}} A_{j,t} + \left(\frac{\xi}{\nu Q_{j,t}}\right)^{\frac{1}{\nu-1}} A^*_{j,t} \right)^{-\alpha}, \tag{20}$$

$$X^*_{j,i,t} \equiv X^*_{j,t} = \left(\frac{\xi}{\nu Q_{j,t}}\right)^{\frac{\nu}{\nu-1}} K^{\alpha}_{j,t} \left(\Omega_{j,t} L_{j,t}\right)^{1-\alpha} \left(\left(\frac{\xi}{\nu}\right)^{\frac{1}{\nu-1}} A_{j,t} + \left(\frac{\xi}{\nu Q_{j,t}}\right)^{\frac{1}{\nu-1}} A^*_{j,t} \right)^{-\alpha}, \tag{21}$$

$$\Pi_{j,i,t} \equiv \Pi_{j,t} = (\nu-1)\, X_{j,t}, \tag{22}$$

$$\Pi^*_{j,i,t} \equiv \Pi^*_{j,t} = (\nu-1)\, X^*_{j,t}. \tag{23}$$

Using Equations (20), (21), and (19) in Equation (5) yields the equilibrium final output:

$$Y_{j,t} = K^{\alpha}_{j,t} \left[\Omega_{j,t} L_{j,t} \left(\left(\frac{\xi}{\nu}\right)^{\frac{1}{\nu-1}} A_{j,t} + \left(\frac{\xi}{\nu Q_{j,t}}\right)^{\frac{1}{\nu-1}} A^*_{j,t} \right) \right]^{1-\alpha}. \tag{24}$$

In each country, the variety of new intermediate goods may expand either by means of their own innovation activities (i.e. R&D) or by importing technology from abroad (i.e. adoption). In the next section, we describe how these two activities take place in our international production economy.

3.3 Technology innovation

R&D. Developers of new patents (innovators) sell their intellectual property to monopolistically competitive firms that buy these patents and produce new intermediate goods. To accomplish their projects in period $t+1$, innovators invest $S_{j,t}$ units of the final good in R&D in period t. We assume that the total mass of domestic variety of patents developed in country j evolves according to the following law of motion:

$$A_{j,t+1} = \upsilon_{j,t} S_{j,t} + (1-\delta_v) A_{j,t}, \qquad e^{\Delta a_{j,t+1}} = \frac{A_{j,t+1}}{A_{j,t}}, \tag{25}$$

where, in each period, a new variety becomes obsolete with probability δ_v, while $\upsilon_{j,t}$ is the time-varying probability to develop new patents. Following Comin and Gertler (2006), we assume that $\upsilon_{j,t}$ evolves as

$$\upsilon_{j,t} = \chi_j \left(\frac{S_{j,t}}{N_{j,t}}\right)^{\eta-1}, \quad \eta \in (0,1),$$

where η denotes the elasticity of new intermediate goods with respect to R&D investments, χ_j is a scale parameter, while

$$N_{j,t} = A_{j,t} + A^*_{j,t} \tag{26}$$

represents the technological frontier of country j at date t (i.e. the total mass of patents available at a given time t).

Adoption. The total mass of foreign variety adopted by country j evolves according to the following law of motion:

$$A^*_{j,t+1} = (1-\delta_v) A^*_{j,t} + \upsilon^A_{j,t}(1-\delta_v)[A_{-j,t} - A^*_{j,t}]. \tag{27}$$

where $A_{-j,t} - A^*_{j,t}$ is the mass of foreign technology that has not been adopted yet by country j at date t, and $\upsilon^A_{j,t}$ is the probability that a new technology is adopted by country j in period t. With probability $1-\upsilon^A_{j,t}$, the adopter j gets nothing. We assume that $\upsilon^A_{j,t}$ evolves according to the following stochastic process:

$$\begin{aligned} \upsilon^A_{j,t} &= \frac{1}{1+e^{-\theta_{j,t}}}, \\ \theta_{j,t} &= (1-\rho_\theta)\bar{\theta}_j + \rho_\theta \theta_{j,t-1} + \epsilon^\theta_{j,t}, \quad \epsilon^\theta_{j,t} \sim N(0, \sigma^2_\theta). \end{aligned} \tag{28}$$

This specification ensures that $\upsilon^A_{j,t} \in (0,1)$. Note that (27) does not allow country j to adopt in period $t+1$ the new varieties made available in period $t+1$ in country $-j$ in period t. This captures the idea that technology adoption may incur time delays, which may be due to legal, institutional, logistic, and other local barriers.

Technology value. We assume that patents are intangible assets. Therefore, they can be sold either domestically or abroad in a competitive market. In each country j, the representative firm uses the patent i to create new intermediate goods. Accordingly, the value $V_{j,i,t}$ of a new patent i at time t is equal to the sum of discounted expected profits the firm is able to make by exploiting the patent, both domestically and abroad. Formally, let $W^V_{j,i,t}$ be the expected value of firms in country j using patent i at time t, and $J_{j,i,t}$ be the expected value of firms in country j with patent i that can potentially be adopted by the foreign country starting from $t+1$. When the adoption is successful, the value of an adopted patent is denoted by $W^{V,*}_{j,t,t}$. We have:

$$V_{j,i,t} = W^V_{j,i,t} + J_{j,i,t}, \tag{29}$$

where

$$W^V_{j,i,t} = \Pi_{j,i,t} + (1-\delta_v)\mathbb{E}_t[\mathbb{M}_{j,t+1} W^V_{j,i,t+1}], \tag{30}$$
$$W^{V,*}_{j,i,t} = \Pi^*_{-j,i,t} + (1-\delta_v)E_t[\mathbb{M}_{j,t+1} W^{V,*}_{j,i,t+1}], \tag{31}$$
$$J_{j,i,t} = (1-\delta_v)\mathbb{E}_t\Big[\mathbb{M}_{j,t+1}\Big(\upsilon^A_{-j,t} W^{V,*}_{j,i,t+1} + (1-\upsilon^A_{-j,t})J_{j,i,t+1}\Big)\Big]. \tag{32}$$

Since we assume that the there are no frictions in selling a new technology in the country where the new technology is developed, say country j, once the new patent enters the market, then it is sold domestically with certainty. Conversely, a new patent may be sold abroad—or, equivalently, adopted from abroad—one period later, and this occurs with uncertainty, according to the process (27). Accordingly, the expected profits realized by selling adopted intermediate goods enter the value of a new patent with probability $\upsilon^A_{-j,t}$, starting from period $t+1$ as specified in Equation (32).[4]

Developers invest $S_{j,t}$ units of the final good in each period t to produce a new technology available in period $t+1$. Their payoff is given by the expected discounted value of future profits obtained by selling the patents to the intermediate goods sector. From Equation (25), the new technology produced in period $t+1$ is given by:

$$A_{j,t+1} - (1-\delta_v)A_{j,t} = \upsilon_{j,t} S_{j,t},$$

and the expected payoff that developers obtain by selling this new technology is:

$$\upsilon_{j,t} S_{j,t} \mathbb{E}_t\left[\mathbb{M}_{j,t+1} V_{j,t+1}\right],$$

where, due to the symmetry of the problem, we have dropped the subscript i since all firms in the intermediate goods sector are identical. Since the R&D sector is a competitive market with free entry, the following zero-profit condition holds in equilibrium:

$$S_{j,t} = \upsilon_{j,t} S_{j,t} \mathbb{E}_t\left[\mathbb{M}_{j,t+1} V_{j,t+1}\right],$$

or, equivalently,

$$\frac{1}{\upsilon_{j,t}} = \mathbb{E}_t\left[\mathbb{M}_{j,t+1} V_{j,t+1}\right]. \tag{33}$$

The left-hand side represents the marginal cost of producing an extra variety in t, while the right-hand side is the marginal revenue by selling an extra variety in $t+1$.

[4] In the intermediate goods sector, the purchase of a new technology and the development of a new intermediate good are processes that occur intratemporal, i.e. at the start of the period and at the end of the period, respectively.

3.4 Government

Expenditure. In each country, the public expenditure $G_{j,t}$ over total production $Y_{j,t}$ evolves stochastically as follows:

$$\frac{G_{j,t}}{Y_{j,t}} = \frac{1}{1+e^{-g_{j,t}}},$$

where we assume that:

$$g_{j,t} = (1-\rho_G)\overline{g} + \rho_G g_{j,t-1} + \epsilon^G_{j,t}, \quad \epsilon^G_{j,t} \sim N(0,\sigma^2_G). \tag{34}$$

The government has two fiscal instruments to finance its public spending: It can either tax labor income, i.e. $T_{j,t} = \tau_{j,t}W_{j,t}L_{j,t}$, or use public debt $B_{j,t}$. Put together, these two measures must satisfy the following budget constraint:

$$B_{j,t} = R^f_{j,t-1}B_{j,t-1} + G_{j,t} - T_{j,t}. \tag{35}$$

However, as will be explained next, we focus on a situation in which one country—a fiscally weak country—is committed to a zero-deficit rule (due to austerity measures, for instance). Therefore, it can only tax labor income to finance its expenditure. On the contrary, the other country—a fiscally strong country—by virtue of its financial discipline might run a temporary fiscal deficit in addition to taxing labor income. As will become clear from the description of the tax policy below, the fiscal deficit will be progressively reduced by means of higher future taxes.

Asymmetric tax regimes. We assume that the two governments adopt two different tax regimes. The government of the home country ($j = H$) is committed to a zero-deficit rule, so that Equation (35) simply becomes $G_{H,t} = T_{H,t}$. To guarantee that the zero-deficit budget constraint holds in each period, the government fixes a labor tax rate equal to:

$$\tau^0_{H,t} = \frac{G_{H,t}/Y_{H,t}}{(1-\alpha)(1-\xi)}, \tag{36}$$

where α and ξ are, respectively, the share of physical capital, and the share of patents in the production technology of the final goods sector as specified in Equation (5). Such a choice of $\tau_{H,t}$ implies that the tax rate perfectly follows the path of the exogenous government expenditure process.

