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Output Divergence in Fixed Exchange Rate Regimes: Is the Euro Area Growing Apart?

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Tinbergen Institute Discussion Paper

Output Divergence in Fixed Exchange Rate Regimes: Is the Euro Area Growing Apart?

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Output Divergence in Fixed Exchange Rate Regimes: Is the Euro Area Growing Apart?*

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Abstract

Can fixed exchange rate regimes cause output divergence among member states? We show that such divergence is a long-run equilibrium characteristic of a two-region model with fixed exchange rates, heterogeneous labor markets, and endogenous growth. Under flexible exchange rates, monetary policy closes output gaps and realizes the associated maximum TFP growth in both regions. Upon fixing exchange rates, the region with higher structural wage inflation falls into a low-growth trap. When calibrated to the euro area, the model implies a slowdown in the TFP growth rate of the euro area's periphery relative to its core. An empirical analysis confirms that the periphery's higher structural wage inflation rate contributed to its lower TFP growth in the aftermath of joining the euro.

Keywords: exchange rate, growth, monetary policy

JEL Codes: E50, F31, O40

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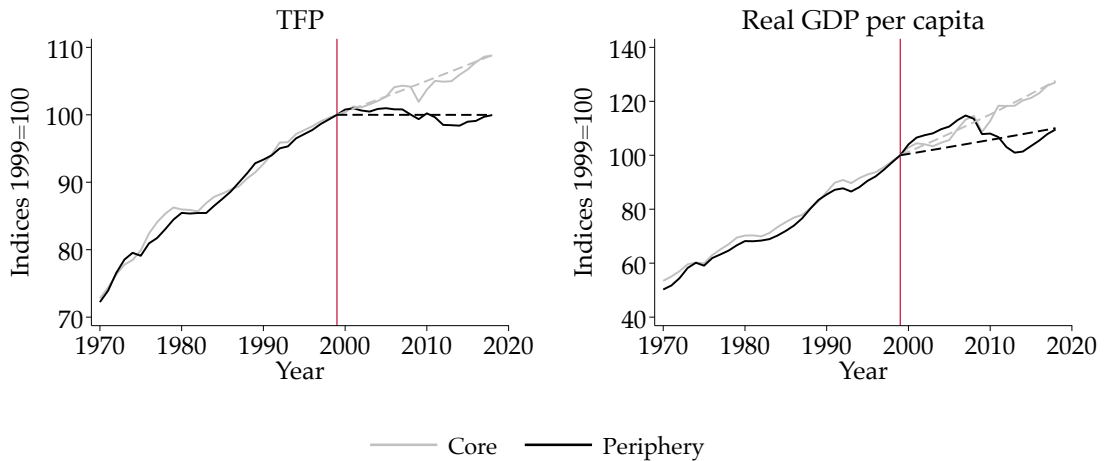
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1. INTRODUCTION

Can the exchange rate regime affect long-run output growth? The recent euro area experience calls for renewed attention to this question. Since the introduction of the euro, productivity and income levels among member states have diverged. Figure 1 illustrates the point by comparing the evolution of total factor productivity (TFP) and gross domestic product (GDP) per capita across the euro area’s core and its periphery. Prior to the euro’s introduction, core and periphery variables follow the same trend. Since then, growth paths have diverged. While the GDP divergence is commonly interpreted as a one-off and hopefully transitory consequence of the euro crisis, we argue that the more worrying scenario of a growth path divergence cannot be dismissed easily.

Figure 1: Divergence in the euro area



Notes: Solid line – actual data. Dash line – linear trend based on average growth rate 1999-2019. *Core* includes Germany and the Netherlands. *Periphery* includes Italy, Spain, Portugal, and Greece. Vertical bar – 1999. Both TFP and real GDP per capita series are population-weighted averages, indexed at 1999=100. TFP series are adjusted for factor-utilization.

The two-region environment whose properties we explore combines rigid wages, endogenous growth, and structural wage inflation differences across regions. In this setup, moving from flexible to fixed exchange rates can cause the two regions to embark upon diverging growth paths. This is because with endogenous growth, monetary policy is no longer neutral in the long-run. Through its effect on aggregate demand, monetary policy influences firms’ innovation activity and thus long-run productivity and output growth. Fixing the exchange rate, however, eliminates regional monetary policy autonomy, which

restricts the set of long-run equilibria that monetary policy can achieve.

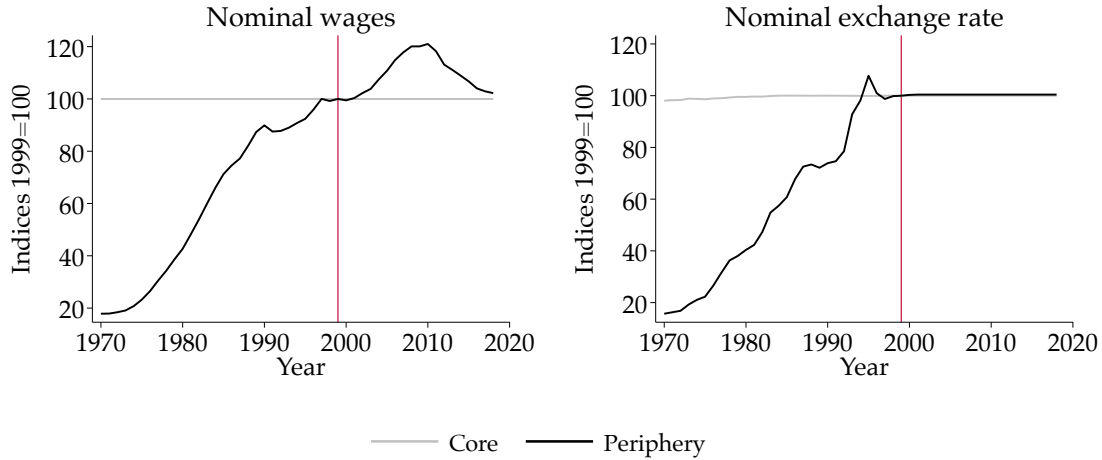
Under flexible exchange rates, a trending exchange rate offsets differences in wage inflation – a state that is characteristic of pre-euro Europe (see Figure 2). The trending exchange rate is a symptom of region-specific monetary policies that pursue full employment and maximum TFP growth in two regions whose wage inflation rates differ structurally. Upon fixing the exchange rate, wage inflation equalization requires internal devaluation, which due to wage rigidity increases the unemployment rate and through the endogenous growth channel gives rise to subpar TFP growth. In this way, fixing the exchange rate can push the region with the higher structural wage inflation into a low growth-trap.

Structural wage inflation differences naturally emerge from different degrees of downward nominal wage rigidity and macroeconomic volatility. The region with higher downward nominal wage rigidity or higher macroeconomic volatility requires a higher level of wage inflation to “grease the wheel” of the labor market. This suffices to give rise to diverging wage level growth paths under flexible exchange rates. After fixing the exchange rate, *actual* wage inflation rates are equalized across regions, whereas *structural* wage inflation rates remain different. Output and productivity divergence prevails for as long as this structural wage inflation difference exists.

In practice, several relevant factors limit the time horizon over which output is likely to diverge. First, prolonged output divergence is likely to provoke an offsetting policy response, such as labor market reforms that erode the structural wage inflation differential. Second, individuals can migrate from low-growth to high-growth regions differentially affecting labor supply across regions. With these caveats in mind, we argue using an open-economy endogenous growth model that a lengthy period of output and TFP divergence in the aftermath of fixing the exchange rate is a distinct possibility that can generate sizable welfare losses.

An empirical analysis using data from countries in the euro area confirms the model’s prediction: the periphery’s higher structural wage inflation rate contributed to its lower TFP growth in the aftermath of joining the euro. Ten years after fixing the exchange rate, a country with a structural wage inflation differential of +1% has a 2% lower TFP level. In a quantitative analysis, we furthermore calibrate the model to the euro area and compare the long-run equilibrium under flexible and fixed exchange rates. The model implies that, absent policies that stave off low-growth traps, euro area membership gives rise to output divergence. Under our baseline calibration, the introduction of the euro accounts for a 0.1 percentage point decline in the annual long-run GDP growth rate of the periphery as well as a level output drop of 3%. Over a 20 year horizon, this cumulates to a 5% GDP loss. Fixing the exchange rate also brings about a sizable welfare loss of around

Figure 2: Wage inflation differentials and exchange rate devaluation



Notes: Nominal exchange rates indexed to 1999=100. To facilitate the comparison between the evolution of nominal exchange rates and nominal wages, the core’s wages are normalized to 100 and periphery wages are expressed relative to that, again indexed to 1999=100. *Core* includes Germany and the Netherlands. *Periphery* includes Italy, Spain, Portugal, and Greece. Vertical bar – 1999. All underlying nominal wage and exchange rate series are population-weighted averages. Vertical line at 1999. Exchange rate series are expressed in price notation. An increase of the exchange rate reflects a depreciation.

2%. This welfare loss is born by the periphery and the core, because annual consumption growth decreases in both regions. Policies that foster labor market convergence alleviate the welfare cost. However, even when allowing for labor market convergence after two decades, the welfare costs of output divergence remain sizable.

The first contribution of this paper is to extend the theoretical implications of exchange rate regime choice from the short-run to the long-run. The existing literature focuses on the short run implications of exchange rate regime choice. Most prominently, optimal currency area theory (OCA), first developed by [Mundell \(1961\)](#), [McKinnon \(1963\)](#), and [Kenen \(1969\)](#), discusses the conditions under which exchange rates can be fixed without impairing a country’s ability to smooth business cycle fluctuations. Beyond the optimality conditions outlined by OCA, exchange rate regimes are often compared according to their ability to insulate an economy against various shocks. Proponents of flexible exchange rates have highlighted how the added nominal flexibility promotes an economy’s ability to absorb real shocks ([Friedman, 1953](#); [Poole, 1970](#)). Proponents of fixed exchange rates have emphasized positive effects on monetary discipline as well as the reduction in nominal shocks stemming from the elimination of speculation-driven exchange rate fluctuations ([Calvo, 2000](#); [Mundell, 2002](#)). While the focus of this literature is on the short-run, proponents of fixed exchange rates have also pointed to the long-run growth that can result from stable exchange rates promoting higher levels of international investment and

trade.

A vast empirical literature has examined the data for indications that the exchange rate regime has growth effects. While initial studies have produced mixed findings (Baxter and Stockman, 1989; Ghosh et al., 1996; Rolnick and Weber, 1997; Ghosh et al., 2003; Levy-Yeyati and Sturzenegger, 2003; Dubas et al., 2005; Husain et al., 2005), more recent research has revealed how the exchange rate interacts with country-specific frictions to affect economic growth. Focusing on financial frictions, Aghion et al. (2009) find that exchange rate fluctuations negatively affect economic growth in countries with low levels of financial development. The authors propose that firms' R&D investment becomes increasingly independent of exchange rate fluctuations as their access to credit improves. Here, we explore the interaction of the exchange rate regime with labor market frictions. In particular, we propose that fixing the exchange rate can give rise to a negative growth effect for countries whose labor markets are characterized by a relatively high structural wage inflation.

The second contribution of this paper is to extend the literature on long-run money non-neutrality to an open-economy setting. We build on the closed economy model by Benigno and Fornaro (2018), who show that in a New Keynesian (NK) model with endogenous growth monetary policy determines the long-run productivity growth rate. Garga and Singh (2021) study the related implication for optimal monetary policy. Also in a closed economy NK model with endogenous growth, Moran and Queralto (2018) show that monetary policy can induce medium-run movements in productivity. Recent empirical evidence in support of long-run money non-neutrality comes from Jordà et al. (2020) and Palma (2021) who make use of historical time series that span more than a century to trace the long-run effects of monetary shocks. We extend this empirical evidence to the open-economy setting by documenting that TFP growth declines upon fixing the exchange rate for countries with a high structural wage inflation rate.

The rest of the paper is structured as follows: section 2 illustrates the long-run growth impact of the exchange rate regime based on a simplified two-region growth model. Section 3 describes our empirical analysis and reports the evidence in support of the long-run non-neutrality of the exchange rate regime. After that, section 4 introduces a medium-sized dynamic general equilibrium (DGE) model that provides the micro-founded theoretical underpinning for the reduced-form model presented in section 2. The DGE model also serves as the framework for the quantitative application in section 5, where we calibrate the model to the euro area and discuss policy implications. Lastly, section 6 concludes.

2. A SIMPLE TWO-REGION GROWTH MODEL

This section introduces a reduced-form model that outlines how the exchange rate regime determines long-run TFP growth in an open-economy model with endogenous growth. The model features two regions with identical economic structures: H and F . TFP growth endogenously increases with regional economic activity, particularly the employment level. Employment, in turn, is influenced by local monetary policy. As the exchange rate regime determines the set of admissible monetary policies, it can affect long-run TFP growth.

The model is kept intentionally stylized. The simple model emphasizes the main mechanism, and is consistent with different assumptions regarding the micro-foundation of the growth process.^[1] For brevity, we describe only the H -region wherever this is possible without loss of clarity. The F -region is modeled analogously. F -variables are denoted with * or the letter F . x' denotes the next period's value of x . As we are interested in the exchange rate regime's long-run effects, we focus on the model's balanced growth path (BGP).

2.1. The simple model

On the demand side, we assume a standard Euler equation for the representative household:

$$1 = \frac{\beta R}{\Pi} \left(\frac{c'}{c} \right)^{-\sigma},$$

where $\beta \in (0, 1)$ is the time discount factor, and $\sigma > 0$ is the inverse of the elasticity of intertemporal consumption substitution. R denotes the risk-free nominal interest rate, Π the nominal CPI inflation rate, and c is a consumption bundle made of H -produced goods c^H and F -produced goods c^F such that

$$c = \frac{c_H^{1-\theta} c_F^\theta}{(1-\theta)^{1-\theta} \theta^\theta}. \tag{1}$$

$\theta \in (0, 1)$ reflects potential home bias in consumption.^[2] The H household's budget constraint is $P_H c_H + P_F c_F = O$, where p_H and p_F are prices for the H - and F -produced goods. O summarizes all components of household income and expenditure compo-

¹The reduced-form growth process we assume in the simplified model is consistent with, for example, Benigno and Fornaro (2018); Bianchi et al. (2019); Garga and Singh (2021). In section 4, we provide a DGE model based on the endogenous growth model developed in Aghion and Howitt (1992); Benigno and Fornaro (2018), and show that, in the steady state, the micro-founded model can be reduced to the simple model.

²This functional form implies that the elasticity of substitution between H - and F - produced goods equals 1, and thus helps to ensure that a balanced growth path exists.

nents other than spending on c^H and c^F . The H -CPI inflation is $\Pi = \Pi_H^\theta \Pi_F^{1-\theta}$, with $\Pi_H \equiv P'_H/P_H, \Pi_F \equiv P'_F/P_F$.

On the supply side, we assume that each country is inhabited by a representative firm. The H -firm produces with the following production technology:

$$y = Al, \quad (2)$$

where y is real output, A is the H -TFP level, and $l \in (0, 1]$ is the H -employment level.³ In the competitive goods market goods price inflation Π_H equals the growth rate of marginal costs, which is increasing in nominal wage growth Π_w and decreasing in TFP growth $g \equiv A'/A$:

$$\Pi_H = \frac{\Pi_w}{g}, \quad (3)$$

We assume that the nominal wage growth is increasing in the local employment level:

$$\Pi_w = \Pi_w(l), \quad \Pi'_w(l) > 0 \quad \& \quad \Pi_w(l = 1) = \check{\Pi}_w \quad (4)$$

The above equation is equivalent to a long-run non-vertical wage Phillips curve, in which wage inflation Π_w is decreasing in unemployment $(1 - l)$.⁴ Full employment in the model, $l = 1$, represents the maximum employment the central bank can achieve in the long-run.⁵ In the following we refer to the wage inflation at full employment, $\check{\Pi}_w$, as the *structural wage inflation*.

TFP evolves according to an endogenous growth process that depends on the local employment level:

$$g = \mathbb{G}(l), \quad \mathbb{G}'(l) > 0. \quad (5)$$

In particular, the TFP growth rate is increasing in l , which according to the production function is proportional to the size of the economy.⁶

³We assume that labor is not mobile.

⁴The assumption of a long-run downward sloping wage Phillips curve plays a crucial role in the discussion of the long-run effect of monetary policy. Absent the downward sloping long-run wage Phillips curve, we are back to a model with long-run money neutrality.

⁵Note that the unemployment in the model, $1 - l$, differs from the unemployment rate in the data. Compared to the unemployment in the model, the unemployment rate in the data also includes, for example, structural unemployment and frictional unemployment, which are beyond the influence of the monetary policy in the long run.

⁶In principle, TFP growth rate can also depends on the other country's TFP growth rate. We will discuss the interdependence between H and F 's TFP growth rate in section 4. Furthermore, endogenous growth models usually feature imperfect competition in goods market to generate positive profit, and investment into innovation is incentivized by the potential profit (see Benigno and Fornaro, 2018). In our reduced-form model, we simple postulate a positive relationship between TFP growth and aggregate

We close the model with an interest rate rule that describes monetary policy:

$$R = \begin{cases} \Upsilon l^\phi & \text{under flexible exchange rate} \\ \Upsilon_u (l^\tau l^{*1-\tau})^{\phi_u} & \text{under fixed exchange rate} \end{cases} \quad (6)$$

$$R^* = \begin{cases} \Upsilon^* l^* \phi^* & \text{under flexible exchange rate} \\ R & \text{under fixed exchange rate} \end{cases} \quad (7)$$

We assume that monetary policy aims to maximize the employment level. This also maximizes TFP growth, as TFP growth is increasing in the employment level.⁷ Under a flexible exchange rate, the H and F central banks choose the parameters Υ and Υ^* such that the nominal interest rate in steady state is consistent with full employment. When the economy is below full employment ($l, l^* < 1$), the central bank lowers the interest rate to stimulate the economy. $\phi, \phi^* > 0$ indicate the strength of the central bank's response to unemployment.

Under a fixed exchange rate, the H central bank sets the common monetary policy, which reacts to an average of the employment level across both regions, $l^\tau l^{*1-\tau}$. $\tau \in [0, 1]$ specifies the two regions' relative weight in the central bank's reaction function. The H central bank sets the parameter Υ_u to maximize the average employment level. The F central bank follows the H central bank by setting $R^* = R$ and thus maintains a fixed exchange rate.

2.2. The growth impact of the exchange rate regime

The household's budget constraint implies that on the BGP the nominal consumption expenditure for H - and F -produced goods grows at the same rate. It follows that the relative inflation of H - and F -produced goods equals the inverse of their relative consumption growth rate: $\frac{\Pi_H}{\Pi_F} = \frac{c'_F/c_F}{c'_H/c_H}$. With employment at steady state and goods market clearing, the relative consumption growth rate in turn equals the relative TFP growth rate: $\frac{c'_F/c_F}{c'_H/c_H} = \frac{g^*}{g}$. Thus, the relative price inflation equals the inverse of the relative TFP growth rate:

$$\frac{\Pi_H}{\Pi_F} = \frac{g^*}{g}$$

economy size. In the DGE model in section 4, we provide the micro-foundation for such a relationship, based on imperfect competition in the intermediate goods sector.

