TI 2022-031/VI
Tinbergen Institute Discussion Paper

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

Revision: October 2022

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

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October 2022

Abstract

Can fixed exchange rate regimes cause output divergence among participating 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, region-specific monetary policies close output gaps and realize the associated maximum TFP growth in both regions. Upon fixing exchange rates, the common monetary policy pushes the region with higher wage inflation 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. Empirical tests confirm that countries with high wage inflation suffer lower TFP growth in the aftermath of fixing the exchange rate.

Keywords: money non-neutrality, open economy, monetary policy, economic growth

JEL Codes: E50, F31, O40

*We wish to thank Adel Issa and Randy Rensen for their excellent research assistance. We also thank Giancarlo Corsetti, Refet Gürkaynak, Peter Karadi, Annie Lee, Nuno Palma, Evi Pappa, Sjak Smulders, Alan M. Taylor, François R. Velde and participants at the CEPR MEF New Member Seminar, the Tilburg Growth, Trade and International Finance Conference, the Leuven Summer Event - International Macroeconomics, the KVS New Paper Sessions, and Asian Meeting of the Econometric Society China 2022 for helpful comments. Any remaining errors are our own.

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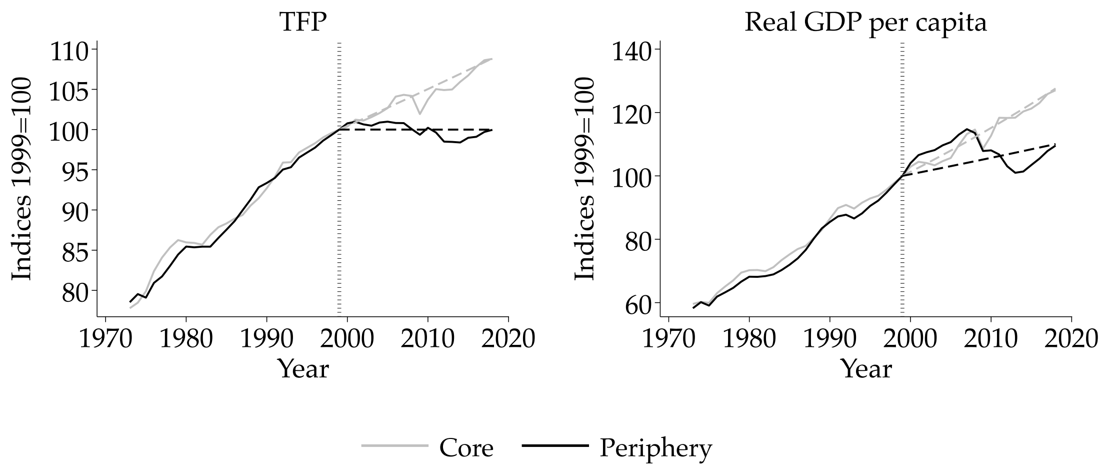
1. Introduction

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 followed the same trend. Since then, growth paths for TFP and GDP have diverged. The GDP divergence is commonly interpreted as a one-off and hopefully transitory consequence of the euro area debt crisis. However, the clear trend-break in TFP underscores the more worrying possibility of a growth path divergence hiding behind the marked boom-bust cycle in periphery GDP. We argue that the latter scenario cannot be dismissed easily.

Figure 1: Divergence in the euro area

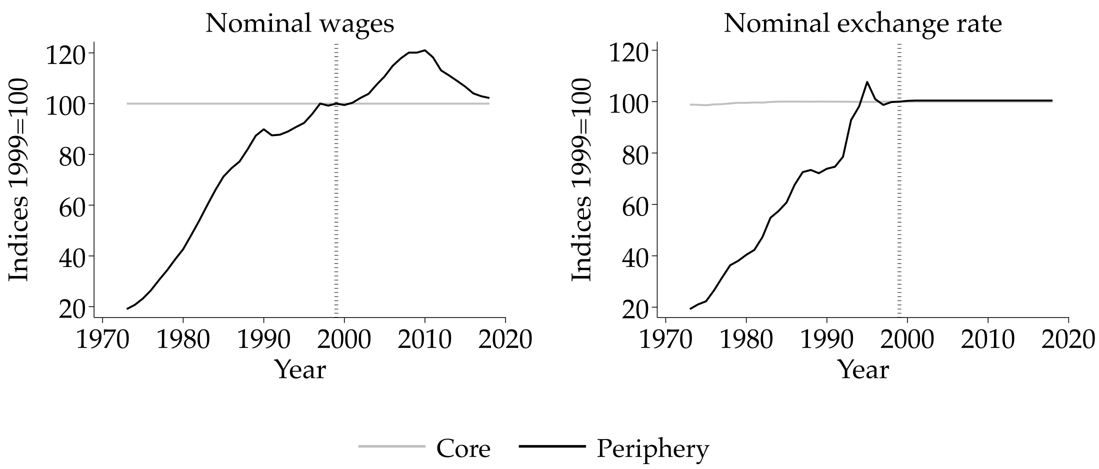


Notes: Solid line – actual data. Dash line – linear trend based on average growth rate 1999-2019. *Core* includes Germany and the Netherlands. *Periphery* includes Italy, Spain, Portugal, and Greece. Vertical bar – 1999. Both TFP and real GDP per capita series are population-weighted averages, indexed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

We show that output divergence is a long-run equilibrium characteristic of a two-region model with rigid wages, endogenous growth, and heterogeneous labor markets. 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, regionally autonomous monetary authorities are free to pursue full employment, and hence maximum TFP growth in both regions. This is achieved by preventing actual wage inflation from falling short of structural wage inflation – the wage inflation rate that supports full employment in the presence of a long-run trade-off between employment and wage inflation. Regional differences in structural wage inflation are offset by a trending exchange rate which establishes the relative law of one price – a state that is characteristic of pre-euro Europe (see Figure 2). Upon fixing the exchange rate, the relative law of one price commands wage inflation equalization. As a consequence, wage inflation in the the high inflation region falls below its structural wage inflation rate, resulting in higher unemployment and, through the endogenous growth channel, giving 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.

Figure 2: Wage inflation differentials and exchange rate depreciation



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 relatively 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. Exchange rates are against the German Mark in price notation. An increase of the exchange rate reflects a depreciation.

Structural wage inflation differences naturally emerge from different degrees of downward nominal wage rigidity (DNWR) and economic volatility. The region with more rigid wages and higher volatility requires a higher level of wage inflation to "grease the wheels" of the labor market, i.e. prevent the DNWR constraint from binding and thus lower the employment level. Under flexible exchange rates, this suffices to give rise to diverging wage level growth paths. Under fixed exchange rates *actual* wage inflation rates are equalized, while *structural* wage inflation rates remain different. Due to nominal wage rigidity, any shortfall of actual wage inflation from structural wage inflation gives rise to unemployment. Productivity and output divergence follow and persist for as long as structural wage inflation rates remain different, owing to endogenous growth.

