Market Regulation, Cycles and Growth in a Monetary Union

Mirko Abbritti[†] Sebastian Weber[‡]

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Abstract

Almost twenty years after the introduction of the euro, income convergence among union members is not in sight. A potential driver of the observed heterogeneity in the cyclical and long-term patterns across member states is their regulatory environment in product and labor markets. We build a two-country DSGE model with endogenous growth that can be used to assess the role that different product and labor market regulations play for long-term growth and for the adjustment to monetary, liquidity, and TFP shocks. We show that in a currency union with endogenous growth, there is no reason to expect real income convergence. In fact, through endogenous TFP movements, large shocks can lead to permanent changes of output, TFP and real exchange rates, and thus to permanent differences across member countries. The issue of real income divergence is exacerbated when member countries have different product and labor market regulations, because more flexible economies are likely to have higher trend growth and to recover faster from negative shocks. Results are consistent with the disappointing TFP growth and the higher inflation and unemployment rates experienced in the less reform-friendly union members.

[†]Universidad de Navarra; E-mail: mabbritti@unav.es.

[‡]International Monetary Fund; E-mail: SWeber@imf.org. The views expressed are those of the authors and do not necessarily reflect those of the IMF.

1 Introduction

The euro was introduced almost 20 years ago to create the largest currency area regime, increasing from its initial 11 members in 1999 to 19 members in 2017. The experience of the euro area since its creation has been mixed. While inflation rates have been stable, close to target and similar across countries compared to the pre-1999 period, differences have persisted, and have partly been reflected in the loss of competitiveness experienced by several member states in the run up to the financial crisis. Figure 1 shows the dynamics of credit risk premiums, total factor productivity (TFP) and GDP for the euro area as a whole and for selected euro area countries.[1] Three observations stand out: First, in concurrence with the onset of the financial crisis, captured by the spike in risk premiums, measured euro area TFP has slowed down significantly and has not yet recovered. Second, both output and TFP seem to have shifted permanently to a lower level, spurring talks of hysteresis and secular stagnation. Third, the crisis has amplified the divergence between member states. In fact, while GDP and TFP are back to the old trend path in Germany and France, they appear permanently on lower paths in Spain and, especially, in Italy.

The objective of this paper is to study the potential role of different product market (PMR) and labor market (LMR) regulations in explaining different growth and business cycle dynamics in the euro area. To this aim, we develop a currency union endogenous growth DSGE model with product and labor market frictions. The model differs from most existing two-country DSGE models in one key aspect: TFP growth is endogenous, and depends on the state and on the institutions of the economy. Thus, labor and product market institutions affect not only the adjustment of member countries to shocks, but also their long run growth prospects. The introduction of endogenous growth into a standard business cycle model allows us to study explicitly TFP dynamics, and to break down the dichotomy between growth and cycle of most macroeconomic models. In particular, temporary risk premium shocks like the ones experienced by many European countries in the last ten years can lead to a permanent reduction of the level of output below the previous trend growth path, and thus affect long run productivity and output. This is in line with recent evidence suggesting that severe recessions may affect permanently the output path and real income level of an economy (see e.g. Blanchard et al. (2015) and Martin et al. (2015)).

To motivate and discipline the model, we first revisit some stylized facts about the relationship between market regulation, R&D investment and TFP dynamics in the euro area. We highlight two main findings. First, we document that less regulated countries are characterized, on average, by higher R&D investment rates, stronger TFP and output growth, and lower inflation rates. Second, we show that in response to risk premium shocks TFP has declined substantially in all countries, but the recovery has been faster in more flexible economies, i.e. in economies with lower product market and labor market rigidities.

To understand and interpret these stylized facts, we introduce three main elements in a two-country model. First, the labor market is modeled using search and matching frictions and Nash bargaining over sticky wages. This gives rise to involuntary unemployment and allows to capture the effects of three labor market institutions: employment protection legislation, unemployment benefits, and union power. In addition a tax on wages is introduced to study the implications of the labor tax wedge. Second, we assume imperfect competition in the retail and intermediate goods sectors. This allows us to measure product market regulation with the price mark-ups of different sectors of the economy. And third, building on Romer (1990) and Kung and Schmidt (2015), we assume that productivity growth is endogenous and sustained by innovation through R&D. The model provides a rigorous, unified, framework to study the short- and long-term effects of heterogeneous product and labor market regulations on the dynamics of the monetary union.

We focus on two types of shocks: monetary policy shocks and risk premium shocks, and we

[1]See section 2 for details on the data sources and construction. To facilitate the comparisons across countries, both TFP and GDP are normalized to 1 in 2008q1.

study the model under two different angles. First, in order to analyze the interactions between growth and business cycle dynamics, we compare the model with endogenous growth with a nested New Keynesian model with exogenous growth. The introduction of endogenous growth has three main effects on the dynamics of the monetary union. First, the presence of R&D investment and intangible capital amplifies the response of key macroeconomic variables to demand shocks and helps matching the moments of the data. Second, through endogenous TFP movements large temporary shocks can lead to sizable permanent effects on TFP, output and relative prices. The mechanism of this result is straightforward: a large negative shock, e.g. a risk premium shock, reduces firms' profits and R&D investment, which in turn reduce the process of intangible capital accumulation, which is ultimately the engine of long run growth. The lower stock of intangible capital shifts permanently the level of TFP and output. Third, we find that in a currency union where technology diffusion across countries is incomplete and growth depends on investment in R&D, there is no reason to expect income convergence across member countries. In fact, even when member countries are ex-ante perfectly identical, real incomes and real exchange rates can diverge permanently when countries are exposed to different shocks, because the history of shocks and policy responses matter for long run dynamics.

The issue of income divergence in the model is further exacerbated when member countries have different economic structures. In the last part of the paper, we study how different product (PMR) and labor (LMR) market regulations affect the short run and long run dynamics of the currency union. The main results of the model capture rather well the stylized facts of the euro area data. LMR and PMR reforms have the expected long-run effects, with symmetric reductions in employment protection legislation, labor tax wedges, and unemployment benefits as well as reductions in the price mark-ups lifting output and consumption growth and reducing unemployment in the long-run. However, asymmetric labor market reforms imply a competitiveness effect. In the reforming country higher demand triggers higher R&D investment, which in turn increases TFP growth. This increases economic activity and leads to a lower inflation rate in the reforming economy. The member that is not reforming experiences lower long-term output growth and a higher inflation rate, although unemployment and consumption growth remain broadly unaffected. As union wide output and consumption growth increase and unemployment rates decrease, asymmetric reforms remain beneficial for the currency union as a whole; or put differently gains in reforming members are higher than losses in non-reforming countries.

Concerning the cyclical properties of the model, we find that LMR and PMR have a sizable effect on the adjustment of member countries to shocks. Consistent with the evidence in Abbritti and Weber (2018), the model implies that less restrictive employment protection legislation increases the employment response, but decreases the price response to shocks. Higher competition in the retail sector, instead, reduces the volatility of employment but increases inflation volatility. Correspondingly, symmetric monetary policy shocks tend to increase the response of inflation in countries with higher competition in product markets and higher employment protection legislation, while the opposite is true for the response of employment.

Finally, we show that market regulation is crucial for the resilience of the currency union to a large adverse financial shock. For example, following a risk premium shock the recovery of TFP is much faster in an economy with flexible labor and product markets than in a similar economy with high LMR and PMR. This happens in the model for a combination of the effect of institutions on short run dynamics (e.g. the collapse of TFP is smaller in countries with low LMR) and long run dynamics (the trend growth rate is larger in countries with low product market and labor market regulation). Overall, the model confirms that more flexible economies are likely to be more resilient to negative financial shocks. The results resemble closely estimates from local projections in response to a financial shock under varying degrees of product and labor market regulation.

The paper is related to a large literature studying the effects of market regulation on economic activity both from an empirical and a theoretical angle. Empirical studies have either focused on long-run effects, e.g. through the use of averages of dependent variables of interest across several years (e.g. Nickell 1997, Masuch et al 2016) or cyclical effects (see e.g. Abbritti and

Weber (2018) and the references therein) or relied on (annual) time series, which implicitly mixes cyclical and long-run effects. The latter may be providing inaccurate assessments as cyclical and long-run effects stemming from labor market regulations may be opposed.[2]

Theoretical studies have mostly relied on calibrated business cycle models. Recent papers have studied the transitional dynamics following labor and product market reforms. For instance, Cacciatore and Fiori (2016) introduce endogenous product creation and labor market frictions in an otherwise standard real business cycle model to study the effect of deregulation of entry costs, firing restrictions and unemployment benefits. Results suggest that reforms can have short run recessionary effects, despite being expansionary in the long run. Cacciatore, Fiori and Ghironi (2016) extend a similar model to the case of a monetary union with sticky prices and wages, and analyze the optimal response of the common central bank. They find that international synchronization of reforms can eliminate policy trade-offs generated by asymmetric deregulation. Eggertsson, Ferrero and Raffo (2014) analyze the effects of structural reforms when monetary policy is constrained by the zero lower bound, and find that these reforms can be contractionary and generate large output losses. Andres, Arce and Thomas (2017) analyze similar reforms in a model with financial constraints and endogenous deleveraging, and show that product market reforms stimulate output and employment even in the short run, despite their deflationary effects. Importantly, all these studies build on standard business cycle models with exogenous growth or no trend, which do not allow to fully account for the long-run growth implications of different LMR and PMR.

The remaining sections of this paper are structured as follows. Section two presents some stylized facts on the relationship between TFP, investment in R&D and output growth in the euro area. Section three describes the model and section four discusses the calibration strategy. Section five compares the model dynamics with the ones of the conventional DSGE model without endogenous growth. Section six provides model simulations showing how labor and product market regulations affect short- and long-run dynamics of the currency union. Finally section seven concludes.

2 Stylized Facts on TFP, Growth and Market Regulation in the Euro Area

In this section we revisit some facts regarding the relationships between market regulation, TFP, output growth and Research and Development (R&D) investment in the euro area. For this purpose we draw on the AMECO database for TFP growth and the OECD database for data on R&D investment, employment protection legislation, product market regulation and unemployment benefit generosity.

According to European Commission estimates, TFP has been the main driver of the growth decline and growth divergence among euro area members. Figure 2 shows the contribution of capital, labor and TFP to GDP growth for the first 12 euro area member countries. GDP growth has declined substantially in the last 60 years, from more than 5 percent in the 1960s to less than 1 percent in the last decade. The decline in measured TFP has been the main cause behind the slow down of growth, with TFP growth declining from close to 4 percent in the early 60s, to a meager 0.1 in the last decade. Thus, the figure suggests that if we want to understand the dismal economic performances, we need to understand TFP dynamics. The top left panel of figure 3 shows the correlation between GDP growth and TFP growth, which is, not surprisingly, strongly positive. Variation in TFP accounts for half the GDP growth differential among euro area members since the creation of the euro area. Thus, differences in TFP growth explain time and cross-country variation of GDP growth in the euro area.

Fact 1: *TFP is the main driver of growth decline and growth divergence among member*

[2]For instance, higher EPL is often found to limit employment adjustment in a downturn, but also reduce long-run growth.

countries.

There are obviously several reasons that can explain such diverse dynamics of growth and productivity. An important factor is investment in R&D (see e.g. Griffith et al 2004, Cameron et al 2005). The top right panel on figure 3 shows a positive relationship between investment in R&D as a percentage of GDP in 1999 and average TFP growth between 1999 and 2015. For example, since 1999, TFP (GDP) growth in Italy and Greece has been more than 0.5 (1) percent lower than the euro area simple average. Both countries entered the euro area with the lowest level of business R&D in 1999.

Fact 2*: Countries that invest more in business R&D have experienced higher TFP growth.*

To understand the effect of labor and product market regulation on growth and TFP dynamics we build a composite regulation index, which is measured as the sum of standardized product market regulation index, employment protection legislation index and the unemployment benefit generosity in deviation from the euro area average.[3] The bottom left panel of figure 3 shows a negative correlation between market regulation and investment in R&D (See also Ciriaci et al 2016). While discoveries from research may support productivity globally, diffusion of knowledge is unlikely to be immediate and returns from innovation are likely to accrue with a home bias (Coe and Helpman 1995). This will also be reflected in the modeling choice. Similarly, countries which entered the monetary union with a less regulated product and labor market experienced higher TFP growth since the existence of the Euro (bottom right panel). The upper left panel in figure 4 suggests that this relationship is also true in a dynamic sense: countries that made stronger reform efforts, i.e. that moved toward less regulated markets, experienced a stronger acceleration in average TFP growth.[4] Even though we made an attempt to limit possible reverse causality by using past values of R&D investment and market regulation in building these correlations, results are no evidence of causality. Nevertheless, they seem to provide a plausible underpinning for the role of the regulatory environment in supporting innovative activity and TFP growth.

Fact 3*: Countries with more regulated labor and product markets have lower levels of investment in business R&D and lower average TFP growth.*

Interestingly, member countries with higher TFP growth have in general experienced lower inflation rates (top right panel of figure 4). This is true when looking at two equal length sub-periods (2000-2008 and 2008-2016) or at the entire sample period. Notably, Greece (and to a much lesser extent Italy) appears not to follow this pattern. While the inflation rates in the sub-periods are undoubtedly driven by a multitude of factors, it is striking that even for the overall period of more than 15 years, the negative correlation between TFP and inflation remains. This suggests that part of the TFP gain (or loss) translated into lower (higher) prices as opposed to moving wages to offset TFP gains. Labor market institutions that generate wage rigidities may have contributed to this pattern.

Fact 4*: Countries with higher TFP growth experienced lower average inflation rates.*

These first four facts analyze the medium-term performances of member countries since the inception of the Euro. Another important question is whether, and how, different market structures have affected the response of productivity and growth of member countries to financial shocks. The difficulty when answering these types of questions, is that no quarterly series for

[3]Several authors have either used interaction terms or principal components of indicators. See for instance Berger and Danninger (2007).