Conversely, the government of the foreign country ($j = F$) is not committed to a zero-deficit rule, and it can finance its public expenditure also by running deficits. Following Croce, Nguyen, and Schmid (2013), we assume that the debt to output ratio is driven by the following dynamics:

$$\frac{B_{F,t}}{Y_{F,t}} = \rho_{B,F}\frac{B_{F,t-1}}{Y_{F,t-1}} + \phi_{B,F}\cdot(\ln(L_{F,ss}) - \ln(L_{F,t})), \tag{37}$$

where $\rho_F \in (0,1)$ captures the delay of debt repayment, $\phi_B \geq 0$ is a scale parameter, and $L_{F,ss}$ is the steady-state level of labor. Using (35) and (37), the tax rate for the foreign country becomes:

$$\tau_{F,t} = \tau^0_{F,t} + \frac{1}{(1-\alpha)(1-\xi)}\left(\frac{R^f_{F,t-1}}{Y_{F,t}/Y_{F,t-1}} - \rho_{B,F}\right)\frac{B_{F,t-1}}{Y_{F,t-1}} + \phi_{B,F}\frac{\ln(L_{F,t}) - \ln(\bar{L}_F)}{(1-\alpha)(1-\xi)}, \tag{38}$$

where $\tau^0_{F,t}$ is the zero-deficit tax rate, similarly to (36). Following Croce, Nguyen, and Schmid (2013), we choose $\phi_{B,F} > 0$ to model an employment-oriented tax rule. In bad times, i.e. labor below the steady-state level, the government cuts taxes on labor income (i.e. increases debt). In good times, it increases taxes (i.e. reduces debt). Note that the second term on the right-hand side of Equation (38) also accounts for the long-lasting effect on taxes caused by debt repayment, and that by imposing $\rho_F \in (0,1)$ we rule out unstable fluctuations of the debt to output ratio.

3.5 Resource constraint

Final output is used for consumption, capital investment, R&D investment, production of domestically developed and foreign adopted intermediate goods, and public expenditure:

$$Y_{j,t} = C_{j,t} + I_{j,t} + S_{j,t} + A_{j,t}X_{j,t} + A^*_{-j,t}X^*_{-j,t} + G_{j,t}. \tag{39}$$

4 Quantitative Analysis

In this section, we first present the benchmark calibration of our model and follow with a discussion of the unconditional moments and their fit to international macroeconomic and financial data. Finally, we analyze the impulse response functions of the key macroeconomic shocks of the model.

4.1 Benchmark calibration

Table 1 summarizes all the parameters used in our benchmark calibration. Table 2 reports those parameter values for four other calibrations ([1], [2], [3], and [4]) which are different from the benchmark calibration [5]. In order to calibrate the model, we rely on German and Italian data.[5] The home country in our model represents Italy and the foreign country Germany. In our benchmark calibration, countries exhibit asymmetric fiscal policies, different labor market frictions, and different adoption probabilities. Italy has been severely affected by the fiscal crisis. Thus both internal and external constraints force it to save and to reduce its deficit due to both internal and external constraints. Hence, the opportunities for Italy to increase fiscal spending by means of increasing its deficit are limited. To capture this, we assume Italy to be committed to a zero-deficit policy in the model. Germany, however, does not have this enormous pressure to save and to reduce its fiscal deficit. Thus, it can relatively easily finance additional expenditure by means of additional debt. Germany, then, can run fiscal deficits via a tax-smoothing policy in the model.[6] In this respect, we set the intensity of the foreign country's smoothing policy $\phi_{B,F}$ and the related inverse of the speed of debt repayment $\rho_{F,B}$ to values of 0.0025 and $\sqrt[4]{0.95}$, respectively. Both values are similar to the calibration reported in Croce, Nguyen, and Schmid (2013). Heterogeneous labor market frictions are then captured by different wage rigidity parameters. Specifically, we assume Italy to have a less flexible labor market

[5] Although Germany and Italy are both part of a currency union and have the Euro as a joint currency, there is real exchange rate risk and $Q_{j,t}$ can differ from 1.

[6] This assumption reflects the current EU situation imposed by the set of common guidelines for the management of public debt for countries in the eurozone (i.e. European Stability and Growth Pact).

than Germany. In this respect, we set $\mu_H = 0.35$ and $\mu_F = 0.20$.[7] These values are similar in magnitude to the values used in the recent asset pricing literature that employ wage rigidities (see, e.g., Uhlig, 2007; Donadelli and Grüning, 2016). Heterogeneity in adoption probabilities is captured by setting $\bar{\theta}_H = -4.4108$ and $\bar{\theta}_F = -4.5951$ in the benchmark calibration. This implies that the home country has a quarterly adoption probability of 0.012 and the foreign country a probability of 0.01. Hence, we assume that Italy relies more on adoption than Germany, since it is probably slightly further away from the technology frontier. We choose these values as we find that the ratio between technology adoption (TA payments) and Business Enterprise Expenditure in R&D (BERD) for the period 1981–2014 is about 1.2 times higher in Italy than in Germany.

Table 1: Quarterly Benchmark Calibration

This table reports the parameters used in the quarterly benchmark calibration of our model. Parameters' sources: 1=Gavazzoni and Santacreu (2015), 2=Uhlig (2007), 3=Croce, Nguyen, and Schmid (2013), 4=Kung and Schmid (2015), 5=own calibration.

Parameter	Description	Source	Home Country	Foreign Country
Preference Parameters				
β	Subjective discount factor	1	$\sqrt[4]{0.984}$	
γ	Risk aversion	1	10	
ψ	Elasticity of intertemporal substitution	1	1.5	
κ_j	Consumption share in utility bundle	5	0.1677	0.1689
σ	Elasticity between consumption and leisure in utility bundle	3	0.7	
Final Goods Sector				
Technology parameters				
α	Capital share in final goods production	1	0.35	
ξ	Intermediate goods share in final goods production	1	0.3939	
δ	Depreciation rate of physical capital	1	0.02	
ζ	Capital adjustment cost parameter	5	3.33	
Productivity parameters				
σ_Ω	Volatility of productivity shocks	5	0.0135	
ρ_Ω	Persistence of productivity shocks	1	$\sqrt[4]{0.95}$	
$\rho(\varepsilon_H^\Omega, \varepsilon_F^\Omega)$	Correlation of productivity shocks	5	0.50	
Intermediate Goods Sector and Patent Development				
Technology parameters				
ν	Elasticity of intermediate goods / monopoly markup	1	2	
δ_v	Patent obsolescence probability	4	0.0375	
R&D and Adoption parameters				
χ_j	Productivity of R&D expenditure	5	0.1704	0.1731
η	Elasticity of R&D expenditure	5	0.75	
$\bar{\theta}_j$	Long-run mean of process controlling adoption probability	1/5	-4.4108	-4.5951
σ_θ	Volatility of shocks to the adoption probability	5	0.001	
ρ_θ	Persistence of shocks to the adoption probability	5	$\sqrt[4]{0.95}$	
$\rho(\varepsilon_H^\theta, \varepsilon_F^\theta)$	Correlation of adoption probability shocks	5	0	
Government				
$\bar{g}$	Long-run mean of process controlling government expenditure to GDP ratio	5	-1.3863	
σ_G	Volatility of shocks to the government expenditure to GDP ratio	5	0.0076	
ρ_G	Persistence of shocks to the government expenditure to GDP ratio	5	$\sqrt[4]{0.95}$	
$\rho(\varepsilon_H^G, \varepsilon_F^G)$	Correlation of shocks to the government expenditure to GDP ratio	5	0.57	
$\phi_{B,j}$	Intensity of debt repayment policy	5	0	0.0025
$\rho_{B,j}$	Inverse of the speed of debt repayment	5	–	$\sqrt[4]{0.95}$
Labor Market				
μ_j	Wage rigidities parameter	2/5	0.35	0.20

[7] Note that our international endogenous growth framework applies to any pair of countries exhibiting differences in their fundamentals (e.g., Canada vs. Unites States or France vs. Spain).

To fully grasp the role of each specific type of country heterogeneity, we also study four other calibrations whose values different from the benchmark calibration are reported in Table 2. Specification [1] refers to the case when both countries are committed to a zero-deficit rule and have both homogeneous labor market frictions and adoption probabilities ($\mu_H = \mu_F = 0.2$ and $\bar{\theta}_H = \bar{\theta}_F = -4.5951$). Specification [2] features symmetric tax regimes and homogeneous adoption probabilities but labor market frictions are heterogeneous, as in the benchmark calibration ($\mu_H = 0.35$ and $\mu_F = 0.2$). In specification [3], we assume that tax regimes are symmetric and labor market frictions are homogeneous but adoption probabilities are heterogeneous, as in the benchmark calibration ($\bar{\theta}_H = -4.4108$ and $\bar{\theta}_F = -4.5951$). Finally, specification [4] considers asymmetric tax regimes, as in the benchmark calibration, but homogeneous labor market frictions and adoption probabilities.

In order to obtain an average output growth rate compatible with the data for Italy and Germany, the R&D productivity parameter χ is chosen to produce an expected output growth rate of about 1.9 percentage points in both countries and across all five calibrations. The consumption share in the utility bundle κ is set so that the steady-state labor supply is one-third of the total time endowment of the household across all calibrations. Consequently, these two parameter values vary slightly across the five calibrations.

Table 2: Other Calibrations

This table reports the parameters used in the different calibrations of our model. Specification [5] refers to our benchmark calibration, reported in Table 1. Specification [1]: symmetric tax regimes, homogeneous adoption probabilities, and homogeneous labor market rigidities. Specification [2]: symmetric tax regimes, homogeneous adoption probabilities, and heterogeneous labor market rigidities. Specification [3]: symmetric tax regimes, heterogeneous adoption probabilities, and homogeneous labor market rigidities. Specification [4]: asymmetric tax regimes, homogeneous adoption probabilities, and homogeneous labor market rigidities. Specification [5]: asymmetric tax regimes, heterogeneous adoption probabilities, and heterogeneous labor market rigidities (benchmark calibration).