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 reduce 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 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 confirms the model's prediction for a sample of 27 developed countries. Using local projections to compare outcomes across countries with different structural wage inflation rates, we find that high inflation countries enter a low-growth trap upon fixing the exchange rate. In particular, ten years after fixing the exchange rate a country with a +1 percentage point (ppt) structural wage inflation differential has a 0.8% lower TFP level and a 2% lower GDP per capita level. Consistent with the model mechanism, we find that these changes are accompanied by a 1 ppt higher unemployment rate and a 13% lower R&D spending level.

We then calibrate the model to the euro area to conduct a welfare analysis that compares the long-run equilibria under flexible and fixed exchange rates. Under our baseline calibration, the introduction of the euro accounts for a 0.3 ppt decline in the annual long-run GDP growth rate of the region with above average structural wage inflation – the euro area's periphery. The periphery's output shortfall cumulates to 9% after 10 years, and 12% after 20 years. The union-wide welfare loss associated with fixing the exchange rate amounts to 5%.

We also use the calibrated model to discuss two policies that can counter output divergence in the euro area. First, policies that foster labor market convergence and thus equalize structural wage inflation present a (theoretically) trivial solution to the divergence problem. However, even a complete convergence of structural wage inflation rates two decades after fixing the exchange rate is still associated with a sizable welfare loss. Given the often slow-paced nature of structural labor market reforms, our findings thus highlight the importance of ensuring structural inflation convergence already prior to fixing the exchange rate. Second, an increase in the euro area's common inflation target can counter output divergence. This is because the higher steady state inflation rate narrows the gap between the periphery's actual and structural inflation rates, allowing it to achieve wage inflation equalization with a higher employment level and faster TFP growth. The consequent growth benefit needs to be compared with the costs of higher steady state inflation to evaluate the overall welfare effect of such a policy. Existing estimates of the negative growth effects of higher steady state inflation, within a range that is relevant to the euro area, straddle the output growth benefit we derive from the calibrated model. This precludes a firm conclusion with respect to changes in the common inflation target.

The first contribution of this paper is to introduce endogenous growth to the literature on open-economy macroeconomics. This allows us 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 in optimal currency area theory (OCA) (Mundell, 1961; McKinnon, 1963; Kenen, 1969), which discusses the conditions under which exchange rates can be fixed without impairing a country's ability to smooth business cycle fluctuations. Beyond 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 affects growth. 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 rate.

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. 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), Palma (2021), and Chen et al. (2022) who make use of historical time series that span more than a century to trace the long-run effects of exogenous monetary variations.

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 when structural wage inflation rates differ across regions. After that, section 4 introduces a medium-size 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).

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

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 denote the prices of the H- and F-produced goods. O summarizes all components of household income and expenditure components other than spending on c^H and c^F. The H-CPI inflation is $\Pi = \Pi_H^{\theta}\Pi_F^{1-\theta}$, with $\Pi_H \equiv P'_H/P_H$ and $\Pi_F \equiv P'_F/P_F$.

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

$$y = A\,l, \tag{2}$$

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 $g \equiv A'/A$:

$$\Pi_H = \frac{\Pi_w}{g}, \tag{3}$$

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

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

The above equation is equivalent to a long-run non-vertical wage Phillips curve, in which

[2] This 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.

[3] We assume that labor is immobile.

wage inflation Π_w is decreasing in unemployment $(1-l)$.[4] Full employment in the model, $l=1$, represents the maximum employment that the central bank can achieve in the long-run.[5] In the following we refer to the wage inflation rate at full employment, $\check{\Pi}_w$, as the *structural wage inflation rate.*

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

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

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]

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

$$R \;=\; \begin{cases} \Upsilon\, l^{\phi} \text{ under flexible exchange rate} \\ \Upsilon_u\, \left(l^{\tau}\, l^{*1-\tau}\right)^{\phi^u} \text{ under fixed exchange rate} \end{cases} \tag{6}$$

$$R^* \;=\; \begin{cases} \Upsilon^*\, l^{*\phi^*} \text{ under flexible exchange rate} \\ R \text{ under fixed exchange rate} \end{cases} \tag{7}$$

We assume that monetary policy aims to maximize the employment level, and thus also TFP growth.[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 banks' response to unemployment.

Under a fixed exchange rate, the H central bank sets the common monetary policy,

[4]The 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.

[5]Note that this model definition of unemployment differs from measures of the unemployment rate as typically provided by statistical offices, in that it abstracts from types of unemployment that are beyond the influence of monetary policy in the long run, such as structural and frictional unemployment. Therefore, full employment in the model, $l=1$, does not necessarily correspond to a 0% unemployment rate in the data.

[6]Endogenous growth models usually feature imperfect competition in the goods market to generate positive profits, the prospect of which incentivizes investment into innovation (Benigno and Fornaro, 2018). In the reduced-form model, we postulate a positive relationship between TFP growth and the economy's 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.

[7]The same monetary policy rule is assumed for the micro-founded model in section 4. While we do not discuss welfare in the simple model, we show that in the micro-founded model under our baseline calibration, a monetary policy rule that maximizes employment corresponds to one that maximizes welfare (Appendix C.3).

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, relative price inflation equals the inverse of the relative TFP growth rate:

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

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 $\bar{g} \equiv g^\theta g^{*1-\theta} = c'/c = c^{*\prime}/c^*$ 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 $\{l, l^*\}$,

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

[9] These equalities are implied by equation (3), the corresponding F equation, and the definition of CPI inflation.

and the depreciation rate Π_e:

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

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

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

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

$$\mathbb{\Pi}_w(l) = \mathbb{\Pi}_w^*(l^*)\Pi_e \tag{12}$$

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 TFP growth 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 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 monetary policy by the fixed exchange rate may render full employment in both regions unachievable.[10]

The most significant source of regional asymmetry in the model is the labor market. To illustrate how labor market heterogeneity can give rise to diverging TFP paths under fixed exchange rates, consider the long-run Phillips curve $\mathbb{\Pi}_w(l) = \check{\Pi}_w - \mu(1-l)$, 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

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

reflecting the constraint that the fixed exchange rate imposes on the set of achievable

[10]Relatedly, Schmitt-Grohé and Uribe (2016) highlight that in a small open economy downward nominal wage rigidity coupled with fixed exchange rates can lead to higher average unemployment over the business cycle.

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.[11] For example, if $\mu/\mu^* = 1$, and 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 $l = 1 > l^*$.[12] Consequently, F experiences persistent unemployment and subpar TFP growth – a low-growth trap. F 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 finite 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 assumptions: (i) the two economies are on a BGP; (ii) the production function (2) establishes a link between goods price inflation Π_H, Π_F, wage inflation $\Pi_w(l), \Pi_w^*(l^*)$, and TFP growth rates g, g^*;[13] (iii) the relative law of one price holds.[14]

[11] The Phillips curve in equation 4 is not defined for employment levels above 1, and thereby precludes a discussion of the possibility of overheating H in an attempt to increase employment in F and thereby counter output divergence. We analyze this policy scenario in Section 5.3.