[4]While we use a composite indicator of market rigidities, defined as the sum of the standardized components of three sub-indicators, the sub-indicators imply individually a similar correlation.

TFP growth for euro area member countries exist.[5] We therefore derive a quarterly series of TFP that is compatible with the annual series provided by the European Commission's AMECO database. To derive the series we follow Levy and Chen (1994). The method uses the annual capital stock data and exploits the capital accumulation relationship between capital stock and the corresponding investment series to estimate quarterly depreciation rates which vary over time and are derived using Newton's iteration formula. A detailed description of the computation is provided in the Annex. Using the quarterly TFP series, standard estimation techniques can be used to analyze the endogenous response of TFP to macroeconomic shocks and shed more light on the dynamic behavior of TFP.

We focus on a shock that affects the incentives for firms to engage in investment activities. This is captured by the spread of the euro area non-financial corporation bond market rates over sovereign rates (see Gilchrist and Mojon 2017). The variable is weakly exogenous, as individual member countries have a limited effect on the overall euro area spread. However, this assumption may be less appropriate for some larger union members. For this reason, the risk premium is regressed on its lag and the contemporaneous and lagged values of euro area inflation and GDP growth.[6] The residual from this regression is used as a proxy for a risk premium shock.

We rely on local projection methods and estimate the impulse response of (the log of) TFP_{it} (y_{it}) for a panel of 11 euro area members (euro area-12 excluding Luxembourg) for the period from 1999q1 to 2016q4. The estimation equation is given by:

$$y_{i,t+k} - y_{i,t} = \alpha_i^k + \beta^k Z_t + \gamma^h X_{i,t} + \varepsilon_{i,t}$$

where α_i^k stands for country fixed effects at horizon k, Z_t is the shock in time t, and $X_{i,t}$ is a vector of control variables, including the lagged log level of TFP and a dummy for the year 2009.[7] The coefficients of interest are the sequence of β^k, which yield the impulse response of TFP to a one standard deviation risk premium shock, which corresponds to an increase of the risk premium by about 35 basis points on impact. The results of this exercise are shown in the bottom left panel of figure 4. Following the risk premium shock, TFP falls on impact, continues to decline until it reaches its low level (about 0.5 percent below its initial value) four quarters after the shock. Following a quick recovery for another four quarters, the TFP level remains below its initial position as further reversion is slow and TFP only appears to fully recover to its initial level after four years.

Extending the method to a smooth transition local projection estimation, we analyze to which extent the response of TFP varies depending on the extent of labor and product market regulation. We continue to use the composite indicator based on product and labor market regulations to distinguish between more or less regulated markets. Estimation results suggest that while the initial TFP response may be stronger in less regulated markets, more regulated markets tend to recover much more slowly towards the initial TFP trend path or even remain permanently below it (bottom right panel). The empirical evidence on the short and medium term dynamics, thus, suggests that TFP reacts in a hump-shaped manner to a financial shock. This could possibly derive from the adverse consequences the shock has first on utilization and subsequently on productivity enhancing investment, which in turn adversely affects TFP. Depending on the structure of the economy, TFP may not recover to its previous long-term level, but remain permanently below the previous trend path.

Fact 5*: Following a euro area wide risk premium shock, the TFP recovery is faster in less regulated economies.*

[5] Quarterly data is mostly relevant to adequately reflect the timing of the shock. It is less relevant for the timing of the effect on investment spending on R&D and its subsequent effect on productivity. The latter may materialize with a lag, while the contemporaneous response of TFP may reflect adjustments in utilization (see, e.g., King and Rebelo, 2000) or in other factors which may be difficult to measure, like intangible capital.

[6] This is comparable to ordering the shock last in a VAR with GDP and inflation. Regressing the shock on its own lag also ensures that the shock's auto-correlation is limited, which addresses possible biases when using local projection methods.

[7] The inclusion of the 2009 dummy has only marginal effects on the impulse responses.

Summing up, a simple look at the evidence of euro area countries in the last two decades seems to suggest a potentially significant effect of labor and product market regulations on both short term and medium term dynamics, with different institutions affecting both the long run growth prospects and the short run resilience of a country to shocks. Countries with more flexible market regulation experienced higher TFP growth and a faster recovery from financial shocks.

3 The Model

This section sets out the currency union model, featuring product and labor market regulations and endogenous growth through R&D accumulation. The monetary union consists of two countries, Home (H) and Foreign (F), of equal size (normalized to 1). Each economy, which is populated by identical, infinitely lived households, is specialized in the production of a bundle of differentiated goods. There is no migration across regions. Following Eggertsson et al. (2014), we assume the existence of a full set of transfers that completely insure against idiosyncratic risk in each country. The only traded asset across countries is a one-period nominal bond denominated in the common currency.

3.1 Households

The representative household in country i ($i = H$ or F) is a large extended family which contains a continuum of members with names on the unit interval. Family members perfectly insure each other against fluctuations in consumption due to the employment status. Each household maximizes:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\log C_t + \varrho_{Ht} \frac{A_{Ht}}{P_t} \right], \quad \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\log C_t^* + \varrho_{Ft} \frac{A_{Ft}}{P_t^*} \right]$$

where variables with star refer to the Foreign country. C_t (C_t^*) denotes household's consumption and A_{Ht} (A_{Ft}) holdings of the riskless bond. This specification has two main features. First, as it is standard in quantitative macroeconomic models, utility is log in consumption. Second and most importantly, we incorporate bonds in the utility function to capture a preference for the safe asset (Krishnamurty and Vissing-Jorgensen, 2012). $\varrho_{it} > 0$ captures a shock to liquidity demand in country i. Fisher (2015) shows that this shock can be thought of as a structural interpretation of the Smetz and Wouters (2007)'s risk premium shock. Moreover, Anzoategui et al. (2016) show that the liquidity demand shock transmits to the economy like a financial shock. Therefore, the shock to ϱ_{it} allows us to study the implications of a risk premium shock without explicitly modeling financial frictions.

C_t and C_t^* are the composite consumption indexes for the home and foreign country respectively, defined as:

$$C_t = \frac{(C_{Ht})^{1-\gamma} (C_{Ft})^{\gamma}}{(1-\gamma)^{1-\gamma} (\gamma)^{\gamma}}, \quad C_t^* = \frac{(C_{Ft}^*)^{1-\gamma} (C_{Ht}^*)^{\gamma}}{(1-\gamma)^{1-\gamma} \gamma^{\gamma}} \tag{1}$$

The index of country i's consumption of the good produced in country j, C_{jt}^i, is given by the usual CES aggregator with elasticity of substitution $\epsilon > 1$. $\gamma \in [0,1]$ is the weight on the imported goods in the utility of private consumption; a value for γ strictly less than $\frac{1}{2}$ reflects the presence of home bias in consumption. The optimal allocation of any given expenditures on the goods produced in a given country yields the demand function:

$$C_{H,z,t}^i = \left(\frac{P_{H,z,t}}{P_{Ht}} \right)^{-\epsilon} C_{Ht}^i \quad ; \quad C_{F,z,t}^i = \left(\frac{P_{F,z,t}}{P_{Ft}} \right)^{-\epsilon} C_{Ft}^i \tag{2}$$

for $i = H, F(^*), z \in [0,1]$. The domestic price indexes of the Home and Foreign countries are given by:

$$P_{Ht} = \left(\int_0^1 (P_{H,z,t})^{1-\epsilon} dz \right)^{\frac{1}{1-\epsilon}} \quad ; \quad P_{Ft} = \left(\int_0^1 (P_{F,z,t})^{1-\epsilon} dz \right)^{\frac{1}{1-\epsilon}} \tag{3}$$

Because the law of one price holds, P_{Ft} represents both the price index for the bundle of goods imported from country F as well as F's domestic price index.

Furthermore, the optimal allocation of expenditures by country of origin implies, for Home:

$$P_{Ht}C_{Ht} = (1-\gamma)P_tC_t \quad ; \quad P_{Ft}C_{Ft} = \gamma P_tC_t$$

while for Foreign:

$$P^*_{Ht}C^*_{Ht} = \gamma P^*_tC^*_t \quad ; \quad P^*_{Ft}C^*_{Ft} = (1-\gamma)\, P^*_tC^*_t$$

where $P_t = (P_{Ht})^{(1-\gamma)}(P_{Ft})^{\gamma}$ and $P^*_t = (P^*_{Ht})^{\gamma}(P^*_{Ft})^{(1-\gamma)}$ are respectively the Home and the Foreign CPI indexes. Even under the law of one price, we may have that $P_t \neq P^*_t$, i.e. that the PPP does not hold, because the two countries consume goods in different proportions.

Combining all previous results, we can write total consumption expenditures by Home households as $P_{Ht}C_{Ht} + P_{Ft}C_{Ft} = P_tC_t$. Thus, conditional on the optimal allocation of expenditures, the period budget constraint is given by:

$$C_t + \frac{A_{Ht}}{P_t} + \frac{\psi_B C_t}{2}\left(\frac{A_{Ht}}{P_tC_t} - \bar{a}\right)^2 = (1-\tau^w_{Ht})\frac{W_{Ht}}{P_t}L_{Ht} + (1-L_{Ht})\, b_{Ht} + R_{t-1}\frac{A_{Ht-1}}{P_t} + D_{Ht}$$

where R_t is the gross (union-wide) nominal interest rate of the nominal bond. Total household income is the sum of the real wage income earned by employed family members $(1-\tau^w_{Ht})\frac{W_{Ht}}{P_t}L_{Ht}$, the benefits earned by the unemployed b_{Ht} and the family share of aggregate profits from firms, net of government lump-sum taxes (D_{Ht}). To ensure balanced growth, we assume that unemployment benefits grow at the same rate as the stock of intangible capital N^C_{Ht}, i.e. $b_{Ht} = b_H N^C_{Ht}$. τ^w_{Ht} is a measure of the taxes on labor income (the tax wedge). Finally, as in Cacciatori et al. (2016), we introduce an intermediation cost $\frac{\psi_B C_t}{2}\left(\frac{A_{Ht}}{P_tC_t} - \bar{a}\right)^2$, with $\bar{a}$ being the equilibrium level of the net foreign assets stock as percentage of consumption.[8] As in Cacciatore et al. (2016), this cost is paid to financial intermediaries whose only function is to collect these transaction fees and rebate the revenue to households in lump-sum fashion.

Denoting by λ_{Ht} the lagrange multiplier associated with the budget constraint and defining $a_{Ht} = \frac{A_{Ht}}{P_t}$ and $\varsigma_{Ht} = \frac{\varrho_{Ht}}{\lambda_{Ht}}$. Household's maximization yields the Euler equation:

$$1 + \psi_B\left(\frac{a_{Ht}}{C_t} - \bar{a}\right) = \mathbb{E}_t\beta_{t,t+1}\frac{R_t}{\pi_{t+1}} + \varsigma_{Ht} \tag{4}$$

where $\beta_{t,t+1} = \beta\frac{\lambda_{Ht+1}}{\lambda_{Ht}}$ and $\pi_{t+1} = \frac{P_{t+1}}{P_t}$ is the gross inflation rate. Similar conditions hold for the Foreign country. As equation (4) indicates, the liquidity demand shock ς_{Ht} has a similar effect as an increase in risk. In fact, for a given riskless rate R_t, the increase in ς_{Ht} induces a precautionary saving effect, as households reduce current consumption in order to satisfy the first order condition on the domestic bond, which requires a drop in the discount factor $\beta_{t,t+1}$. In turn, the decline of the discount factor raises the required return on capital and creates a spread with the riskless rate, which reduce investment in physical capital and R&D. Therefore, the shock generates positive co-movements between investment and consumption like the ones usually experienced in economic downturns.[9]

[8] This intermediation cost is introduced in the model only to ensure the determination of the net foreign asset positions and stationary responses to temporary shocks. See, e.g., Benigno (2009) for a discussion.

[9] See also, e.g., Anzoategui et al. (2017) for a discussion.

3.2 Some definitions and identities

We define the bilateral terms of trade between Home and Foreign as the price of country F's domestically produced goods in terms of country H's:

$$T_t = \frac{P_{Ft}}{P_{Ht}} \tag{5}$$

Because the law of one price holds (i.e. $P_{Ft} = P^*_{Ft}$ and $P_{Ht} = P^*_{Ht}$), the CPI indexes and the domestic price levels are related according to:

$$P_t = P_{Ht} \left(T_t\right)^{\gamma} \text{ and } P^*_t = P_{Ft} \left(T_t\right)^{-\gamma}$$

The real exchange rate is defined as the ratio between Foreign and Home CPI:

$$Q_t = \frac{P^*_t}{P_t} = \left(T_t\right)^{1-2\gamma} \tag{6}$$

Union-wide variables are defined as a geometric average of Home and Foreign economic aggregates, e.g. $P^U_t = \left(P_{Ht}\right)^{0.5} \left(P_{Ft}\right)^{0.5}$ and $Y^U_t = \left(Y_{Ht}\right)^{0.5} \left(Y_{Ft}\right)^{0.5}$.

3.3 The product market

The production side of the monetary union builds on Kung and Schmidt (2015). There are four sectors in each economy. Monopolistically competitive retailers buy homogeneous wholesale goods and transform them one for one into differentiated retail goods at no additional cost. Firms in the perfectly competitive wholesale sector use labor, physical capital and domestic patented goods to produce the homogeneous wholesale good. Patented goods are produced in the intangible goods sector using innovations (new patents). Innovations are discovered through R&D in the innovation sector. Price rigidities, in the form of convex adjustment costs, arise in the retail sector, while search frictions together with convex wage adjustment costs exist in the wholesale sector. The main differences to Kung and Schmidt (2015) are the presence of search and matching frictions and sticky wages in the labor markets, which affect the wholesale good sector and the presence of price rigidities which affect the retail sector.