Parameter	[1]	[2]	[3]	[4]	[5]
κ_H	0.1676	0.1676	0.1677	0.1676	0.1677
κ_F	0.1676	0.1676	0.1701	0.1676	0.1701
χ_H	0.1726	0.1726	0.1684	0.1726	0.1685
χ_F	0.1726	0.1726	0.1735	0.1726	0.1736
μ_H	0.20	0.35	0.20	0.20	0.35
μ_F	0.20	0.20	0.20	0.20	0.20
$\bar{\theta}_H$	-4.5951	-4.5951	-4.4108	-4.5951	-4.4108
$\bar{\theta}_F$	-4.5951	-4.5951	-4.5951	-4.5951	-4.5951
$\phi_{B,F}$	0	0	0	0.0025	0.0025
$\rho_{B,F}$	—	—	—	$\sqrt[4]{0.95}$	$\sqrt[4]{0.95}$

Preference parameters are set in line with the long-run risk literature (see, e.g., Bansal and Yaron, 2004; Kung and Schmid, 2015; Gavazzoni and Santacreu, 2015). Thus, the risk aversion parameter γ is set to 10 and the elasticity of intertemporal substitution ψ to 1.5. Hence, the households exhibit preferences for early resolution of uncertainty as observed by recent experimental studies (see Brown and Kim, 2014). As in Gavazzoni and Santacreu (2015), we set the discount factor β to $\sqrt[4]{0.984}$. Finally, the elasticity between consumption and leisure σ is set to 0.7, which is a standard value used in the literature and, for example, also used by Croce, Nguyen, and Schmid (2013).

The choice of technology parameters in the final goods sector are quite standard in the macroeconomics literature. We set α, the capital share, δ, the quarterly depreciation rate of capital, and ξ, the intermediate goods share, to values of 0.35, 0.02, and 0.3939, respectively. In order to obtain in the model that investment is much more volatile than output (as observed in the data), we impose relatively low investment adjustment costs and set $\zeta = 3.33$.

Values for the productivity shock volatility σ_Ω and persistence ρ_Ω are chosen similarly to the values used by Kung and Schmid (2015). Specifically, we set $\sigma_\Omega = 0.0135$ and $\rho_\Omega = \sqrt[4]{0.95}$. To replicate the observed correlation between Italian and German output growth rates (i.e. 0.73), we assume cross-country productivity shocks to be positively correlated. Specifically, we impose $\rho(\varepsilon_H^\Omega, \varepsilon_F^\Omega) = 0.50$.

In the intermediate goods sector, we choose $\eta = 0.75$ for the R&D elasticity. Moreover, the monopoly markup parameter is chosen as in Gavazzoni and Santacreu (2015), i.e. $\nu = 1.65$, and the quarterly patent obsolescence rate is chosen as in Kung and Schmid (2015), i.e. $\delta_v = 0.0375$.

We now turn to the adoption probability parameters. As discussed previously, we calibrate the probability of a successful adoption to 0.01 in the foreign country in the steady state and the probability of a successful adoption to 0.012 in the home country in the steady state. Gavazzoni and Santacreu (2015) apply a value of 0.01 for the adoption probability in both countries. However, in their model the adoption probability is a constant. The volatility of shocks to the adoption probability σ_θ is set to 0.001 to allow for small deviations from the long-run mean of the adoption probability. For parsimony, we assume that the persistence of adoption probability shocks ρ_θ is equal to the persistence of aggregate productivity. Therefore, $\rho_\theta = \sqrt[4]{0.95}$. Adoption probability shocks are not correlated across the countries, i.e. $\rho(\varepsilon_H^\theta, \varepsilon_F^\theta) = 0$.

Finally, we discuss the parameters related to government expenditure. We set $\overline{g} = -1.3863$ to obtain a government expenditure to GDP ratio of 20%.[8] Once again, for parsimony, we let the persistence of government spending shocks ρ_G be equal to the persistence of the productivity and adoption shocks (i.e. $\sqrt[4]{0.95}$). This value is in line with Croce, Nguyen, and Schmid (2013). To obtain a volatility of the government expenditure to GDP ratio of slightly above one percentage point—as observed in the data—we set the volatility of government expenditure shocks σ_G to 0.0076. The correlation between Germany's and Italy's government expenditure to GDP ratio in the data is 0.57. Hence, we set $\rho(\varepsilon_H^G, \varepsilon_F^G) = 0.57$ to replicate this fact in the model.

The model is solved using a third-order perturbation around the stochastic steady state implemented in Dynare++ 4.4.3.

4.2 Cross-country heterogeneity, macro quantities, and asset returns

In Table 3, we report the moments of macroeconomic quantities and those of asset prices. Specification [1] in Table 3 refers to the economy where the two countries feature identical labor market frictions, homogeneous adoption probabilities, and the same fiscal rule (i.e. the zero-deficit policy). Hence, the moments of macro quantities and asset prices are identical across countries. The model is reasonably

[8] This value corresponds to the average government spending to GDP ratio observed in Italy (i.e. 20.58%) and Germany (i.e. 19.34%) over the period 1970–2015 (source: OECD National Accounts).

well in line with the level of the risk-free rates in the countries, and it produces an equity premium of about two percentage points, which is less than a third of the empirical counterpart. The volatilities of macroeconomic growth rates are matched reasonably well. However, consumption growth seems slightly too stable relative to the data. The cross-country correlations in the model are all largely positive with the exception of consumption growth, which is only moderately positive and thus matches the empirical counterparts reasonably well. Exceptions are consumption growth, which is insufficiently correlated in the model, and equity excess returns, which are too highly correlated in the model.

Because of the trade channel and the assumption of complete markets, the cross-country correlation of consumption growth is much lower than the correlation of output growth and stock market returns. Therefore, our model is broadly in line with the data and can thus account for the international consumption correlation puzzle (see Bodenstein, 2008). Using their related international endogenous growth model, Gavazzoni and Santacreu (2015) show in detail how the adoption channel is capable of creating highly correlated equity returns while keeping fundamentals moderately correlated.

Macro and asset pricing moments diverge when we introduce heterogeneous wage rigidities (Specification [2]): The country with higher rigidities features more volatile macroeconomic aggregates and, at the same time, slightly higher excess stock returns, consistent with empirical evidence. An exception is consumption which is still basically equally volatile across both countries.

In specification [3], the two counties have the same wage rigidities and fiscal policies but the home country features higher steady-state adoption probabilities. This structural difference is hardly reflected in the moments. The home country seems to face marginally higher volatilities in most macroeconomic growth rates (an exception is R&D expenditure), but asset pricing moments remain homogeneous across countries.

Specification [4] introduces asymmetric fiscal policies when the two countries exhibit the same moderate wage rigidities and identical adoption possibilities. Thanks to the tax-smoothing mechanism, the foreign country features less volatile macro quantities. The differences in volatility of fundamentals are reflected in asset prices and; therefore, the country employing a strict fiscal policy pays higher returns than the country employing tax-smoothing policies. We stress that the asymmetry in moments generated by asymmetric tax regimes is the largest among the considered types of heterogeneity employed in our model.

Specification [5] brings together the three sources of heterogeneity between the two countries. Quantitatively, we observe a larger difference between home and foreign volatilities of macro aggregates and stock returns. Qualitatively, the signs of the differences between the home and foreign volatilities of macro aggregates in the model are consistent with the empirical evidence, with the exception of labor growth volatilities. Specifically, consumption, output, R&D investment, and capital investment growth are all more volatile in the rigid economy (i.e. the home country or Italy in this example) than in the flexible economy (i.e. the foreign country or Germany in this example). However, labor growth is more volatile in the home country than in the foreign country, contrary to the empirical data. This equilibrium effect is rooted in the different degrees of wage rigidities and heterogeneous fiscal policies. These differences affect labor income taxes in the model and imply more volatile labor growth for the rigid economy, i.e. the home economy. In addition, the model does not match the observed spread between the interest rates of the two countries. This result is due to the precautionary savings motive.

Table 3: Model vs. Data: International Macro Quantities and Asset Prices

This table reports the results of simulating 1,000 economies for 200 quarters by drawing sequences of normally distributed random numbers for all shocks in the model. The moments are computed by removing the initial 40 quarters of the simulated data ("burn-in" period). The reported moments are annualized. Means and volatilities are reported in percentage points. Note that the equity return in country $j \in \{H, F\}$ is the return on the claim on the aggregate dividend $D^a_{j,t}$, which is defined by $D^a_{j,t} = D_{j,t} + A_{j,t}\Pi_{j,t} + A^*_{-j,t}\Pi^*_{-j,t}$. As in Croce (2014), the aggregate log excess returns, $r_H - r^f_H$ and $r_F - r^f_F$, are levered using a leverage parameter of 2.

Moments for asset prices and macroeconomic quantities are reported for the benchmark calibration (specification [4]) and for four other calibrations. Specification [1]: symmetric tax regimes, homogeneous adoption probabilities, and homogeneous labor market rigidities. Specification [2]: symmetric tax regimes, homogeneous adoption probabilities, and heterogeneous labor market rigidities. Specification [3]: symmetric tax regimes, heterogeneous adoption probabilities, and homogeneous labor market rigidities. Specification [4]: asymmetric tax regimes, homogeneous adoption probabilities, and homogeneous labor market rigidities. Specification [5]: asymmetric tax regimes, heterogeneous adoption probabilities, and heterogeneous labor market rigidities (benchmark calibration).

The home country represents Italy, and the foreign country represents Germany. Here, $\mathbb{E}[\cdot]$, $\sigma(\cdot)$, and $\rho(\cdot)$ denote the mean, the volatility, and the correlation, respectively. Equity market returns for Italy and Germany are computed from Morgan Stanley Capital International (MSCI) Total Return Indexes (TRI). Short-term interest rates retrieved from the OECD are used as countries' risk-free rate proxies. Nominal returns are converted to real using the Consumer Price Index (All Items), which is obtained from the OECD. All macroeconomic aggregates for Italy and Germany are obtained from the OECD. Data are annual and run from 1971 (or later) to 2015. Additional details on the used data are given in Appendix A.