[12] For 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.

[13] Adding non-tradable goods to the model does not change the factor price equalization result. 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 uncovered interest rate parity (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 in limiting the set of parameter choices that are consistent with a BGP. For UIP to hold, the model requires H- and F-households to aggregate their consumption of regional goods as described in equation (1).

[14] Empirical evidence in support of the stationarity of relative prices across regions is presented by Crucini and Shintani (2008). With a half-life of about 1.5 years among OECD cities, the median level of persistence in law of one price deviations is low.

A **long-run tradeoff between wage inflation and employment** has been theoretically derived in environments with downward nominal wage rigidity (DNWR): 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 (Tobin, 1972; Akerlof et al., 1996; Benigno and Ricci, 2011). The widely documented prevalence of DNWR 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 (i) the degree of DNWR and (ii) firm profit volatility. (i) For high degrees of DNWR fewer wages are cut, and a larger fraction of firms pays wages above the efficient level, resulting in a higher unemployment level (Akerlof et al., 1996; Abbritti et al., 2021). It is important to note that the degree of DNWR 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 DNWR being associated with higher structural wage inflation rates.

Empirical studies document substantial differences in the degree of DNWR across countries. For the euro area, Holden and Wulfsberg (2008) and Babecký et al. (2010) find that the degree of nominal wage rigidity differs substantially across countries. The observed differences in DNWR 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 employment protection legislation have all been argued to contribute to nominal wage rigidity.[15] With respect to these institutional factors, euro area member states exhibit a considerable degree of heterogeneity.[16]

[15]On the theory side, Lindbeck and Snower (1989) show that DNWR is more severe when permanent contracts are prevalent. 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 DNWR. 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.

[16]For 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.

(ii) The second source of cross-country differences in structural wage inflation are cross-country differences in firm profit volatility, which can originate in macroeconomic volatility or cross-sectional volatility. The intuition is straightforward: the larger the profit volatility a firm faces, the higher the probability that the downward wage rigidity constraint binds. At the aggregate level, the higher volatility gives rise to higher long-run unemployment for a given degree of wage rigidity and a given long-run wage inflation level (Benigno and Ricci, 2011).

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?[17]

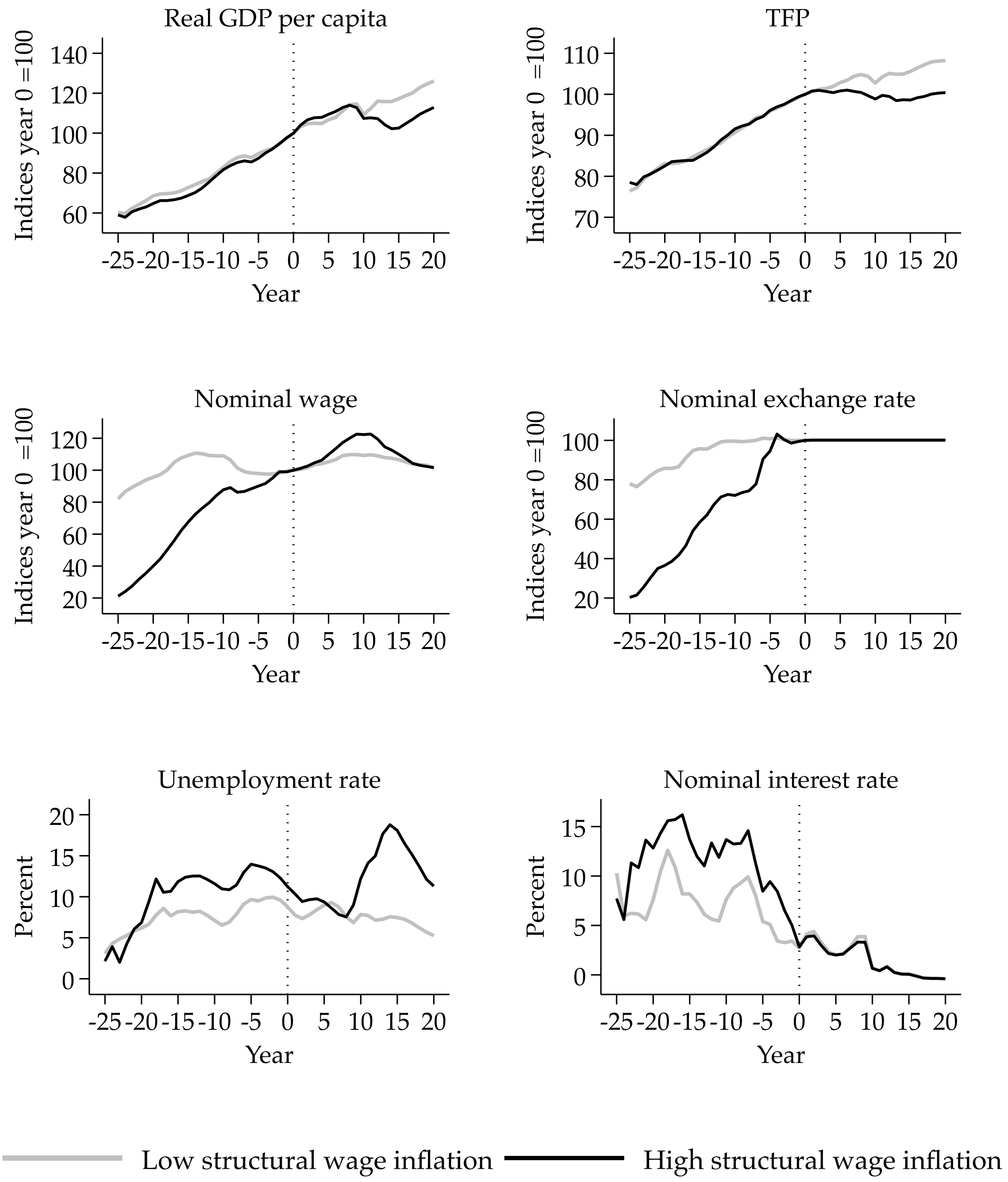
To address this question we measure relative structural wage inflation, $ln(\Pi_w^*/\Pi_w)$, as a country's pre-peg nominal wage inflation relative to Germany – the base country. In particular, we use 15-year backward looking moving averages of nominal wage trend growth for this purpose.[18] We then classify countries as high structural wage inflation countries if their relative structural wage inflation at the time of euro entry exceeds the median structural wage inflation across all countries. The complementary group of countries makes up the low structural wage inflation category.

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. Countries with low structural wage inflation rates – Austria, Belgium, Finland, France, Germany, Luxembourg, Ireland, and the Netherlands – experience no major trend breaks upon fixing their exchange rate. By contrast, countries with higher structural wage inflation rates –

[17]Up 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 euro in 1999 nominal exchange rates became irrevocably fixed.