3.3.1 Retail sector

Firms in the retail sector purchase wholesale goods at nominal price $P_{Ht}\varphi_{Ht}$ and convert them into differentiated goods sold to households and domestic firms. There is a measure one of monopolistic retailers indexed by z on the unit interval, each of them producing one differentiated good, that is aggregated to become the final composite good:

$$Y_{Ht} = \left[\int_0^1 \left(Y_{H,z,t}\right)^{\frac{\epsilon-1}{\epsilon}} dz\right]^{\frac{\epsilon}{\epsilon-1}} \tag{7}$$

where ϵ represents the elasticity of substitution between retail goods. Retailers share the same technology, which transforms one unit of wholesale good into one unit of final retail good, so that $Y_{H,z,t} = Y^I_{H,z,t}$. We introduce nominal rigidities for retailers assuming firms face Rotemberg-style quadratic costs of adjusting prices. The representative firm chooses prices to solve the following maximization problem:

$$\max_{P_{H,z,t}} \quad \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\lambda_{Ht}}{\lambda_{H0}} \left[\frac{\left(1-\tau^p_{Ht}\right) P_{H,z,t} - P_{Ht}\varphi_{Ht}}{P_{Ht}} - \Gamma_{H,z,t}\right] Y_{H,z,t}$$

subject to the demand function $Y_{H,z,t} = \left(\frac{P_{H,z,t}}{P_{Ht}}\right)^{-\epsilon} Y_{Ht}$ and the adjustment cost function $\Gamma_{H,z,t} = \frac{\psi}{2}\left(\frac{P_{H,z,t}}{P_{H,z,t-1}} - \bar{\pi}_H\right)^2$. τ^p_{Ht} is a policy instrument the government can use to affect the competitiveness of the retail sector. $\bar{\pi}_H$ is trend inflation. In equilibrium, assuming symmetry, the first order conditions for retail firms earn a Phillips curve:

$$\Gamma'_{Ht}\pi_{Ht} = \epsilon\left(\varphi_{Ht} + \Gamma_{Ht}\right) - (\epsilon - 1)\left(1 - \tau^p_{Ht}\right) + \mathbb{E}_t\beta\frac{\lambda_{Ht+1}}{\lambda_{Ht}}\frac{Y_{Ht+1}}{Y_{Ht}}\left[\Gamma'_{Ht+1}\pi_{Ht+1}\right]$$

Notice that under flexible prices ($\Gamma_{Ht} = \Gamma'_{Ht} = 0$), optimal price setting requires:

$$\varphi_{Ht} = \frac{\epsilon - 1}{\epsilon}\left(1 - \tau^p_{Ht}\right)$$

3.3.2 Wholesale sector

Each firm in the wholesale sector combines physical capital (K_{Ht}), labor (L_{Ht}) and a composite of patented goods (G_{Ht}) to produce according to the following technology:

$$Y_{Ht} = \left(\left(Z_{Ht}L_{Ht}\right)^{1-\alpha}\left(K_{Ht}\right)^{\alpha}\right)^{1-\xi} G^{\xi}_{Ht}$$

where Z_{Ht} is an exogenous AR(1) technology shock. Following, Kung and Schmidt (2015) and Gruning (2017), the composite of patented goods is defined according to the CES aggregator:

$$G_{Ht} = \left[\left(\int_0^{N_{Ht}}\left(X_{H,k,t}\right)^{v} dk\right)\right]^{\frac{1}{v}};$$

where N_{Ht} is the number of patents used in period t and $X_{H,k,t}$ is the amount of the domestically produced patented good k used at Home. $1/\left(1 - v\right)$, with $v < 1$, is the elasticity of substitution between varieties of patents. The law of motion of physical capital is:

$$K_{Ht+1} = \left(1 - \delta_K\right) K_{Ht} + I_{Ht}$$

In order to find a worker, firms must actively search for workers in the unemployment pool. The cost of posting a vacancy is $\kappa_t = \kappa N_{Ht}$, where N_{Ht} is the stock of intangible capital available in the domestic economy. The number of workers available for production in each wholesale firm is:

$$L_{Ht} = \left(1 - s_H\right) L_{Ht-1} + q_{Ht}v_{Ht} \tag{8}$$

where s_H is the separation rate, v_{Ht} is the number of vacancies the firm posts and q_{Ht} the probability of filling the vacancy. Moreover, we assume that wholesale firms face quadratic costs of changing nominal wages:

$$c^w_{Ht}\left(\pi^W_{Ht}\right) = \frac{\phi^w}{2}\left(\frac{\pi^W_{Ht}}{\left(\pi_t\right)^{\iota}} - \gamma^W_H\right)^2$$

where $\pi^W_{Ht} = W_{Ht}/W_{Ht-1}$ denotes gross wage inflation and γ^W_H is the steady state wage inflation rate. π_t represents gross inflation used for indexation and ι the degree of indexation.

Wholesale firms sell their goods to retailers at given relative price φ_{Ht} and choose capital, labor, investment and patented goods to maximize shareholder value:

$$\max \mathbb{E}_0\left[\sum_{t=0}^{\infty}\beta_{0,t}\mathcal{D}_{d,t}\right]$$

where firm's dividends are given by:

$$\mathcal{D}_{d,t} = \varphi_{Ht}Y_{Ht} - \frac{W_{Ht}}{P_{Ht}}L_{Ht}\left(1 + c^w_{Ht}\right) - \kappa_t v_{Ht} - \left(1 + \Phi_{Kt}\right) I_{Ht} - \int_0^{N_{H,t}} P^I_{H,k,t}X_{H,k,t}dk$$

subject to the production function, the law of motions of labor, and physical capital. $\Phi_{Kt} = \frac{\Theta_I}{2}\left(\frac{I_{Ht}}{\gamma_H I_{Ht-1}} - 1\right)^2$ is a standard, quadratic, investment cost function and γ_H is the steady state growth rate of investment. Maximization leads to the following Euler equation for capital accumulation:

$$Q_{Ht} = \mathbb{E}_t \beta_{t+1} \left\{ \alpha (1-\xi) \varphi_{Ht+1} \frac{Y_{Ht+1}}{K_{Ht+1}} + (1-\delta_K) Q_{Ht+1} \right\}$$

where Q_{Ht} denotes the shadow value of capital (in units of consumption):

$$Q_{Ht} = (1+\Phi_{Kt}) + \Phi'_{Kt} \frac{I_{Ht}}{\gamma_H I_{Ht-1}} - \mathbb{E}_t \beta_{t,t+1} \left[\Phi'_{Kt+1} \frac{1}{\gamma_H} \left(\frac{I_{Ht+1}}{I_{Ht}} \right)^2 \right]$$

The first order condition for vacancies equates the expected cost of filling a vacancy to the value of a filled positions:

$$\frac{\kappa_t}{q_{Ht}} = J_{Ht}$$

where J_{Ht}, the value of en existing relationship, consists of the revenues generated by the match, net of wages and their adjustment costs, and the expected continuation value of the job next period:

$$J_{Ht} = \varphi_{Ht} (1-\alpha)(1-\xi) \frac{Y_{Ht}}{L_{Ht}} - \frac{W_{Ht}}{P_{Ht}} (1 + c^w_{Ht}) + \mathbb{E}_t \left[\beta_{t+1} (1-s_H) J_{Ht+1} \right]$$

Finally, the wholesale firm's demand for patented good k is determined by:

$$X_{H,k,t} = \left(\xi \frac{\varphi_{Ht} Y_{Ht}}{G^v_{Ht} P^I_{H,k,t}} \right)^{\frac{1}{1-v}}$$

where the price $P^I_{H,k,t}$ is taken as given by the single wholesale firm.

3.3.3 Intangible good sector

In each country, a set of monopolistic competitive firms produce a differentiated good transforming one unit of the final retail good into one unit of their patented good. Formally, monopolists solve the following static maximization problem:

$$\max_{P^I_{H,k,t}} \Pi^I_{H,k,t} = \max_{P^I_{H,k,t}} \left(1 - \tau^I_{Ht}\right) P^I_{H,k,t} X_{H,k,t} \left(P^I_{H,k,t}\right) - X_{H,k,t} \left(P^I_{H,k,t}\right)$$

subject to the demand schedules $X_{H,k,t}\left(P^I_{H,k,t}\right)$ set by wholesale producers. τ^I_{Ht} is a policy instrument the government can use to affect the equilibrium in the intangible good sector. In equilibrium, patented goods producers set the price as a constant mark-up over marginal costs (which are equal to unity under our assumptions):

$$P^I_{H,k,t} = \frac{1}{v} \frac{1}{\left(1 - \tau^I_{Ht}\right)}$$

and total profits depend on the demand for patented goods and are thus pro-cyclical (as in the data):

$$\Pi^I_{H,k,t} = \left(\frac{1}{v} - 1 \right) X_{H,k,t}$$

3.3.4 Innovation sector

In each country, innovations (new patents) are developed by conducting R&D. Innovators use domestic retail goods as input and sell their innovation to patent producers. Assuming perfect competition, the price of an innovation equals its value to patent producers, $V_{H,k,t}$.

The number of innovations evolves according to:

$$N_{H,t+1} = \vartheta_{H,t} S_{H,t} + (1-\delta_N) N_{H,t}$$

where $S_{H,t}$ is the R&D expenditure and $\vartheta_{H,t}$ represent the productivity of the R&D sector, which is taken as given by innovating firms. Following Kung and Schmidt (2015), its functional form is:

$$\vartheta_{H,t} = \frac{\chi N_{Wt}}{(S_{Wt})^{1-\varkappa} (N_{Wt})^{\varkappa}}$$

where $\varkappa \in [0,1]$ is the elasticity of innovations with respect to R&D and $\chi > 0$. This specification implies decreasing marginal returns to R&D investments, $\partial\vartheta_H/\partial S_W < 0$ (a congestion effect), while at the same time implying that new discoveries facilitate new innovative ideas, $\partial\vartheta_H/\partial N_W > 0$.[10] N_{Wt} and S_{Wt} capture the total relevant stock of intangible capital and of R&D investment:

$$N_{Wt} = (N_{H,t})^{\sigma_R} (N_{F,t})^{1-\sigma_R} \quad ; \quad S_{Wt} = (S_{H,t})^{\sigma_R} (S_{F,t})^{1-\sigma_R}$$

This functional form makes the productivity of the R&D sector dependent not only on domestic R&D and stock of intangible capital, but also on foreign R&D and intangible capital. The parameter $1-\sigma_R$ captures the degree of international R&D spillovers on the productivity of R&D investment.

Value of innovation The main force behind the cyclicality of R&D investment is the value of innovation $V_{H,k,t}$, which is the present discounted value of the profits that innovator k expects to obtain selling the new discovery:

$$V_{H,k,t} = \Pi_{H,k,t} + (1-\delta_N)\, \mathbb{E}_t \beta_{t,t+1} V_{H,k,t+1}$$

The payoffs to innovation are the discounted future profits, i.e. $\mathbb{E}_t \beta_{t,t+1} V_{H,k,t+1}$. Because the R&D sector is competitive, the total amount of R&D investment is determined by a free entry condition which equates the costs with the expected benefits of R&D:

$$\mu_{Ht} S_{H,t} = \mathbb{E}_t \beta_{t,t+1} V_{H,t+1} \left(N_{H,t+1} - (1-\delta_N) N_{H,t}\right)$$

$\mu_{Ht} = \left(1 + \tau^{RD}_{Ht}\right)$ are the unit costs of investment in R&D in terms of the final good, where we allow for a policy instrument τ^{RD}_{Ht}. Notice that this implies that, at the margin:

$$\frac{\mu_{Ht}}{\vartheta_{H,t}} = \mathbb{E}_t \beta_{t,t+1} V_{H,t+1}$$

By determining the amount of R&D investment, this condition ultimately pins down the equilibrium growth rate in the economy. Similar conditions characterize the Foreign country, which is symmetric to the Home one.

3.4 The labor market

Labor markets in each country are characterized by search and matching frictions á la Diamond-Mortensen-Pissarides, which affect the choice of labor input in the wholesale sector.

[10]See Kung and Schmidt (2015) and Comin and Gertler (2006) for a discussion.

3.4.1 Search and matching frictions

Let m_{Ht} denote the newly formed firm–worker matches in the Home labor market. Their number depends on the measure of vacancies v_{Ht} and job seekers u_{Ht} following a constant return to scale matching technology:

$$m_{Ht} = \bar{m}_H u_{Ht}^{\zeta} v_{Ht}^{1-\zeta},$$

where $\bar{m} > 0$, $\zeta \epsilon (0, 1)$ and $u_{Ht} = 1 - (1 - s_H) L_{Ht-1}$ is the number of *searching workers* at the beginning of period t. The probability for the firm to fill an open vacancy is

$$q_{Ht} = \frac{m_{Ht}}{v_{Ht}} = \bar{m}\theta_{Ht}^{-\zeta}$$

where $\theta_{Ht} = \frac{v_{Ht}}{u_{Ht}}$ denotes labor market tightness. The probability that a worker looking for a job is matched with an open vacancy is

$$f_{Ht} = \frac{m_{Ht}}{u_{Ht}} = \theta_{Ht} q_{Ht}.$$

Employment evolves following a process of job matching and destruction. A fraction s_H of employment relationships is destroyed in every period t and a number m_{Ht} becomes immediately operative. The law of motion is thereby

$$L_{Ht} = (1 - s_H) L_{Ht-1} + m_{Ht} \tag{9}$$

For future reference, we also define *(after-hiring) unemployment* as the fraction of searching workers that remain unemployed after hiring takes place:

$$ur_{Ht} = 1 - L_{Ht} \tag{10}$$

Analogous relationships hold in the Foreign labor market.