⁷Appendix C.3 discusses the optimality of this monetary policy.

Let Π_e denote the depreciation of the H currency vis-à-vis the F currency.⁸ The relative law of one price, $\Pi_H = \Pi_H^* \Pi_e$, implies the following relations:

$$\begin{aligned}\Pi_w &= \Pi_w^* \Pi_e, \\ \Pi &= \Pi_w / \bar{g}, \\ \Pi^* &= \Pi_w^* / \bar{g},\end{aligned}$$

with $\bar{g} \equiv g^\theta g^{*1-\theta} = c'/c = c^{*'} / c^*$ denoting the consumption growth rate.⁹

The model's steady state can then be summarized in a system of five equations that jointly determine the H - and F -TFP growth rates $\{g, g^*\}$, the employment levels $\{l, l^*\}$, and the depreciation rate Π_e :

$$1 = \beta \frac{\mathbb{R}(l)}{\mathbb{I}_w(l)} \bar{g}^{1-\sigma} \quad (8)$$

$$1 = \beta \frac{\mathbb{R}^*(l^*)}{\mathbb{I}_w^*(l^*)} \bar{g}^{1-\sigma} \quad (9)$$

$$g = \mathbb{G}(l) \quad (10)$$

$$g^* = \mathbb{G}^*(l^*) \quad (11)$$

$$\mathbb{I}_w(l) = \mathbb{I}_w^*(l^*) \Pi_e \quad (12)$$

How does the exchange rate regime affect long-run TFP growth? Under flexible exchange rates, central banks in H and F can freely set the parameters Υ and Υ^* in their interest rate rules. These two free parameters supply enough degrees of freedom to enable central banks to achieve full employment while satisfying (8) and (9). As TFP growth increases in employment, full-employment monetary policies also maximize the TFP growth rates in both regions. Any wage inflation differential that opens up as a consequence of the H and F central banks' independent monetary policy-making is then compensated for by nominal exchange rate growth Π_e , which establishes (12).

Under a fixed exchange rate regime, H - and F - monetary policies are no longer independent. Whether full employment in both H and F is feasible depends on the economic structure of the two regions. If both regions are perfectly symmetric, then the monetary policy that leads to full employment in one region coincides with the monetary policy necessary for full employment in the other region. In this case, a common monetary policy is consistent with full employment and maximum TFP growth in both regions. If the two regions are asymmetric, however, then the additional constraint imposed on

⁸The exchange rate is expressed in price notation from H 's perspective. Thus, $\Pi_e > 1$ reflects a depreciation of the H -currency.

⁹To derive these equations, we use (3) and the F -corresponding equation, as well as the definition of CPI inflation.

monetary policy by the fixed exchange rate may render full employment in both regions unachievable.

The most significant source of regional asymmetry in the model are labor markets. To illustrate how labor market heterogeneity can give rise to diverging TFP paths under fixed exchange rates, consider the long-run Phillips curve $\Pi_w(l) = \check{\Pi}_w - \mu(1 - l)$, where $\mu > 0$ reflects the sensitivity of wage inflation with respect to unemployment. For $\Pi_e = 1$, the H - and F -unemployment levels are linked according to

$$1 - l^* = \frac{\check{\Pi}_w^* - \check{\Pi}_w}{\mu^*} + \frac{\mu}{\mu^*}(1 - l), \quad (13)$$

reflecting the constraint that the fixed exchange rate imposes on the set of achievable H - and F - employment combinations. Since (13) implies a positive relationship between l and l^* , the maximum average employment level across both regions is achieved when one or both employment levels reach the full employment level of 1. For example, if F has a higher structural wage inflation rate than H ($\check{\Pi}_w^* > \check{\Pi}_w$), then the maximum attainable employment across both regions for any $\tau \in [0, 1]$ satisfies $l = 1 > l^*$ ¹⁰. Consequently, F experiences persistent unemployment and subpar TFP growth – a low-growth trap. F 's involuntary unemployment increases with the structural wage inflation differential ($\check{\Pi}_w^* - \check{\Pi}_w$) and decreases with the sensitivity of wages inflation with respect to unemployment (μ^*).

2.3. Model discussion

How applicable are these theoretical results? To answer this question, we discuss the model's key underlying assumptions. Three model ingredients combine to generate the result that fixing the exchange rate can give rise to differential TFP growth rates in steady state:

1. The two regions' nominal wage inflation rates are linked through (12).
2. The long-run Phillips curve is non-vertical, i.e. there exists a long-run tradeoff between wage inflation and employment.
3. Structural wage inflation rates can differ across regions.

The following discusses each of these in turn.

The linkage of nominal wage inflation rates through (12) rests on three model as-

¹⁰For employment maximizing central banks the steady state is the same for any $\tau \in [0, 1]$. While the exact value of τ therefore does not matter for the steady state, it does affect the transition path between steady states.

assumptions:¹¹ (i) the two economies are on a BGP; (ii) goods price inflation Π_H, Π_F , wage inflation $\Pi_w(l), \Pi_w^*(l^*)$, and TFP growth rates g, g^* are linked through the production function (2); (iii) the relative law of one price holds, or in other words; the relative prices are stationary as documented in Crucini and Shintani (2008).¹²

A long-run tradeoff between wage inflation and employment has been theoretically derived in environments with downward nominal wage rigidity: if nominal wages cannot be sufficiently adjusted downward, then a higher steady state wage inflation rate can help to “grease” the wheels of the labor market and reduce involuntary unemployment by allowing firms to achieve real wage reductions without cutting nominal wages (Akerlof et al., 1996; Benigno and Ricci, 2011). The widely documented prevalence of downward nominal wage rigidity in developed countries indicates the theory’s applicability (Dickens et al., 2007; Holden and Wulfsberg, 2008; Babecký et al., 2010). Recent findings by Barnichon and Mesters (2021), based on instrumental variable regressions and controlling for inflation expectations, support the notion of a finite long-run tradeoff between the unemployment rate and inflation.

The literature proposes two origins for cross-country heterogeneity in structural wage inflation rates: cross-country differences in the *degree of downward nominal wage rigidity* and *firm revenue volatility*. (i) For high degrees of *downward nominal wage rigidity* fewer wages are cut, and a larger fraction of firms pays wages above the efficient level, resulting in a higher unemployment level (see Akerlof et al., 1996; Abbritti et al., 2021). It is important to note that the degree of downward nominal wage rigidity not only determines the sensitivity of wage inflation with respect to the unemployment level, but it also determines the level of wage inflation that sustains a given level of unemployment. This includes the structural wage inflation rate that sustains full employment, with higher degrees of downward nominal wage rigidity being associated with higher structural wage inflation rates. Empirical studies document substantial differences in the degree of downward nominal wage rigidity across countries. For the euro area, Holden and Wulfsberg (2008) and Babecký et al. (2010) find that the degree of nominal wage rigidity differ substantially across countries. The observed differences in downward wage rigidity are often attributed to differences in labor market institutions. More centralized wage bargaining processes, a broader coverage of union contracts and permanent contracts, and stricter

¹¹Adding non-tradable goods to the model does not change the factor price equalization result. Interestingly, the factor price equalization does not rely on international capital being mobile but is a result purely of international goods trade. Capital mobility and the resulting UIP do not appear in the four equations that pin down the BGP. However, the degree of capital mobility influences the equilibrium through its role on limiting the set of parameter choices that is consistent with a BGP. In our model, we need to assume that H - and F -households aggregate their consumption of regional goods as described in (1) to ensure UIP.

¹²Crucini and Shintani (2008) find that the median level of persistence in law of one price deviations is low with a half-life of about 1.5 year for OECD cities.

employment protection legislation have all been argued to contribute to nominal wage rigidity.¹³ With respect to these institutional factors, euro area member states exhibit a considerable degree of heterogeneity.¹⁴

(ii) A second origin of cross-country differences in structural wage inflation are *differences in the volatility of firm revenues*. The intuition is straightforward: the larger the revenue volatility a firm faces, the higher the probability that the downward wage rigidity constraint binds. At the aggregate level, the higher revenue volatility gives rise to higher long-run unemployment for given degrees of wage rigidity and for given long-run wage inflation levels (Benigno and Ricci, 2011).¹⁵

3. EMPIRICAL ANALYSIS

The world's largest fixed exchange rate project since the collapse of the Bretton Woods system in the early 1970s was the creation of the euro area. The persistence of this project allows for an analysis of the long-run growth effects of fixing the exchange rate. To which extent are the model's theoretical predictions born out by the euro area's experience? Did countries with relatively high structural wage inflation experience slower output growth after adopting the euro?¹⁶

¹³On the theory side, Lindbeck and Snower (1989) show that downward nominal wage rigidity is more severe, the more prevalent permanent contracts are. Shister (1943), Dunlop et al. (1944), and Oswald (1986) show that the centralization of wage bargaining and a broader coverage of union contracts tend to increase wage rigidity. Empirically, Babecký et al. (2010) find that permanent contracts and employment protection are positively associated with the degree of downward nominal wage rigidity. The evidence regarding the role of collective bargaining institutions and labor unions is mixed. Holden and Wulfsberg (2008) find that higher union density is associated with more downward rigidity for real and nominal wages. By contrast, Dickens et al. (2007) and Babecký et al. (2010) only find a positive relationship between union coverage and downward rigidity for real wages, not for nominal wages.

¹⁴For a detailed discussion of labor market heterogeneity among euro area member states see Deutsche Bundesbank (2016). Nickell (1997) documents substantial labor market heterogeneity among European countries prior to the introduction of the euro.

¹⁵The exchange rate regime itself potentially affects the economy's volatility, and thus the structural wage inflation rate. The exchange rate regime's effect on the economy's volatility has long been discussed in the literature (see Friedman, 1953; Baxter and Stockman, 1989; Duarte and Obstfeld, 2008). On the one hand, switching to a less flexible exchange rate regime can reduce the volatility that originates from nominal shocks, such as shocks to the nominal exchange rate and interest rates. On the other hand, a less flexible exchange rate regime can reduce an economy's ability to absorb real shocks and thus potentially increase volatility. See Aghion et al. (2009) for a model with both nominal and real shocks, in which exchange rate regimes is associated with higher productivity growth depends on the relative sizes of the nominal vs. the real shock.

¹⁶Up to 1999, the European Monetary System (EMS) still allowed for exchange rate fluctuations among member states within a +/-2.25% band. Some currencies were allowed to fluctuate within a wider band of 6%, such as the currencies of Italy, Portugal, and Spain. In practice, nominal exchange rate adjustments could occasionally exceed predefined bands (e.g. Italy, 1973), and during the European currency crises of the early 1990s exchange rates were allowed to fluctuate within a wider +/-15% band. Two years before the introduction of the euro in 1999 euro area member states nominal exchange rate fluctuations began to stabilize as required by the Maastricht Treaty's convergence criteria. With the introduction of the

We quantify relative structural wage inflation rate as a country’s pre-peg nominal wage inflation relative to that in the base country. In particular, we calculate a 15-year backward looking moving average nominal wage inflation trend as compared to the trend in the base country.¹⁷ As we are focusing on the entry to the euro area, Germany is set as the base for all countries during the sample.

Figure 3 compares the economic experience of euro area members with high and low structural wage inflation rates in the 20 years before and after joining the euro.¹⁸ Countries with low structural wage inflation rates – Austria, Belgium, Finland, France, Germany, Luxembourg, Ireland, and the Netherlands – experience no major trend break upon fixing their exchange rate. By contrast, countries with higher structural wage inflation rates – Cyprus, Italy, Greece, Malta, Portugal, Spain, Slovak Republic, and Slovenia – grow markedly differently after fixing the exchange rate than before: the nominal convergence in exchange rates, wage growth, and nominal interest rates was accompanied by a slowdown in the trend growth rates of TFP and real GDP per capita.¹⁹ While the GDP path also allows for a cyclical interpretation according to which high wage inflation countries experienced severe recessions during the euro area debt crisis around 2010, the clear trend-break in TFP growth highlights the more worrying possibility of a trend break in GDP growth being obscured by a marked boom-bust cycle. The unemployment rate data harbors the same ambiguity as the GDP data. Overall, however, the euro area data are broadly consistent with the model’s prediction that the nominal convergence brought about by fixing the exchange rate is accompanied by an episode of real divergence.

3.1. Data and methodology

To empirically test the model prediction, we conduct regressions in which relative structural inflation is interacted with exchange rate regime on annual data from 1970 to 2019 for countries that joined the euro area.²⁰ In the following, we first describe the methodology and the variables used, then discuss our empirical findings.²¹

euro in 1999 nominal exchange rates became irrevocably fixed.

¹⁷We use the HP-filter with smoothing parameter λ set to 6.25 for detrending. We use the average trend growth rate rather than the raw data’s average growth rate because the latter gives considerable weight to large single year fluctuations that reflect large shocks rather than structural inflation. Whenever a 15-year window contains missing values, we separately apply the HP-filter to each spell of data that contains at least five consecutive observations.

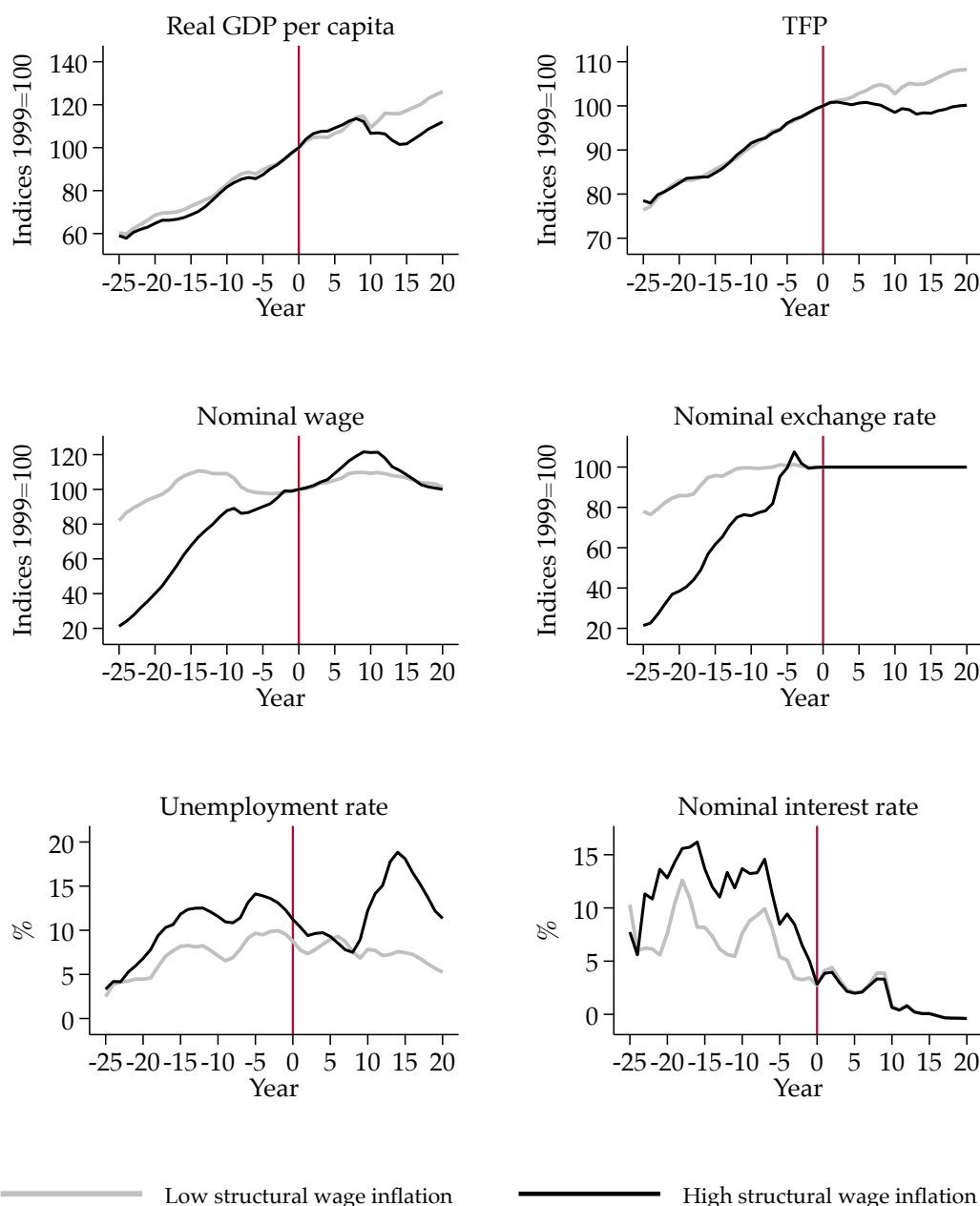
¹⁸For Figure 3, countries are classified as having high structural wage inflation rates if their structural inflation measured using nominal wage inflation are above the median of all countries. Using mean instead of median, or using structural inflation based on nominal depreciation rates slightly changes the classification but gives a similar result.

¹⁹Appendix B.2 shows the GDP per capita and TFP time series for individual countries.

²⁰Among developed countries there are few cases of currencies switching from float to fixed and sustaining the peg during our sample period. We focus on the euro area countries due to data availability.

²¹See Appendix A for the list of countries included in our sample.

Figure 3: Different trend before and after joining the euro



Notes: Low structural wage inflation countries: Austria, Belgium, Finland, France, Germany, Luxembourg, Ireland, and The Netherlands. High structural wage inflation countries: Cyprus, Italy, Greece, Malta, Portugal, Spain, Slovak Republic, and Slovenia. All series are population-weighted averages. Nominal wages and nominal exchange rates are expressed relative to Germany. The event window is based on data over the 1970-2019 period. Year 0 represents the date when a country adopted the euro. Appendix [A](#) provides a detailed description of the data.