[18]We use the HP-filter with smoothing parameter λ set to 6.25 for detrending (Hodrick and Prescott, 1997). 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.

Figure 3: Nominal convergence and real divergence



Notes: Low structural wage inflation countries: Austria, Belgium, Finland, France, Germany, Luxembourg, Ireland, and the Netherlands. High structural wage inflation countries: Cyprus, Estonia, 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.

Cyprus, Estonia, Italy, Greece, Malta, Portugal, Spain, Slovak Republic, and Slovenia – grew very differently after fixing the exchange rate than before. In particular, nominal convergence in exchange rates, wage growth, and nominal interest rates was accompanied by a slowdown in the trend growth rates for 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 formally test the model's output divergence prediction, we conduct a regression analysis based on a sample of 27 developed countries between 1970 and 2019.[20] Our empirical approach relies on the local projection (LP) method (Jordà, 2005). In particular, we estimate the following sequence of fixed effect models:

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

for horizons $h = 0, 1, ..., H$, countries $i = 1, ..., N$, and periods $t = t_0, ..., T$. $z_{i,t+h}$ is the outcome variable of interest. Our main outcome variable is the natural logarithm (ln) of utilization-adjusted TFP, but we also consider other productivity indicators.[21] $\alpha_{i,h}$ denotes horizon-specific country fixed effects. $\boldsymbol{x}_{i,t}$ 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 ($e_{i,t}$) and the structural inflation rate differential ($s_{i,t}$). These coefficients delineate a cumulative impulse response function (IRF) that describes the TFP effect of fixing the exchange rate in a country whose structural inflation rate exceeds that of its base country by 1 percentage point. Throughout, we consider a maximum projection horizon of 10 years, $H = 10$. We use Driscoll-Kraay standard errors to accompany each point estimate with a confidence interval that accounts for cross-sectional and temporal dependencies in the data (Driscoll and Kraay, 1998).

[19] Appendix B.1 shows the GDP per capita and TFP time series for individual countries.

[20] Except for euro area member states, there exist few examples of developed countries switching from a flexible to a fixed exchange rate regime in our sample. Our dataset thus primarily reflects the experience of the 19 euro area member states contained in it. The other eight developed countries included in the sample are Australia, Canada, Denmark, Japan, New Zealand, the United States, the United Kingdom, and Switzerland.

[21] We adjust the TFP series for capital and labor utilization following the procedure outlined in Imbs (1999). For details on the adjustment procedure see Appendix A.1. Regressions with non-adjusted TFP as the dependent variable yield similar results (Appendix B.4.4).

As we are interested in the long-run effect of fixing the exchange rate, we set $e_{i,t}$ to 1 only if country i has a peg in period t and stays a peg for the next H years. Analogously, $e_{i,t}$ equals 0 only if country i has a flexible exchange rate in period t and stays floating for the next H years. $s_{i,t}$ measures the structural wage inflation rate of country i relative to its base country. A significantly negative estimate for β_h therefore indicates that a positive structural wage inflation differential lowers productivity h years after fixing the exchange rate.

As before, we measure relative structural inflation as a country's pre-peg nominal wage inflation rate relative to the base country. We use the same 15-year backward looking moving averages of nominal wage trend growth to separate structural from transitory inflation. Germany is the base country for euro area member states. Otherwise, base countries are set according to the exchange rate regime classification dataset by Ilzetzki et al. (2019). We consider a currency peg to begin in the year in which a country's exchange rate regime becomes classified as "no separate legal tender" or "pre announced peg or currency board arrangement".

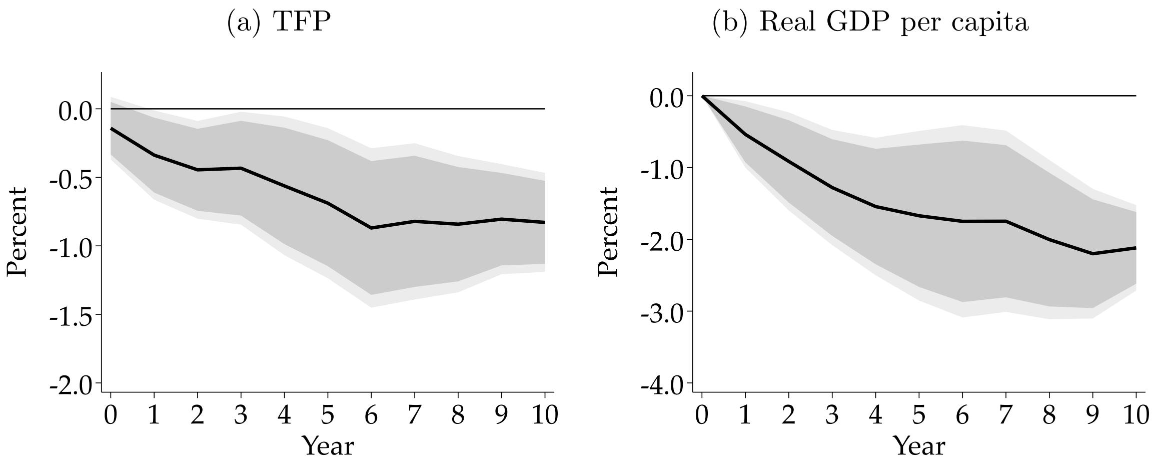
Our choice of controls follows that of two closely related studies: Aghion et al. (2009) and Jordà et al. (2020). In particular, $\boldsymbol{x}_{i,t}$ includes the dependent variable's growth rate, ln real GDP per capita in USD, ln real consumption per capita, ln real investment per capita, the ln domestic private credit to GDP ratio, the ln trade to GDP ratio, the ln government consumption to GDP ratio, CPI inflation, real GDP per capita growth in local currency, ln schooling, relative structural inflation, and the exchange rate regime indicator. Following Aghion et al. (2009), we also include the interaction term between the domestic private credit to GDP ratio and the exchange rate regime indicator to account for the negative relationship between exchange rate volatility and foreign credit access. Following Jordà et al. (2020), we include global real GDP growth to account for global business cycle dynamics.[22] In addition to the control variables used in Aghion et al. (2009) and Jordà et al. (2020), we include the ln service sector share of GDP to account for slower TFP growth in the service sector (Mano et al., 2015). We only include the contemporaneous values of all slow-moving level controls. For growth rate variables, we also include two lags to account for fluctuations at the business cycle frequency.[23] For the dependent variable's growth rate, we do not include the contemporaneous value, as it is part of the outcome of interest.

We also include the cumulative leads, between $t-1$ and $t+h$, of the following three variables, to account for alternative mechanisms through which fixing the exchange rate

[22] Using sample real GDP growth instead of global real GDP growth gives similar results.

[23] By including the contemporaneous values of all control variables, we are implicitly assuming that none of them exhibits an on-impact response to a change in the exchange rate regime. The results, however, are robust to replacing all contemporaneous values with lagged ones (Appendix B.4.2).