	DATA	[1]	[2]	[3]	[4]	[5]
		STR	STR	STR	ATR	ATR
		$\phi_{B,H} = \phi_{B,F} = 0$	$\phi_{B,H} = \phi_{B,F} = 0$	$\phi_{B,H} = \phi_{B,F} = 0$	$\phi_{B,H} = 0$, $\phi_{B,F} = 0.0025$	$\phi_{B,H} = 0$, $\phi_{B,F} = 0.0025$
		$\mu_H = \mu_F = 0.20$	$\mu_H = 0.35$, $\mu_F = 0.20$	$\mu_H = \mu_F = 0.20$	$\mu_H = \mu_F = 0.20$	$\mu_H = 0.35$, $\mu_F = 0.20$
		$\bar{\theta}_H = \bar{\theta}_F = -4.5951$	$\bar{\theta}_H = \bar{\theta}_F = -4.5951$	$\bar{\theta}_H = -4.4108$, $\bar{\theta}_F = -4.5951$	$\bar{\theta}_H = \bar{\theta}_F = -4.5951$	$\bar{\theta}_H = -4.4108$, $\bar{\theta}_F = -4.5951$
Asset Prices						**Benchmark**
$\mathbb{E}[r_H - r^f_H]$	6.87	2.04	2.05	2.05	2.03	**2.06**
$\mathbb{E}[r_F - r^f_F]$	6.45	2.04	2.03	2.05	1.94	**1.99**
$\sigma(r_H - r^f_H)$	28.54	4.93	5.05	4.94	4.92	**5.03**
$\sigma(r_F - r^f_F)$	19.90	4.93	4.94	4.94	4.86	**4.88**
$\mathbb{E}[r^f_H]$	2.51	2.16	2.14	2.19	2.17	**2.19**
$\mathbb{E}[r^f_F]$	2.29	2.16	2.14	2.19	2.20	**2.21**
$\sigma(r^f_H)$	3.20	0.36	0.37	0.36	0.36	**0.37**
$\sigma(r^f_F)$	1.86	0.36	0.36	0.36	0.40	**0.40**
$\rho(r_H - r^f_H, r_F - r^f_F)$	0.64	0.99	1.00	0.99	0.99	**1.00**
$\rho(r^f_H, r^f_F)$	0.62	0.86	0.83	0.86	0.85	**0.82**
Macro Quantities						**Benchmark**
$E[\Delta y_H]$	1.99	1.88	1.88	1.88	1.88	**1.88**
$E[\Delta y_F]$	1.78	1.88	1.88	1.88	1.88	**1.88**
$E[G_H/Y_H]$	20.74	20.00	20.00	20.00	20.00	**20.00**
$E[G_F/Y_F]$	19.36	20.00	20.00	20.00	20.00	**20.00**
$\sigma(G_H/Y_H)$	1.07	1.07	1.07	1.07	1.07	**1.07**
$\sigma(G_F/Y_F)$	1.10	1.07	1.07	1.07	1.07	**1.07**
$\sigma(\Delta c_H)$	2.26	1.25	1.26	1.25	1.25	**1.24**
$\sigma(\Delta c_F)$	1.64	1.25	1.25	1.23	1.25	**1.23**
$\sigma(\Delta y_H)$	2.41	2.33	2.40	2.34	2.33	**2.40**
$\sigma(\Delta y_F)$	2.01	2.33	2.32	2.33	2.29	**2.30**
$\sigma(\Delta s_H)$	5.20	3.14	3.24	3.10	3.13	**3.17**
$\sigma(\Delta s_F)$	3.91	3.14	3.13	3.13	3.06	**3.09**
$\sigma(\Delta i_H)$	4.55	3.45	3.55	3.46	3.45	**3.54**
$\sigma(\Delta i_F)$	4.21	3.45	3.44	3.44	3.38	**3.41**
$\sigma(\Delta l_H)$	0.74	0.98	1.10	0.99	0.98	**1.10**
$\sigma(\Delta l_F)$	0.85	0.98	0.98	0.97	0.92	**0.92**
$\rho(G_H/Y_H, G_F/Y_F)$	0.57	0.57	0.57	0.57	0.57	**0.57**
$\rho(\Delta c_H, \Delta c_F)$	0.51	0.10	0.11	0.13	0.10	**0.13**
$\rho(\Delta y_H, \Delta y_F)$	0.73	0.74	0.73	0.73	0.74	**0.73**
$\rho(\Delta s_H, \Delta s_F)$	0.51	0.87	0.86	0.87	0.87	**0.86**
$\rho(\Delta i_H, \Delta i_F)$	0.43	0.74	0.73	0.73	0.74	**0.72**
$\rho(\Delta l_H, \Delta l_F)$	0.44	0.87	0.86	0.88	0.87	**0.86**

In our model, the home country is riskier than the foreign country because of higher labor market rigidities and because of the zero-deficit policy. Therefore, households in the home country have higher precautionary saving needs than households in the foreign country, lowering the risk-free rate in the home country relative to the foreign country.

The cross-country correlation of the equity risk premia is relatively high in all the calibrations and close to unity. This moment does not change significantly when heterogeneity between countries is introduced. The correlation of the risk-free rates across countries is more in line with empirical data and depends on the heterogeneity across countries and, in particular, on labor market heterogeneity. Wage rigidities make the home economy more exposed to macroeconomic shocks than the foreign economy, thus reducing the correlation between the risk-free rates of the two countries[9] (compare specifications [2] and [5] with other specifications).

Overall, the analysis presented above suggests that a fraction of the international difference between stock returns and macro quantities can be explained by differences in labor market rigidities, adoption probabilities, and fiscal policies. Thus, in the following Section 4.3 we study the diffusion of macroeconomic shocks between our two benchmark countries in the presence of the aforementioned structural differences.

4.3 Asymmetric tax regimes and international transmission of shocks

Fiscally weak countries, especially in Europe, are generally characterized by restrictive fiscal policies and, at the same time, tend to sustain economic growth by adopting new technologies from abroad. Therefore, the questions we ask ourselves are: What is the effect of a shock to the probability of adoption when a country is constrained to a zero-deficit policy? How is the shock transmitted internationally when the two countries are heterogeneous?

In Figure 1, we depict the impulse response functions of domestic and foreign macro quantities in response to a positive domestic adoption probability shock for the benchmark calibration. After the increase in the adoption probability, the home country experiences a positive wealth effect that increases consumption today. Due to the assumed temporal lag in technology adoption, the initial increase in consumption is accompanied by an initial decrease in capital investment and labor. After the initial period, however, the effect of the higher adoption rates materializes, capital investment increases and so does output. The beneficial effect of the positive shock in the probability of adoption is transmitted to the foreign country through the channel of trade in intermediate goods. As a result, output, capital investment, labor, and R&D investment increase (Figure 1, Panels B, C, D, and E). The tax-smoothing policy in the foreign country leads to a slightly higher tax rate over the whole 80 quarters which allows the foreign country to run a small fiscal surplus (Figure 1, Panels F and H). In addition, due to complete international markets, macroeconomic shocks induce negative spillover effects through the exchange rate channel and the price of the home good in foreign good units depreciates (Figure 1, Panel J). These two effects together (higher tax rates and money appreciation) reduce consumption initially in the foreign country (Figure 1, Panel A). However, due to the current

[9]Note that a recent class of models featuring segmented international capital markets and financial frictions tend to generate perfectly correlated international asset returns, inconsistent with financial data (Devereux and Yetman, 2010).

higher investment rates and labor, expected consumption growth is higher in the future in the foreign country as well (Figure 1, Panel I).

In our model, economic growth also depends on the internal production of intermediate goods and thus on the productivity of domestic capital. It is, therefore, important to understand the effect of productivity shocks and, in particular, how these shocks are transmitted internationally and their contribution to global risk. In Figure 2, we depict the impulse response functions corresponding to a positive productivity shock of the home country. After the shock, the home country's consumption increases significantly (Panel A). Moreover, expected consumption growth is above long-term trend (Panel I). The higher level of productivity boosts investment, labor, and output. These beneficial effects are transmitted abroad through the trading channel and generate an increase in output, labor, and investments, albeit to a lesser extent in the foreign country (Figure 2, Panels B, C, and E). The improvement in economic conditions in the foreign country raises the tax rate, which implies that foreign consumption persistently declines in response to a positive home productivity shock whereas home consumption persistently increases (Figure 2, Panel A).

However, expected consumption growth increases as well in the foreign country (Panel I), albeit at a different speed. After the shock, the expected growth rate of consumption of the home country rises immediately by 0.018 percentage points, but it reverts back to the steady state from the third quarter onward. For the foreign country, the positive effect is smaller in magnitude (0.01 percentage points) but more long-lasting (i.e. after 60 quarters expected growth is still above its steady state value).

In summary, our analysis demonstrates that i) technology adoption stimulates economic growth and creates a channel through which macroeconomic shocks spread across countries, and ii) the impact of the shock is affected by the country's structural characteristics such as labor market flexibility, amount of technology adopted from abroad, or fiscal policies.

Figure 1: Asymmetric Tax Regimes and Heterogeneous Labor Markets: The Effects of a Home Country Adoption Probability Shock

This figure depicts impulse response functions for 80 quarters of the following home country (solid black line) and foreign country (dashed red line) macroeconomic quantities and asset returns: consumption $C_{j,t}$, output $Y_{j,t}$, capital investment $I_{j,t}$, R&D expenditure $S_{j,t}$, labor hours $L_{j,t}$, total government revenues $T_{j,t}$, patent value $V_{j,t}$, labor tax rate $\tau_{j,t}$, debt to GDP ratio $B_{j,t}/Y_{j,t}$, expected consumption growth $\mathbb{E}_t[\Delta c_{j,t+1}]$, terms of trade $Q_{j,t}$, risk-free rate $r^f_{j,t}$, with respect to a positive one standard deviation adoption probability shock in the home country $\upsilon^A_{H,t}$ (i.e. $\epsilon^\theta_H > 0$). Panels A, B, C, D, E, G, J, and K show log deviations from the steady state in percentage points. Panels F, H, I, and L show absolute deviations from the steady state in percentage points. All parameters are set as in Table 1, benchmark calibration [4].