Our empirical approach relies on the local projection method ([Jordà, 2005](#)). In particular, we use an annual panel data set to estimate cumulative impulse response functions

based on the following equation:

$$z_{i,t+h} - z_{i,t-1} = \alpha_{i,h} + \gamma_{t,h} + (e_{i,t} * s_{i,t})\beta_h + \mathbf{x}_{i,t}\boldsymbol{\lambda}_h + u_{i,t+h}, \quad (14)$$

for $h = 0, 1, \dots, H; i = 1, \dots, N; t = t_0, \dots, T$. $z_{i,t+h}$ is the outcome variable of interest for country i , h years from period t . We examine four productivity measures: log utilization-adjusted TFP, log labor productivity, log cumulative per capita patent applications, and log cumulative per capita real R&D spending.²² $\alpha_{i,h}$ refers to country fixed effects for each horizon h , and $\gamma_{t,h}$ is the time fixed effect for each horizon h . $\mathbf{x}_{i,t}$ is a vector of control variables, and $u_{i,t+h}$ is a country- and horizon-specific error term. The coefficients of interest are $\{\beta_h\}_{h=0}^H$, which accompany the interaction term between the exchange rate regime and the relative structural inflation rate, $(e_{i,t} * s_{i,t})$. More concretely, $e_{i,t}$ is a dummy variable that indicates an exchange rate regime change. As we are interested in the long-run effect of fixing the exchange rate, we set $e_{i,t}$ to 1 if country i switches from non-peg to peg in period t and stays a peg for the next H years. $e_{i,t}$ is set to 0 if there is no change of the exchange rate regime for the next H years. $s_{i,t}$ measures the structural wage inflation of country i relative to its base country. A significantly negative estimate for β_h indicates that the higher the structural wage inflation relative to the base country, the lower a country’s productivity h years after fixing the exchange rate. We set $H = 10$.

As before, we measure the relative structural inflation rate as a country’s pre-peg nominal wage inflation compared to the base country. More concretely, we use the 15-year backward looking moving average growth rate of the trend growth rate of nominal wage relative to that in Germany. We consider the currency peg to begin in the year in which a country becomes classified as “no separate legal tender” or “pre announced peg or currency board arrangement” in the exchange rate regime classification system of Ilzetzki et al. (2019). In the context of the euro area this implies that countries move from non-peg to peg status upon introducing the euro.²³

Our choice of controls follows that of closely related studies (Aghion et al., 2009; Jordà et al., 2020). In particular, $\mathbf{x}_{i,t}$ includes log productivity growth measures, log real GDP per capita in USD, log real consumption per capita, log real investment per capita, log domestic private credit to GDP ratio, log trade to GDP ratio, log government consumption to GDP ratio, CPI inflation, log real GDP per capita growth rate in local currency, log schooling, relative structural inflation, a dummy that captures peg to float transitions,

²²We adjusted the TFP series with capital and labor utilization following the procedure outlined in Imbs (1999). For details on the adjustment procedure, see Appendix A.1. A regression with non-adjusted TFP as the dependent variable give similar results, see Appendix B.3.3.

²³This exchange regime classification implies that pre-euro countries whose exchange rates could appreciate and depreciate by between 2.25% and 15% per year (depending on country and time period) according to the bands set within the European Monetary System (EMS) are treated as non-pegs.

and an interaction term between the domestic private credit to GDP ratio and $e_{i,t}$. In addition to the control variables used in [Aghion et al. \(2009\)](#) and [Jordà et al. \(2020\)](#), we include the log service sector share of GDP to account for slower TFP growth in the service sector ([Mano et al., 2015](#)). As the baseline model is already saturated and most of the control variables are slow moving, we include only the contemporaneous values, except for log productivity growth rate, log real GDP per capita growth rate in local currency, and log CPI inflation. For the last two variables, we include both the contemporaneous values and two lags to account for fluctuations at the business cycle frequency. For the log productivity growth rate, we do not include the contemporaneous value, as it is part of the outcome of interest.

Appendix [A](#) provides a detailed description of the definitions and the sources of all variables.

3.2. Results

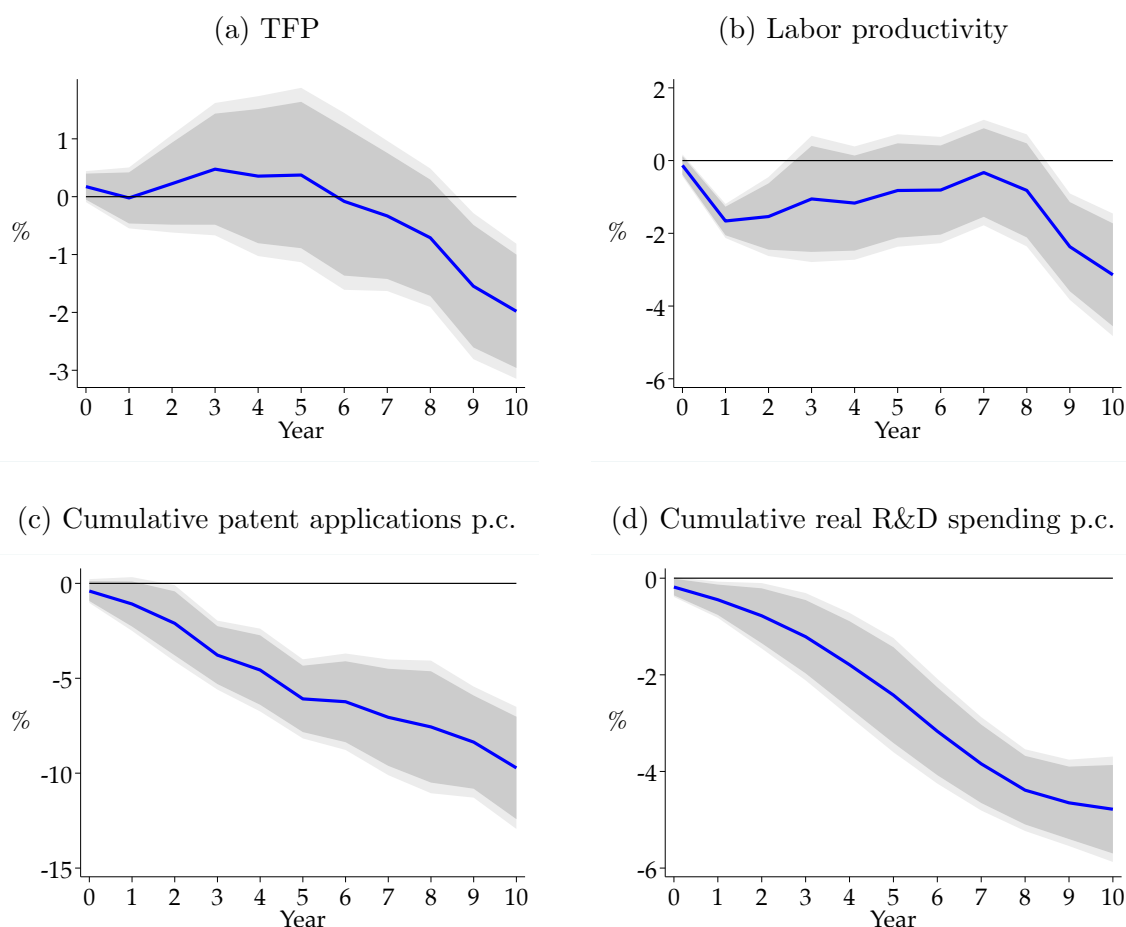
Does fixing the exchange rate result in lower TFP growth for countries with high structural inflation? Figure [4a](#) displays the answer provided by our cumulative IRF estimate $\{\beta_h\}_{h=0}^{10}$. The point estimates are negative and trending downwards. Ten years after fixing the exchange rate, a country with a structural wage inflation differential of +1% has an almost 2% lower TFP level. Figure [4b](#) confirms that productivity growth in high inflation regions suffers in the aftermath of fixing the exchange rate based on labor productivity data. Figure [4c](#) and [4d](#) show that a similar pattern can be observed in cumulative per capita patent applications as well as cumulative per capita real R&D spending: countries with a higher structural wage inflation have a lower level of inventive activity after joining a peg.

To see whether our finding is robust to the measurement of relative structural inflation, we repeat the analysis with relative structural inflation measured with depreciation rates (Appendix [B.3.1](#)). The depreciation rate is a suitable proxy for relative structural inflation, because a country with a relatively high structural wage inflation should see its currency depreciate under flexible exchange rates according to the model.^{[24](#)} Similar to our baseline results, we find regions with higher depreciation rates grew slower in the aftermath of pegging, both in terms of TFP, labor productivity, patent applications, and R&D spending.^{[25](#)}

²⁴A third measurement of relative structural wage inflation can be derived from the pre-peg long-run CPI inflation differential vis-à-vis the base country. The results are similar, see Appendix [B.3.4](#).

²⁵The TFP data is from the AMECO database of the European Commission. For both measurement of relative structural inflation, unadjusted TFP data from AMECO and factor-utilization-adjusted TFP data from the Penn World Table yields a similar result. See, Appendix [B.3.3](#).

Figure 4: Effect of pegging with a nominal wage inflation differential of 1%



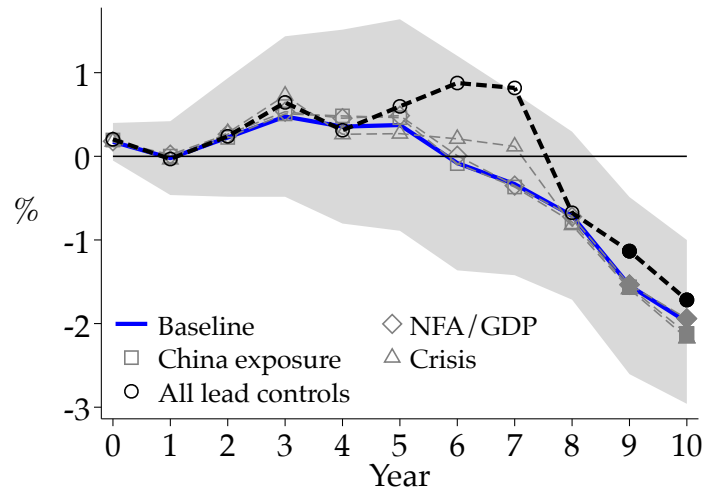
Notes: Blue solid line – mean estimate. Dark shaded area – 90% confidence interval. Light shaded area – 95% confidence interval.

There exist alternative mechanisms that might be behind our empirical finding. First, a country with a higher inflation under a float may attract more capital inflows after becoming pegged (Aguiar et al., 2014). The attracted capital flow, especially when it meets with a less developed financial sector, can lead to capital misallocation and thus negatively affect productivity growth (Gopinath et al., 2017). Second, the divergence of TFP growth may be due to the different exposure to competition from China. Bloom et al. (2016) and Dorn et al. (2020) document that Chinese import competition in the aftermath of China’s 2001 WTO accession affected TFP growth in advanced economies. We examine the role of these alternative channels by including leads of the net foreign asset (NFA) to GDP ratio, or the measures of exposure to China in the vector of control variables, thereby purging the coefficient estimates of effects that are mediated through these variables.²⁶ Furthermore, to see to which extent the euro area debt crisis drives

²⁶In particular, to control for effect of the capital inflows, we include cumulative changes of net-foreign-

the productivity findings, we also control for leads of the financial crisis dummy.²⁷ As shown in Figure 5, the baseline result remains robust to the inclusion of these controls.²⁸ Thus, the negative relationship between fixing the exchange rate, relative structural wage inflation and TFP growth that we estimate is not driven by these alternative channels.

Figure 5: TFP effect of pegging with a nominal wage inflation differential of 1%, including lead controls



Notes: blue solid line – mean baseline estimate. Shaded area – 90% confidence interval of the mean baseline estimate. Dash line with markers – mean estimate when lead controls are included. Solid markers – significance at the 10% level. Hollow markers – no significance at the 10% level.

4. A TWO-REGION ENDOGENOUS GROWTH MODEL

In this section, we continue the analysis with a medium-sized DGE model. The DGE model serves two purposes: First, it provides the micro-foundation for the reduced-form model from section 2. Second, by including various extensions, the DGE model offers a more realistic framework for the quantitative analysis in section 5 and the policy discussion in section 5.3.

position to GDP ratio between $t - 1$ and $t + h$ as a lead control. To account for the different exposure to competition from China, we include cumulative changes of the share of Chinese goods imports in total goods imports between $t - 1$ and $t + h$ as a lead control.

²⁷The financial crisis dummy is set to 0 if the country is not in a crisis in $t + h$ and equals the number of years since the start of the crisis if the country is in a crisis in $t + h$. By using utilization-adjusted TFP, our baseline result is also less sensitive to the impact of economic crises during the regression horizon. As the adjusted TFP already accounts for the crisis triggered drop in factor utilization, it is less cyclical than the unadjusted TFP series.

²⁸Our baseline results regarding the real R&D spendings and patent applications are also robust to the inclusion of the lead controls. See Appendix B.3.2

4.1. Model environment

The model is a two-region extension of the closed economy Keynesian growth model developed in [Benigno and Fornaro \(2018\)](#). There are two regions, H and F , each containing households, final goods producers, and intermediate goods producers. The two regions trade in final goods and one-period risk-free bonds. The endogenous growth process is driven by intermediate firms' investment into innovation. The higher the expected profit, the larger the investment into innovation and thus the higher the TFP-growth rate. Monetary policy influences the expected profit through its effect on aggregate demand. Thus, as in the simple model, monetary policy is non-neutral in the long-run, and the exchange rate regime can affect the long-run TFP growth rate.

Households

Time is discrete and infinite. Households consume H - and F - produced final goods and inelastically supply one unit of labor l . Households optimize over their expected discounted lifetime utility:

$$\mathbb{E}_0 \sum_t \left\{ \beta^t \frac{c_t^{1-\sigma} - 1}{1-\sigma} \right\}. \quad (15)$$

$\beta \in (0, 1)$ is the time discount factor, and $u(\cdot)$ is the period utility function: $\sigma > 0$ is the inverse of the elasticity of intertemporal consumption substitutions and c_t is a composite consumption good consisting of H - produced final goods $c_{H,t}$ and imported F - produced final goods $c_{F,t}$, defined as in the simple model: $c_t = \frac{c_{H,t}^{1-\theta} c_{F,t}^\theta}{(1-\theta)^{1-\theta} \theta^\theta}$. The corresponding H consumer price is $P_t = P_{H,t}^{1-\theta} P_{F,t}^\theta$. Households face the following period budget constraint:

$$P_t c_t + \frac{B_{H,t}}{R_t} + \frac{B_{F,t} e_t}{R_t^*} + Adj_t = (1 - u_t) W_t l_t + B_{H,t-1} + B_{F,t-1} e_t + D_t + T_t. \quad (16)$$

$B_{H,t}$ and $B_{F,t}$ are nominal one-period risk-free bonds that are issued in H - and F currency, respectively. The H -bond pays a gross interest rate R_t and the F -bond pays gross interest rate R_t^* . e_t is the nominal exchange rate between the H - and F -currency, expressed in price notation from H 's perspective.²⁹ Investing in foreign currency denominated bonds is subject to a quadratic adjustment cost $Adj_t = \frac{\bar{A}_t P_t^* e_t}{R_t^*} \frac{K}{2} \left(\frac{B_{F,t}}{A_t P_t^*} - o \right)^2$, where \bar{A}_t is the average productivity of H and F and $K > 0$ is the adjustment cost parameter.³⁰ The adjustment costs are rebated back to households in a lump-sum fashion.

²⁹ e denotes the amount of H -currency that can be obtained for one unit of F -currency. Thus, an increase in e reflects an H -currency depreciation.

³⁰This functional form helps to ensure that a balanced growth path exists.

Labor is immobile. W_t is the nominal wage, and l_t is hours worked. The model features uninsurable unemployment risk for a better match with the data.³¹ At the beginning of each period, with an exogenous probability ι , households may be hit by an uninsurable, idiosyncratic employment shock and become unemployed ($l = 0$) for one period. In case of unemployment, the household receives an unemployment benefit equaling a fraction $\zeta \in (0, 1)$ of the labor income of employed households. Unemployment households have no access to borrowing. $u_t = 1$ indicates that the household is unemployed, and $u_t = 0$ if employed.

Besides labor income, the households also receive D_t , a lump-sum transfer that includes the profits earned by firms and rebated adjustment costs. T_t is a tax for employed households and an unemployment benefit for unemployed households. The tax on employed households is levied to finance unemployment benefits.

The following equations describe the households' consumption and investment decisions:

$$c_t^{-\sigma} = \beta \rho R_t \mathbb{E}_t \frac{c_{t+1}^{-\sigma}}{\Pi_{t+1}} \quad (17)$$

$$c_t^{-\sigma} = \beta \rho R_t^* \frac{1}{1 + K \left(\frac{B_{F,t}}{P_t A_t} - o \right)} \mathbb{E}_t \frac{c_{t+1}^{-\sigma} e_{t+1}}{\Pi_{t+1} e_t} \quad (18)$$

$$c_{H,t} = (1 - \theta) \left(\frac{P_{H,t}}{P_t} \right)^{-1} c_t \quad (19)$$

$$c_{F,t} = \theta \left(\frac{P_{F,t}}{P_t} \right)^{-1} c_t \quad (20)$$

where $\rho = 1 - \iota + \iota/\zeta^\sigma > 1$. A version of the uncovered interest rate parity (UIP) follows immediately from (17) and (18):

$$R_t = R_t^* \frac{1}{1 + K \left(\frac{B_{F,t}}{P_t A_t} - o \right)} \frac{\mathbb{E}_t \frac{c_{t+1}^{-\sigma} e_{t+1}}{\Pi_{t+1} e_t}}{\mathbb{E}_t \frac{c_{t+1}^{-\sigma}}{\Pi_{t+1}}} \quad (21)$$

Final goods sector

The final goods sector uses two local production inputs: intermediate goods, x , and labor. The products are sold internationally in competitive markets where the law of one price

³¹In particular, unemployment helps the model to target the nominal interest rate in the quantitative analysis. The intuition is that the uninsurable idiosyncratic unemployment risk increases the incentive of households to save out of a precautionary motive. Higher savings then lead to less discounting of future consumption and a lower equilibrium nominal interest rate. The unemployment risk is, however, not required for the theoretical results. In modeling the unemployment risk we closely follow [Benigno and Fornaro \(2018\)](#).

holds: $P_{H,t} = P_{H,t}^* e_t$, $P_{F,t} = P_{F,t}^* e_t$. Firms operating in the final goods sector maximize their period profit subject to the production function

$$\max_{\{x_{j,t}\}_{j,t}} P_{H,t} y_t - \int_0^1 P_{H,j,t} x_{j,t} dj - W_t l_t \quad (22)$$

$$\text{s.t. } y_t = l_t^{1-\alpha} \int_0^1 A_{j,t}^{1-\alpha} x_{j,t}^\alpha dj, \quad (23)$$

with $\alpha \in (0, 1)$. $x_{j,t}$ denotes the H -produced intermediate goods. Intermediate goods come in different varieties indexed by $j \in [0, 1]$. Each variety has a price of $P_{H,j,t}$ and is associated with a productivity of $A_{j,t}$ in the final goods production process. $P_{H,t}$ is the price of the H -produced final goods. y_t is the output of H final goods. Profit-maximizing final goods producers ensure that the marginal product of each production input equals its price:

$$\alpha P_{H,t} l_t^{1-\alpha} A_{j,t}^{1-\alpha} x_{j,t}^{\alpha-1} = P_{H,j,t}, \quad \forall j \quad (24)$$

$$(1 - \alpha) P_{H,t} l_t^{-\alpha} \int_0^1 A_{j,t}^{1-\alpha} x_{j,t}^\alpha dj = W_t \quad (25)$$

Intermediate goods sector

The intermediate goods sector is where innovation takes place and thus sustained TFP growth originates. Different industries produce different types of intermediate goods indexed by j . Each industry contains oligopolistic intermediate goods producers that can produce one unit of the intermediate good using one unit of the final good purchased at $P_{H,t}$. However, the quality of the intermediate goods produced in each industry differs between the industry leader, who has the patent for the most productive version, and all other producers. While the intermediate goods produced by the industry leader have a productivity of $A_{j,t}$ in the final goods production process, the intermediate goods produced by the leader's competitors only have a productivity of $A_{j,t}/\gamma$, $\gamma > 1$. Thus, γ indicates the distance in quality between the leader and its competitors. At the end of each period, the patent of the industry leader expires with exogenous probability η , in which case the patent is randomly transferred to a competitor who will become the new industry leader. In addition, the patent also expires if an upgraded version of the good is discovered through innovation, as described further below.³²

The industry leader sets the optimal price

$$P_{H,j,t} = \xi P_{H,t}, \quad \text{with } \xi \equiv \min(\gamma^{1-\alpha}, 1/\alpha)$$

³²As in [Benigno and Fornaro \(2018\)](#), only one upgraded version of the good can be discovered in each period. The exogenous probability η helps to target expected patent duration in the quantitative exercise.

and thereby captures the whole demand for the intermediate good $x_{j,t}$ (Benigno and Fornaro, 2018).³³ Combined with the final goods producers' optimality conditions, (24) and (25), the industry leader's optimal price-setting results in

$$x_{j,t} = \left(\frac{\alpha}{\xi}\right)^{1/(1-\alpha)} A_{j,t} l_t \quad (26)$$

$$y_t = A_t l_t \left(\frac{\alpha}{\xi}\right)^{\alpha/(1-\alpha)} \quad (27)$$

where $A_t \equiv \int_0^1 A_{j,t} dj$ measures the average productivity of H -produced intermediate goods. The profit in the intermediate goods sector, Γ , is thus

$$\Gamma_t = \bar{\omega} P_{H,t} A_{j,t} l_t, \quad \text{with } \bar{\omega} \equiv (\xi - 1) \left(\frac{\alpha}{\xi}\right)^{1/(1-\alpha)}.$$

Intermediate goods producers can invest in R&D. Successful R&D generates an upgraded version of the intermediate good in the period following the investment, and the new version is γ times more productive than the current version produced by the market leader. Upon the discovery of this improved version, the innovator acquires a patent and becomes next period's market leader.