3.4.2 Wage determination

Nominal wages are determined according to a standard Nash bargaining protocol. The main difference from the standard solution is due to the presence of wage adjustment costs in the value of an employment relationship to the firm. Specifically, the firm and the worker choose nominal wages to maximizes the Nash product:

$$\arg\max_{W_{Ht}} \left[\left(\tilde{J}_{Ht}\right)^{1-\eta_H} \left(\tilde{N}_{Ht}\right)^{\eta_H} \right]$$

where $\eta_H \in (0, 1)$ is the bargaining power of workers, $\tilde{J}_{Ht} = \frac{P_{Ht}}{P_t} J_{Ht}$ is the value to the firm of an employment relationship in term of the final consumption goods and

$$\tilde{N}_{Ht} = (1 - \tau_{Ht}^w) w_{Ht} - b_{Ht} + (1 - s_H) \mathbb{E}_t \left[\beta_{t+1} (1 - f_{Ht+1}) \tilde{N}_{Ht+1} \right]$$

is the corresponding value for the household. Similarly to Abbritti and Fahr (2013) and Arseneau and Chugh (2008), bargaining over nominal wages yields the optimal sharing rule:

$$\omega_t \tilde{J}_{Ht} = (1 - \omega_t) \tilde{N}_{Ht}$$

where

$$\omega_t = \frac{\eta_H (1 - \tau_{Ht}^w)}{\eta_H (1 - \tau_{Ht}^w) + (1 - \eta_H) \tau_{t,t+1}} \tag{11}$$

is the effective bargaining power of workers and $\tau_{t,t+1}$ is a time-varying term capturing the evolution of current and future expected wage adjustment costs

$$\tau_{t,t+1} = \left\{ 1 + c_{Ht}^w + \frac{\partial c_{Ht}^w}{\partial W_{Ht}} W_{Ht} + (1 - s_H) \mathbb{E}_t \beta_{t+1} \left(\frac{T_t}{T_{t+1}} \right)^{-\gamma} \frac{W_{Ht+1}}{\pi_{t+1}} \left(\frac{\partial c_{Ht+1}^w}{\partial W_{Ht}} \right) \right\}$$

The implied bargained wage for the Home country can be written as:

$$\begin{aligned} w_{Ht} &= \omega_t \left[\varphi_{Ht} mpl_t - w_{Ht} c^w_{Ht} + \mathbb{CV}^F_t \right] \\ &\quad + (1-\omega_t) \left[b_{Ht} + \tau^w_{Ht} w_{Ht} - \mathbb{CV}^W_t \right] \end{aligned} \tag{12}$$

where $mpl_t = (1-\alpha)(1-\xi) \frac{Y_{Ht}}{L_{Ht}} (S_t)^{-\gamma}$ denotes the marginal product of labor and $\mathbb{CV}^F_t = \mathbb{E}_t \left[\beta_{t+1} \left(\frac{S_t}{S_{t+1}} \right)^{-\gamma} \left((1-s_H) \tilde{J}_{Ht+1} \right) \right]$ and $\mathbb{CV}^W_t = \mathbb{E}_t \left[\beta_{t+1} (1-s_H)(1-f_{Ht+1}) \left(\tilde{N}_{Ht+1} \right) \right]$ are the continuation values for the firm and the worker respectively.

As in Arseneau and Chugh (2008) and Abbritti and Fahr (2013), wage adjustment costs distort the wage bargaining solution. Since $\partial c^w_{Ht} / \partial W_{Ht} > 0$, during periods of rising wages $\tau_{t,t+1}$ increases and ω_t declines, dampening the fluctuations of the wage bill. The opposite happens during periods of declining wages.

3.5 Aggregate relationships

The resource constraint for the Home and Foreign regions are respectively:

$$\begin{aligned} Y_{Ht}(1-\Gamma_{Ht}) - c^w_{Ht} \frac{W_{Ht}}{P_{Ht}} L_{Ht} &= C_{Ht} + C^*_{Ht} + (1+\Phi_{Kt}) I_{Ht} + X_{H,t} N_{H,t} + S_{Ht} + \kappa_t v_{Ht} \\ Y_{Ft}(1-\Gamma_{Ft}) - c^w_{Ft} \frac{W_{Ft}}{P_{Ft}} L_{Ft} &= C_{Ft} + C^*_{Ft} + (1+\Phi^*_{Kt}) I_{Ft} + X_{F,t} N_{F,t} + S_{Ft} + \kappa^*_t v_{Ft} \end{aligned}$$

Asset market clearing requires:

$$a_{Ht} + Q_t a_{Ft} = 0$$

Integrating the budget constraints across households in the country H, one can derive the following relationship for Home net foreign assets:

$$a_{Ht} = \frac{R_{t-1}}{\pi_t} a_{Ht-1} + \gamma (Q_t C^*_t - C_t)$$

We assume the central bank sets the short term nominal interest rate by reacting to the average inflation and output growth levels in the currency union. More specifically, the central bank adopts an augmented Taylor type rule for the nominal interest rate:

$$R_t = (R_{t-1})^{\omega_r} \left[R \left(\frac{\pi^U_t}{\pi^U} \right)^{\omega_\pi} \left(\frac{Y^U_t}{g_u Y^U_{t-1}} \right)^{\omega_{\Delta y}} \right]^{1-\omega_r} \varepsilon^m_t$$

where $\pi^U_t = (\pi_{Ht})^{0.5} (\pi_{Ft})^{0.5}$, $Y^U_t = (Y_{Ht})^{0.5} (Y_{Ft})^{0.5}$ and g_u is the steady state level growth rate of the union. Consistently with empirical evidence, we assume that monetary policy displays a certain degree ω_r of interest rate smoothing. The parameters ω_π and $\omega_{\Delta y}$ are the response coefficients to inflation and output growth. The term ε^m_t captures an *i.i.d* monetary policy shock.

Finally, inflation differentials are related to the real exchange rate according to:

$$\frac{Q_t}{Q_{t-1}} = \frac{\pi^*_t}{\pi_t}$$

3.6 Long run equilibrium

The specifications of households' preferences and firms' technology allow one to find a balanced growth path for the monetary union - even in the case in which the two regions grow at different steady state growth rates.[11] Using equilibrium conditions, one can rewrite Home production as:

$$Y_{Ht} = \Xi_{Ht} \left(\left(Z_{Ht} L_{Ht} \right)^{1-\alpha} \left(K_{Ht} \right)^{\alpha} \right) N_{Ht}^{\frac{1-v}{v} \frac{\xi}{1-\xi}}$$

where $\Xi_{Ht} = \left\{ \frac{\xi}{\mu_I \mu_{Ht}} \right\}^{\frac{\xi}{1-\xi}}$, $\mu_{Ht} = 1/\varphi_{Ht}$ is the mark-up in the retail sector while $\mu_I = 1/\left(v \left(1 - \tau_{Ht}^I \right) \right)$ is the mark-up in the intangible good sector.

To obtain balanced growth, we need to impose the following parametric restriction:[12]

$$\frac{1-v}{v} \frac{\xi}{1-\xi} = 1 - \alpha$$

If this condition is satisfied, aggregate production is homogeneous of degree one in the accumulating factors K_{Ht} and N_{Ht},

$$Y_{Ht} = TFP_{Ht} \left(L_{Ht} \right)^{1-\alpha} \left(K_{Ht} \right)^{\alpha} \tag{13}$$

and observed TFP is endogenously determined as:

$$TFP_{Ht} = \Xi_{Ht} \left(Z_{Ht} N_{Ht} \right)^{1-\alpha} \tag{14}$$

Productivity is increasing in the exogenous forcing process Z_{Ht} and in the endogenous component that depends on the domestic stock of intangible capital, N_{Ht}, while it is inversely related to the mark-ups of the retail and intangible good sectors, μ_{Ht} and μ_I. The stock of intangible capital grows at an endogenous rate through the accumulation of patents, which in turn depends on the investment in R&D:

$$\Delta N_{H,t+1} \equiv \frac{N_{H,t+1}}{N_{H,t}} = (1 - \delta_N) + \vartheta_{H,t} \frac{S_{H,t}}{N_{H,t}}$$

Similar relationships hold for the Foreign country:

$$\begin{aligned} Y_{Ft} &= TFP_{Ft} \left(L_{Ft} \right)^{1-\alpha} \left(K_{Ft} \right)^{\alpha} \\ \Delta N_{F,t+1} &= (1 - \delta_N) + \vartheta_{F,t} \frac{S_{F,t}}{N_{F,t}} \end{aligned}$$

where $TFP_{Ft} = \Xi_{Ft} \left(Z_{Ft} N_{Ft} \right)^{1-\alpha}$ and $\Xi_{Ft} = \left\{ \frac{\xi}{\mu_I^* \mu_{Ft}} \right\}^{\frac{\xi}{1-\xi}}$.

While the growth rate of domestic production depends on the domestic stock of intangible capital, the growth rate of consumption reflects both domestic and foreign technological progress. In particular, it can be shown that, along the balanced growth path, the growth rates of consumption, $\Delta C_{t+1} \equiv \frac{C_{t+1}}{C_t}$ and $\Delta C_{t+1}^* \equiv \frac{C_{t+1}^*}{C_t^*}$, are proportional to the growth rates of N_{Ht}^C and N_{Ft}^C, the stocks of intangible capital embodied into the aggregate consumption baskets:

$$N_{Ht}^C = \left(N_{Ht} \right)^{1-\gamma} \left(N_{Ft} \right)^{\gamma} \quad ; \quad N_{Ft}^C = \left(N_{Ft} \right)^{1-\gamma} \left(N_{Ht} \right)^{\gamma}$$

Differences in trend growth in turn translate into different steady state inflation rates, where the country growing faster has a lower inflation rate:

$$\pi_H = \pi^U \left(\frac{\Delta N_F}{\Delta N_H} \right)^{0.5} \quad ; \quad \pi_F = \pi^U \left(\frac{\Delta N_F}{\Delta N_H} \right)^{-0.5}$$

[11] Because the aggregate consumption baskets are Cobb-Douglas in the domestic and foreign goods, the differences in real growth rates in consumption are exactly neutralized by the secular trend in relative prices.

[12] See also Kung and Schmidt (2015), Gruning (2017).

and cause a secular trend in the real exchange rate and in the terms of trade:

$$\Delta Q = \frac{\pi^*}{\pi} = \frac{\Delta N_H^C}{\Delta N_F^C} \;\; ; \;\; \Delta T = \frac{\pi_F}{\pi_H} = \frac{\Delta N_H}{\Delta N_F}$$

In summary, the model implies that member countries with higher R&D investment enjoy higher average TFP growth, which translate into higher GDP growth, lower average inflation rates and a secular real exchange rate depreciation. Importantly, this long run equilibrium is consistent with the stylized facts 1 to 4 documented in section 2, which provide credibility to the channel proposed in this paper.

4 Calibration

In the baseline calibration we assume that the Home and Foreign countries are perfectly symmetric. The model is calibrated at the quarterly frequency. Parameters are set to capture the main structural features of the euro area and are close to the standard values used in the literature. The empirical moments correspond to the euro area and cover the sample from 1970q1 to 2015q4. The model is solved by second-order perturbation methods using Dynare ver. 4.5.1.

Preferences. The discount factor β is set to 0.99. The elasticity of substitution of retail goods is $\epsilon = 11$, as in Christoffel et al. (2009) and Fahr and Smets (2010). The home bias parameter γ, representing the share of imported goods on total consumption, is set to 0.25, broadly in line with the share of imports of goods and services in the euro area.

Labor markets. Following Abbritti and Mueller (2013), we set the steady state unemployment rate in each country i to $ur_i = 8$ percent, and the corresponding job finding rate to $f_i = 0.45$. This latter value corresponds to a monthly job finding rate of 0.18. The implied value for the job separation rate is $s_i = 0.071$. The quarterly job filling rate is set to the standard value of $q_i = 0.9$. The elasticity of job matches with respect to vacancies is set to 0.5, consistently with the estimations of Petrongolo and Pissarides (2001). The workers' bargaining power is set to $\eta_i = 0.5$, as e.g. Blanchard and Galí (2010). Following Monacelli et al. (2010), job posting costs are chosen such that aggregate hiring costs are 0.44 percent of steady state output.[13] The parameter b_i, capturing the value of unemployment benefits and non-work activities, and the matching efficiency parameter $\bar{m}_i$ are determined through steady state relationships. We get $\bar{m}_i = 0.636$ and $b_i = 0.024$. The latter corresponds to a benefit replacement ratio of 0.523.

Wage and price adjustment costs. Following Fahr and Smets (2010), we set the degree of price rigidities to $\phi^p = 45$. This is consistent with a Calvo parameter of 0.63 which represents a mean price duration of about 3 quarters. The degree of wage rigidity, ϕ^W, is set to match the observed relative volatility of nominal wage inflation. We get $\phi^W = 16$. We assume no indexation of wages to inflation, i.e. $\iota = 0$.

Production. In the wholesale sector, α is set to the standard value of 0.33 in order to match the average capital share. The quarterly capital depreciation rate is set to $\delta_K = 0.02$, corresponding to an annual capital depreciation rate of 8 percent. As standard in the literature, the material share ξ is set to 0.5 (see e.g. Comin and Gertler, 2006, and Kung and Schmidt, 2015). The implied inverse mark-up parameter in the intangible good sector is $v = 0.6$. The investment adjustment cost is set to $\Theta_I = 0.282$, in order to match the relative standard deviation of investment to GDP.

R&D sector. The R&D sector is calibrated as in Kung and Schmidt (2015). Specifically, as in Kung and Schmidt (2015) we set the patent obsolescence rate to $\delta_N = 0.0375$ and the elasticity of new patents to R&D to $\varkappa = 0.83$, close to the midpoint of the estimates presented by Griliches (1990). The scale parameter χ is chosen to match the average annual growth rate $g_u = 1.6$ of the euro area economy in our sample. In the baseline calibration we also allow for a small degree of technological spillovers $1 - \sigma_R = 0.1$, as in Gruning (2017).