Figure 4: Productivity and output trajectories after pegging with a nominal wage inflation differential of +1 ppt



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

might affect TFP growth: first, the net-foreign-asset-to-GDP ratio, to account for capital misallocation during the capital inflow bonanzas that often ensue when fixing the exchange rate (Reis, 2013; Aguiar et al., 2014; Gopinath et al., 2017).[24] Second, the value-added share of the manufacturing sector, to account for potential post-peg shifts in comparative advantage and sectoral structure, away from manufacturing towards sectors with lower TFP growth (Bergin and Corsetti, 2020). Third, the share of goods imports from China to total goods imports, to account for differences in exposure to Chinese import competition in the aftermath of China's 2001 WTO accession (Bloom et al., 2016; Dorn et al., 2020). Appendix A gives a detailed description of all variables' definitions and data sources.[25]

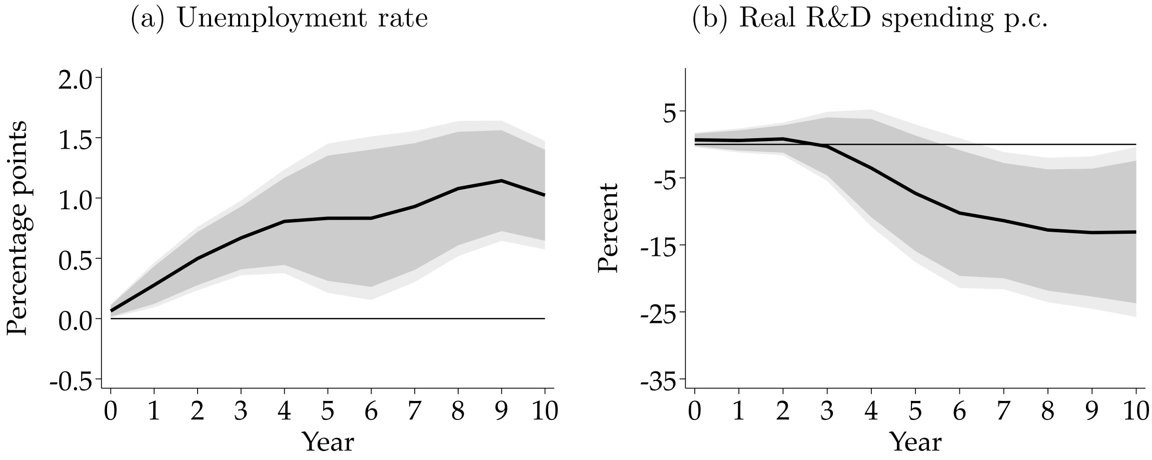
3.2. Results

Does fixing the exchange rate result in lower TFP and output growth for countries with high structural wage inflation? Figure 4 presents the answer provided by the cumulative IRF estimates: upon fixing the exchange rate, countries with high structural wage inflation exhibit a shortfall in TFP and output growth. In particular, ten years after pegging, a country with a structural wage inflation differential of +1 percentage point (ppt) has a

[24]The results are robust to using the cumulative change of the net-foreign-asset position instead of the corresponding GDP ratio.

[25]While we saturate the baseline specification with a rich set of controls (Stock and Watson, 2018), we obtain similar results for a parsimonious specification that, besides the interaction term between the exchange rate regime and relative structural wage inflation, only includes two lags of TFP growth, the exchange rate regime indicator, and the relative structural wage inflation rate among the explanatory variables (Appendix B.4.1).

Figure 5: Unemployment and R&D trajectories after pegging with a nominal wage inflation differential of +1 ppt



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

0.8% lower TFP level and a 2% lower real GDP per capita level.[26]

According to the model proposed in section 2, the negative output growth effect of pegging in countries with high structural wage inflation stems from a shortfall in aggregate demand that implies a lower employment level and a decrease in R&D investment. The IRF estimates presented in Figure 5 are consistent with this mechanism: ten years after fixing the exchange rate, a country with a structural wage inflation differential of +1 ppt suffers from a 1 to 2 ppt higher unemployment rate and a 13% lower real R&D spending level per capita.[27]

This divergence finding is robust to a variety of robustness checks. First, we obtain similar results when using alternative measures of the structural inflation differential (Appendix B.2): varying the pre-peg time window used for calculating the structural in-

[26]By using utilization-adjusted TFP, our result is less sensitive to the impact of economic crises during the regression horizon than the unadjusted TFP series. Nevertheless, to see to which extent the Global Financial Crisis and the euro area debt crisis affect our baseline findings, we also add leads of the cumulative change of a financial crisis indicator to the set of controls. For each country, the financial crisis indicator is set to 0 at the beginning of the sample. The indicator then increases by 1 unit for each year that a country subsequently finds itself in a financial crisis as defined by Reinhart and Rogoff (2009) and Lo Duca et al. (2017). By thus tracing the total number of years a country spent in financial crisis, we can use the cumulative change in this variable between t and $t+h$ to control for financial crisis effects throughout the projection horizon. Figure B.10 in Appendix B.4.3 shows that our results remain robust to the inclusion of the crisis indicator.

[27]Using private sector real R&D spending instead of total real R&D spending as the outcome variable yields similar results (see Appendix B.4.5). Two additional controls are added when analyzing the R&D spending to account for substantial cross-country heterogeneity in the R&D tax credit during our sample period. These tax incentives can have a substantial effect on R&D spending (Thomson, 2017). We therefore include leads of the implied tax subsidy rate on R&D expenditure for SMEs and large enterprises. The implied tax subsidy rates are only available after 1995. The consequent lack of time variation in the structural wage inflation differential prevents us from also including country fixed effects.

flation differential does not affect the findings (Appendix B.2.1). The use of an indicator of the degree of downward nominal wage rigidity (Knoppik and Beissinger, 2009) – a labor market characteristic that underlies the structural wage inflation differential – yields comparable findings (Appendix B.2.2). We also corroborate the findings based on the pre-peg exchange rate depreciation trend – an equivalent measure of the structural wage inflation differential in theory (equation 12) (Appendix B.2.3). Second, we obtain similar results when accounting for dynamic heterogeneity (Pesaran, 2006; Canova, forthcoming) (Appendix B.3): results for different subgroups of countries are similar, indicating that any bias due to dynamic heterogeneity is small (Appendix B.3.1). In addition, we apply a methodological approach that estimates treatment effects for each euro area member individually before averaging across core and periphery countries – the synthetic control method, which yields comparable findings (Abadie and Gardeazabal, 2003; Abadie et al., 2010; Cavallo et al., 2013) (Appendix B.3.2). Finally, Appendix B.4 presents corroborating findings based on a variety of alternative specifications that use (i) a parsimonious set of controls (Appendix B.4.1), (ii) a control vector that excludes contemporaneous control variables (Appendix B.4.2), (iii) additional controls for lead financial crises (Appendix B.4.3), (iv) non-adjusted TFP as dependent variable (Appendix B.4.4), and (v) private sector performed R&D as dependent variable (Appendix B.4.5).