The incentive to invest in R&D is determined by the net gain from investing, which depends on the cost of investment, the probability of discovering an upgraded version, and the monopolist profit that comes with the patent for the upgraded version. The cost of innovation is the amount of domestic final goods that are used up in the innovation process, $I_{j,t}$. The probability of discovery, $q_{j,t}$, is assumed to be increasing in R&D investment but decreasing in the productivity level.³⁴ To account for technology spillovers from abroad, the probability of discovery also depends on foreign innovation:

$$\begin{aligned} q_{j,t} &= \min \left[\chi \left(\frac{I_{j,t}}{A_{j,t}}\right)^\kappa \left(\frac{I_{j,t}^*}{A_{j,t}^*}\right)^\nu, 1 \right] \\ &= \min \left[\chi Z_{j,t}^\kappa Z_{j,t}^{*\nu}, 1 \right], \quad Z_{j,t} \equiv \frac{I_{j,t}}{A_{j,t}}, \quad Z_{j,t}^* \equiv \frac{I_{j,t}^*}{A_{j,t}^*}. \end{aligned} \quad (28)$$

$\chi > 0$ denotes the efficacy of R&D investment, $\kappa \in (0, 1]$ is the elasticity of the discovery probability with respect to R&D investment, and ν quantifies the spillover effect of foreign

³³The intuition of this price setting behavior is well-explained in Benigno and Fornaro (2018). $1/\alpha$ is the optimal monopolist markup if there were no potential entry of competitors. $\gamma^{1-\alpha}$ is the highest markup, above which the market demand will be captured by competitors. Thus, the maximum of the two markup is the one that maximizes profit and defer entries of competitors.

³⁴This reflects the increasing difficulty of achieving innovation on already mature products and ensures model stationarity.

R&D investment into the corresponding local industry's discovery probability.³⁵

The discounted expected revenue from discovery, denoted by V_t , is the discounted expected monopolist profit:

$$V_{j,t} = \beta\rho\mathbb{E}_t\frac{\lambda_{t+1}}{\lambda_t} [\Gamma_{t+1} + (1 - \eta - q_{t+1})V_{j,t+1}]. \quad (29)$$

λ_t denotes households' marginal utility of nominal income.³⁶ $\Gamma_{t+1} = \bar{\omega}P_{H,t+1}\gamma A_{j,t}l_{t+1}$ is the market leader's profit in $t+1$. $(1 - \eta - q_{t+1})$ is the probability of retaining the patent in $t+1$, and $V_{j,t+1}$ is the continuation value if the patent is retained.

Assuming free entry, discounted expected revenues must not exceed the costs of innovation: $q_{j,t}V_{j,t} \leq P_{H,t}I_{j,t}$. As long as R&D investment is positive in each industry, we have $q_{j,t}V_{j,t} = P_{H,t}I_{j,t}$.³⁷ Given an equal discovery probability in all industries, equilibrium R&D investment is described by the following equation, which combines (28), (29), and the free entry condition:

$$1 = Z_t^{\kappa-1}Z_t^{*v}\mathbb{E}_t\frac{\lambda_{t+1}}{\lambda_t}\Pi_{H,t+1}\left[\Omega l_{t+1} + \frac{\beta\rho}{Z_{t+1}^{\kappa-1}Z_{t+1}^{*v}}(1 - \eta - q_{t+1})\right] \quad (30)$$

where $\Omega \equiv \chi\beta\rho\bar{\omega}\gamma$. The symmetry of industries with respect to the discovery probability allows us to drop the index j . The law of large numbers implies that the discovery probability q_t equals the fraction of industries with a discovery. Accordingly, the average region productivity evolves according to

$$A_{t+1} = q_t\gamma A_t + (1 - q_t)A_t. \quad (31)$$

The average productivity growth rate is

$$g_{t+1} \equiv \frac{A_{t+1}}{A_t} = q_t\gamma + (1 - q_t). \quad (32)$$

³⁵This modeling of cross-border technological spillover follows [Abbritti and Weber \(2019\)](#). If $v > 0$, there is a positive technological spillover: higher R&D in F increases the probability of discovery in H . If $v < 0$, foreign R&D negatively influences domestic innovation, which can result from intellectual property theft or the difficulty of obtaining a patent in the presence of congestion externalities.

³⁶In particular $\frac{\lambda_{t+1}}{\lambda_t} = \left(\frac{c_{t+1}}{c_t}\right)^{-\sigma} \frac{1}{\Pi_{t+1}}$. This discount factor reflects the ownership of firms by local households.

³⁷The assumption simplifies the model exposition.

Wage and price inflation

In equilibrium, the final goods price level is linked to the wage level and the technology level. Using (25) and (26), we have

$$P_{H,t} = \frac{W_t}{A_t} \frac{1}{1-\alpha} \left(\frac{\xi}{\alpha} \right)^{\frac{\alpha}{1-\alpha}}. \quad (33)$$

Thus, domestic final goods' price inflation is linearly increasing in wage inflation and decreasing in the productivity growth rate

$$\Pi_{H,t} = \frac{\Pi_{w,t}}{g_t}, \quad (34)$$

where $\Pi_{w,t} \equiv W_t/W_{t-1}$.

We assume that the nominal wage evolves according to a wage Phillips curve:

$$\Pi_{w,t} = \Pi_w(1 - l_t, \mathbb{E}_t \Pi_{t+1}), \quad \frac{\partial \Pi_w}{\partial (1 - l_t)} < 0, \quad \frac{\partial \Pi_w}{\partial \mathbb{E}_t \Pi_{t+1}} > 0, \quad \check{\Pi}_w = \Pi_w(l = 1). \quad (35)$$

Wage inflation, $\Pi_{w,t}$, is decreasing in contemporaneous unemployment ($1 - l_t$), and increasing in expected CPI inflation, $\mathbb{E}_t \Pi_{t+1}$ through CPI inflation indexation.³⁸

Monetary policy

Monetary policy follows a dynamic version of the policy rules described in the simple model – (6) and (7). The nominal interest rate therefore reacts to the contemporaneous employment level

$$R_t = \mathbb{R}(l_t) = \begin{cases} \Upsilon l_t^\phi, & \text{if flexible exchange rates} \\ \Upsilon_u (l_t^\tau l_t^{*1-\tau})^{\phi_u}, & \text{if fixed exchange rates} \end{cases} \quad (36)$$

$$R_t^* = \mathbb{R}^*(l_t^*) = \begin{cases} \Upsilon^* l_t^{*\phi^*}, & \text{if flexible exchange rates} \\ \text{a rate that ensures } \Pi_{e,t} = 1, & \text{if fixed exchange rates} \end{cases} \quad (37)$$

³⁸To the extent that CPI-indexation is typically imperfect (Babeçy et al., 2010), the associated long-run wage Phillips curve remains non-vertical and describes a finite tradeoff between the unemployment rate and wage inflation.

Market clearing

The model equilibrium features goods and asset market clearing. Goods market clearing requires

$$y_t = \int_0^1 x_{j,t} dj + c_{H,t} + c_{H,t}^* + \int_0^1 I_{j,t} dj \quad (38)$$

$$y_t^* = \int_0^1 x_{j,t}^* dj + c_{F,t} + c_{F,t}^* + \int_0^1 I_{j,t}^* dj. \quad (39)$$

The real GDP of a country equals its output of final goods minus its production of intermediate goods:

$$GDP_t = y_t - \int_0^1 x_{j,t} = \Psi A_t l_t \quad (40)$$

$$GDP_t^* = \Psi^* A_t^* l_t^*, \quad (41)$$

where $\Psi \equiv \frac{\alpha}{\xi} \alpha^{1-\alpha} (1 - \frac{\alpha}{\xi})$, $\Psi^* \equiv \frac{\alpha^*}{\xi^*} \alpha^{*1-\alpha^*} (1 - \frac{\alpha^*}{\xi^*})$. Asset market clearing requires

$$B_{H,t} + B_{H,t}^* = 0 \quad (42)$$

$$B_{F,t} + B_{F,t}^* = 0. \quad (43)$$

The model equilibrium is summarized by the set of non-linear equations in Appendix [C.1](#)

4.2. Balanced growth path

On the BGP, all variables are either constant or grow at a constant rate. However, growth rates can differ across variables. In particular, we are interested in a BGP where H - and F -TFP growth rates differ. To ensure the existence of a BGP for any combination of H - and F -TFP growth rates, several parameter conditions need to be satisfied.

Assumption 1 *The parameters satisfy the following conditions:*

- *the elasticity of substitution between H - and F -produced goods equals 1*
- $\theta = 1 - \theta^*$
- $\rho^* = \rho$

First, the BGP requires a unit elasticity of substitution between H - and F -produced goods, which is the reason behind the assumed functional form for the aggregation of final goods into the consumption bundle [\(1\)](#). The second assumption, $\theta = 1 - \theta^*$, ensures that H - and F -households have the same consumption baskets. As a consequence, H - and F -consumption grows at the same rate, and purchasing power parity follows from the

law of one price. Finally, for the BGP, H - and F -unemployment risk is assumed to be the same, $\rho^* = \rho$.³⁹

The model variables can be categorized into three groups according to their growth rates on the BGP: (1) those that are stationary; (2) those that grow at the same rate as H -TFP: g ; (3) and those that grow at the same rate as F -TFP: g^* . To transform the model into one with a stationary equilibrium, we normalize variables belonging to the second group by H -TFP, and those belonging to the third group by F -TFP. We use \tilde{X} to denote the normalized version of variable X , and we omit the time index.

The model's BGP can be described by a system of equations that resemble the simple model introduced in section 2.⁴⁰ In particular, on the demand side we have

$$1 = \beta \rho \frac{\mathbb{R}(l)}{\mathbb{\Pi}_w(1-l)} \bar{g}^{1-\sigma} \quad (44)$$

$$1 = \beta \rho \frac{\mathbb{R}^*(l^*)}{\mathbb{\Pi}_w^*(1-l^*)} \bar{g}^{1-\sigma}. \quad (45)$$

These equations express the optimal intertemporal allocation of consumption from the households' perspective. The average TFP growth rate, $\bar{g} = g^{1-\theta} g^{*\theta}$, equals the consumption growth rate and it has two opposing effects on the intertemporal allocation of consumption. First, a higher TFP growth rate implies a higher consumption growth rate, which generates a desire among households to front-load consumption. Second, a higher TFP growth rate also makes future consumption more attractive as the lower price inflation decreases the relative price of future consumption. Which effect dominates depends on the parameter σ . Consistent with the empirical evidence (Havránek, 2015), we set $\sigma > 1$, which renders the former effect dominant.

The employment level also has two opposing effects on the TFP growth rate. On the one hand, a higher employment level is met with a higher nominal interest rate by the monetary authority, leading to more saving and thus a higher TFP growth rate. On the other hand, the reduced labor market slack puts upward pressure on wages and thus price inflation, which reduces the real interest rate, as well as the TFP growth rate. In the following we assume that the nominal interest rate's reaction to changes in employment level outweighs the effect of employment level on wage inflation, $\partial(\mathbb{R}(l)/(\mathbb{\Pi}_w(1-l)))/\partial l > 0$ and $\partial(\mathbb{R}^*(l^*)/(\mathbb{\Pi}_w^*(1-l^*)))/\partial l^* > 0$, which implies a positive relationship between the employment level and the real interest rate and, at the same time, ensures local determinacy.

³⁹Alternatively, if $\theta \neq 1 - \theta^*$, then the BGP requires that $\rho/\rho^* = (g/g^*)^{(\sigma-1)(1-\theta-\theta^*)}$. This implies that a certain level of ρ/ρ^* is not consistent with all relative TFP growth rates. This is problematic because different exchange rate regimes can feature different relative TFP growth rates. Thus, values for ρ/ρ^* that ensure the existence of a BGP under flexible exchange rates do not necessarily ensure the existence of a BGP under fixed exchange rates.

⁴⁰Appendix C.2 provides a detailed derivation of the equation system that characterizes the BGP.

Under these assumptions, summarized below, the TFP growth rate is increasing in the domestic employment level.

Assumption 2 *The parameters satisfy*

- $\sigma > 1$
- $\frac{\partial \mathbb{R}(l)/(\mathbb{I}_w(1-l))}{\partial l} > 0$
- $\frac{\partial \mathbb{R}^*(l^*)/(\mathbb{I}_w^*(1-l^*))}{\partial l^*} > 0$

On the production side, we have the following two equations that are the extended and micro-founded versions of (10) and (11), and that describe the relationship between TFP growth and employment:

$$1 = \bar{g}^{1-\sigma} g^{-1} \left[\Omega \Xi l \frac{(g-1)^{1-\kappa/(\kappa^2-v^2)}}{(g^*-1)^{-v/(\kappa^2-v^2)}} + \left(1 - \frac{g-1}{\gamma-1} - \eta\right) \beta \rho \right] \quad (46)$$

$$1 = \bar{g}^{1-\sigma} g^{*-1} \left[\Omega^* \Xi^* l^* \frac{(g^*-1)^{1-\kappa/(\kappa^2-v^2)}}{(g-1)^{-v/(\kappa^2-v^2)}} + \left(1 - \frac{g^*-1}{\gamma-1} - \eta\right) \beta \rho \right] \quad (47)$$

$$\Xi = \left[\frac{(\gamma-1)^\kappa \chi^\kappa}{(\gamma^*-1)^v \chi^{*v}} \right]^{\frac{1}{v^2-\kappa^2}}, \quad \Xi^* = \left[\frac{(\gamma^*-1)^\kappa \chi^{*\kappa}}{(\gamma-1)^v \chi^v} \right]^{\frac{1}{v^2-\kappa^2}}.$$

Assumption 3 *The parameters satisfy: $|v| < \kappa$.*

Under assumption 3, which requires the discovery probability to be more sensitive to domestic than foreign R&D, equation (46) implies that H -TFP growth is increasing in H -employment, for any given level of g^* .⁴¹ This reflects the market size effect of aggregate demand on R&D investment: the larger the market, which is proportional to l , the higher the potential profit from innovation, and the higher productivity growth. The same relationship applies to F -TFP growth and employment, as described in (47).

The domestic TFP growth rate is also influenced by foreign TFP growth. First, F -growth affects H -growth through the cross-border technological spillover. This effect is positive if the technological spillover is positive, $v > 0$. Second, F -growth affects H -growth through its effect on the stochastic discount factor: A higher g^* implies faster consumption growth in both regions and is thus associated with a larger stochastic discount factor for nominal returns. This reduces the current utility from a unit of expected future profits from innovation. Thus, the discount factor effect is negative – a higher g^*

⁴¹This is a sufficient condition: The right-hand side (RHS) of (46) is increasing in l , and therefore g is increasing in l if and only if the RHS is decreasing in g . A sufficient condition is $|v| < \kappa$. This condition implies $1 - \kappa/(\kappa^2 - v^2) < 0$, since $\kappa \in (0, 1]$.

reduces g .⁴² The net effect of TFP growth in F on TFP growth in H depends on whether the former or latter effect dominates.

Finally, as in the simple model, nominal wage inflation in H and F are linked according to (12): $\Pi_w(l) = \Pi_w^*(l^*)\Pi_e$. As a result, the DGE model shares the simple model's main conclusion: Fixing the exchange rate ($\Pi_e = 1$) forces the region with higher structural wage inflation onto a growth path with higher unemployment and subpar TFP growth.

5. AN APPLICATION TO THE EURO AREA

In this section we calibrate the full model to the euro area. The calibration aims to provide a rough idea of how large the long-run growth impact of eliminating all nominal exchange rate flexibility under the euro might be.

5.1. Calibration

We calibrate the model to an annual frequency and choose parameter values so that the initial steady state with flexible exchange rates reflects conditions in the euro area prior to the introduction of the common currency. H corresponds to the euro area's core, represented by countries with low structural wage inflations as identified in section 3; F corresponds to its periphery, represented by countries with high structural wage inflations. Table 1 summarizes the calibration.