[13] See Monacelli et al. (2010) for a discussion.

Monetary policy. We assume that the (common) central bank reacts to union-wide inflation with an elasticity $\omega_\pi = 1.5$ and a persistence in interest rates $\omega_r = 0.85$. As in Gilchrist et al. (2016), the response coefficient on output growth is set to $\omega_{\Delta y} = 0.25$, the mid-point of the range suggested by Taylor (1993). The standard deviation of the monetary policy shock is set to 0.1 percent, consistent with the estimates by Thomas and Zanetti (2009) and Christoffel et al. (2009). Consistently with the ECB's inflation target, trend inflation is set to $\pi^U = 2$ (annualized).

Tax rates. In the baseline calibration, we assume the presence of policy-induced distortions in the retail market and in the labor market in both countries, i.e. $\tau^p_{Ht} = \tau^p_{Ft} = 0.2$ and $\tau^w_{Ht} = \tau^w_{Ft} = 0.4$. For simplicity, we abstract from taxes or subsidies affecting the intangible good sector or the R&D sector: $\tau^{RD}_{Ht} = \tau^{RD}_{Ft} = \tau^I_{Ht} = \tau^I_{Ft} = 0$. Intermediation costs are set to $\psi_B = 0.001$.

Shock processes. We assume that Home and Foreign technology shocks are purely country-specific, i.e. uncorrelated. The persistence parameter of the technology shocks is set to $\rho_{Zi} = 0.95$. The volatility of the technology shock is set to $\sigma_{zi} = 0.45$ percent in order to match the average volatility of GDP per capita. To calibrate the Home and Foreign liquidity demand shock processes, we use recent measures of risk premiums calculated by Gilchrist and Mojon (2017) for Germany, France, Italy, Spain, and the euro area. Specifically, we fit an AR(1) process to the risk premium series of non financial corporations with respect to corresponding sovereign rates. The data covers the sample period 1999q1-2015q4. The standard deviation of the residuals range between 0.0721 percent in the case of Germany and above 0.12 percent for Spain and Italy, while the corresponding AR(1) coefficient ranges between 0.816 and 0.859. Based on this evidence, we follow Abbritti and Fahr (2013) and calibrate the persistence and volatility of the Home and Foreign liquidity demand shocks to $\rho_{\varrho_i} = 0.8$ and $\sigma_{\varrho_i} = 0.1$ percent. The cross-correlation between Home and Foreign risk premium shocks is calibrated to match the average cross-country correlation of GDP between the four euro area member countries, which is equal to 0.65 in our sample period. We get $\sigma_{\varrho_H,\varrho_F} = 0.40$.

Benchmark NK model. To understand the role of R&D investment and intangible capital for the dynamics of the union, it will be instructive to compare the dynamics of our benchmark endogenous growth model with those of a nested New Keynesian (NK) model with exogenous growth. Specifically, the NK model we consider is a version of our model with constant R&D investment intensity. This is equivalent to specifying an exogenous trend growth component in productivity.[14] To facilitate comparison, the calibration of the benchmark NK model is identical to the one of the baseline growth model.

4.1 Model fit

Table 1 compares the second moments of the high frequency fluctuations in the data and in the model. The high frequency component corresponds to cycles shorter than 32 quarters and is obtained by filtering the actual and simulated data with the HP(1600) filter.

The model does a remarkably good job in matching most of the moments of the data. Our calibration strategy forces the model to match the standard deviation of output and the relative volatilities of wage inflation and investment. In addition, the model does a very good job in matching the relative volatility of TFP, employment and unemployment, and comes close to matching the relative volatility of price inflation. We fail instead in matching the relative volatility of real wages, which is larger in the data than in the model. The model also does a good job in matching the cross-correlation of most variables with output, while it underpredicts the persistence of most series.

Table 2 compares the medium and long term cycle components of the model with the ones of the data. The medium term component corresponds to cycles with periods between 32 and 100 quarters. The long term component corresponds to cycles with periods between 32 and

[14]Kung and Schmidt (2015) follow a similar strategy to compare the asset pricing implications of growth cycles and business cycles.

200 quarters. Both are obtained by filtering the data with a band-pass filter. Even though our calibration strategy does not target these moments, the model is also reasonably consistent with basic medium term cycle properties of the euro area economy. In particular, the model does a good job in matching the medium and long term volatility of output, TFP, employment and unemployment. We take it as indication that our calibration of the endogenous productivity process is reasonable. The model, instead, fails to match the relatively high medium and long term volatility of wage and price inflation that we observe in the data. This discrepancy can be explained by noticing that we keep a stable annual inflation target of 2 percent in the model, while we observe different inflation regimes throughout our data sample and, in particular, episodes of high inflation in the 70s and in the 80s.

Comparing the second moments of the baseline endogenous growth model with the ones of the benchmark NK model, reveals that endogenous movements in R&D induce a strong propagation mechanism. Closing down the innovation sector, in fact, reduces the volatility of output at business cycle frequency from 1.16 to 0.84, at the medium term cycle frequency from 1.51 to 1.06 and at the long term cycle frequency from 3.60 to 2.37. On the other hand, the simulations show that the introduction of an innovation sector leads to a reduction of wage and price inflation volatility, which are reduced by more than 10 percent.

5 The Dynamics of the Monetary Union

To understand the working of the model, in this section we present the responses of selected variables to an asymmetric risk premium shock and compare it with the ones of a nested New Keynesian model with exogenous growth.

Figure 5 shows the impact of a large risk premium shock to the Home country. The shock corresponds to an increase of the risk premium by 40 basis points (i.e. 1.6 percent if annualized), which is in line with the increases in risk premia in countries like Spain and Italy in 2008 and 2011. Following the increase in the demand for liquid assets, domestic households reduce their consumption demand and their saving in risky assets. These effects imply an increase in the required return on capital and lead to a fall in both home investment in physical capital and home R&D. Due to the presence of nominal rigidities, the drops in investment and consumption lead to a drop in domestic output.

The Home risk premium shock is transmitted to the foreign country through spillover effects of the risk premium shock, movements of the terms of trade and monetary policy. The direct spillover effects come into play because, under our calibration, a risk premium shock to one country partially spills over to the other country and leads to a reduction of consumption and investment also at Foreign. Moreover, the strong reduction in the prices of the home goods exerts deflationary pressure abroad as consumers in both countries shift their consumption towards the home good. Finally, the central bank lowers the interest rate, which has a stimulating effect on the foreign economy. Since the first two effects dominate, the overall result is a drop of foreign inflation and a decrease of the foreign employment rate.

Putting the impulse responses of the country specific variables together, a negative risk premium shock at Home leads to positive, and quite persistent, inflation, employment, and R&D differentials.

To isolate the effects of the endogenous productivity mechanism, Figure 5 shows also the responses of the version of our model where technology is purely exogenous. Comparing the responses of the baseline growth model with the ones of the benchmark NK, one can notice that endogenous productivity and R&D investment magnify the negative effects of an asymmetric risk premium shock, and lead to an increase of employment and inflation differentials of almost 50 percent on impact.

An important implication of the model is that temporary shocks can lead to very persistent effects not only on the cycle, but also on the trend of the economy. Figure 6 shows the effect of the home risk premium shock on the *level* of output and TFP. In the benchmark NK model, the risk premium shock to the Home country leads to a short-lived drop in home GDP, which is almost completely absorbed in around three years. These results stand in stark contrast with the ones of the model with endogenous growth. The presence of R&D investment and intangible capital has two main effects. First, the output collapse following the negative financial shock is now 1 percent larger. Second, the negative shock permanently shifts downward the home economy's trend. In this sense, our model is able to reproduce the strong GDP contraction and the shift in the trend of GDP that many European countries experienced after the Great Recession and the subsequent euro area debt crisis.

Home and foreign output dynamics follow closely the ones of measured TFP. In the benchmark NK model, measured TFP decreases on impact because of the increase in the average mark-up of the retail sector μ_{Ht} which enters the Solow residual (see eq. 14). This effect however is very short-lived, as it vanishes after 6 quarters. In contrast, in the model with endogenous growth the drop of measured TFP is much larger on impact, and does not disappear in the long run.

To give a different perspective, figure 7 shows the effect of the asymmetric risk premium shock on the *relative* output dynamics (defined as Y_{Ht}/Y_{Ft}) and the real exchange rate dynamics of the two regions. In the benchmark NK model, temporary risk premium shocks reduce temporarily Home GDP below the Foreign level, and cause a temporary appreciation of the real exchange rate. The effect, however, is relatively small and disappears in the long run. On the contrary, in the model with endogenous growth, a temporary shock has permanent effects on relative output and real exchange rates. This result has drastic implications, as it implies that there is no reason to expect real income convergence among member countries, because the history of shocks and the policy responses matter for long run dynamics.

5.1 The role of synchronization of risk premium shocks

The effects of a large shock, and more in general the costs of sharing the same currency, depend crucially on the degree of synchronization of shocks across different member states. In this regard, figure 1 suggests that while the spikes in risk spreads in 2008 were symmetric across member states, the risk premium increases in 2011 were asymmetric, with risk spreads in Italy and Spain diverging considerably from the ones of Germany and France.

To understand the effects of the degree of synchronization of financial shocks, figure 8 simulates the impulse responses to a large home risk premium shock for different degrees of spillovers to the Foreign country. Specifically, we compare the results of the baseline calibration, where home and foreign risk premium shocks are weakly correlated ($corr(\varrho_H, \varrho_F) = 0.4$), with the ones obtained when risk premium shocks are purely idiosyncratic ($corr(\varrho_H, \varrho_F) = 0.001$) or almost perfectly correlated ($corr(\varrho_H, \varrho_F) = 0.999$).

The degree of shock synchronization has important effects on the dynamics of the union, and especially on the Foreign country. In the Home country the negative effects on employment and output are smaller when the shock is symmetric, because in this case the common monetary policy response is stronger and thus more in line with the needs of the Home economy. These effects, however, are quantitatively small. In the Foreign country, the negative effects of the shock strongly increase with the degree of synchronization. When the home risk premium shock is purely idiosyncratic, Foreign employment and production actually increase on impact, because the negative effects of the shock on trade are more than offset by the monetary policy reaction of the central bank. As a consequence, purely idiosyncratic shocks create quite large permanent income differentials among member countries – significantly larger than the ones created under the baseline calibration of our model.

6 Market Regulation, Cycles and Growth

In this section we analyze how different labor and product market institutions affect the short run and long run dynamics of the currency union. Specifically, we consider the effects of four reforms. The first reform is product market deregulation. Following Eggertsson et al. (2014), we model this policy as a reduction of the tax rate of the retail sector which decreases the mark-up and increases competition. Specifically, we reduce the tax rate from $\tau_{it}^p = 0.2$ to $\tau_{it}^p = 0.185$. This translates into a reduction of the net mark-up of the retail sector of 7 percent, from 0.375 to 0.35.

Regarding labor markets, we focus on three institutions. The first exercise consists in a permanent reduction of unemployment benefits by 20 percent, which lowers the equilibrium benefits over wage ratio from 0.523 to 0.431. The second exercise consists in a reduction of the tax wedge τ_{it}^w from 40 to 30 percent. Finally, in the third exercise we change the overall degree of rigidity of labor market flows. Specifically, following Blanchard and Galí (2010), we define a labor market as "flexible" when the job-finding and the separation rate are high; the opposite holds in a "sclerotic" labor market. In practice, we change the efficiency of matches $\bar{m}_i$ and the exogenous separation rate s_i such that in steady state the job-finding rate is 0.7 and the unemployment rate is 5 percent. This implies an increase in the separation rate from $s_i = 0.07$ to 0.12. As shown in Abbritti and Mueller (2013), this calibration of labor market rigidities captures, in a reduced form but intuitive way, the effect of lower hiring and firing costs. In fact, we will show that reducing employment rigidities has the same effects on inflation and output volatilities as reductions in firing costs in Zanetti (2011) and Thomas and Zanetti (2009).[15]

6.1 Steady-state growth under varying market regulation

In the model, TFP is an endogenous variable and the steady state growth rates of output, consumption, prices etc. are a function of the deep parameters of the model. This allows us to get an (admittedly simplified) idea of the effect of reforms on the long run equilibrium of the currency union.

Table 3 shows the effects of varying labor and product market parameters on the steady state of the economy. The exercise is performed by fixing all the deep parameters of the model to their values of the baseline calibration, and allowing all the endogenous variables to adjust to changes in the policy parameters of interest. We consider both symmetric reforms, where both countries are characterized by more flexible markets, and asymmetric reforms, in which case we assume that there is deregulation in the Home economy but not in the Foreign economy.

Let us discuss first the effects of symmetric reforms. The results are in line with conventional wisdom. All the four reforms improve the long run growth of the economy, and lower the unemployment rate, though by different amounts. A reduction of the mark-up of retailers (column τ_i^p in the table) increases the growth rate of the union and reduces the unemployment rate. Intuitively, higher competition in the retail market increases the demand for wholesale goods and thus for intangible goods. This stimulates investment in R&D and leads to a strong effect on output growth.