4. A two-region endogenous growth model

In this section, we continue the analysis with a medium-size dynamic general equilibrium (DGE) model. The DGE model serves two purposes: First, it provides the microfoundation 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 and the policy discussion in section 5.

4.1. Model environment

The model is an open economy 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 goods producers' 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:

$$\mathbb{E}_0 \sum_t^{\infty} \beta^t \frac{c_t^{1-\sigma} - 1}{1-\sigma}. \tag{15}$$

$\beta \in (0,1)$ is the time discount factor. $\sigma > 0$ 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:

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

$B_{H,t}$ 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.[28] Investing in foreign currency denominated bonds is subject to a quadratic adjustment cost $Adj_t = \frac{\bar{A}_t P_t^* e_t}{R_t^*} \frac{K}{2} \left(\frac{B_{F,t}}{\bar{A}_t P_t^*} - o \right)^2$, where $\bar{A}_t$ is the average productivity of H and F and $K > 0$ is the adjustment cost parameter.[29] The adjustment costs are rebated back to households in a lump-sum fashion.

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.[30] At the beginning of each period, with an exogenous probability ρ, 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 $u_t = 0$

[28] As before, 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.

[29] This functional form helps to ensure that a balanced growth path exists.

[30] The unemployment risk helps 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).

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 lump-sum tax for employed households and an unemployment benefit for unemployed households. The tax on employed households is levied to finance unemployment benefits.

Final goods sector

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

$$\max_{\{x_{j,t}\}_j, l_t} P_{H,t}y_t - \int_0^1 P_{H,j,t}x_{j,t}dj - W_t l_t \tag{17}$$

$$\text{s.t. } y_t = l_t^{1-\alpha} \int_0^1 A_{j,t}^{1-\alpha} x_{j,t}^{\alpha} dj, \tag{18}$$

with $\alpha \in (0,1)$. $x_{j,t}$ denotes the H-produced intermediate goods.[31] 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 good. 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:

$$\alpha P_{H,t} l_t^{1-\alpha} A_{j,t}^{1-\alpha} x_{j,t}^{\alpha-1} = P_{H,j,t}, \quad \forall j \tag{19}$$

$$(1-\alpha) P_{H,t} l_t^{-\alpha} \int_0^1 A_{j,t}^{1-\alpha} x_{j,t}^{\alpha} dj = W_t \tag{20}$$

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 a monopolistic intermediate goods producer that engages in innovation.[32]

[31] In the baseline model, final goods firms produce with locally produced intermediate goods. Allowing foreign-produced intermediate goods to enter production can lead to cross-border technology spillovers. We analyze an extended model with technology spillovers in Appendix C.5.

[32] This setup corresponds to the model environment where innovation is carried out by incumbent firms instead of entrants (Barro and Sala-i Martin, 2003, chapter 7). Following Barro and Sala-i Martin (2003), we assume that existing firms enjoy a cost advantage in research with respect to entrants. The cost advantage is sufficiently large so that all innovation activity is performed by incumbents. This modeling choice is motivated by the data. First, in countries with low entry costs, e.g. the U.S. and

The intermediate goods producer produces one unit of the intermediate good, using one unit of the domestic final good purchased for $P_{H,t}$. The intermediate good is associated with a productivity of $A_{j,t}$ in the final goods production process. The monopolistic intermediate goods producer then sets the optimal price $P_{H,j,t} = \xi P_{H,t}$, with $\xi \equiv 1/\alpha$. Combined with the final goods producers' optimality conditions, (19) and (20), we have

$$x_{j,t} = \left(\frac{\alpha}{\xi}\right)^{1/(1-\alpha)} A_{j,t} l_t \tag{21}$$

$$y_t = A_t l_t \left(\frac{\alpha}{\xi}\right)^{\alpha/(1-\alpha)} \tag{22}$$

where $A_t \equiv \int_0^1 A_{j,t} dj$ measures the average productivity of H-produced intermediate goods.

The quality of the intermediate good, i.e. its productivity, can be improved through investment into innovation. At the beginning of each period, the intermediate goods producer turns out intermediate goods of productivity level $A_{j,t}$. The productivity level is inherited from the end of last period. Then, with probability $\eta \in (0, 1)$, the intermediate goods producer ceases to exist and is replaced by another firm that obtains its technology. If the intermediate goods producer survives, it decides how much to invest into innovation. With some probability $q_{j,t}$ the innovation is successful and the intermediate goods producer discovers an upgraded version of its intermediate good that has productivity $A_{j,t+1} = \gamma A_{j,t}$, $\gamma > 1$. If the innovation is not successful, the productivity of the intermediate good remains unchanged: $A_{j,t+1} = A_{j,t}$.

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 profit that comes with 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

Denmark, new entrants' contribution to aggregate TFP growth amounts to around 1/4 (Bartelsman and Doms, 2000; Foster et al., 2001; Lentz and Mortensen, 2008; Akcigit and Kerr, 2018; Garcia-Macia et al., 2019). Moreover, euro area countries generally have higher administrative entry costs (Djankov et al., 2002), potentially reducing the number of entries. Djankov et al. (2002) calculate the entry costs to be around 1.7% of GDP in the US and 11.2% in Denmark. Entry costs are much higher in most European countries, e.g., 31% in the Netherlands, 33% in Germany, 35% in France, 42% in Austria, 45% in Italy, 49% in Portugal, 50% in Spain, and 73% in Greece.

productivity level:[33]

$$\begin{aligned} q_{j,t} &= \min\left[\chi\left(\frac{I_{j,t}}{A_{j,t}}\right)^{\kappa}, \quad 1\right], \quad \kappa \in (0,1] \\ &= \min\left[\chi Z_{j,t}^{\kappa}, \quad 1\right], \quad Z_{j,t} \equiv \frac{I_{j,t}}{A_{j,t}}. \end{aligned} \tag{23}$$

$\chi > 0$ denotes the efficacy of R&D investment and κ is the elasticity of the discovery probability with respect to R&D investment.