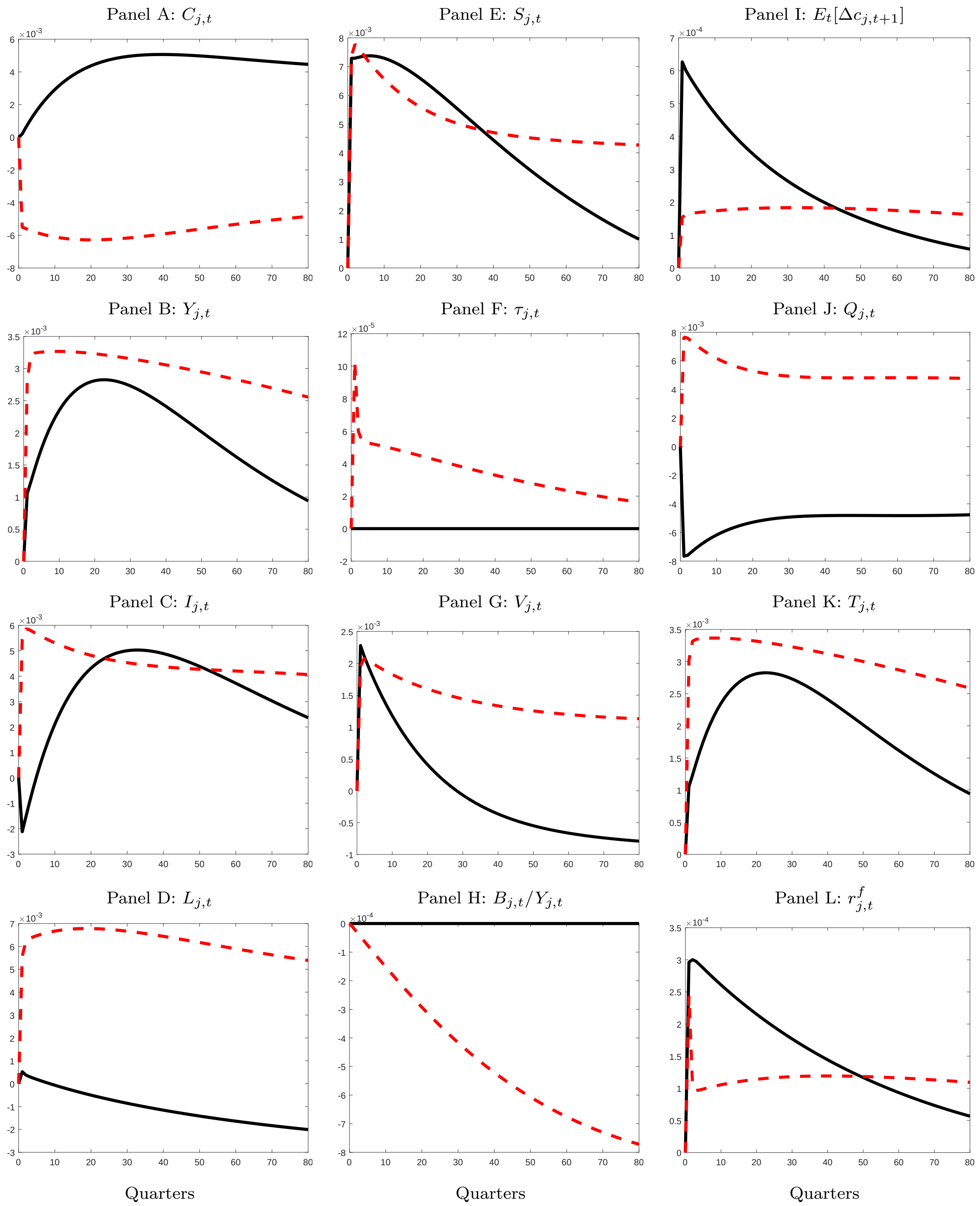
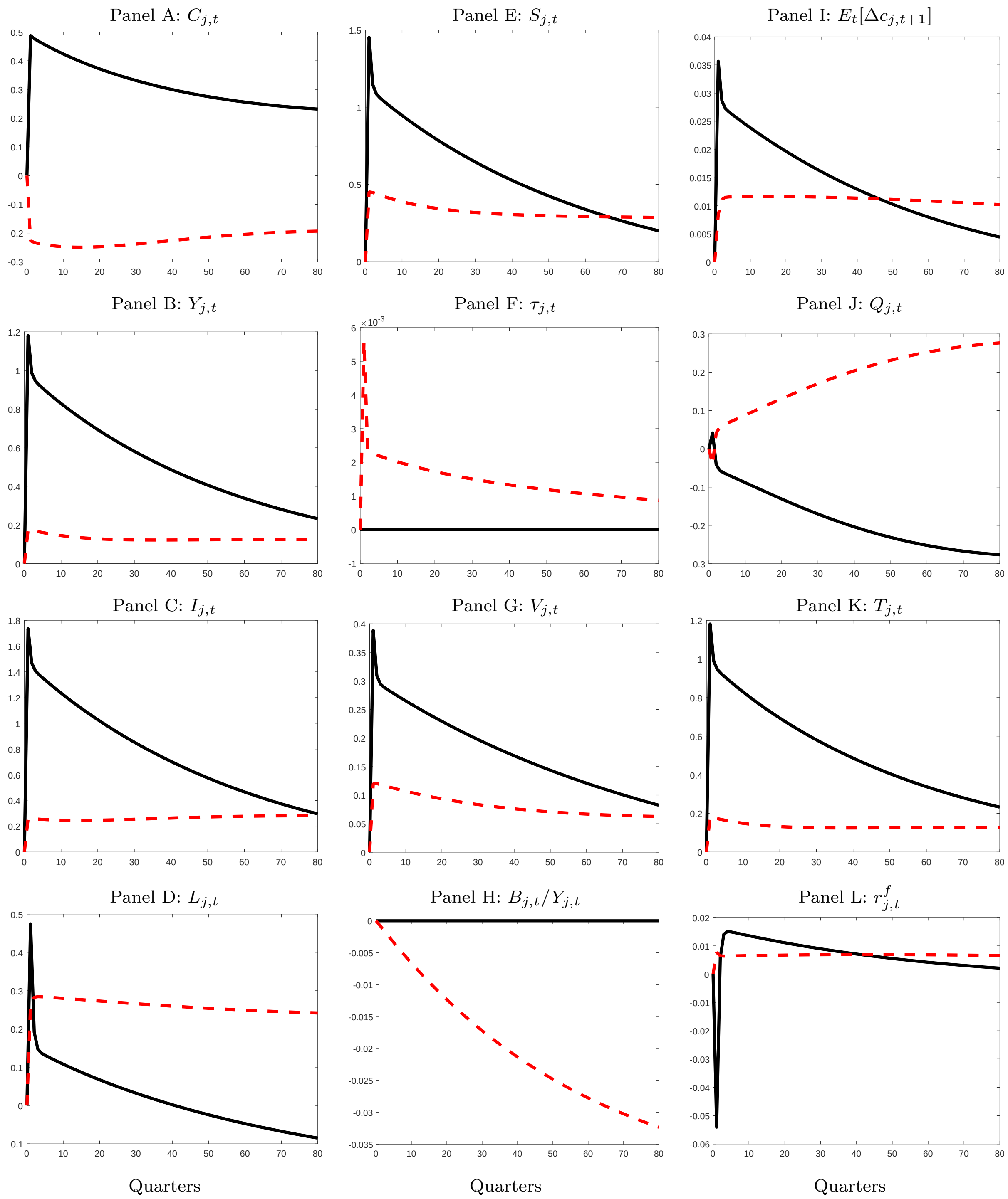


Figure 2: Asymmetric Tax Regimes and Heterogeneous Labor Markets: The Effect of a Home Country productivity Shock

This figure depicts impulse response functions for 80 quarters of the following home country (solid black line) and foreign country (dashed red line) macroeconomic quantities and asset returns: consumption $C_{j,t}$, output $Y_{j,t}$, capital investment $I_{j,t}$, R&D expenditure $S_{j,t}$, labor hours $L_{j,t}$, total government revenues $T_{j,t}$, patent value, $V_{j,t}$, labor tax rate $\tau_{j,t}$, debt to GDP ratio $B_{j,t}/Y_{j,t}$, expected consumption growth $\mathbb{E}_t[\Delta c_{j,t+1}]$, terms of trade $Q_{j,t}$, risk-free rate $r^f_{j,t}$, with respect to a positive one standard deviation productivity shock in the home country $\Omega_{H,t}$ (i.e. $\epsilon^{\Omega}_{H} > 0$). Panels A, B, C, D, E, G, J, and K show log deviations from the steady state in percentage points. Panels F, H, I, and L show absolute deviations from the steady state in percentage points. All parameters are set as in Table 1, benchmark calibration [4].



5 Robustness Check: Model without Capital

The benchmark model analyzed so far features endogenous capital accumulation. Naturally, this is more realistic than a model without endogenous capital accumulation. However, it is instructive to also look at an equivalent model without capital, in which only a bundle of domestically developed and foreign adopted intermediate goods and labor are needed to produce the final good. Hence, in this section we provide the solution to this model without capital and analyze its quantitative performance. This model setup implies that one important trade-off is missing in contract to the benchmark model, namely the trade-off between labor or R&D investment on the one side and capital investment on the other. However, the trade-off between R&D investment and labor is still present here. In the following paragraphs, we first develop and solve the model without endogenous capital accumulation and then analyze the simulated moments from that model.