Similarly, a reduction in the tax wedge or in unemployment benefits lowers the unemployment rate and increases long run growth. To understand this result, it is useful to rewrite the equilibrium wage schedule of the Home country:

$$\begin{aligned} w_{Ht} &= \omega_t \left[\varphi_{Ht} mpl_t - w_{Ht} c_{Ht}^w + \mathbb{CV}_t^F \right] \\ &\quad + (1-\omega_t) \left[b_{Ht} + \tau_{Ht}^w w_{Ht} - \mathbb{CV}_t^W \right] \end{aligned} \tag{15}$$

A reduction in the tax wedge τ_{Ht}^w has two effects on the equilibrium wage. First, it reduces the minimum wage that the worker is willing to accept (last term in squared brackets). Second it increases the effective bargaining power of workers ω_t, because firms and workers internalize, through bargaining, the effects of the policy change on wages (see eq. 11). The first

[15] It is important to remark that we compare the properties of a currency union with different product and labor market institutions, but we do not study in this paper the transition dynamics from the old to the new equilibrium.

effect dominates, and a lower tax wedge reduces the equilibrium wage and increases production, R&D investment and growth. Similarly, a reduction of unemployment benefits b_H worsens the outside option of workers, lowers the equilibrium wage and increases long run production and growth. Finally, a more flexible labor market (LMR_i in the table) implies, by definition, lower unemployment rates and higher job finding rates, production and output growth. These model patterns are consistent with facts 2 and 3, establishing that countries with higher levels of market regulation exhibit lower levels of R&D spending and lower TFP growth (Figure 3).

When reforms are asymmetric, the impact on unemployment, production and growth of the Home country (i.e. the country affected by the reform) are qualitatively similar, but even larger. At Home, in fact, the positive effect of the reform on output growth is amplified by the inaction of the Foreign country because the reforms improves the competitiveness of home firms at the expenses of foreign firms. As a consequence, in the Foreign country output growth is reduced but unemployment only weakly affected. This is consistent with fact 3 (Figure 4), which states that the change in a country's TFP growth relative to the euro area average is increasing in the extent of market deregulation relative to the euro area average. Thus, a country that undertakes no reforms is expected to exhibit relatively lower TFP growth if other union members liberalize labor or product markets. Different steady state output growth rates translate into different inflation rates and an equilibrium depreciation of the Home country's terms of trade and real exchange rate. This result is in line with fact 4 (Figure 4).

6.2 Regulation and monetary policy shocks

To analyze the effects of market structures on the functioning of the currency union, we analyze how a common monetary policy shock is transmitted asymmetrically across countries when member countries have heterogeneous product or labor markets. For simplicity, we focus the attention on two institutional reforms: product market deregulation (i.e. a decrease in the markup of retailers) and a reform reducing hiring and firing costs, which makes labor markets more flexible. Figure 9 shows the effect of a common monetary policy shock in an asymmetric currency union. We consider three calibrations: the baseline calibration (A), a currency union where the Home country has low product market regulation (B) and a currency union where the Home country has low employment rigidities (C). When market structures are asymmetric, symmetric shocks can have large asymmetric effects and lead to long-lasting inflation and employment differentials. A lower degree of product market regulation increases the response of inflation to shocks (home inflation goes down by more on impact, which induces an increase in the inflation differential) but reduces the employment response. A lower degree of employment rigidities has exactly the opposite effect: employment reacts by more and inflation is more muted in a flexible region. The effects are large and persistent, especially in the case of employment rigidities.

We thus find that product market rigidities and labor market rigidities have opposite dynamic effects on inflation and employment. Intuitively, this happens because a lower degree of product market regulations steepens the Phillips curve, while lower employment rigidities flatten it. To see this, one can write the Phillips curve of the Home country, up to a first order, as:

$$\hat{\pi}_{Ht} = \frac{(\epsilon - 1)\left(1 - \tau^p_{Ht}\right)}{\psi \bar{\pi}^2_H} \hat{\varphi}_{Ht} + \beta \frac{\Delta N_H}{\Delta N^C_H} \hat{\pi}_{Ht+1}$$

Notice that the slope of the Phillips curve $\frac{(\epsilon-1)\left(1-\tau^p_{Ht}\right)}{\psi\bar{\pi}^2_H}$ is decreasing in the policy rate τ^p_{Ht}. Therefore, a reduction of τ^p_{Ht} increases the elasticity of inflation to marginal costs, $\hat{\varphi}_{Ht}$.

On the other hand, to understand the effect of labor market rigidities, notice that in a flexible labor market, average job finding and separation rates are large, and changes in employment lead to small variations in labor market tightness:

$$\hat{\theta}_{Ht} = \frac{1}{s_H (1 - \zeta)} \left\{ \hat{L}_{Ht} - (1 - s_H)(1 - f_H) \hat{L}_{Ht-1} \right\}$$

This translates into a lower elasticity of marginal costs, real wages and inflation to changes in labor, and the Phillips curve gets flatter.

To get an idea of the quantitative effect of different labor and product market institutions on business cycle dynamics, Table 4 and 5 show how the moments of the model at business cycle and medium term cycle frequencies change with different calibrations of the model. Specifically, we simulate the model for different calibrations of the product and labor markets and show the standard deviation of the filtered time series of the macroeconomic variables. The volatility of inflation is annualized.

A lower degree of product market regulation reduces the volatility of employment but slightly increase the volatility of inflation. As a consequence, the volatility trade-off, which we define as the ratio between the inflation volatility and employment volatility, increases after liberalizing the product market. Notice that this trade-off has a nice economic interpretation, as it is related to the slope of the Phillips Curve and represents how much inflation volatility needs to be afforded in order to reduce the volatility of employment by one percent.

Similarly, reforms reducing the tax wedge or the generosity of the unemployment benefits system increase the volatility of inflation and reduce the one of employment, leading to a significant increase in the volatility trade-off. Intuitively, both reforms increase the flexibility of real wages and facilitate the possibility of firms to absorb shocks using this margin: when real wages are more flexible, the firms' share of the match surplus does not change that strongly with shocks and hence hiring and employment react more smoothly to changing economic conditions.

A reduction of hiring and firing costs, captured in the model by different degrees of labor market rigidities, has the opposite effect on business cycle fluctuations: the volatility of employment increases, while the responsiveness of inflation is reduced. As a consequence, the volatility trade-off is strongly reduced in a more flexible labor market, as the Phillips curve gets flatter. In this sense, a reform reducing hiring and firing costs is steady-state efficient because it increases the long run growth prospect of the economy, but dynamically inefficient, because it flattens the Phillips curve and make macroeconomic stabilization more costly.

6.3 Regulation and risk premium shocks

The final question we try to address is how labor and product market institutions influence the response of member countries to positive and negative risk premium shocks. In the empirical part, we documented that following a union-wide risk premium shock the TFP recovery is faster in less regulated economies (fact 5). Can the model with endogenous growth explain this observation?

To answer this question, figure 10 shows the response of home TFP to a large risk premium shock in the baseline economy and in economies with low product market rigidities or with low labor market rigidities. The left panel shows the effects of an increase in the risk premium, while the right panel the effect of a risk premium reduction. Labor and product market regulation have a strong impact on the TFP response to risk premium shocks. Following an increase in the risk premium (left panel), the recovery of TFP is much faster in an economy with flexible labor and product markets. Similarly, following a risk premium reduction, the more flexible economy benefits more and faster from lower rates than a sclerotic economy.

The results of the model following an increase in the risk premium resemble quite closely the local projections of the empirical part (see figure 4). This happens in the model for a combination of the effect of institutions on short run dynamics (e.g. the collapse of TFP is smaller in countries with low LMR) and long run dynamics (the trend growth rate is larger in countries with low product market and labor market regulation). Overall, our model confirms that more flexible economies are likely to be more resilient to negative financial shocks.

7 Concluding Remarks

We have presented a DSGE currency union model where productivity grows endogenously through R&D investment and industrial innovation. The model constitutes a rigorous laboratory to study interactions between business cycles and growth dynamics, and to analyze the short- and long-term effects of different product and labor market regulations. As an illustration of the properties of the model, we have analyzed four different institutions: product market regulation, the tax wedge, unemployment benefits and employment rigidities. The analysis suggests three main conclusions. First, reforms aimed at making product and labor markets more flexible are likely to be welfare enhancing in the long run, because they have a positive effect on long run growth and the natural unemployment rate. Second, we show that while product market deregulation, tax wedge reforms and unemployment benefits reductions make the Phillips curve steeper, a lower degree of employment rigidities tends to flatten the Phillips curve and make macroeconomic stabilization more difficult. Third, we shows that in a currency union with endogenous productivity and different market structures there is no reason to expect real income convergence among member countries. Countries with relatively more flexible market structures benefit from higher long-term growth. In addition, members facing large negative shocks can remain on a permanently lower output trajectory, because such shocks can reduce firms' profits and investment in R&D, which in turn reduce the process of intangible capital accumulation. Applied to the euro area, higher rigidities in labor and product markets provide one explanation for lower growth trajectories in some euro area countries prior to the crisis. This was exacerbated during the Great Recession and then the euro area debt crisis, shifting output permanently lower, particular for those members with more rigid market structures and facing asymmetric risk shocks.

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Annex 1: Derivation of quarterly TFP series

No single source for quarterly series of TFP growth in the euro area is available. For the purpose of analyzing short-and medium term dynamics it is, however, necessary to use such a series. We follow Levy and Chen (1994) to derive the relevant series for our sample of euro area members. The method uses the annual capital stock data and exploits the capital accumulation relationship between capital stock and the corresponding investment series to estimate quarterly depreciation rates which vary over time and are derived using Newton's iteration formula. Specifically, denoting the investment of a given quarter j in year i by $I_{j,i}$ the net real capital stock is given by:

$$K_{j,i} = (1 - \delta_i)\, K_{j-1,i} + I_{j,i}$$

where the deprecation rate in a given year is assumed to be constant. Iterating this equation to replace the net capital stock such that only end-year net capital stocks remain, yields:

$$K_{4,i} = (1 - \delta_i)\hat{}^{4}\, K_{4,i-1} + \sum_{k=1}^{4} (1 - \delta_i)^{4-k}\, I_{k,i}$$

The equation expresses the depreciation rate as a non-linear function of last year's and this year's annual capital stock and the real quarterly investment.[16] The discount rate for a given year can, thus, be obtained by solving for δ_i using Newton's iteration formula.[17] For the 11 euro area countries in the sample the quarterly discount factor is very stable over time, showing only some variation for Greece, Belgium and Ireland. Values are clustered around 1.5% for most countries and in remain within the interval of 1-2% across countries.

After obtaining the estimated discount factors, the recursive capital accumulation equation can be used to derive the quarterly capital stock. Once the quarterly capital stock series is computed, the quarterly TFP series can be derived using quarterly real GDP, employment,[18] and wage share data under the Cobb-Douglas production function assumption.[19]

[16] This could be modified to exclude residential investment, to better capture the channel from productivity enhancing investment to TFP.

[17] In the case of our sample, convergence was achieved at least after 3 iterations.

[18] Using total hours worked instead of employment would be preferable, but is left for future extensions.

[19] The quarterly series of TFP is derived in a way that is compatible with the annual series provided by the European Commission's AMECO database.

HP-Filtered Business Cycle									
	$\sigma(x)/\sigma(y)$			$\rho(x,y)$			$\rho(x_t,x_{t-1})$		
Variable	euro area Data	Baseline Model	NK Model	euro area Data	Baseline Model	NK Model	euro area Data	Baseline Model	NK Model
Nominal wages	1.71	1.73	1.91	0.50	0.88	0.80	0.16	0.17	0.25
Prices	1.07	0.89	1.03	0.31	0.94	0.89	0.22	0.35	0.46
Real wages	0.84	0.32	0.38	0.67	0.87	0.95	0.92	0.72	0.75
Unemployment	5.46	5.97	6.40	-0.85	-0.97	-0.97	0.91	0.62	0.69
Employment	0.43	0.52	0.56	0.80	0.97	0.97	0.95	0.62	0.70
Investment	2.36	2.31	3.77	0.91	0.84	0.92	0.89	0.80	0.81
TFP	0.74	0.68	0.67	0.93	0.99	0.98	0.83	0.37	0.53
Output	1.00	1.00	1.00	1.00	1.00	1.00	0.88	0.46	0.58
$\sigma(y)$	1.16	1.16	0.84						

Table 1: This table presents selected HP-filtered macroeconomic moments from the data and the baseline calibration of the model. The standard deviations of price and wage inflations are annualized.

Medium and Long Term Cycle						
	$\sigma(x)/\sigma(y)$			$\rho(x,y)$		
Variable	euro area Data	Baseline Model	NK Model	euro area Data	Baseline Model	NK Model
Medium term component (frequency 32-100)						
Nominal wages	7.43	3.85	4.22	0.27	0.60	0.64
Prices	6.02	2.63	3.24	-0.41	0.41	0.37
Real wages	1.45	0.39	0.41	0.78	0.79	0.91
Unemployment	6.62	5.28	5.64	-0.95	-0.91	-0.95
Employment	0.67	0.46	0.49	0.92	0.92	0.95
Investment	3.41	2.05	3.37	0.93	0.79	0.87
TFP	0.51	0.70	0.67	0.80	0.99	0.95
Output	1.00	1.00	1.00	1.00	1.00	1.00
$\sigma(y)$	1.53	1.51	1.06			
Long term component (frequency 32-200)						
Nominal wages	9.15	3.17	3.62	-0.65	0.60	0.65
Prices	10.29	2.07	2.70	-0.85	0.41	0.37
Real wages	1.14	0.34	0.37	0.62	0.76	0.89
Unemployment	5.20	5.14	5.59	-0.81	-0.91	-0.94
Employment	0.49	0.45	0.49	0.91	0.91	0.94
Investment	3.60	1.76	3.02	0.96	0.74	0.83
TFP	0.55	0.72	0.69	0.90	0.99	0.96
Output	1.00	1.00	1.00	1.00	1.00	1.00
$\sigma(y)$	3.05	3.60	2.37			

Table 2: This table presents the medium and low frequency component of selected macroeconomic moments from the data and the baseline calibration of the model. The medium term component corresponds to cycle with periods between 32 and 100 quarters and is obtained by filtering the data with a Band-pass filter. The long term component corresponds to cycle with periods between 32 and 200 quarters and is obtained by filtering the data with a Band-pass filter.