Our calibration of the innovation process follows Benigno and Fornaro (2018). The step size of innovation, $\gamma = \gamma^* = 1.55$, targets an innovation success probability of 3.6% per year at full employment. This is consistent with the empirical findings by Howitt (2000). We set the exogenous patent expiration probability, $\eta = \eta^*$, to 0.114. This implies an annual probability of losing a patent in the full employment steady state of 15% – a value that reflects the R&D stock depreciation rate estimated by the Bureau of Labor Statistics (Kung and Schmid, 2015; Benigno and Fornaro, 2018). κ and κ^* , the elasticity of discovery probability with respect to R&D investment, equals 0.9 as in Guerron-Quintana and Jinnai (2019).⁴³ Based on pre-euro data from 1972 to 1998 we set the efficacy of investment parameters, χ and χ^* , to target an average full employment TFP growth rate of 1.2%, which implies $\chi = 1.4$ and $\chi^* = 2.3$.⁴⁴ Core and periphery labor

⁴²Although a higher g^* also reduces CPI inflation – a counteracting effect – this is more than offset by the higher g^* 's impact on consumption growth due to the assumption $\sigma > 1$.

⁴³ $\kappa = 0.9$ is also comparable with the calibration used in related literature (see Comin and Gertler 2006; Kung and Schmid, 2015).

⁴⁴1972 constitutes the beginning of the sample because it marks the end of the Bretton Woods system. After the collapse of the Bretton Woods system and before the introduction of the euro, many Euro-

Table 1: Calibration

Parameters	Value	Source/Target
γ, γ^*	1.55	Probability discovery 3.6% Howitt (2000)
η, η^*	0.114	Kung and Schmid (2015)
κ, κ^*	0.9	Guerron-Quintana and Jinnai (2019)
		to investment in innovation
χ	1.42	Core TFP growth rate 1.2%
χ^*	2.31	Periphery TFP growth rate 1.2%
$1 - \alpha$	0.75	Core R&D-to-GDP ratio 2.1%
$1 - \alpha^*$	0.91	Periphery R&D-to-GDP ratio 0.8%
v, v^*	0	Standard value
μ^*	0.44	Estimation of the long-run wage Phillips curve, periphery
ψ^*	0.8	Estimation of the long-run wage Phillips curve, periphery
$\tilde{\Pi}_w$	1.03	Core nominal wage inflation of 8% p.a.
$\tilde{\Pi}_w^*$	1.05	Periphery pre-peg exchange rate depreciation of 7% p.a.
$1/\sigma$	1/2	Standard value
β	0.98	Real interest rate 1.02
θ	0.38	Periphery share of GDP
K, K^*	0.001	Schmitt-Grohé and Uribe (2003)
ρ	1.04	Core nominal interest rate 1.07 p.a.
ϕ, ϕ^*, ϕ^u	2.5	Local determinancy
τ	0.62	Core share of GDP
o, o^*	0	Balanced trade on long-run equilibrium

income shares are set to target average R&D-to-GDP ratios of 2.1% and 0.8%, respectively, implying $\alpha = 0.25$ and $\alpha^* = 0.09$. For simplicity, we eliminate cross-border technology spillovers from the baseline calibration, i.e. $v = v^* = 0$. Appendix [B.5](#) documents the robustness of the baseline results to various degrees of technology spillovers. With the parameter v and v^* varying from -0.05 to 0.1, a sizable degree of spillover when compared to the domestic elasticity of discovery probability, the result remains quantitative similar.

The effect of the exchange rate regime on TFP growth hinges on the long-run tradeoff between wage inflation and employment. For the calibration exercise, we assume a log-linear functional form for the wage Phillips curve in [F⁴⁵](#)

$$\ln \Pi_{w,t}^* = \ln \tilde{\Pi}_w^* - \mu^*(1 - l_t^*) + \psi^* \ln \mathbb{E}_t \Pi_{t+1}^*, \quad \mu^* > 0, \quad \psi^* \in (0, 1), \quad (48)$$

where μ^* reflects the degree of wage rigidity and ψ^* captures wage inflation indexation to the expected CPI inflation. We do not need to further specify the wage Phillips curve for H . As H is at full employment under both fixed and flexible rate regimes (see section [2](#)),

pean countries participated in systems of European monetary cooperation aimed at limiting fluctuations between different European currencies, i.e., the snake-in-the-tunnel and the Exchange Rate Mechanism (ERM). While under these exchange arrangements, the exchange rates among many European currencies fluctuated within a pre-specified band. This soft peg regime, however, provided sufficient flexibility for persistent depreciation vis-à-vis the base currency, as is apparent in the exchange rate between the Italian Lira and the German Mark, or between the Spanish Peseta and German Mark.

⁴⁵While the theoretical literature has pointed out that the long-run wage Phillips curve is nonlinear ([Akerlof et al. 1996](#); [Benigno and Ricci, 2011](#)), the linear form is a simplifying assumption suitable for our purposes. This is because the wage Phillips curve we use in the calibration exercise only need to reflect the part of the curve that is associated with a relatively high wage inflation, since it is the employment implication of reducing wage inflation in this range that determines the long-run impact of an exchange rate regime switch from flexible to fixed.

the functional form and the parametrization of the H wage Phillips curve do not influence the long-run steady state. To quantify the tradeoff of wage inflation and employment, we follow [Barnichon and Mesters \(2021\)](#) in using exogenous variation in monetary policy to identify the slope of the long-run wage Phillips curve, μ^* . The estimation results imply that an increase of the long-run unemployment of 1 percentage point is associated with a decrease of the long-run wage inflation of around 0.44 percentage points, conditional on the CPI expectations. This result leads us to set $\mu^* = 0.44$. Also based on the regression results, the CPI-indexation parameter, ψ^* , is set to 0.8. Appendix [C.4](#) describes the wage Phillips curve estimations in greater detail.^{[46](#)}

We set the H structural wage inflation rate $\check{\Pi}_w = 1.03$. This leads to a long-run wage inflation of 8% p.a. in core, corresponding to the average nominal wage inflation in the group of countries with low structural wage inflation between 1972 and 1998. This assumes that, on average, core countries operated at full employment between the end of the Bretton Woods system and the introduction of the euro. We do not use wage inflation rates after joining the euro, as the model implies changes in long-run employment and wage inflation rates in the aftermath of fixing the exchange rate.^{[47](#)} Based on H 's wage inflation at full employment, we set F 's structural wage inflation rate, $\check{\Pi}_w^*$, to target an annual depreciation rate of the F -currency vis-à-vis the H -currency of 7%. This value corresponds to the average depreciation of periphery currencies vis-à-vis core currencies prior to the introduction of the euro.

The remaining parameters are either set to standard values widely used in the literature or can be directly identified from observables.^{[48](#)} The inverse of the elasticity of intertemporal substitution $\sigma = 2$, and the time discount factor $\beta = 0.98$. We set the weight of F produced final goods in the consumption bundle, θ , equal to 0.38 – a value which eliminates home-bias in consumption as it corresponds to the periphery's average GDP share between 1972 and 2019. Following [Schmitt-Grohé and Uribe \(2003\)](#), we set the portfolio adjustment cost parameters $K = K^* = 0.001$. We set $\rho = 1.04$ – the probability of becoming unemployed – to target an H nominal interest rate of 1.07 p.a. This corresponds to the average policy interest rate in the euro area's core prior to the introduction of the euro. The monetary policy reaction parameters ϕ, ϕ^* , and ϕ^U equal 1.5, which ensures local determinacy. The weight in the union-wide monetary policy τ is set to 0.62, reflecting the average share of H GDP. Under our baseline calibration, the

⁴⁶An alternative way to quantitatively determine the tradeoff between wage inflation and employment is to estimate reduced-form wage Phillips curves. However, such an estimation has several drawbacks compared to the exogenous demand variation approach, as discussed in the Appendix [C.4](#).

⁴⁷The Maastricht Treaty requires a stable exchange rate in the two years prior to the entry into the euro system. Accordingly, exchange rates became very stable already in 1996. Ending the pre-euro sample already in 1996 instead of 1998, however, has little effect on the sample averages that inform the calibration.

⁴⁸Appendix [A](#) describes the data we use in detail.

Table 2: Steady states

	Employment		GDP growth		
	Core l	Periphery l^*	Core g	Periphery g^*	Whole area \bar{g}
Flexible	1.00	1.00	1.012	1.012	1.012
Fixed	1.00	0.97	1.012	1.011	1.012
Changes	0%	-3.08%	0.01%	-0.09%	-0.03%

Notes: Changes are expressed as percentage changes of steady state under fixed exchange rates relative the steady state value under flexible exchange rates.

assumed monetary policy also corresponds to the optimal monetary policy (Appendix C.3). Finally, for the baseline calibration we assume that the current account is balanced in long run $o = o^* = 0$. Assuming different levels for the long-run external balance has a negligible impact on the results.⁴⁹

5.2. Quantitative results

What are the growth implications of fixing the exchange rate between the euro area's core and periphery regions in the calibrated model? The core – the region with the lower structural wage inflation – maintains full employment and maximum TFP growth after the regime change. The periphery, however, embarks upon a growth path with higher unemployment and lower TFP growth.

Table 2 compares the steady-state TFP growth rates and steady-state employment levels under flexible and fixed exchange rates. In the periphery, the steady-state employment rate decreases by 3 percentage points, whereas steady-state employment in the core remains unchanged. Regarding TFP growth, the core's annual steady-state growth rate slightly increases after fixing the exchange rate, while the periphery's growth rate decreases by about 0.1 percentage points. The decline in the periphery's TFP growth rate implies a decline in the euro area's average TFP growth rate of 0.03 percent. Note that this decline in TFP growth is reflected in correspondingly lower consumption growth rates in the core as well as the periphery.

Table 3 displays the cumulative GDP effect that the steady state growth rates changes imply. Together with the level effect on the GDP due to lower employment, small changes in steady-state growth rates can imply substantial output losses, when cumulated over

⁴⁹On the BGP, H and F consumption grows at the same rate, independently of the external balance. However, the level of the external balance can affect the level of consumption and thus affect the welfare cost of fixing the exchange rate for H and F . Quantitatively, however, the external balance levels only has a negligible effect on the overall welfare cost. This is because the exchange rate regime's impact on the net return of foreign assets is negligible.

Table 3: GDP changes relative to flexible exchange rate baseline

Years after fixing	10	20	50
H	0.06%	0.14%	0.37%
F	-4.02%	-4.92%	-7.59%

the years. After 10 years, the periphery’s output under fixed exchange rates is around 4% lower than it would have been under flexible exchange rates. The annual output loss increases to 5% after 20 years, and almost 8% after 50 years. By contrast, fixing the exchange rate has a minimal effect on the core’s GDP. Even after 50 years the core’s GDP is about half a percent higher under fixed exchange rates than under the flex-exchange rate counterfactual. The decline in the average TFP growth rate translate into a 2 percentage point loss of welfare as measured by comparing certainty equivalent consumption of the BGP under fixed and flexible exchange rates.⁵⁰

In sum, the welfare implications of giving up flexible exchange rates are not necessarily limited to the short-run. Our analysis highlights an adverse steady-state effect of fixing the exchange rate, whose welfare implications have the potential to exceed those springing from most existing analyses that purely focus on business cycle fluctuations (Lucas, 1987). Our analysis in particular cautions against pre-maturely fixing the exchange rate between regions whose structural wage inflation rates have not yet converged.

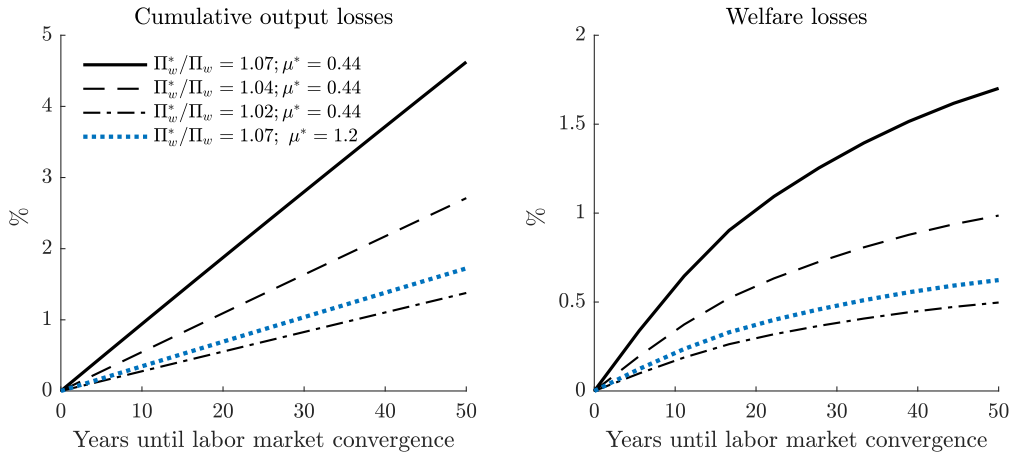
5.3. Policy discussion

The displayed values in the last subsection represent effect sizes under the assumption that labor markets have not converged in the meantime. In practice, the eventual size of the divergence effect crucially depends on how quickly labor markets policies can reduce or eliminate the structural wage inflation differential between the two regions. This subsection will analyze the impact of such labor market policies.

First, we consider the effect of policies that promote labor market convergence. Once the structural wage inflations become identical in both regions, the area-wide monetary policy will be able to achieve full employment in both regions. The labor market convergence will not only bring the periphery back to its maximum TFP and output growth

⁵⁰We compares household welfare at the initial steady-state under flexible exchange rates, with household welfare at the new steady state under fixed exchange rates. The welfare measure neglects the transition phase, because multiple transition paths exist. Under the baseline calibration, with balanced external accounts, fixing the exchange rate has the same welfare effects in the core and the periphery, as H and F consume the same consumption bundle. Appendix ?? reports core- and periphery-specific welfare effects when the external account is not balanced in steady state.

Figure 6: Effect of labor market policies



Notes: solid line – result under baseline calibration. Dash line – result under alternative calibrations under various labor market policy scenarios.

rates but will also undo the output gap caused by the peg. This can have a substantial effect on reducing welfare and output losses, as illustrated in Figure 6. In the extreme case, when the convergence occurs immediately after joining the peg, welfare and output losses are reduced to zero. However, under the baseline calibration (the solid black line), even if structural wage inflation rates converge after 20 years, fixing the exchange rate is still associated with a sizable welfare loss that amounts to 1% and a cumulative output loss in the periphery of 2%.

Similarly, a policy that aims to enhance the degree of labor market homogenization before the introduction of the common currency reduces welfare and output losses. Figure 6 shows that if countries enter the fixed rate regime with more minor structural wage inflation differentials – $\Pi_w^*/\Pi_w = 1.04\%$ or 1.02% – the welfare loss associated with the regime change is substantially reduced. If we, optimistically, assume $\Pi_w^*/\Pi_w = 1.02\%$ and convergence of labor market institutions within 20 years, the welfare loss amounts to 0.3% – a number comparable to the welfare losses of business cycles.

Finally, we consider a policy that increases F nominal wage flexibility.⁵¹ Higher wage flexibility in F implies that the wage inflation equalization under fixed rates can be achieved to a larger extent through wage adjustment instead of quantity adjustment of the employment level. To see the effect of increased wage flexibility, we recalibrate the model and strengthen the relationship between the unemployment rate and wage inflation from $\mu^* = 0.44$ to $\mu^* = 1.2$, a number consistent with the empirical evidence for the US⁵²

⁵¹The degree of H wage flexibility, μ , does not matter for our analysis, as H is at full employment under both exchange rate regimes, see (13).

⁵²Barnichon and Mesters (2021) estimate a price Phillips curve of quarterly frequency. We use their estimate at the 20-quarter horizon for the sample 1969q1-1989q4 as a proxy for the US wage Phillips curve slope. We multiply the estimated coefficient by 4 to translate it to an annual frequency.

At this higher level of wage flexibility, the welfare cost of fixed rates is reduced by slightly more than half of our baseline results.

6. CONCLUSION

Whether to fix or float the exchange rate is a key decision that policymakers in all economy's face. Our analysis highlights an adverse steady-state effect of fixing the exchange rate: upon fixing the exchange rate, economies with a relatively high structural wage inflation lose the ability to offset rapid nominal wage growth through nominal exchange rate depreciation. When TFP growth is endogenous, the ensuing loss in competitiveness pushes economies with high structural wage inflation into a low-growth trap which is characterized by heightened unemployment and subpar output growth. Our findings caution against pre-maturely fixing the exchange rate between two economies whose structural wage inflation rates have not yet converged. The capacity of fixed exchange rates to bring about output divergence can also be countered through policies that reduce cross-region differences in structural wage inflation rates.

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Appendix

to “*Growing Apart: Output Divergence in Fixed Exchange Rate Regimes*”

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A. DATA

This section provides detailed information on the data used in the paper.

A.1. Utilization-adjusted TFP

We adjust the PWT TFP series for capital and labor utilization following the procedure outlined in [Imbs \(1999\)](#); [Jordà et al. \(2020b\)](#). For the adjustment, the aggregate output is assumed to be described by the following production function:

$$y_t = A_t(u_t k_t)^\alpha (e_t l_t)^{1-\alpha},$$

with y_t is the total output, A_t is utilization-adjusted TFP, u_t is the degree of utilization of capital k_t , and e_t is the effort level for the employment l_t . The utilization rates u_t, e_t are calculated as³

$$u_t = \left(\frac{y_t/k_t}{y/k} \right)^{\frac{\delta}{r+\delta}}; \quad e_t = \left(\alpha \frac{y_t}{c_t} \right)^{\frac{1}{1+v}},$$

where c_t denotes households' consumption. Variables without a time index denote their steady state values. δ is the depreciation rate of physical capital, r is the (net) real return on capital, v is the inverse of the Frisch elasticity of labor supply, α is the share of capital income. The unadjusted TFP, $TFP_t = y_t/(k_t^\alpha l_t^{1-\alpha})$, is then adjusted with the utilization rates to arrive as the adjusted TFP:

$$A_t = \frac{TFP_t}{u_t^\alpha e_t^{1-\alpha}}.$$

For the adjustment, we assume $\delta = 0.08$, $r = 0.04$, $\alpha = 0.33$, $v = 1$, following [Jordà et al. \(2020b\)](#). We use country-specific two-sided HP-filtered trend values for the steady-state ratio y/k . The results are robust to changing parameters within plausible ranges.

A.2. List of countries included in the empirical analysis

List of countries: Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Portugal, Slovak Republic, Slovenia, Spain.

³See [Imbs \(1999\)](#) for a detailed derivation.

A.3. Variable definitions and data sources

Table [A.1](#) - [A.2](#) summarize the variable definitions and data sources used in the paper.