Specifically, we assume that the production function is now given by the following expression:

$$Y_{j,t} = \Omega_{j,t} L_{j,t}^{1-\alpha} \left[\int_0^{A_{j,t}} (X_{j,i,t})^\alpha di + \int_0^{A^*_{j,t}} (X^*_{j,l,t})^\alpha dl \right]. \tag{40}$$

The dividends of the final goods firm are now given by:

$$D_{j,t} = Y_{j,t} - W_{j,t} L_{j,t} - \int_0^{A_{j,t}} P_{j,i,t} X_{j,i,t} di - \int_0^{A^*_{j,t}} P^*_{j,l,t} X^*_{j,l,t} dl. \tag{41}$$

The first-order conditions of the final goods problem (i.e. maximizing firm value by choosing labor, the demand for domestically developed intermediate goods, and the demand for foreign adoption intermediate goods) look as follows:

$$W_{j,t} = \frac{(1-\alpha) Y_{j,t}}{L_{j,t}}, \tag{42}$$

$$P_{j,i,t} = \Omega_{j,t} L_{j,t}^{1-\alpha} \alpha (X_{j,i,t})^{\alpha-1}, \tag{43}$$

$$P^*_{j,l,t} = \Omega_{j,t} L_{j,t}^{1-\alpha} \alpha (X^*_{j,l,t})^{\alpha-1}. \tag{44}$$

The latter two conditions can be rewritten as:

$$X_{j,i,t} = \alpha^{\frac{1}{1-\alpha}} \Omega_{j,t}^{\frac{1}{1-\alpha}} (P_{j,i,t})^{\frac{1}{\alpha-1}} L_{j,t}, \tag{45}$$

$$X^*_{j,l,t} = \alpha^{\frac{1}{1-\alpha}} \Omega_{j,t}^{\frac{1}{1-\alpha}} (P^*_{j,l,t})^{\frac{1}{\alpha-1}} L_{j,t}. \tag{46}$$

Profit maximization of the intermediate goods producers (similar to Equations (12) and (13) of the main text) implies:

$$P_{j,i,t} \equiv \frac{1}{\alpha}, \tag{47}$$

$$P^*_{j,l,t} \equiv \frac{1}{\alpha} Q_{j,t}. \tag{48}$$

This yields the following expressions for aggregate quantities:

$$X_{j,t} = \alpha^{\frac{2}{1-\alpha}} \Omega_{j,t}^{\frac{1}{1-\alpha}} L_{j,t}, \tag{49}$$

$$X^*_{j,t} = \alpha^{\frac{2}{1-\alpha}} Q_{j,t}^{\frac{1}{\alpha-1}} \Omega_{j,t}^{\frac{1}{1-\alpha}} L_{j,t}, \tag{50}$$

$$\Pi_{j,t} = \left(\frac{1}{\alpha} - 1\right) X_{j,t}, \tag{51}$$

$$\Pi^*_{j,t} = \left(\frac{1}{\alpha} - 1\right) X^*_{j,t}, \tag{52}$$

$$Y_{j,t} = \alpha^{\frac{2\alpha}{1-\alpha}} \Omega_{j,t}^{\frac{1}{1-\alpha}} L_{j,t} \left[A_{j,t} + Q_{j,t}^{\frac{\alpha}{\alpha-1}} A^*_{j,t}\right]. \tag{53}$$

Tables 4 and 5 provide the five calibrations of this model, which are analogous to the five calibrations of the benchmark model, and Table 6 reports the corresponding simulated moments.

Table 4: Quarterly Benchmark Calibration (Model without Capital)

This table reports the parameters used in the quarterly benchmark calibration of our model without capital. Parameters' sources: 1=Gavazzoni and Santacreu (2015), 2=Uhlig (2007), 3=Croce, Nguyen, and Schmid (2013), 4=Kung and Schmid (2015), 5=own calibration.

Parameter	Description	Source	Home Country	Foreign Country
Preference Parameters				
β	Subjective discount factor	1	$\sqrt[4]{0.984}$	
γ	Risk aversion	1	10	
ψ	Elasticity of intertemporal substitution	1	1.5	
κ_j	Consumption share in utility bundle	5	0.1474	0.1473
σ	Elasticity between consumption and leisure in utility bundle	3	0.7	
Final Goods Sector				
Technology parameters				
α	One minus labor share in final goods production	5	0.35	
Productivity parameters				
σ_Ω	Volatility of productivity shocks	5	0.0065	
ρ_Ω	Persistence of productivity shocks	1	$\sqrt[4]{0.95}$	
$\rho(\varepsilon_H^\Omega, \varepsilon_F^\Omega)$	Correlation of productivity shocks	5	0.65	
Intermediate Goods Sector and Patent Development				
Technology parameters				
ν	Elasticity of intermediate goods / monopoly markup	1	2	
δ_v	Patent obsolescence probability	4	0.0375	
R&D and Adoption parameters				
χ_j	Productivity of R&D expenditure	5	0.2459	0.2519
η	Elasticity of R&D expenditure	5	0.75	
$\bar{\theta}_j$	Long-run mean of process controlling adoption probability	1/5	-4.4108	-4.5951
σ_θ	Volatility of shocks to the adoption probability	5	0.001	
ρ_θ	Persistence of shocks to the adoption probability	5	$\sqrt[4]{0.95}$	
$\rho(\varepsilon_H^\theta, \varepsilon_F^\theta)$	Correlation of adoption probability shocks	5	0	
Government				
$\bar{g}$	Long-run mean of process controlling government expenditure to GDP ratio	5	-1.3863	
σ_G	Volatility of shocks to the government expenditure to GDP ratio	5	0.0076	
ρ_G	Persistence of shocks to the government expenditure to GDP ratio	5	$\sqrt[4]{0.95}$	
$\rho(\varepsilon_H^G, \varepsilon_F^G)$	Correlation of shocks to the government expenditure to GDP ratio	5	0.57	
$\phi_{B,j}$	Intensity of debt repayment policy	5	0	0.0025
$\rho_{B,j}$	Inverse of the speed of debt repayment	5	–	$\sqrt[4]{0.95}$
Labor Market				
μ_j	Wage rigidities parameter	2/5	0.35	0.20

Table 5: Other Calibrations (Model without Capital)

This table reports the parameters used in the different calibrations of our model. Specification [5] refers to our benchmark calibration, reported in Table 4. Specification [1]: symmetric tax regimes, homogeneous adoption probabilities, and homogeneous labor market rigidities. Specification [2]: symmetric tax regimes, homogeneous adoption probabilities, and heterogeneous labor market rigidities. Specification [3]: symmetric tax regimes, heterogeneous adoption probabilities, and homogeneous labor market rigidities. Specification [4]: asymmetric tax regimes, homogeneous adoption probabilities, and homogeneous labor market rigidities. Specification [5]: asymmetric tax regimes, heterogeneous adoption probabilities, and heterogeneous labor market rigidities (benchmark calibration).

Parameter	[1]	[2]	[3]	[4]	[5]
κ_H	0.1473	0.1473	0.1474	0.1473	0.1474
κ_F	0.1473	0.1473	0.1473	0.1473	0.1473
χ_H	0.2521	0.2521	0.2461	0.2519	0.2459
χ_F	0.2521	0.2521	0.2521	0.2519	0.2519
μ_H	0.20	0.35	0.20	0.20	0.35
μ_F	0.20	0.20	0.20	0.20	0.20
$\bar{\theta}_H$	-4.5951	-4.5951	-4.4108	-4.5951	-4.4108
$\bar{\theta}_F$	-4.5951	-4.5951	-4.5951	-4.5951	-4.5951
$\phi_{B,F}$	0	0	0	0.0025	0.0025
$\rho_{B,F}$	—	—	—	$\sqrt[4]{0.95}$	$\sqrt[4]{0.95}$

There are a number of differences in the moments of this model specification as compared to the full model with endogenous capital accumulation.

First, the means of equity excess returns are higher and the means of risk-free rates are lower in this model. Moreover, the volatilities of equity excess returns and risk-free rates are higher. This is mainly due to two facts. In the full model, productivity shocks affect labor productivity, but in the reduced model they affect total productivity. Moreover, capital investment can be used to smooth the productivity shock in the full model. However, this possibility is not given to the final goods firm here.

Second, consumption growth volatilities are higher in this model, for the same reasons.

Third, the correlation of consumption growth is significantly higher here, and now much better in line with the data, albeit slightly on the high side. In the full model, households can choose to invest more or less and/or enjoy more or less leisure in response to a positive productivity shock. Due to the assumed preferences structure, the households invests more in the full model. This possibility is absent in the reduced model; thus, households can only change their amount of leisure in response to a productivity shock. Therefore, the substitution effect that makes consumption growth less correlated than output growth across countries is consequently much weaker now. Hence, consumption growth is only slightly less correlated than output growth across countries.

Fourth, the differences in the moments induced by heterogeneity in labor frictions are more pronounced here. Since labor plays a much more important role in this reduced model, this does not come as a surprise. Qualitatively, the differences still go in the same direction.

Table 6: Simulated Moments (Model without Capital)

This table reports the results of simulating 1,000 economies for 200 quarters by drawing sequences of normally distributed random numbers for all shocks in the model. The moments are computed by removing the initial 40 quarters of the simulated data ("burn-in" period). The reported moments are annualized. Means and volatilities are reported in percentage points. Note that the equity return in country $j \in \{H, F\}$ is the return on the claim on the aggregate dividend $D^a_{j,t}$, which is defined by $D^a_{j,t} = D_{j,t} + A_{j,t}\Pi_{j,t} + A^*_{-j,t}\Pi^*_{-j,t}$. As in Croce (2014), the aggregate log excess returns, $r_H - r^f_H$ and $r_F - r^f_F$, are levered using a leverage parameter of 2.

Moments for asset prices and macroeconomic quantities are reported for the benchmark calibration (specification [5]) and for four other calibrations. Specification [1]: symmetric tax regimes, homogeneous adoption probabilities, and homogeneous labor market rigidities. Specification [2]: symmetric tax regimes, homogeneous adoption probabilities, and heterogeneous labor market rigidities. Specification [3]: symmetric tax regimes, heterogeneous adoption probabilities, and homogeneous labor market rigidities. Specification [4]: asymmetric tax regimes, homogeneous adoption probabilities, and homogeneous labor market rigidities. Specification [5]: asymmetric tax regimes, heterogeneous adoption probabilities, and heterogeneous labor market rigidities (benchmark calibration).

The home country represents Italy, and the foreign country represents Germany. Here, $\mathbb{E}[\cdot]$, $\sigma(\cdot)$, and $\rho(\cdot)$ denote the mean, the volatility, and the correlation, respectively. Equity market returns for Italy and Germany are computed from Morgan Stanley Capital International (MSCI) Total Return Indexes (TRI). Short-term interest rates retrieved from the OECD are used as countries' risk-free rate proxies. Nominal returns are converted to real using the Consumer Price Index (All Items), which is obtained from the OECD. All macroeconomic aggregates for Italy and Germany are obtained from the OECD. Data are annual and run from 1971 (or later) to 2015. Additional details on the used data are given in Appendix A.