Long Run Mean		Baseline Calibration	Symmetric Reforms τ_i^p	τ_i^w	b_i	LMR_i	Asymmetric Reforms τ_H^p	τ_H^w	b_H	LMR_H
Union	Δy^U	**1.60**	2.34	2.02	2.12	1.93	1.97	1.81	1.86	1.76
	Δc^U	**1.60**	2.34	2.02	2.12	1.93	1.97	1.81	1.86	1.76
	u^U	**8.00**	6.62	4.24	3.30	5.00	7.28	5.82	5.13	6.35
	π^U	**2.00**	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Home	Δy^H	**1.60**	2.34	2.02	2.12	1.93	2.68	2.19	2.34	2.06
	Δc^H	**1.60**	2.34	2.02	2.12	1.93	2.33	2.00	2.10	1.91
	u^H	**8.00**	6.62	4.24	3.30	5.00	6.51	4.26	3.32	5.09
	π^H	**2.00**	2.00	2.00	2.00	2.00	1.28	1.62	1.53	1.71
Foreign	Δy^F	**1.60**	2.34	2.02	2.12	1.93	1.25	1.43	1.39	1.47
	Δc^F	**1.60**	2.34	2.02	2.12	1.93	1.61	1.62	1.63	1.62
	u^F	**8.00**	6.62	4.24	3.30	5.00	8.14	7.94	7.92	7.93
	π^F	**2.00**	2.00	2.00	2.00	2.00	2.72	2.38	2.48	2.29
Rel. prices	ΔToT	**0.00**	0.00	0.00	0.00	0.00	1.44	0.76	0.95	0.58
	ΔRER	**0.00**	0.00	0.00	0.00	0.00	0.72	0.38	0.48	0.30

Table 3: This table reports comparative statics analysis of the steady state growth rate for different values of product and labor market institutions.

Second moments (HP-filtered)		euro area Data	Baseline Calib.	Symmetric Reforms τ_i^p	τ_i^w	b_i	LMR_i	Asymmetric Reforms τ_H^p	τ_H^w	b_H	LMR_H
Union	$\sigma(\pi_U)$	1.25	**1.03**	1.06	1.07	1.08	0.95	1.05	1.05	1.06	0.99
	$\sigma(L_U)$	0.50	**0.60**	0.57	0.46	0.43	0.90	0.59	0.53	0.51	0.75
	$\sigma(\pi_U)/\sigma(L_U)$	2.49	**1.72**	1.86	2.33	2.51	1.06	1.78	1.98	2.08	1.32
Home	$\sigma(\pi_H)$	-	**1.12**	1.15	1.16	1.18	1.03	1.16	1.18	1.20	1.02
	$\sigma(L_H)$	-	**0.67**	0.63	0.51	0.47	0.98	0.63	0.52	0.48	0.98
	$\sigma(\pi_H)/\sigma(L_H)$	-	**1.67**	1.83	2.27	2.51	1.05	1.84	2.27	2.50	1.04
Foreign	$\sigma(\pi_F)$	-	**1.12**	1.15	1.16	1.18	1.03	1.11	1.10	1.10	1.13
	$\sigma(L_F)$	-	**0.67**	0.63	0.51	0.47	0.98	0.67	0.66	0.65	0.67
	$\sigma(\pi_F)/\sigma(L_F)$	-	**1.67**	1.83	2.27	2.51	1.05	1.66	1.67	1.69	1.69
Differentials	$\sigma(\pi_F)/\sigma(\pi_H)$	-	**1.00**	1.00	1.00	1.00	1.00	0.96	0.93	0.92	1.11
	$\sigma(L_F)/\sigma(L_H)$	-	**1.00**	1.00	1.00	1.00	1.00	1.06	1.27	1.35	0.68

Table 4: This table reports second moments for different values of product and labor market institutions.

Medium and Long Term Cycle		euro area Data	Baseline Cal.	Symmetric Reforms τ_i^p	τ_i^w	b_i	LMR_i	Asymmetric Reforms τ_H^p	τ_H^w	b_H	LMR_H
Medium term component (frequency 32-100)											
Union	$\sigma(Y_U)$	1.53	**1.51**	1.50	1.44	1.43	1.56	1.51	1.47	1.47	1.53
	$\sigma(L_U)$	1.02	**0.67**	0.63	0.52	0.49	1.06	0.65	0.59	0.58	0.87
	$\sigma(\pi_U)$	9.17	**3.43**	3.46	3.47	3.49	3.37	3.45	3.45	3.46	3.40
Long term component (frequency 32-200)											
Union	$\sigma(Y_U)$	3.05	**3.60**	3.62	3.51	3.50	3.70	3.61	3.55	3.54	3.65
	$\sigma(L_U)$	1.48	**1.55**	1.49	1.27	1.21	2.59	1.52	1.41	1.37	2.08
	$\sigma(\pi_U)$	25.35	**5.95**	6.01	6.04	6.07	5.78	5.98	6.00	6.01	5.86

Table 5: This table presents the medium and low frequency component of selected macroeconomic moments from different calibration of the model. The medium term component corresponds to cycle with periods between 32 and 100 quarters and is obtained by filtering the data with a Band-pass filter. The long term component corresponds to cycle with periods between 32 and 200 quarters and is obtained by filtering the data with a Band-pass filter.

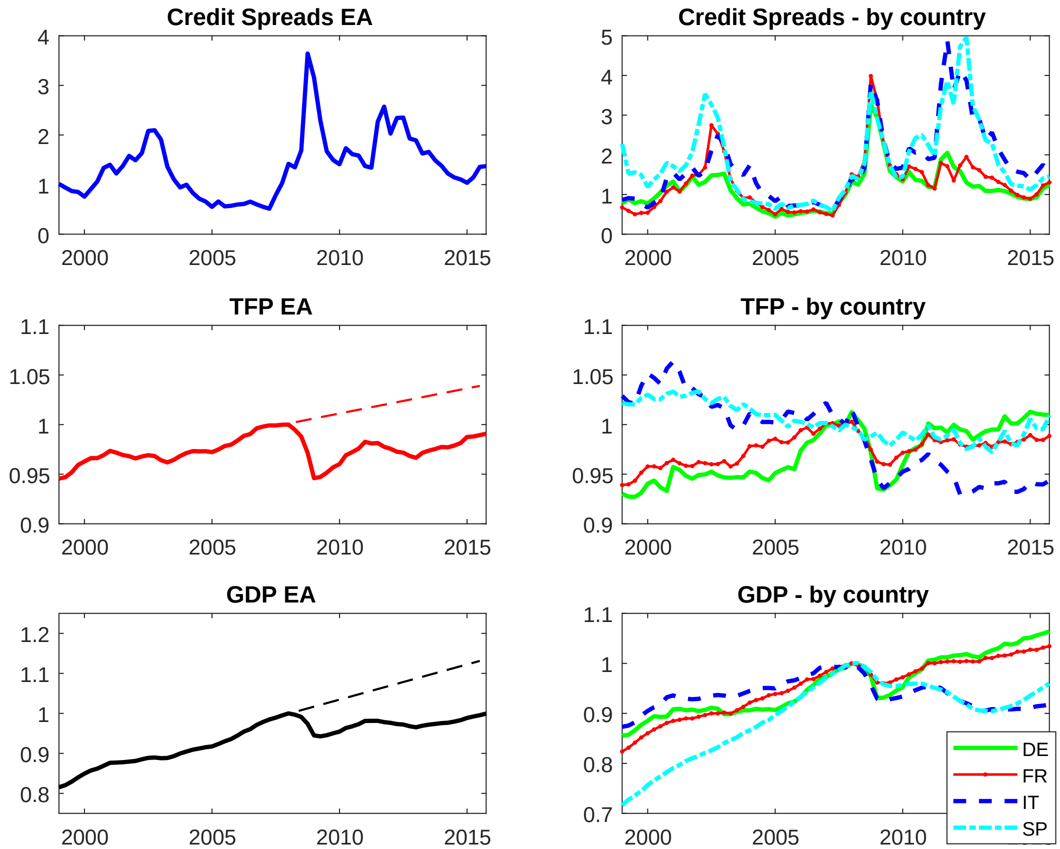

Figure 1: Credit spreads, TFP and GDP dynamics in the euro area and selected countries.