Table A.1: Variable definition and data sources

Variable	Detailed description	Source
Consumer price index		World Bank
Real GDP per capita	GDP at constant 2015 USD	World Bank
Nominal GDP	in local currency unit	World Bank
R&D ^a	as percentage of GDP	OECD , World Bank
Real effective exchange rate		World Bank
Service share	% value added	World Bank
Financial development ^a	private credit by deposit money banks and and other financial institutions to GDP ratio	World Bank
Trade to GDP ratio	import and export of goods and services to GDP ratio	World Bank
Government burden	general government final consumption expenditure to GDP ratio	World Bank
Schooling ^a	gross secondary school enrollment ratio, gross (%)	World Bank
Total compensation of employees	in local currency ^b	World Bank
Average hourly nominal wage	calculated as total compensation of employees/(average annual hours worked per worker *number of persons engaged)	see sources for individual items
Labor productivity	GDP per hour worked, at USD constant prices, 2015 PPPs	OECD
Total factor productivity (baseline)	unadjusted	AMECO database, the European Commission
Goods import (from the world and China) ^a	trade value in USD	UN Comtrade database & IMF
Nominal exchange rate	units of national currency per USD	Penn World Table 10.0 (PWT) (Feenstra et al., 2015)
Total factor productivity	unadjusted, at constant national prices	PWT
Real consumption and investment	at constant 2017 national prices (in mil. 2017USD)	PWT
Real consumption	at constant 2017 national prices (in mil. 2017USD)	PWT
Real investment	calculated as real consumption and investment - real consumption	see above
Capital stock	at constant 2017 national prices (in mil. 2017USD)	PWT
Real GDP	at constant 2017 national prices (in mil. 2017USD)	PWT
Real consumption	at constant 2017 national prices (in mil. 2017USD)	PWT
Average annual hours worked	by persons engaged	PWT
Number of persons engaged	in millions	PWT
Population	total population	United Nations
Patent application	to the EPO by priority year per million inhabitants	eurostat

^aFor missing values, we linearly interpolated the series if the gap is less than four year.

^bTotal compensation of employees consists of all payments in cash and in kind, as well as government contributions to social insurance schemes and pensions.

Table A.2: Variable definition and data sources (cont.)

Variable	Detailed description	Source
Crisis dummy	= 1 if either a currency crisis or a banking crisis or a systemic crisis	see below
Currency crisis & banking crisis		Reinhart and Rogoff (2009) until 2016, = 0 for 2017-2019
Systemic crisis		Lo Duca et al. (2017) until 2016, = 0 for 2017-2019
Exchange rate regime	binary Dummy variable that classify a currency: peg or non-peg. Peg if fine classification = 1 “no separate legal tender” or 2 “Pre announced peg or currency board arrangement”, non-peg otherwise	based on the fine classification from Ilzetzki et al. (2019) ^a
Nominal interest rates before 1999	country central bank official rate or call money/interbank rate (less than 24 Hours)	Center for Financial Stability & Deutsche Bundesbank, & OECD
Nominal interest rates after 1999	ECB marginal lending rate	European Central Bank (ECB)
Unemployment rates, Germany ^b	as % of total labor force	OECD, 1991-2019; World Bank, 1983-1990; Mitchell (2013), 1972-1982
Unemployment rates, Greece ^b	as % of total labor force	OECD, 1991-2019; World Bank, 1981-1990; OECD, 1977-1980
Unemployment rates, the Netherlands ^b	as % of total labor force	OECD, 1983-2019; World Bank and Mitchell (2013), 1970-1982
Unemployment rates, Italy ^b	as % of total labor force	OECD, 1983-2019; World Bank, 1971-1982; Mitchell (2013), 1977 & 1981
Unemployment rates, Portugal ^b	as % of total labor force	OECD, 1983-2019; World Bank, Banco de Portugal, and ILO-STAT, 1972-1984
Unemployment rates, Spain ^b	as % of total labor force	OECD, 1987-2019; World Bank, 1972-1986

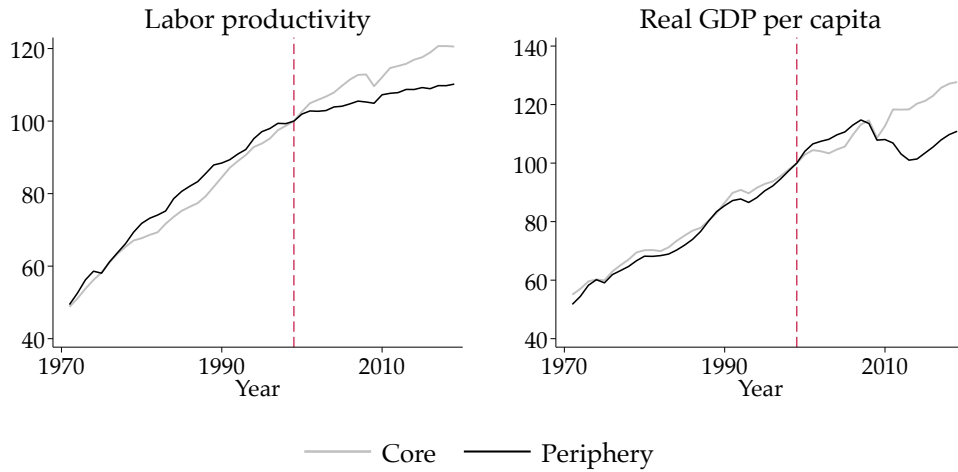
^a Ilzetzki et al. (2019) classify Greece as “no separate legal tender” starting from 1999. However, Greece only officially joined the euro area in 2001. Thus, we classify Greece as non-peg before 2001 and as peg afterward.

^b We use OECD harmonized unemployment rates when available. We use several other sources to extend the OECD series to earlier periods by means of splicing: World Bank, national estimates; Mitchell (2013), Table: B2 Europe: Unemployment.

B. ADDITIONAL RESULTS

B.1. Divergence in labor productivity

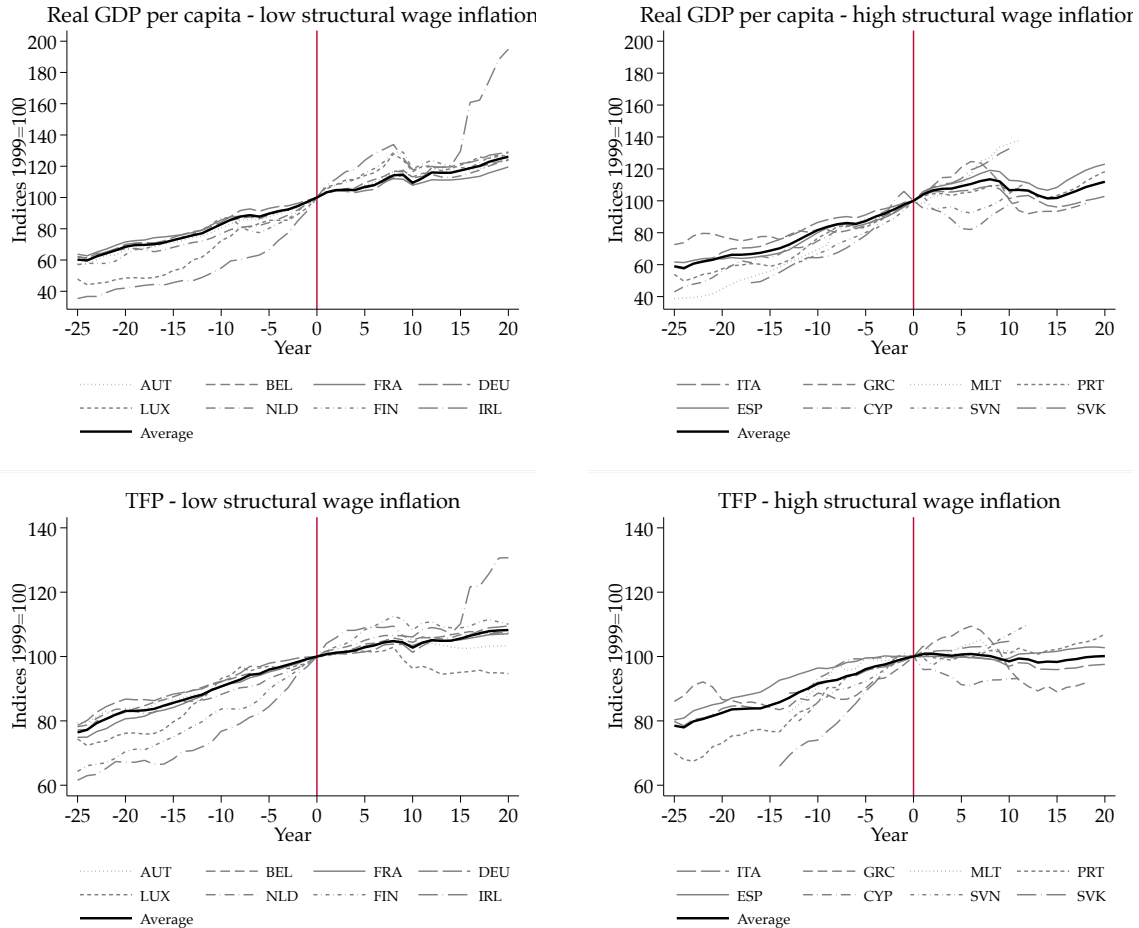
Figure B.1: Divergence in the euro area: labor productivity



Notes: Core includes Germany and the Netherlands. Periphery includes Spain, Italy, Greece, and Portugal. Both TFP and real GDP per capita series are population-weighted average, indexed at 1999=100.

B.2. GDP per capita and TFP: individual country time series

Figure B.2: Divergence in the euro area: individual country time series



Notes: All series are indexed at year 0 =100. Year 0 denotes the year of euro adoption.

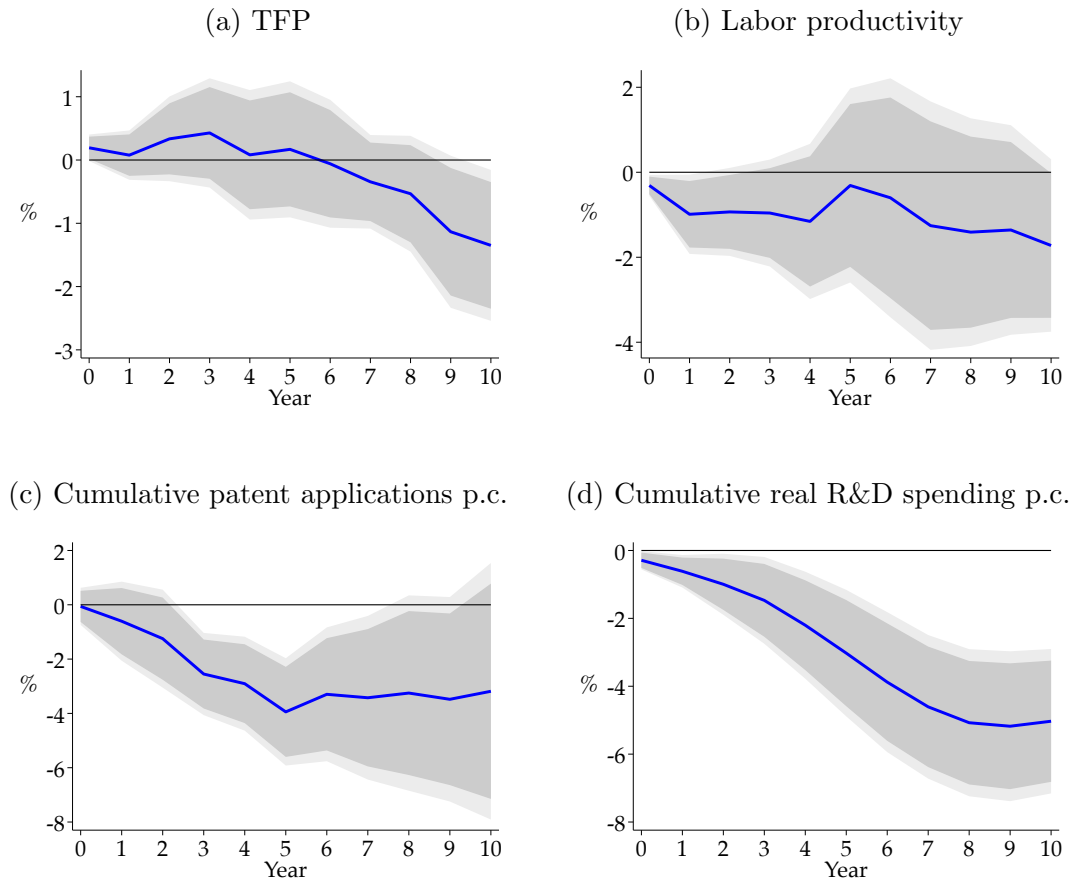
B.3. Empirical analysis: robustness

B.3.1 Robustness: structural wage inflation differential measured using pre-euro depreciation rate

In this subsection, we show the empirical results when the relative structural inflation rate is measured using pre-peg depreciation rates. The depreciation rate is a suitable proxy for relative structural inflation, because a country with a relatively high structural wage inflation should see its currency depreciate under flexible exchange rates according to the model. Analogously to the nominal wage inflation, we use a 15-year backward looking

moving average growth rate of the exchange rate trend against the base country.⁴

Figure B.3: Effect of pegging with a nominal depreciation differential of 1%



Notes: Blue solid line – mean estimate. Dark shaded area – 90% confidence interval. Light shaded area – 95% confidence interval.

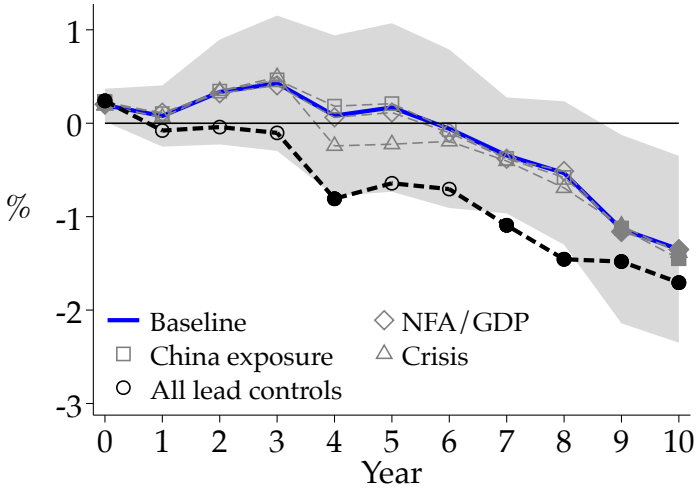
B.3.2 Robustness: including sets of lead controls

In this subsection, we analyze the robustness of our baseline results and consider alternative mechanisms that might result in productivity divergence across the euro area member states. First, to control for the productivity effect of the capital inflows into the periphery after joining the euro (Gopinath et al., 2017), we include cumulative changes of net-foreign-position to GDP ratio between $t - 1$ and $t + h$ as a lead control to the baseline specification. Second, to account for the different exposure to competition from China (Bloom et al., 2016), we include cumulative changes of the share of Chinese goods

⁴To exclude countries whose nominal wage inflation or exchange rate vis-à-vis the base is constrained through an indirect peg the exchange rate moving average is only calculated for country-year observations that are characterized by non-fixed exchange rates. The exchange rate classification is described in details below.

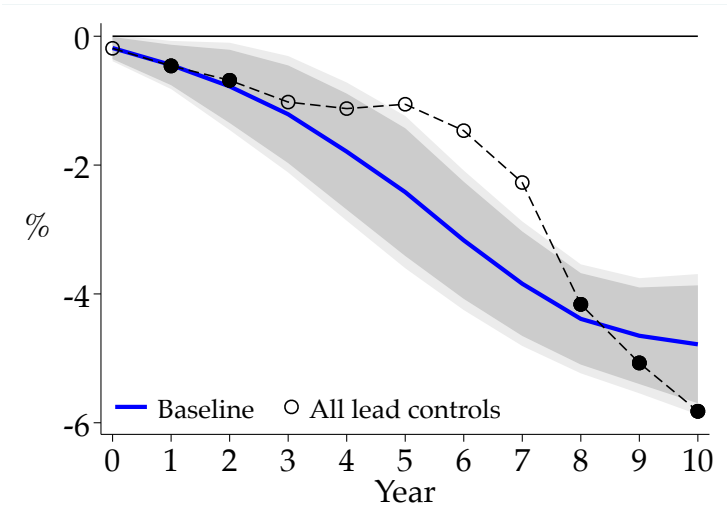
imports in total goods imports between $t - 1$ and $t + h$ as a lead control to the baseline specification. Finally, we include a financial crisis dummy to examine the effect of the Global Financial Crisis and the euro area debt crisis on our baseline result. The dummy equals 0 if the country is not in a crisis in $t + h$ and equals the number of years since the start of the crisis if the country is in a crisis in $t + h$. The estimation results are shown in Figure 5 – B.4. The baseline result remains robust to the inclusion of these controls. Thus, the negative relationship between fixing the exchange rate, relative structural wage inflation and TFP growth that we estimate is not driven by these alternative channels.

Figure B.4: TFP effect of pegging with a nominal depreciation differential of 1%, including lead controls



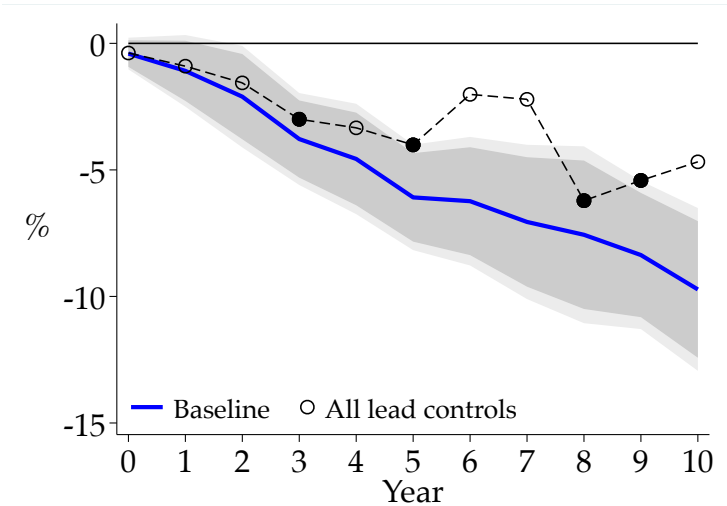
Notes: blue solid line – mean baseline estimate. Shaded area – 90% confidence interval of the mean baseline estimate. Dash line with markers – mean estimate when lead controls are included. Solid markers – significance at the 10% level. Hollow markers – no significance at the 10% level.

Figure B.5: Effect of pegging on cumulative real R&D spending per capita with a nominal wage inflation differential of 1%, including lead controls



Notes: blue solid line – mean baseline estimate. Shaded area – 90% confidence interval of the mean baseline estimate. Dash line with markers – mean estimate when lead controls are included. Solid markers – significance at the 10% level. Hollow markers – no significance at the 10% level.