	DATA	[1]	[2]	[3]	[4]	[5]
		STR	STR	STR	ATR	ATR
		$\phi_{B,H} = \phi_{B,F} = 0$	$\phi_{B,H} = \phi_{B,F} = 0$	$\phi_{B,H} = \phi_{B,F} = 0$	$\phi_{B,H} = 0$, $\phi_{B,F} = 0.0025$	$\phi_{B,H} = 0$, $\phi_{B,F} = 0.0025$
		$\mu_H = \mu_F = 0.20$	$\mu_H = 0.35$, $\mu_F = 0.20$	$\mu_H = \mu_F = 0.20$	$\mu_H = \mu_F = 0.20$	$\mu_H = 0.35$, $\mu_F = 0.20$
		$\bar{\theta}_H = \bar{\theta}_F = -4.5951$	$\bar{\theta}_H = \bar{\theta}_F = -4.5951$	$\bar{\theta}_H = -4.4108$, $\bar{\theta}_F = -4.5951$	$\bar{\theta}_H = \bar{\theta}_F = -4.5951$	$\bar{\theta}_H = -4.4108$, $\bar{\theta}_F = -4.5951$
Asset Prices						**Benchmark**
$\mathbb{E}[r_H - r^f_H]$	6.87	2.92	3.18	2.92	2.92	**3.13**
$\mathbb{E}[r_F - r^f_F]$	6.45	2.92	2.95	2.92	2.90	**2.92**
$\sigma(r_H - r^f_H)$	28.54	6.78	6.88	6.77	6.77	**7.27**
$\sigma(r_F - r^f_F)$	19.90	6.78	6.82	6.76	6.74	**6.78**
$\mathbb{E}[r^f_H]$	2.51	1.73	1.59	1.74	1.72	**1.61**
$\mathbb{E}[r^f_F]$	2.29	1.73	1.69	1.71	1.72	**1.71**
$\sigma(r^f_H)$	3.20	0.34	0.54	0.34	0.34	**0.54**
$\sigma(r^f_F)$	1.86	0.34	0.35	0.34	0.34	**0.35**
$\rho(r_H - r^f_H, r_F - r^f_F)$	0.64	0.98	0.98	0.98	0.98	**0.98**
$\rho(r^f_H, r^f_F)$	0.62	0.79	0.74	0.80	0.79	**0.75**
Macro Quantities						**Benchmark**
$E[\Delta y_H]$	1.99	1.88	1.88	1.88	1.88	**1.88**
$E[\Delta y_F]$	1.78	1.88	1.88	1.88	1.88	**1.88**
$E[G_H/Y_H]$	20.74	20.00	20.00	20.00	20.00	**20.00**
$E[G_F/Y_F]$	19.36	20.00	20.00	20.00	20.00	**20.00**
$\sigma(G_H/Y_H)$	1.07	1.07	1.07	1.07	1.07	**1.07**
$\sigma(G_F/Y_F)$	1.10	1.07	1.07	1.07	1.07	**1.07**
$\sigma(\Delta c_H)$	2.26	1.65	1.70	1.65	1.65	**1.70**
$\sigma(\Delta c_F)$	1.64	1.65	1.65	1.65	1.65	**1.64**
$\sigma(\Delta y_H)$	2.41	2.16	2.33	2.16	2.16	**2.33**
$\sigma(\Delta y_F)$	2.01	2.16	2.17	2.16	2.15	**2.15**
$\sigma(\Delta s_H)$	5.20	3.43	3.87	3.43	3.43	**3.84**
$\sigma(\Delta s_F)$	3.91	3.43	3.41	3.43	3.39	**3.45**
$\sigma(\Delta l_H)$	0.74	0.30	0.62	0.30	0.30	**0.63**
$\sigma(\Delta l_F)$	0.85	0.30	0.30	0.30	0.29	**0.29**
$\rho(G_H/Y_H, G_F/Y_F)$	0.57	0.57	0.57	0.57	0.57	**0.57**
$\rho(\Delta c_H, \Delta c_F)$	0.51	0.65	0.65	0.65	0.65	**0.65**
$\rho(\Delta y_H, \Delta y_F)$	0.73	0.73	0.72	0.73	0.73	**0.73**
$\rho(\Delta s_H, \Delta s_F)$	0.51	0.79	0.77	0.79	0.79	**0.78**
$\rho(\Delta l_H, \Delta l_F)$	0.44	0.67	0.72	0.67	0.66	**0.72**

Fifth, the differences in the moments induced by heterogeneity in tax regimes and adoption probabilities are slightly less pronounced but qualitatively identical here. This implies that the mechanism in our benchmark model are robust with respect to the exclusion of endogenous capital accumulation.

6 Conclusion

This paper studies the implications of international technology diffusion in a dynamic stochastic general equilibrium model where countries have different fiscal policies and labor market structures. Moreover, they differ in their ability to adopt foreign technologies. These sources of heterogeneity help to explain the observed differences in key moments of macroeconomic quantities and asset prices of European countries. Our framework also implies heterogeneity in the transmission mechanism of macroeconomic shocks across countries. Thus, country heterogeneity does not only account for differences in the dynamics of macroeconomic quantities and asset prices but also provides a better understanding of the international transmission mechanism of shocks.

References

Bansal, R., and A. Yaron (2004): "Risks for the Long Run: A Potential Resolution of Asset Pricing Puzzles," Journal of Finance, 59(4), 1481–1509.

Bena, J., L. Garlappi, and P. Grüning (2016): "Heterogeneous Innovation, Firm Creation and Destruction, and Asset Prices," Review of Asset Pricing Studies, 6(1), 46–87.

Benhabib, J., and M. Spiegel (1994): "The role of Human capital in Economic Development: Evidence from Aggregate Cross-Country Data," Journal of Monetary Economics, 34(2), 143–173.

Bodenstein, M. (2008): "International Asset Markets and Real Exchange Rate Volatility," Review of Economic Dynamics, 11(3), 688–705.

Brown, A. L., and H. Kim (2014): "Do Individuals Have Preferences Used in Macro-Finance Models? An Experimental Investigation," Management Science, 60, 939–958.

Choi, S. M., D. T. González, and P. Gray (2013): "International Technology Adoption, R&D and Productivity Growth," B.E. Journal of Macroeconomics, 13(1), 331–354.

Coe, D., and E. Helpman (1995): "International R&D spillovers," European Economic Review, 39(5), 859–887.

Colacito, R., and M. M. Croce (2013): "International Asset Pricing with Recursive Preferences," Journal of Finance, 68(6), 2651–2686.

Comin, D., and M. Gertler (2006): "Medium-Term Business Cycles," American Economic Review, 96(3), 523–551.

Comin, D., and B. Hobijn (2004): "Neoclassical Growth and the Adoption of Technologies," NBER Working Paper No. 10733.

Croce, M. M. (2014): "Long-run Productivity Risk: A new Hope for Production-Based Asset Pricing?," Journal of Monetary Economics, 66, 13–31.

Croce, M. M., T. T. Nguyen, and L. Schmid (2013): "Fiscal Policy and the Distribution of Consumption Risk," Working Paper.

——— (2015): "Global Entropy," Working Paper.

Devereux, M. B., and J. Yetman (2010): "Leverage Constraints and the International Transmission of Shocks," Journal of Money, Credit and Banking, 42(1), 71–105.

Donadelli, M., and P. Grüning (2016): "Labor market dynamics, endogenous growth, and asset prices," Economics Letters, 143, 32–37.

Eaton, J., and S. Kortum (1996): "Trading in Ideas: Patenting and Productivity in the OECD," Journal of International Economics, 40(3–4), 251–278.

——— (1999): "International Technology Diffusion: Theory and Measurement," International Economic Review, 40(3), 537–570.

Epstein, L., and S. Zin (1989): "Substitution, Risk Aversion, and the Temporal Behavior of Consumption Growth and Asset Returns: A Theoretical Framework," Econometrica, 57(4), 937–969.

Garleanu, N., S. Panageas, and J. Yu (2012): "Technological Growth and Asset Pricing," Journal of Finance, 67(4), 1265–1292.

Gavazzoni, F., and A. M. Santacreu (2015): "International R&D Spillovers and Asset Prices," FRB St. Louis Working Paper No. 2015-41.

Jahan-Parvar, M., X. Liu, and P. Rothman (2013): "Equity Returns and Business Cycles in Small Open Economies," Journal of Money, Credit and Banking, 45(6), 1117–1146.

Jermann, U. (1998): "Asset Pricing in Production Economies," Journal of Monetary Economics, 41(2), 257–275.

Kung, H., and L. Schmid (2015): "Innovation, Growth, and Asset Prices," Journal of Finance, 70(3), 1001–1037.

Nickell, S. (1997): "Unemployment and Labor Market Rigidities: Europe versus North America," Journal of Economic Perspectives, 11(3), 55–74.

Parente, E., and E. W. Prescott (1994): "Barriers to Technology Adoption and Development," Journal of Political Economy, 102(2), 298–321.

Peri, G. (2005): "Determinants of Knowledge Flows and Their Effect on Innovation," Review of Economics and Statistics, 87(2), 308–322.

Romer, P. M. (1990): "Endogenous Technological Change," Journal of Political Economy, 98(5), 71–102.

Uhlig, H. (2007): "Explaining Asset Prices with External Habits and Wage Rigidities in a DSGE Model," American Economic Review, 97(2), 239–243.