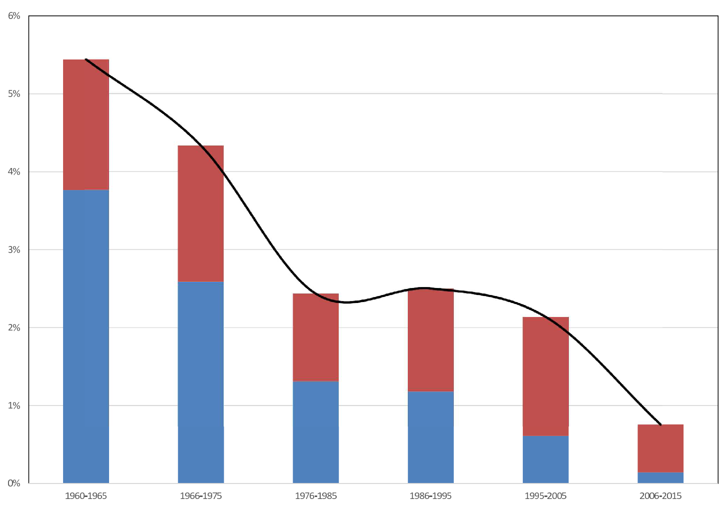

Figure 2: Euro area: TFP contribution to growth since 1965

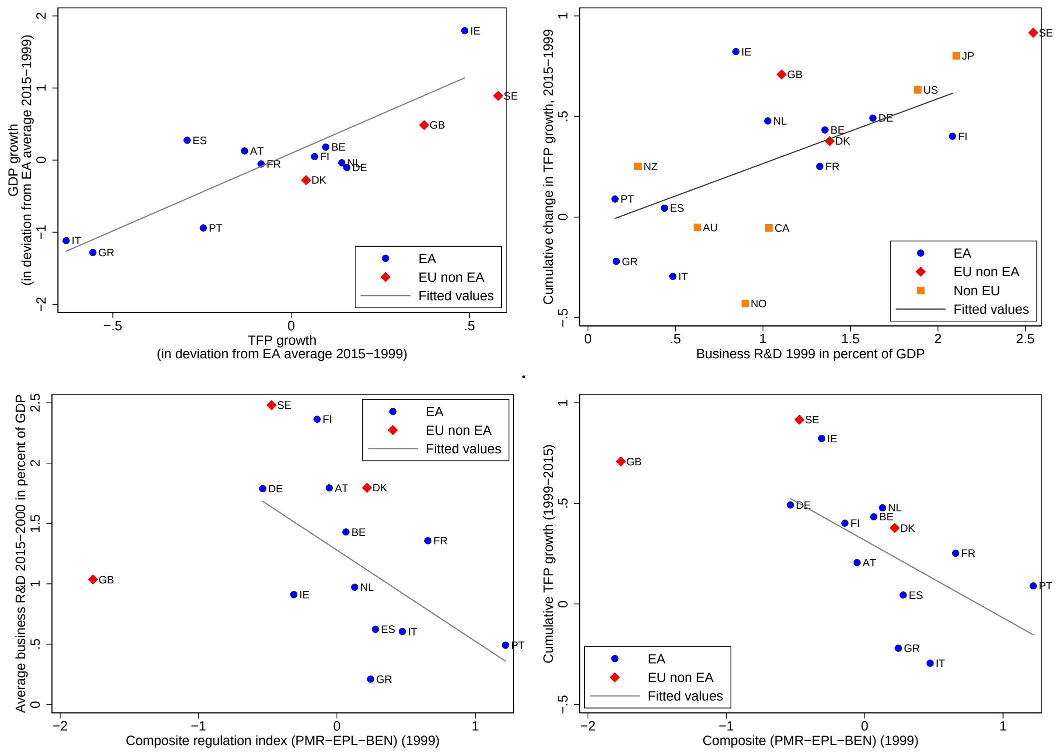

Figure 3: Long run relationships between TFP, regulation and growth

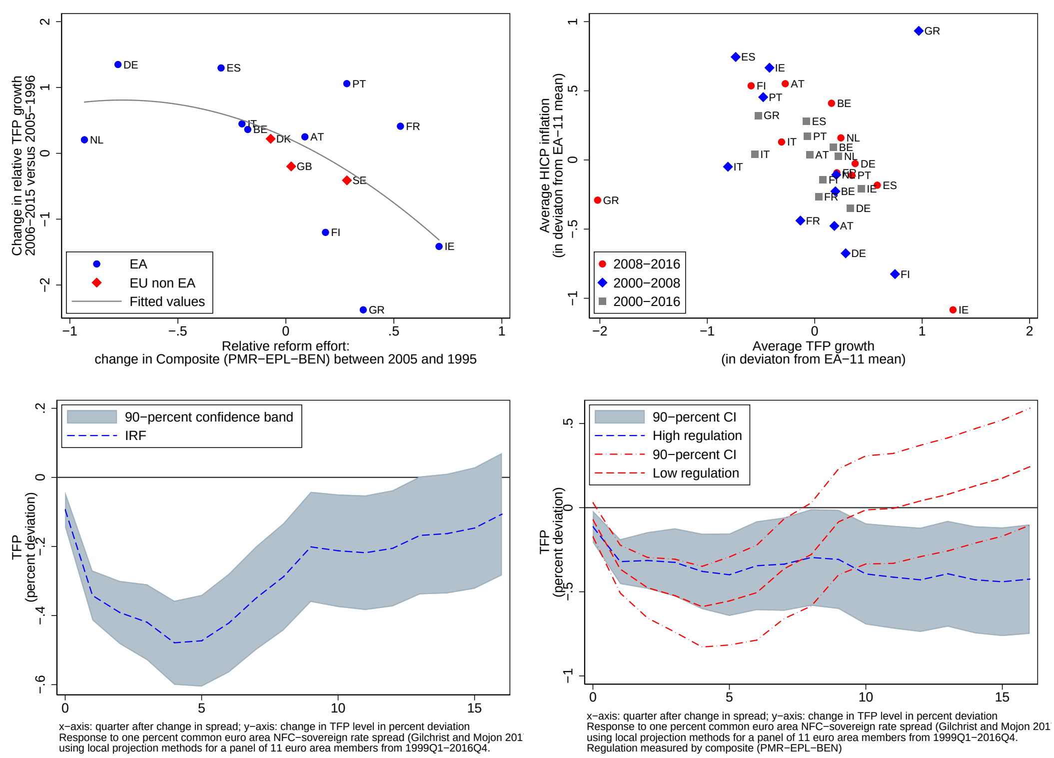

Figure 4: Short and medium term dynamics of TFP

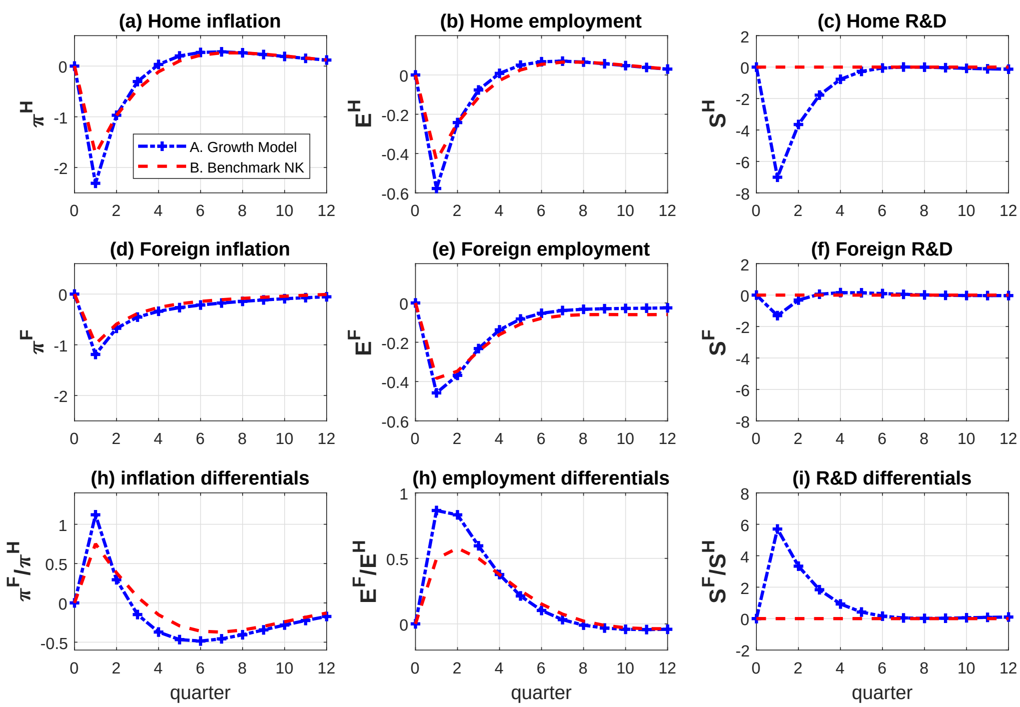

Figure 5: Home risk premium shock (+40 b.p.)

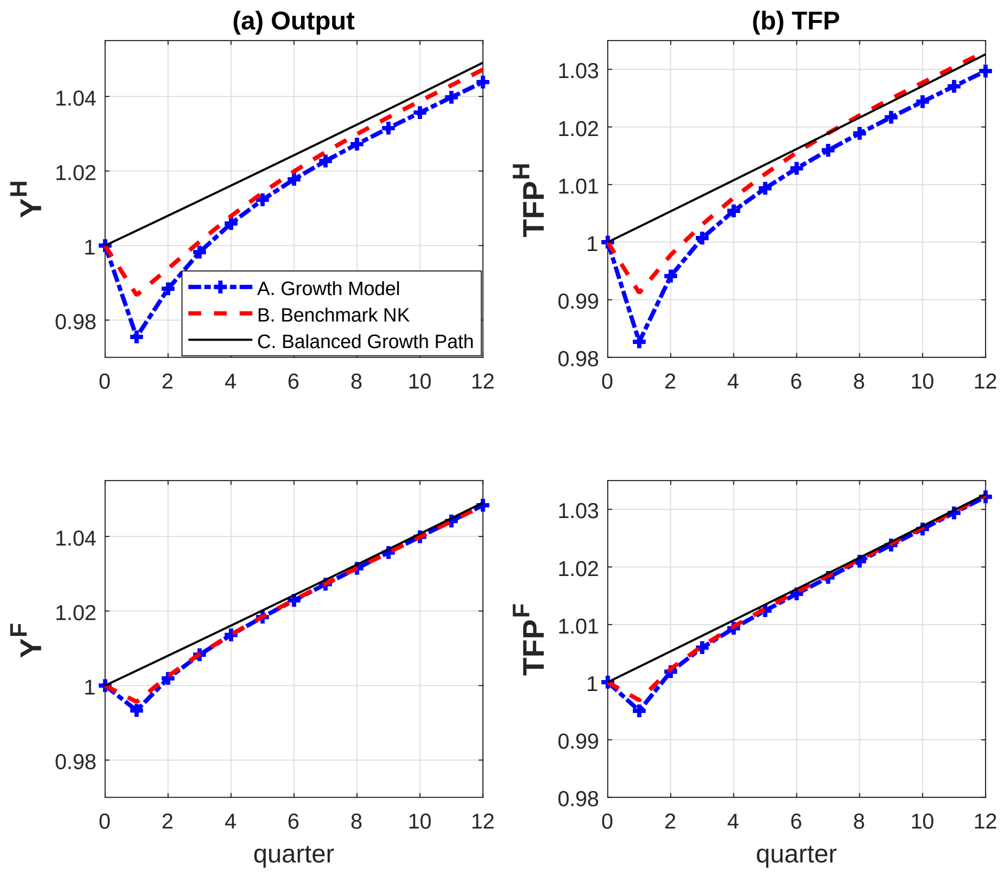

Figure 6: Home risk premium shock, output and TFP dynamics

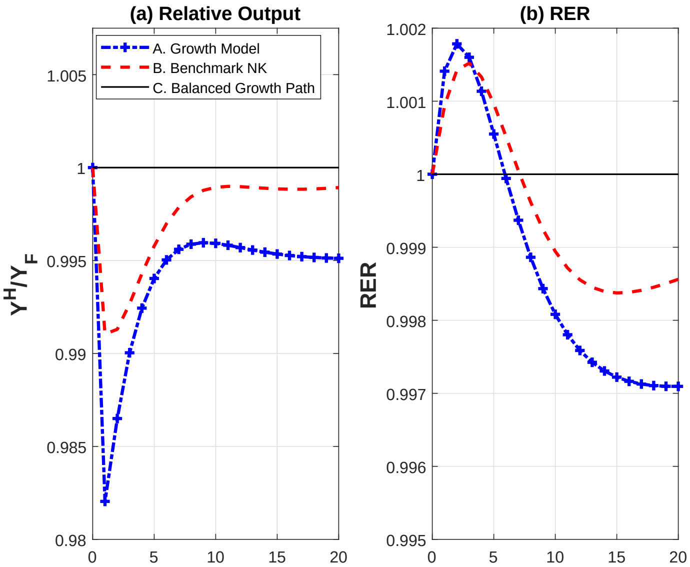

Figure 7: Home risk premium shock, output and real exchange rate

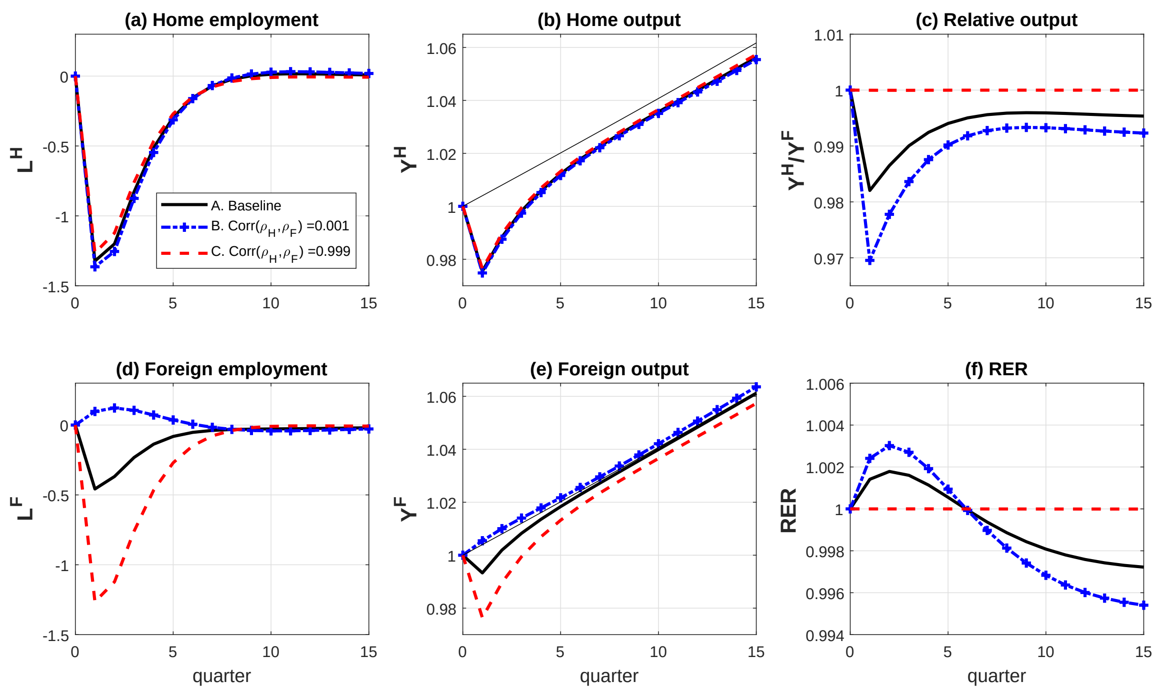

Figure 8: Risk premium spillovers and income divergence

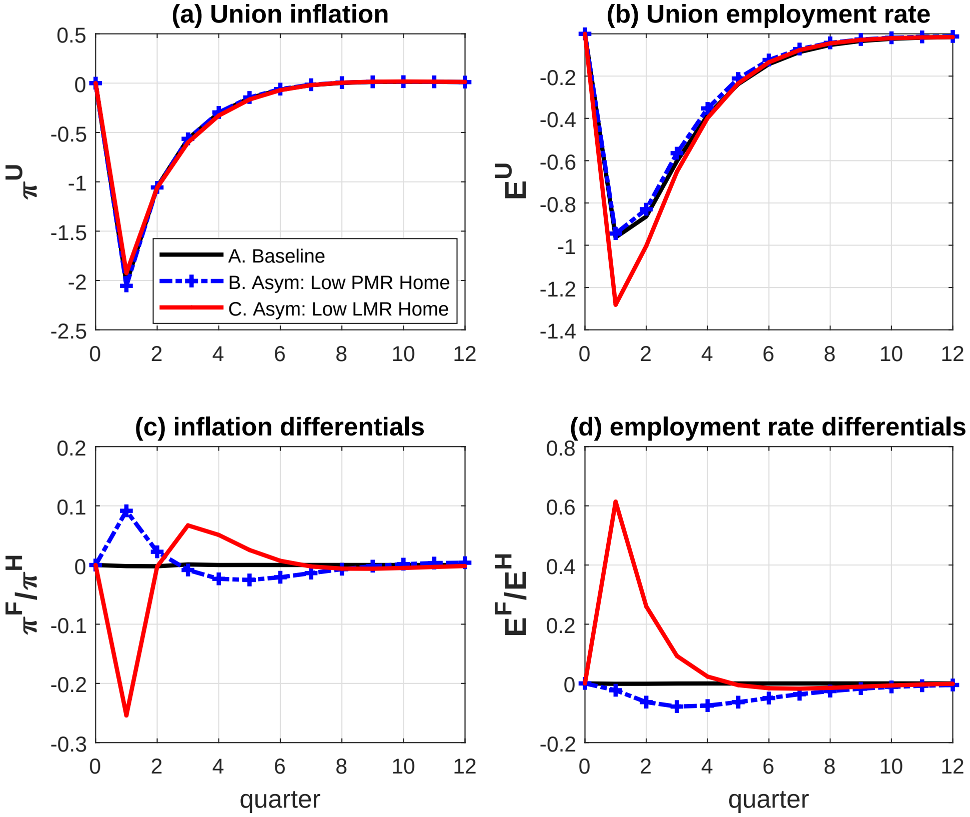

Figure 9: Monetary policy and labor and product market asymmetries

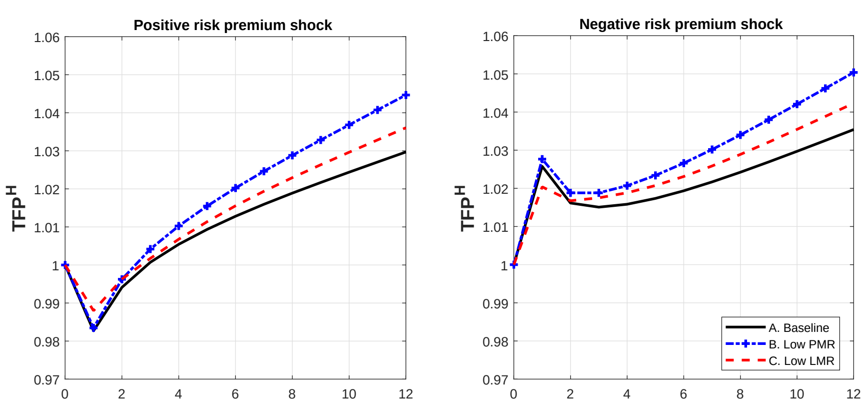

Figure 10: Institutions and risk premium shocks