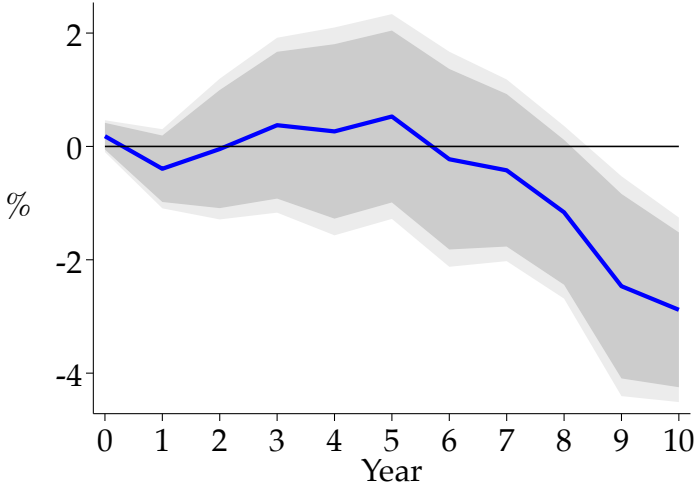
Figure B.6: Effect of pegging on cumulative patent applications per capita with a nominal wage inflation differential of 1%, including lead controls



Notes: blue solid line – mean baseline estimate. Shaded area – 90% confidence interval of the mean baseline estimate. Dash line with markers – mean estimate when lead controls are included. Solid markers – significance at the 10% level. Hollow markers – no significance at the 10% level.

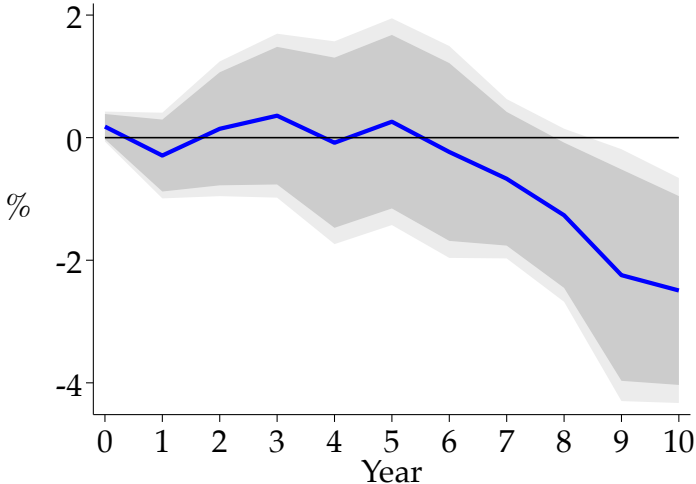
B.3.3 Robustness: alternative productivity measures

Figure B.7: TFP (non-adjusted) effect of pegging with a nominal wage inflation differential of 1%



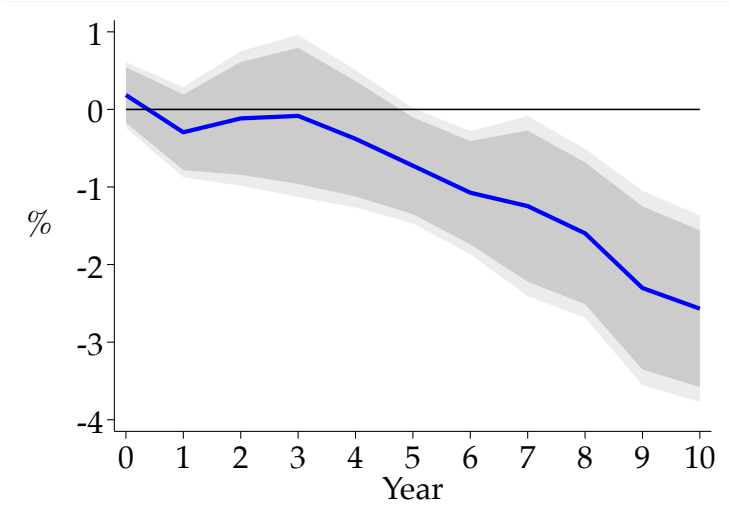
Notes: blue solid line – mean estimate. dark shaded area – 90% confidence interval. light shaded area – 95% confidence interval.

Figure B.8: TFP (non-adjusted) effect of pegging with a nominal depreciation differential of 1%



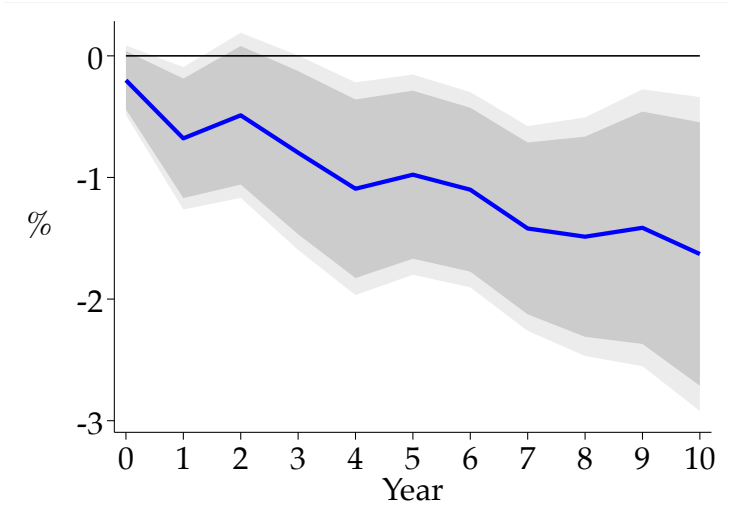
Notes: blue solid line – mean estimate. dark shaded area – 90% confidence interval. light shaded area – 95% confidence interval.

Figure B.9: TFP (Penn World Table, utilization-adjusted) effect of pegging with a nominal wage inflation differential of 1%



Notes: blue solid line – mean estimate. dark shaded area – 90% confidence interval. light shaded area – 95% confidence interval.

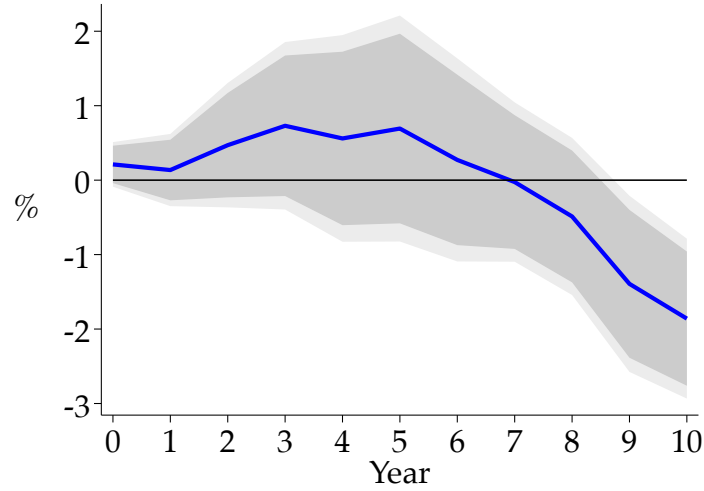
Figure B.10: TFP (Penn World Table, utilization-adjusted) effect of pegging with a nominal depreciation differential of 1%



Notes: blue solid line – mean estimate. dark shaded area – 90% confidence interval. light shaded area – 95% confidence interval.

B.3.4 Robustness: alternative structural wage inflation measures

Figure B.11: TFP effect of pegging with a nominal CPI inflation differential of 1%



Notes: blue solid line – mean estimate. dark shaded area – 90% confidence interval. light shaded area – 95% confidence interval. TFP series are the same as in the baseline specification.

B.4. Additional results: policy experiments

Table B.1: Steady state changes relative to flexible exchange rate

		Employment		GDP growth		
		Core	Periphery	Core	Periphery	Whole area
		l	l^*	g	g^*	\bar{g}
Baseline		0.00%	-3.08%	0.01%	-0.09%	-0.03%
Reduced wage infl. differences	$\Pi_w^*/\Pi_w = 1.04$	0.00%	-1.78%	0.00%	-0.05%	-0.02%
Reduced wage infl. differences	$\Pi_w^*/\Pi_w = 1.02$	0.00%	-0.90%	0.00%	-0.03%	-0.01%
Higher wage flexibility	$\mu^* = 1.2$	0.00%	-1.13%	0.00%	-0.03%	-0.01%

Notes: percentage changes reflect the change implied by moving from the flexible exchange rate steady state to the fixed exchange rate steady state.

B.5. Robustness analysis

B.5.1 Cross-border technology spillovers

This section analyzes the robustness of the baseline results with respect to cross-border technological spillovers as reflected in v . A positive spillover results in a higher correlation

between H and F growth rates, as high TFP growth in H makes foreign investments into innovation more productive. A negative spillover has the opposite effect. As the literature does not provide much guidance, we recalibrate our model to consider three degrees of technological spillover. The welfare results are shown in Table B.3.⁵ Surprisingly, a positive technology spillover exacerbates the welfare losses brought about by fixing the exchange rate. This is because the H growth rate decreases by more than the F growth rate increases. Thus, despite the shrinking gap between H and F TFP growth rates, the welfare loss is larger. The opposite holds for negative technological spillover effects: The welfare cost of fixing the exchange rate shrinks, despite an increase in the TFP growth gap between H and F .

Table B.2: Steady state changes relative to flexible exchange rate

		Employment		GDP growth		
		Core	Periphery	Core	Periphery	Whole area
		l	l^*	g	g^*	\bar{g}
Baseline		0.00%	-3.08%	0.01%	-0.09%	-0.03%
Positive tech. spillover	$v = 0.05$	0.00%	-3.08%	-0.01%	-0.09%	-0.04%
	$v = 0.1$	0.00%	-3.08%	-0.02%	-0.09%	-0.05%
Negative tech. spillover	$v = -0.05$	0.00%	-3.08%	0.02%	-0.10%	-0.02%

Notes: percentage changes reflect the change implied by moving from the flexible exchange rate steady state to the fixed exchange rate steady state.

Table B.3: Welfare change relative to flexible exchange rate baseline

		Labor market convergence		
		Never	after 50 years	after 20 years
Baseline		-2.13%	-1.70%	-1.02%
Positive tech. spillover	$v = 0.05$	-2.38%	-1.90%	-1.14%
	$v = 0.1$	-2.65%	-2.11%	-1.27%
Negative tech. spillover	$v = -0.05$	-1.89%	-1.51%	-0.91%

Notes: Welfare is measured in certainty equivalent consumption. Percentage changes reflect the change implied by moving from the flexible exchange rate steady state to the fixed exchange rate steady state.

⁵To be comparable with the baseline results we recalibrate the parameters χ, χ^* to target a TFP growth rate of 1% in H and F under flexible exchange rates for each alternative calibration of v .

C. MODEL

C.1. System of nonlinear equations

This section lays out the system of nonlinear equations that determines the model equilibrium. First, we present equations that describe the household and firm decisions. For brevity, we only describe the model's H region wherever this is possible without loss of clarity. After that, we present a normalized system of equations that fully determines the model equilibrium. The normalization is necessary to ensure the stationarity of all variables.

The following equations describe the households' consumption and investment decisions:

$$c_t^{-\sigma} = \beta \rho R_t \mathbb{E}_t \frac{c_{t+1}^{-\sigma}}{\Pi_{t+1}} \quad (\text{C.1})$$

$$c_t^{-\sigma} = \beta \rho R_t^* \frac{1}{1 + K(\frac{B_{F,t}}{P_t A_t} - o)} \mathbb{E}_t \frac{c_{t+1}^{-\sigma} e_{t+1}}{\Pi_{t+1} e_t} \quad (\text{C.2})$$

$$c_{H,t} = (1 - \theta) \left(\frac{P_{H,t}}{P_t} \right)^{-1} c_t \quad (\text{C.3})$$

$$c_{F,t} = \theta \left(\frac{P_{F,t}}{P_t} \right)^{-1} c_t \quad (\text{C.4})$$

where $\rho = 1 - \iota + \iota/\zeta^\sigma > 1$. A version of the uncovered interest rate parity (UIP) follows immediately from [\(C.1\)](#) and [\(C.2\)](#):

$$R_t = R_t^* \frac{1}{1 + K(\frac{B_{F,t}}{P_t A_t} - o)} \frac{\mathbb{E}_t \frac{c_{t+1}^{-\sigma} e_{t+1}}{\Pi_{t+1} e_t}}{\mathbb{E}_t \frac{c_{t+1}^{-\sigma}}{\Pi_{t+1}}} \quad (\text{C.5})$$

To ensure stationarity, we normalize variables according to their long-run growth rates. The model variables can be divided into four groups. The first group of variables are already stationary, and do not require any normalization. This group includes $R, R^*, l, l^*, g, g^*, \bar{g}, \Pi, \Pi_e, \Pi_H, \Pi_F, \Pi_w, \Pi_w^*, Z_H, Z_F, q, q^*$. The second group of variables grows at the H TFP steady-state growth rate g and thus is normalized by $A_{H,t}$. This group includes c_H, c_H^* . The third group of variables inherits the long-run growth rate from F TFP, and thus is normalized by $A_{F,t}$. This group includes c_F, c_F^* . The final group of variables grows at the average steady-state TFP growth rate \bar{g} and is thus normalized by \bar{A}_t . This group includes c, c^* , and the real asset positions $b_H = B_H/P, b_H^* = B_H^*/P, b_F = B_F/P^*, b_F^* = B_F^*/P^*$. We denote the normalized version of a variable x with \tilde{x} .

The price levels are not determined in the model, but the relative prices are. To

ensure stationarity, we introduce the normalized relative price $\tilde{P}_{H,t} \equiv \frac{P_{H,t}}{P_t} \left(\frac{A_{H,t}}{A_{F,t}} \right)^\theta$ for H . Analogously, for F , $\tilde{P}_{F,t} \equiv \frac{P_{F,t}^*}{P_t^*} \left(\frac{A_{F,t}}{A_{H,t}} \right)^{1-\theta}$.⁶

The complete set of nonlinear equations is listed below. Here, we make use of $\Pi_{H,t} = \Pi_{H,t}^* \Pi_{e,t}$, $\Pi_{F,t} = \Pi_{F,t}^* \Pi_{e,t}$, $\Pi_t = \Pi_t^* \Pi_{e,t}$, which follows from the law of one price and Assumption 1. Equations (C.1) - (C.2) describe households' intertemporal consumption allocation. (C.3) - (C.4) are the households' budget constraints. (C.5) - (C.6) follow from international asset arbitrage. (C.7) - (C.11) describe the nominal wage and price inflation. (C.12) - (C.13) follow from the definition of variables \tilde{P}_H, \tilde{P}_F . (C.14) - (C.15) result from the free-entry condition in the intermediate goods sector. (C.16) - (C.19) describe the innovation processes. (C.21) - (C.22) are the monetary policy rules. (C.22) - (C.24) show the market clearing conditions. Finally, (C.25) defines the average TFP growth rate.

$$\tilde{c}_t^{(-\sigma)} = \mathbb{E}_t \left[\frac{\beta \rho R_t (\tilde{c}_{t+1} \bar{g}_{t+1})^{(-\sigma)}}{\Pi_{t+1}} \right] \quad (\text{C.6})$$

$$\tilde{c}_t^{*(-\sigma)} = \mathbb{E}_t \left[\frac{\Pi_{e,t+1} \beta \rho^* R_t^* (\tilde{c}_{t+1}^* \bar{g}_{t+1})^{(-\sigma)}}{\Pi_{t+1}} \right] \quad (\text{C.7})$$

$$\tilde{c}_t + \frac{\tilde{b}_{H,t}}{R_t} + \frac{\tilde{b}_{F,t}}{R_t^*} = \frac{\tilde{b}_{H,t-1}}{\Pi_t \bar{g}_t} + \frac{\tilde{b}_{F,t-1} \Pi_{e,t}}{\Pi_t \bar{g}_t} + \Psi \tilde{P}_{H,t} l_t - \tilde{P}_{H,t} Z_{H,t} \quad (\text{C.8})$$

$$\tilde{c}_t^* + \frac{\tilde{b}_{F,t}^*}{R_t^*} + \frac{\tilde{b}_{H,t}^*}{R_t} = \frac{\tilde{b}_{F,t-1}^* \Pi_{e,t}}{\Pi_t \bar{g}_t} + \frac{\tilde{b}_{H,t-1}^*}{\Pi_t \bar{g}_t} + \Psi^* \tilde{P}_{F,t} l_t^* - \tilde{P}_{F,t} Z_{F,t} \quad (\text{C.9})$$

$$R_t \mathbb{E}_t \frac{\tilde{c}_{t+1}^{-\sigma}}{\Pi_{t+1}} = R_t^* \frac{1}{1 + K(\tilde{b}_{F,t} - o)} \mathbb{E}_t \frac{\tilde{c}_{t+1}^{-\sigma}}{\Pi_{t+1}} \frac{e_{t+1}}{e_t} \quad (\text{C.10})$$

$$R_t^* \mathbb{E}_t \frac{\tilde{c}_{t+1}^{*-\sigma}}{\Pi_{t+1}^*} = R_t \frac{1}{1 + K^*(\tilde{b}_{H,t}^* - o^*)} \mathbb{E}_t \frac{\tilde{c}_{t+1}^{*-\sigma}}{\Pi_{t+1}^*} \frac{e_t}{e_{t+1}} \quad (\text{C.11})$$

⁶It is easy to show that these two relative prices are stationary. In steady state, $c_{H,t}, c_{H,t}^*$ grow at rate g_H ; $c_{F,t}, c_{F,t}^*$ grow at rate g_F , and aggregate consumption levels, c_t, c_t^* , grow at rate $\bar{g}_t = g_{H,t}^{1-\theta} g_{F,t}^\theta$. Using (??) [WRONG] and its F -version, we also can derive the demand schedule $c_{H,t} P_{H,t} = (1 - \theta) c_t P_t, c_{F,t} P_{F,t} = \theta c_t P_t$. It follows that in the long-run $\frac{P_H}{P} = (1 - \theta) \frac{c}{c_H}$ grows at the rate of $\left(\frac{A_{F,t}}{A_{H,t}} \right)^\theta$.