A Data

Table A.1: Data Description

Variable	Period	Source
Macroeconomic Aggregates		
Gross domestic product (expenditure approach)	1971--2015	OECD: National Accounts
Final consumption expenditure of households	1971--2015	OECD: National Accounts
Gross fixed capital formation	1971--2014	OECD: National Accounts
Average Annual Hours Worked by Persons Engaged for Germany/Italy	1971--2011	University of Groningen, University of California, Davis
Final consumption expenditure of general government	1971--2015	OECD: National Accounts
Business Enterprise Expenditure in R&D (BERD)	1981--2014	OECD: Main Science and Technology Indicators
Technology balance of payments: TA Payments	1981--2014	OECD: Main Science and Technology Indicators
Consumer price index (all items)	1979--2015	OECD: Consumer Prices
Asset Prices		
MSCI TRI	1979--2015	Datastream
Short-term interest rates, Per cent per annum	1979--2015	OECD: Monthly Monetary and Financial Statistics

B Equilibrium Conditions

For each country $j \in \{H, F\}$ the decentralized equilibrium of our model is defined as

- a sequence of exogenous stochastic processes $\{\Omega_{j,t}, g_{j,t}, \theta_{j,t}\}_{t=0}^{\infty}$;
- an initial vector $\left\{A_{j,0}, A_{j,0}^{*}, K_{j,0}\right\}$;
- a set of common parameters $\left\{\beta, \gamma, \psi, \sigma, \alpha, \xi, \delta, \zeta, \sigma_{\Omega}, \rho_{\Omega}, \rho(\varepsilon_H^{\Omega}, \varepsilon_F^{\Omega}), \nu, \delta_{\upsilon}, \eta, \sigma_{\theta}, \rho_{\theta}, \bar{g}, \sigma_G, \rho_G\right\}$;
- a set of country-specific parameters $\left\{\phi_{B,j}, \rho_{B,j}, \mu_j, \bar{\theta}_j, \kappa_j, \chi_j\right\}$;
- a sequence of prices, value functions, profits, wages, and adoption probabilities $\Big\{P_{j,t}, P_{j,t}^{*}, V_{j,t}, W_{j,t}^{V}, W_{j,t}^{V,*}, J_{j,t}, \Pi_{j,t}, \Pi_{j,t}^{*}, W_{j,t}, W_{j,t}^{u}, \upsilon_{j,t}^{A}\Big\}_{t=0}^{\infty}$;
- a sequence of aggregate macro quantities $\{Y_{j,t}, S_{j,t}, G_{j,t}, I_{j,t}, K_{j,t}, L_{j,t}, \upsilon_{j,t}, Q_{j,t}, \Upsilon_{j,t}\}_{t=0}^{\infty}$;
- a sequence of labor tax rates and debt levels $\{\tau_{j,t}, B_{j,t}\}_{t=0}^{\infty}$
- a sequence of pricing kernels and risk-free rates $\left\{\mathbb{M}_{j,t+1}, R_{j,t}^{f}\right\}_{t=0}^{\infty}$;
- a sequence of quantities and numbers of intermediate goods $\left\{X_{j,t}, X_{j,t}^{*}, N_{j,t}, A_{j,t}, A_{j,t}^{*}\right\}_{t=0}^{\infty}$.

such that:

- the state variables $\left\{N_{j,t}, A_{j,t}, A_{j,t}^{*}, K_{j,t}, \Omega_{j,t}, g_{j,t}, \theta_{j,t}\right\}_{t=0}^{\infty}$ satisfy the laws of motion in Equations (26), (25), (27), (7), (6), (34), and (28);
- the endogenous variables solve the households', producers' and innovators' problems in Equations (1), (2), (3), (20), (21), (22), (23), (24), and (33) and the exchange rate is pinned down by (17) and (18);
- both the government's budget constraint (35) and the economy's resource constraint (39) are satisfied;
- prices, value functions, returns, tax rates, and debt levels are such that all markets clear: Equations (14), (15), (29), (4), (36), (38), and (37).

The following list gives the equilibrium conditions of this economy:

$$\begin{aligned}
K_{j,t+1} &= (1-\delta)K_{j,t} + \Lambda\left(\frac{I_{j,t}}{K_{j,t}}\right)K_{j,t} \\
1 &= \mathbb{E}_t\left[\mathbb{M}_{j,t+1}\Lambda'_{j,t}\left\{\frac{\alpha(1-\xi)Y_{j,t+1} - I_{j,t+1}}{K_{j,t+1}} + \left(\frac{1-\delta+\Lambda_{j,t+1}}{\Lambda'_{j,t+1}}\right)\right\}\right], \\
W_{j,t}L_{j,t} &= (1-\alpha)(1-\xi)Y_{j,t}, \\
W_{j,t} &= (e^{\Delta a_{j,t}}W_{j,t-1})^{\mu_j}(W_{j,t}^{u})^{1-\mu_j}, \\
P_{j,t} &= \nu, \\
P_{j,t}^{*} &= \nu Q_{j,t}, \\
\Pi_{j,t} &= (\nu-1)\,X_{j,t}, \\
\Pi_{j,t}^{*} &= (\nu-1)\,X_{j,t}^{*},
\end{aligned}$$

$$
\begin{aligned}
X_{j,t} &= \left(\frac{\xi}{\nu}\right)^{\frac{\nu}{\nu-1}} K_{j,t}^{\alpha} \left(\Omega_{j,t} L_{j,t}\right)^{1-\alpha} \left(\left(\frac{\xi}{\nu}\right)^{\frac{1}{\nu-1}} A_{j,t} + \left(\frac{\xi}{\nu Q_{j,t}}\right)^{\frac{1}{\nu-1}} A_{j,t}^{*}\right)^{-\alpha}, \\
X_{j,t}^{*} &= \left(\frac{\xi}{\nu Q_{j,t}}\right)^{\frac{\nu}{\nu-1}} K_{j,t}^{\alpha} \left(\Omega_{j,t} L_{j,t}\right)^{1-\alpha} \left(\left(\frac{\xi}{\nu}\right)^{\frac{1}{\nu-1}} A_{j,t} + \left(\frac{\xi}{\nu Q_{j,t}}\right)^{\frac{1}{\nu-1}} A_{j,t}^{*}\right)^{-\alpha}, \\
\ln(\Omega_{j,t}) &= \rho_{\Omega} \ln(\Omega_{j,t-1}) + \epsilon_{j,t}^{\Omega}, \\
u_{j,t} &= \left\{\kappa_j C_{j,t}^{1-\frac{1}{\sigma}} + (1-\kappa_j)[N_{j,t}(\bar{L}_j - L_{j,t})]^{1-\frac{1}{\sigma}}\right\}^{\frac{1}{1-\frac{1}{\sigma}}}, \\
(1-\tau_{j,t}) W_{j,t}^{u} &= \frac{1-\kappa_j}{\kappa_j} N_{j,t}^{1-1/\sigma} \left(\frac{C_j, t}{\bar{L}_j - L_{j,t}}\right)^{1/\sigma}, \\
\mathbb{M}_{j,t+1} &= \beta \left(\frac{u_{j,t+1}}{u_{j,t}}\right)^{1/\sigma - 1/\psi} \left(\frac{C_{j,t+1}}{C_{j,t}}\right)^{-1/\sigma} \left(\frac{U_{j,t+1}^{1-\gamma}}{\mathbb{E}_t[U_{j,t+1}^{1-\gamma}]}\right)^{\frac{1/\psi-\gamma}{1-\gamma}}, \\
1 &= \mathbb{E}_t\left[\mathbb{M}_{j,t+1} R_{j,t}^{f}\right], \\
\upsilon_t^{A} &= 1/(1+e^{-\theta_{j,t}}), \\
\theta_{j,t} &= (1-\rho_{\theta})\bar{\theta}_j + \rho_{\theta}\theta_{j,t-1} + \epsilon_{j,t}^{\theta}, \\
A_{j,t+1} &= \upsilon_{j,t} S_{j,t} + (1-\delta_v) A_{j,t}, \\
e^{\Delta a_{j,t+1}} &= A_{j,t+1}/A_{j,t}, \\
\upsilon_{j,t} &= \chi_j N_{j,t}^{-(\eta-1)} S_{j,t}^{\eta-1}, \\
N_{j,t} &= A_{j,t} + A_{j,t}^{*}, \\
\frac{1}{\upsilon_{j,t}} &= \mathbb{E}_t[\mathbb{M}_{j,t+1} V_{j,t+1}], \\
A_{j,t+1}^{*} &= (1-\delta_v) A_{j,t}^{*} + \upsilon_{j,t}^{A}(1-\delta_v)(A_{-j,t} - A_{j,t}^{*}), \\
V_{j,t} &= W_{j,t}^{V} + J_{j,t}, \\
W_{j,t}^{V} &= \Pi_{j,t} + (1-\delta_v)\mathbb{E}_t[\mathbb{M}_{j,t+1} W_{j,t+1}^{V}], \\
W_{j,t}^{V,*} &= \Pi_{-j,t}^{*} + (1-\delta_v)\mathbb{E}_t[\mathbb{M}_{j,t+1} W_{j,t+1}^{V,*}], \\
J_{j,t} &= (1-\delta_v)\mathbb{E}_t\left[\mathbb{M}_{j,t+1}\left(\upsilon_{-j,t}^{A} W_{j,t+1}^{V,*} + (1-\upsilon_{-j,t}^{A}) J_{j,t+1}\right)\right], \\
Y_{j,t} &= C_{j,t} + S_{j,t} + A_{j,t} X_{j,t} + A_{j,t}^{*} X_{j,t}^{*} + G_{j,t} + I_{j,t}, \\
Y_{j,t} &= K_{j,t}^{\alpha}\left(\Omega_{j,t} L_{j,t}\left(\left(\frac{\xi}{\nu}\right)^{\frac{1}{\nu-1}} A_{j,t} + \left(\frac{\xi}{\nu Q_{j,t}}\right)^{\frac{1}{\nu-1}} A_{j,t}^{*}\right)\right)^{1-\alpha}, \\
\frac{G_{j,t}}{Y_{j,t}} &= 1/(1+e^{-g_{j,t}}), \\
g_{j,t} &= (1-\rho_G)\bar{g} + \rho_g g_{j,t-1} + \epsilon_{j,t}^{G}, \\
T_{j,t} &= \tau_{j,t} W_{j,t} L_{j,t}, \\
\frac{B_{H,t}}{Y_{H,t}} &= 0, \\
B_{F,t} &= R_{F,t-1}^{f} B_{F,t-1} + G_{F,t} - T_{F,t}, \\
\frac{B_{F,t}}{Y_{F,t}} &= \rho_{B,F}\frac{B_{F,t-1}}{Y_{F,t-1}} + \phi_{B,F}(\ln(L_{F,ss}) - \ln(L_{F,t})),
\end{aligned}
$$

$$\begin{aligned}
\frac{Q_{j,t+1}}{Q_{j,t}} &= \frac{\mathbb{M}_{j,t+1}}{\mathbb{M}_{-j,t+1}}, \\
\Upsilon_{j,t} &= Q_{j,t}(C_{j,t}/C_{-j,t})^{-1/\psi}, \\
\Upsilon_{j,t+1} &= \Upsilon_{j,t}\frac{\mathbb{M}_{j,t+1}}{\mathbb{M}_{-j,t+1}}\frac{(C_{j,t+1}/C_{j,t})^{-1/\psi}}{(C_{-j,t+1}/C_{-j,t})^{-1/\psi}}.
\end{aligned}$$