The end-of-period value of an incumbent firm with productivity $A_{j,t}$ is given by

$$\begin{aligned} V_t(A_{j,t}) = \quad & \mathbb{E}_t \beta\rho \frac{\lambda_{t+1}}{\lambda_t}[\Gamma_{t+1} \\ & +(1-\eta)\left[q_{j,t+1}V_{t+1}(\gamma A_{j,t}) + (1-q_{j,t+1})V_{t+1}(A_{j,t}) - P_{H,t+1}I_{j,t+1}\right]]. \end{aligned} \tag{24}$$

$\beta\rho\frac{\lambda_{t+1}}{\lambda_t}$ is the discount factor for nominal cashflows. λ_t denotes households' marginal utility of nominal income and $\frac{\lambda_{t+1}}{\lambda_t} = \left(\frac{c_{t+1}}{c_t}\right)^{-\sigma}\frac{1}{\Pi_{t+1}}$.[34] $\Gamma_{t+1} = \bar{\omega}P_{H,t+1}A_{j,t}l_{t+1}$ is the intermediate goods producer's profit in $t+1$, with $\bar{\omega} \equiv (\xi-1)\left(\frac{\alpha}{\xi}\right)^{1/(1-\alpha)}$. $(1-\eta)$ is the probability that the intermediate goods producer continues operating in $t+1$. With probability $q_{j,t+1}$, an updated version of the intermediate good is discovered, in which case the continuation value is $V_{t+1}(\gamma A_{j,t})$. With probability $(1-q_{j,t+1})$, the quality of the goods is not improved and the continuation value is $V_{t+1}(A_{j,t})$. $P_{H,t+1}I_{j,t+1}$ captures the cost of the investment in innovation.

The intermediate goods producer chooses the amount of investment $I_{j,t}$ such as to maximize the expected return on investment in innovation:

$$\max_{I_{j,t}} q_{j,t}\left[V_t(\gamma A_{j,t}) - V_t(A_{j,t})\right] - P_{H,t}I_{j,t}, \quad \text{s.t.} \quad (23).$$

We focus on symmetric equilibria in which investment in innovation is positive and finite with $V_t(A_{j,t}) = V_t A_{j,t}$, $\forall j$. We can then derive the following relationship:

$$\begin{aligned} 1 = \quad & Z_t^{\kappa-1}\mathbb{E}_t\frac{\lambda_{t+1}}{\lambda_t}\Pi_{H,t+1}[\Omega l_{t+1} \\ & +(1-\eta)\beta\rho[\frac{1}{Z_{t+1}^{\kappa-1}} + (\gamma-1)\ (1-\kappa)\ \chi\, g_t\, Z_{t+1}]] \end{aligned} \tag{25}$$

where $\Omega \equiv \chi\beta\rho\bar{\omega}$. The symmetry of industries with respect to the discovery probability

[33] This reflects the increasing difficulty of achieving innovation on already mature products and ensures model stationarity. In the baseline model, we assume no cross-border technology spillovers. Appendix C.5 introduces a model with cross-border technology spillovers and discusses its quantitative implications.

[34] The use of households' marginal utility of nominal income and the unemployment probability ρ in this discount factor reflects the ownership of firms by local households.

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, average region productivity evolves according to

$$A_{t+1} = q_t \gamma A_t + (1 - q_t) A_t. \tag{26}$$

The average productivity growth rate is

$$g_{t+1} \equiv \frac{A_{t+1}}{A_t} = q_t \gamma + (1 - q_t). \tag{27}$$

Wage and price inflation

In equilibrium, the final goods price level is linked to the wage level and the technology level. Using (20) and (21), we have

$$P_{H,t} = \frac{W_t}{A_t} \frac{1}{1-\alpha} \left(\frac{\xi}{\alpha} \right)^{\frac{\alpha}{1-\alpha}}. \tag{28}$$

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

$$\Pi_{H,t} = \frac{\Pi_{w,t}}{g_t}, \tag{29}$$

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

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

$$\Pi_{w,t} \;=\; \sqcap_w(1 - l_t, \mathbb{E}_t \Pi_{t+1}), \quad \frac{\partial \sqcap_w}{\partial (1 - l_t)} < 0, \quad \frac{\partial \sqcap_w}{\partial \mathbb{E}_t \Pi_{t+1}} > 0, \quad \check{\Pi}_w = \sqcap_w(l = 1). \tag{30}$$

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.[35]

Monetary policy

Monetary policy follows a dynamic version of the policy rules described in the simple model (equations (6) and (7)). The nominal interest rate therefore reacts to the contem-

[35] To the extent that CPI-indexation is typically imperfect (Babecký 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.

poraneous employment level

$$R_t = \mathbb{R}(l_t) = \begin{cases} \Upsilon\, l_t^{\phi}, \text{ if flexible exchange rates} \\ \Upsilon_u \, \left(l_t^{\tau}\, l_t^{*1-\tau}\right)^{\phi^u}, \text{ if fixed exchange rates} \end{cases} \tag{31}$$

$$R_t^* = \mathbb{R}^*(l_t^*) = \begin{cases} \Upsilon^*\, l_t^{*\phi^*}, \text{ if flexible exchange rates} \\ \text{a rate that ensures } \Pi_{e,t} = 1, \text{ if fixed exchange rates} \end{cases} \tag{32}$$

Market clearing

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

$$y_t = \int_0^1 x_{j,t} dj + c_{H,t} + c_{H,t}^* + \int_0^1 I_{j,t} dj \tag{33}$$

$$y_t^* = \int_0^1 x_{j,t}^* dj + c_{F,t} + c_{F,t}^* + \int_0^1 I_{j,t}^* dj. \tag{34}$$

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

$$GDP_t = y_t - \int_0^1 x_{j,t} = \Psi A_t l_t \tag{35}$$

$$GDP_t^* = \Psi^* A_t^* l_t^*, \tag{36}$$

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

$$B_{H,t} + B_{H,t}^* = 0 \tag{37}$$

$$B_{F,t} + B_{F,t}^* = 0. \tag{38}$$

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.

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, $\rho^* = \rho$.[36]

The model variables can be categorized into four 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; (3) those that grow at the same rate as F-TFP, (4) and those that grow at the same rate as the average-TFP. To transform the model into one with a stationary equilibrium, we normalize variables belonging to the second group by H-TFP, those belonging to the third group by F-TFP, and those belonging to the fourth group by average-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.[37] In particular, on the demand side we have

$$1 = \beta\rho \frac{\mathbb{R}(l)}{\Pi_w(1-l)} \bar{g}^{1-\sigma} \tag{39}$$

$$1 = \beta\rho \frac{\mathbb{R}^*(l^*)}{\Pi_w^*(1-l^*)} \bar{g}^{1-\sigma}. \tag{40}$$

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. Under

[36] Alternatively, 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.

[37] Appendix C.2 provides a detailed derivation of the equation system that characterizes the BGP.

our baseline calibration, the nominal interest rate's reaction to changes in employment level outweighs the effect of the employment level on wage inflation, $\partial(\mathbb{R}(l)/(\Pi_w(1-l))/\partial l > 0$ and $\partial(\mathbb{R}^*(l^*)/(\Pi^*_w(1-l^*))/\partial l^* > 0$, which implies a positive relationship between the employment level and the real interest rate and, at the same time, ensures local determinacy.