$$\Pi_{H,t} = \frac{\Pi_{w,t}}{g_t} \quad (\text{C.12})$$

$$\frac{\Pi_{F,t}}{\Pi_{e,t}} = \frac{\Pi_{w,t}^*}{g_t^*} \quad (\text{C.13})$$

$$\Pi_t = \Pi_{H,t}^{1-\theta} \Pi_{F,t}^\theta \quad (\text{C.14})$$

$$\Pi_{w,t} = \check{\Pi}_w - \mu (1 - l_t) \quad (\text{C.15})$$

$$\Pi_{w,t}^* = \check{\Pi}_w^* - \mu^* (1 - l_t^*) \quad (\text{C.16})$$

$$\frac{\tilde{P}_{H,t}}{\tilde{P}_{H,t-1}} = \frac{\Pi_{H,t}}{\Pi_t} \left(\frac{g_t}{g_t^*} \right)^\theta \quad (\text{C.17})$$

$$1 = \tilde{P}_{H,t}^{1-\theta} \tilde{P}_{F,t}^\theta \quad (\text{C.18})$$

$$\begin{aligned} \mathbb{E}_t \left(\frac{\Pi_{H,t+1} l_{t+1} \Omega Z_{H,t}^{\kappa-1} Z_{F,t}^v \left(\frac{\tilde{c}_{t+1}}{\tilde{c}_t} \bar{g}_{t+1} \right)^{(-\sigma)}}{\Pi_{t+1}} - 1 \right. \\ \left. + (1 - q_{t+1} - \eta) \frac{\Pi_{H,t+1} \rho \beta \left(\frac{Z_{H,t}}{Z_{H,t+1}} \right)^{\kappa-1} \left(\frac{Z_{F,t}}{Z_{F,t+1}} \right)^v \left(\frac{\tilde{c}_{t+1}}{\tilde{c}_t} \bar{g}_{t+1} \right)^{(-\sigma)}}{\Pi_{t+1}} \right) = 0 \end{aligned} \quad (\text{C.19})$$

$$\begin{aligned} \mathbb{E}_t \left(\frac{\Pi_{F,t+1} l_{t+1}^* \Omega^* Z_{F,t}^{\kappa-1} Z_{H,t}^v \left(\frac{\tilde{c}_{t+1}^*}{\tilde{c}_t^*} \bar{g}_{t+1} \right)^{(-\sigma)}}{\Pi_{t+1}} - 1 \right. \\ \left. + (1 - q_{t+1}^* - \eta^*) \frac{\Pi_{F,t+1} \rho^* \beta \left(\frac{Z_{F,t}}{Z_{F,t+1}} \right)^{\kappa-1} \left(\frac{Z_{H,t}}{Z_{H,t+1}} \right)^v \left(\frac{\tilde{c}_{t+1}^*}{\tilde{c}_t^*} \bar{g}_{t+1} \right)^{(-\sigma)}}{\Pi_{t+1}} \right) = 0 \end{aligned} \quad (\text{C.20})$$

$$Z_{H,t} = \frac{\left(\frac{q_t}{\chi} \right)^{\frac{\kappa}{\kappa^2 - v^2}}}{\left(\frac{q_t^*}{\chi^*} \right)^{\frac{v}{\kappa^2 - v^2}}} \quad (\text{C.21})$$

$$Z_{F,t} = \frac{\left(\frac{q_t^*}{\chi^*}\right)^{\frac{\kappa}{\kappa^2 - v^2}}}{\left(\frac{q_t}{\chi}\right)^{\frac{v}{\kappa^2 - v^2}}} \quad (\text{C.22})$$

$$q_t (\gamma - 1) = g_{t+1} - 1 \quad (\text{C.23})$$

$$q_t^* (\gamma^* - 1) = g_{t+1}^* - 1 \quad (\text{C.24})$$

$$R_t = \begin{cases} \Upsilon l_t^\phi, & \text{if flexible exchange rates} \\ \Upsilon^u (l_t^\tau l_t^{*1-\tau})^\phi, & \text{if fixed exchange rates} \end{cases} \quad (\text{C.25})$$

$$R_t^* = \begin{cases} \Upsilon^* l_t^{*\phi^*}, & \text{if flexible exchange rates} \\ \text{a rate that ensures } \Pi_{e,t} = 1, & \text{if fixed exchange rates} \end{cases} \quad (\text{C.26})$$

$$\Psi l_t = Z_{H,t} + \frac{\tilde{c}_t (1 - \theta)}{\tilde{P}_{H,t}} + \frac{\tilde{c}_t^* (1 - \theta)}{\tilde{P}_{H,t}} \quad (\text{C.27})$$

$$\Psi^* l_t^* = Z_{F,t} + \frac{\tilde{c}_t \theta}{\tilde{P}_{F,t}} + \frac{\tilde{c}_t^* \theta}{\tilde{P}_{F,t}} \quad (\text{C.28})$$

$$\tilde{b}_{H,t} + \tilde{b}_{H,t}^* = 0 \quad (\text{C.29})$$

$$\bar{g}_t = g_t^{1-\theta} g_t^{*\theta} \quad (\text{C.30})$$

C.2. Balanced growth path

In this section we derive equations (44) - (47), which together pin down the steady state of g, g^*, l, l^* . On the BGP, the nominal consumption expenditures spent on H - and F -produced goods have to grow at the same rate. This also implies that the relative inflation of H - and F -produced goods equals the inverse of the relative growth in the consumption of the corresponding goods, which on the BGP reflects relative technological progress $\Pi_H/\Pi_F = \Pi_H^*/\Pi_F^* = g^*/g$. Using (C.12), which reflects the production technology, and

the law of one price $\Pi_H = \Pi_H^* \Pi_e$, we can derive the equalization of wage inflation discussed in the main text:

$$\Pi_w = \Pi_w^* \Pi_e$$

It also follows that $\Pi_F = \Pi_w/g^*$. Using (C.12) and (C.14), we have $\Pi = \Pi_w/\bar{g}$, $\Pi_H/\Pi = \bar{g}/g$, $\Pi_F/\Pi = \bar{g}/g^*$. (44) follows from (C.6), as \tilde{c} is constant at the steady state, and $\Pi = \Pi_w/\bar{g} = (\bar{\Pi}_w - \mu(1-l))/\bar{g}$. We can derive (45) analogously. To derive (46), we evaluate (C.19) at the steady state, replace Z_H, Z_F with q, q^* using (C.21) and (C.22), and then replace q, q^* with g, g^* using (C.23) and (C.24). Finally, we use $\Pi_H/\Pi = \bar{g}/g$, $\Pi_F/\Pi = \bar{g}/g^*$ to replace relative inflation rates with relative growth rates.

C.3. Optimal monetary policy

The assumed monetary policy is optimal under the baseline calibration described in detail in section 5. As we are focusing on the long-run steady state, we consider a monetary policy to be optimal if it maximizes steady state consumption and thus steady state welfare.⁷ There are three sources of inefficiency in the model economy that can affect welfare. (1) potential involuntary unemployment; (2) a consumption-output ratio that is too low or too high due to sub-optimal level of investment; (3) too little production of intermediate goods due to monopolistic competition, (see Benigno and Fornaro, 2018). While aiming to maximize employment, the monetary policy directly address (1). At the same time, the level of output is increasing in employment, as the productivity growth rate is increasing in employment (40) - (41). An increase in employment is associated with an increase in both output and investment, and thus consumption level may go up or down. Under our baseline calibration, we show that the increase in investment is slower than the increase in output, thus the consumption is itself increasing in the employment level in both H and F .

To find the optimal monetary policy, we look at the relationship between the employment level and the consumption level. The steady state consumption level, and thus steady state welfare, can be separated into the steady state growth rate and the steady state productivity-normalized level of consumption. The steady state growth rate is increasing in the employment level under assumption 3. The productivity-normalized level of consumption, \tilde{c}, \tilde{c}^* , however, can be increasing or decreasing in the employment level

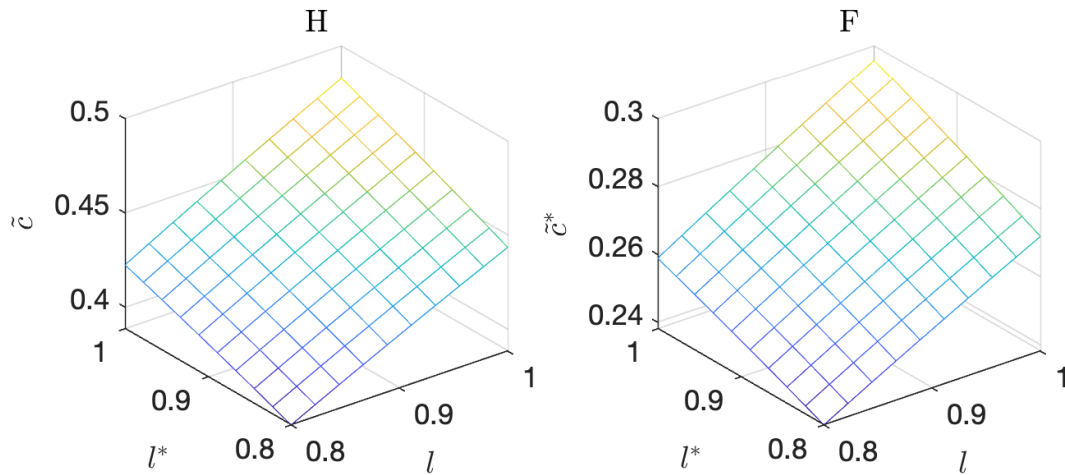
⁷Benigno and Fornaro (2018) show that with ZLB, the economy features two steady states, one with full employment and one with involuntary unemployment. In that context, the optimal monetary policy with commitment can help to avoid the steady state with unemployment while the discretionary policy can not. Here, we do not analyze the ZLB and thus do not run into the issue of discretionary vs. commitment issue. The optimal monetary policy when business cycle fluctuations are considered would also need to take into account the volatility of consumption. For target volatilities, the monetary policy can, for example, be augmented by terms reacting to deviations from the steady state.

l, l^* , depending on the level of investment, (C.27) - (C.28). The following Figure (C.1) shows the steady state levels of \tilde{c}, \tilde{c}^* for combinations of l, l^* .

Under flexible exchange rates, owing to the independent monetary policy, all points on the plotted surface are achievable. For any level of F -employment, l^* , \tilde{c} is monotonously increasing in H -employment, l . The same applies to F . Thus, \tilde{c}, \tilde{c}^* are maximized when both H and F are at full employment. In other words, the employment maximizing monetary policy assumed in the baseline model is optimal.

Under fixed exchange rates, steady states are constrained to combinations of l, l^* that satisfy (12). Since both \tilde{c}, \tilde{c}^* are increasing in l, l^* , and (12) dictates a positive association between l and l^* , the average welfare $u(c)^{1-\tilde{\theta}}u(c^*)^{\tilde{\theta}}, \tilde{\theta} \in [0, 1]$ is increasing in the average employment level $l^\tau l^{*1-\tau}, \tau \in [0, 1]$. It follows that the fixed exchange rate model's common monetary policy, which maximizes the average employment level, is also optimal.⁸

Figure C.1: Consumption and employment



C.4. Estimation of the long-run wage inflation-employment tradeoff

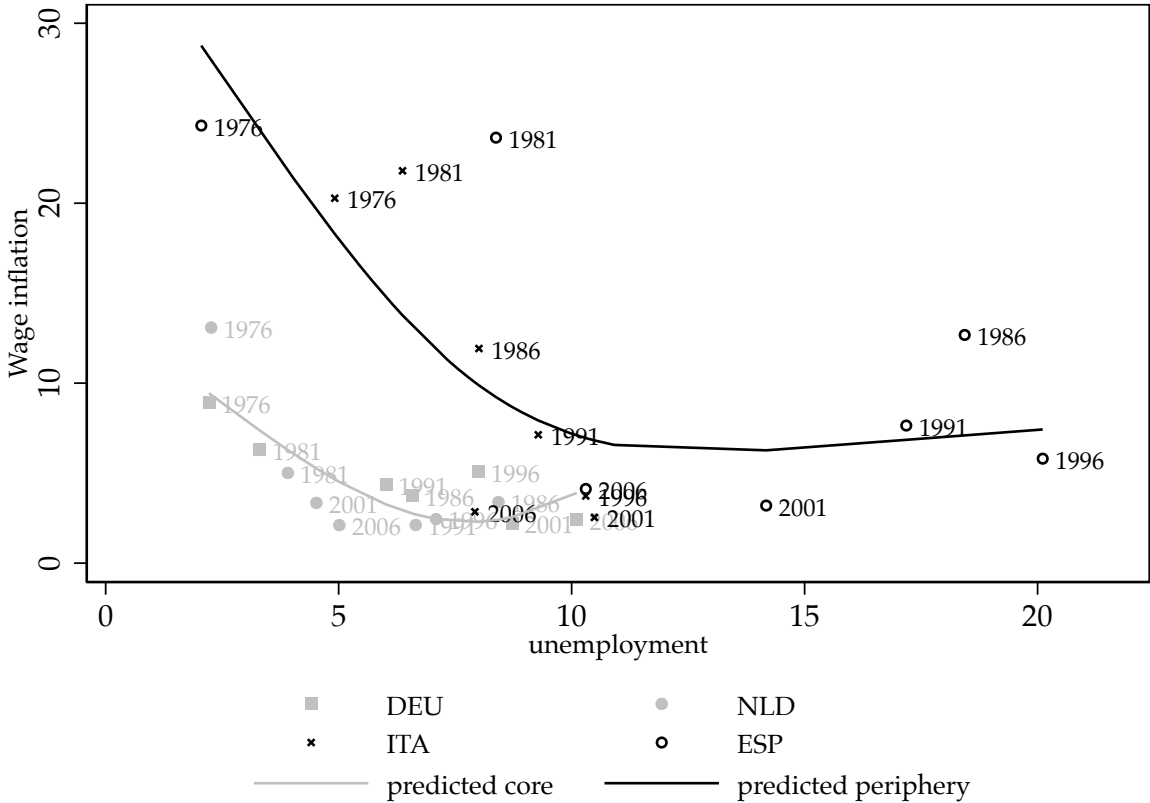
In the baseline model, the effect of the exchange rate regime on TFP growth depends on the long-run tradeoff between wage inflation and employment. This long-run tradeoff is graphically reflected in a non-vertical (downward sloping) long-run wage Phillips curve. As a result of the downward sloping wage Phillips curve, an unemployment gap opens up when, by fixing the exchange rate, a country moves from an environment with high long-run wage inflation to one with low long-run wage inflation. The unemployment gap translates into an output gap which endogenously depresses TFP growth.

One way to quantitatively determine the tradeoff between wage inflation and em-

⁸This holds for any weight used to calculate the average utility and the average employment level.

ployment is to estimate a reduced-form wage Phillips curve, with wage inflation as the dependent variable and unemployment as the independent variable. Figure C.2 displays such Phillips curve estimates based on five-year non-overlapping wage inflation and unemployment averages.⁹ The theoretical literature has pointed out that the long-run wage Phillips curve is nonlinear (Akerlof et al., 1996; Benigno and Ricci, 2011). Thus, following Byrne and Zekaite (2020), we fit a non-linear model to the data using a restricted cubic spline with three knots. Consistent with the theoretical literature, results from this naive estimation indicate a steeper wage Phillips curve at higher levels of wage inflation and a flattened wage Phillips curve at lower levels of wage inflation. In our baseline calibration, the change from flexible to fixed exchange rates is accompanied by a drop of the periphery’s long-run wage inflation from 12% to 5%. According to these reduced-form Phillips curve estimates, such change in long-run wage inflation would result in an increase in the long-run unemployment rate of around 6 percentage points.

Figure C.2: Long-run wage Phillips curve: reduced form estimates



Notes: Non-linear estimation using restricted cubic splines with three knot on 5-year averages pooled data. Core: Germany and the Netherlands. Periphery: Italy and Spain. See Appendix A for detailed data description.

⁹Appendix A provides a detailed data description.

Reduced-form Phillips curve estimates, however, has several drawbacks that have been extensively discussed in the literature (Hazell et al., 2020). First, such estimates are afflicted by endogeneity problems, especially because monetary policy tends to tighten in response to higher inflation rates, thereby affecting employment. In addition, the reduced-form Phillips curve estimate does not account for CPI indexation in wage negotiations. Finally, the observational data is contaminated with supply shocks that push unemployment and wage inflation into opposite directions.

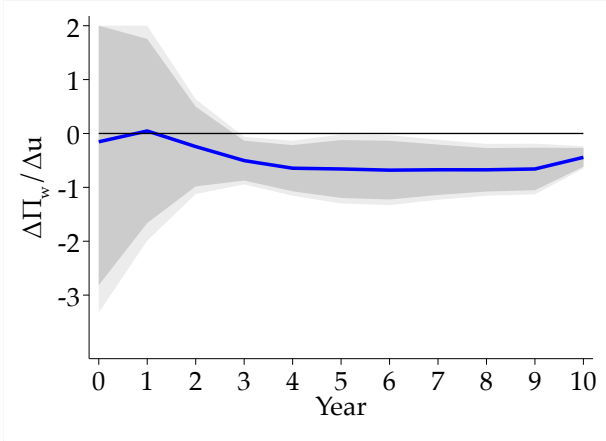
To address these issues, we follow Barnichon and Mesters (2021) in estimating the wage Phillips curve by using exogenous monetary policy shocks, while controlling for CPI indexation. Barnichon and Mesters (2021) defines the Phillips multiplier as “the expected cumulative change in inflation caused by a monetary shock that lowers expected unemployment by 1ppt”. We propose the corresponding wage Phillips multiplier definition – *the expected cumulative change in wage inflation caused by a monetary shock that lowers expected unemployment by 1ppt*. We use the Trilemma instrumental variable (IV) as our source of exogenous variation in monetary policy (Jordà et al. (2020a)). The Trilemma IV strategy roots in the international policy Trilemma, which implies that when a country pegs its exchange rate to a base country’s currency, the local interest rate has to (partially) co-move with that of the base country. At the same time, base country interest rate changes are exogenous to economic conditions in the peg. The Trilemma IV thus relies on fixed exchange rates to isolate exogenous variation in monetary policy. We nevertheless are able to use the Trilemma IV to identify the Phillips curve slope of euro area member countries before the introduction of the euro because the European Monetary System (EMS) and the Exchange Rate Mechanism (ERM) imposed constraints on intra-European exchange rate fluctuations. Under the ERM, the exchange rates among many European currencies fluctuated within a relatively narrow band around a central value. This soft peg regime left open the possibility of persistent yet limited depreciation vis-à-vis the base currency, as is apparent in the exchange rate between the Italian Lira and the German Mark, or between the Spanish Peseta and German Mark. However, in the short-run, to keep the exchange rate within the bands, countries had to follow German interest rate changes. As a result, we can exploit the interest rate variation in the base country – Germany – as a source of exogenous variation for interest rate movements in Italy and Spain during the pre-euro period.

We use the Trilemma IV as defined by Schularick et al. (2021) for the period 1972 - 1998 for the group of countries with high structural wage inflation as identified in section 3. We estimate the wage inflation Phillips multiplier over a ten-year horizon while controlling for expected CPI and the lagged unemployment rate.¹⁰ We furthermore control

¹⁰Absent survey data to capture the CPI inflation expectation for our sample, we rely instead on the HP-detrended CPI inflation as a proxy for the inflation expectation.

for contemporaneous world GDP growth as in [Jordà et al. \(2020b\)](#) to capture changes in the base country’s interest rate that are driven by global factors that affect many countries simultaneously. The resulting wage Phillips multipliers from a panel regression are shown in [Figure C.3](#).

Figure C.3: Wage Phillips multiplier



Notes: Blue solid line – mean estimate. Dark shaded area – 90% confidence interval. Light shaded area – 95% confidence interval.

The point estimate at year 10 indicates that an exogenous monetary policy shock that elevates the unemployment rate by an average of 1 percentage point over a 10-year period is associated with a significant drop in the average wage inflation. The magnitude of the drop amounts to 0.44 percentage points. The point estimates are also fairly stable over the horizon of 5 to 10 years. We use the point estimate at year 10 to calibrate the model’s long-run wage Phillips curve, under the assumption that the long-run Phillips curve is invariant to the exchange rate regime.

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