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

$$1 = \bar{g}^{1-\sigma} g^{-1} \left[\Omega l \left(\frac{g-1}{(\gamma-1)\chi} \right)^{1-1/\kappa} + (1-\eta)\beta\rho[1 + g(g-1)(1-\kappa)] \right] \quad (41)$$

$$1 = \bar{g}^{1-\sigma} g^{*-1} \left[\Omega^* l^* \left(\frac{g^*-1}{(\gamma^*-1)\chi^*} \right)^{1-1/\kappa} + (1-\eta)\beta\rho[1 + g^*(g^*-1)(1-\kappa)] \right] \quad (42)$$

An increase in l has two opposite effects on g for any given level of g^*. First, an increase in l implies a larger market size, which raises the potential profit from innovation and thus increases productivity growth. Second, decreasing returns to R&D investment ($\kappa < 1$) imply that the probability of discovery is lower when the productivity growth is already high, i.e., when l is high. In this way high l can also discourage R&D investment and thus lower productivity growth. Under our baseline calibration, the first effect dominates. Thus, H-TFP growth is increasing in H-employment for any given level of F-TFP growth.

As in the simple model, nominal wage inflation in H and F are linked according to equation (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 an idea of how large the long-run growth impact of eliminating all nominal exchange rate flexibility under the euro might be, and to provide a quantitative framework for policy discussion.

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 euro area countries with low structural wage inflation rates. F corresponds to euro area countries with high structural wage inflation rates. In the following, we will also refer to the H region as "core", and the F region as "periphery". 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 exit probability of the intermediate goods producers, $\eta = \eta^*$, to 0.114. This implies an annual probability of exit 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).[38] Based on pre-euro data from 1972 onward, we set the efficacy of investment parameters to target an average full employment TFP growth rate of 1.2%, which implies $\chi = 1.4$ and $\chi^* = 2.3$.[39] H and F labor income shares are set to target average R&D to GDP ratios of 2.1% and 0.8%, respectively, implying $\alpha = 0.29$ and $\alpha^* = 0.09$.

The effect of the exchange rate regime on TFP growth hinges on the long-run tradeoff between wage inflation and employment. For the calibration, we assume a log-linear functional form for the wage Phillips curve in F[40]

$$\ln \Pi^*_{w,t} \quad = \quad \ln \check{\Pi}^*_w - \mu^*(1 - l^*_t) + \psi^* \ln \mathbb{E}_t \Pi^*_{t+1}, \quad \mu^* > 0, \quad \psi^* \in (0, 1), \tag{43}$$

where μ^* reflects the steepness of the wage Phillips curve 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 exchange rate regimes (see section 2), the functional form and the parametrization of the H wage

[38] The 0.9 value for κ is comparable with the calibration practice in the related literature (Comin and Gertler, 2006; Kung and Schmid, 2015).

[39] 1972 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 European 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). Under these exchange rate arrangements, the exchange rates among many European currencies fluctuated within a pre-specified band. This soft peg regime 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 the German Mark.

[40] While 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 purpose. This is because the wage Phillips curve that we use in the calibration exercise only needs 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.

Table 1: Calibration

Parameters		Value	Source/Target
γ, γ^*	Innovation step	1.55	Probability discovery 3.6% Howitt (2000)
η, η^*	Probability patent expires	0.114	Kung and Schmid (2015)
κ, κ^*	Elasticity of discovery probability to investment in innovation	0.9	Guerron-Quintana and Jinnai (2019)
χ	Innovation productivity	1.42	H TFP growth rate 1.2%
χ^*	Innovation productivity	2.31	F TFP growth rate 1.2%
$1-\alpha$	Labor income share	0.71	H R&D-to-GDP ratio 2.1%
$1-\alpha^*$	Labor income share	0.91	F R&D-to-GDP ratio 0.8%
μ^*	F wage eq. slope	0.6	Estimation of the F long-run wage Phillips curve
ψ^*	F wage indexation	0.35	Average F CPI indexation
$\check{\Pi}_w$	H structural wage inflation	1.06	H nominal wage inflation of 8% p.a.
$\check{\Pi}_w^*$	F structural wage inflation	1.10	F pre-peg nominal wage inflation relative to H of 6% p.a.
$1/\sigma$	Elasticity intertemporal substitution	1/2	Standard value
β	Time discount factor	0.98	Real interest rate 1.02
θ	Consumption basket	0.38	F share of GDP
K, K^*	Portfolio adjustment costs	0.001	Schmitt-Grohé and Uribe (2003)
ρ	Prob. unemployment	1.04	H nominal interest rate 1.07 p.a.
ϕ, ϕ^*, ϕ^u	Monetary policy reaction	1.5	Local determinancy
τ	Weight in the union monetary policy	0.62	H share of GDP
o, o^*	Foreign asset holding	0	Balanced trade on long-run equilibrium

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 a 1 percentage point increase in the long-run unemployment rate is associated with a 0.6 percentage point decrease in the long-run wage inflation rate, conditional on CPI expectations. This result leads us to set $\mu^* = 0.6$. Appendix C.4 describes the wage Phillips curve estimation in greater detail.[41] We set the CPI-indexation parameter, ψ^*, to 0.35, which corresponds to the average fraction of firms that report having an internal policy that adjusts wages to inflation in the four main countries with high structural wage inflation – Italy, Greece, Portugal, and Spain (Druant et al., 2009).[42]

We set $\check{\Pi}_w$ to 1.06. This leads to a long-run wage inflation of 8% p.a., corresponding to the average nominal wage inflation in the group of countries with low structural wage inflation between 1972 and their euro entry date. This assumes that, on average, H 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

[41] An alternative way to quantitively 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 Appendix C.4 .

[42] The results in Druant et al. (2009) are based on the 2007-2008 firm level survey developed within the Wage Dynamics Network. An internal policy adapting wages to inflation does not just include cases where wages are linked to inflation through a formal rule, but also cases where inflation is (informally) considered in wage negations. The four countries together account for more than 90% of the total population of the F region.

aftermath of fixing the exchange rate. Based on H's wage inflation at full employment, we set $\check{\Pi}_w^*$ to target an annual nominal wage inflation in F that is 6% higher than in H. This value corresponds to the average difference in nominal wage inflation between the euro area's core and periphery 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.[43] The inverse of the elasticity of intertemporal substitution σ equals 2, and the time discount factor β equals 0.98. We set the weight of F produced final goods in the consumption bundle, θ, equal to 0.38 – a value that corresponds to the periphery's average GDP share between 1972 and 2019 and thus eliminates home-bias in consumption. Following Schmitt-Grohé and Uribe (2003), we set the portfolio adjustment cost parameters, K and K^*, to 0.001. We set ρ to 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 H prior to the introduction of the euro. The monetary policy reaction parameters ϕ, ϕ^*, and ϕ^U equal 1.5, which ensures local determinacy.[44] The weight in the union-wide monetary policy τ is set to 0.62, reflecting the average share of H GDP. Finally, for the baseline calibration, we assume that the current account is balanced in the long run $o = o^* = 0$. Assuming different levels for the long-run external balance has a negligible impact on the results.

5.2. Quantitative results

What are the growth implications of fixing the exchange rate in the calibrated model? H – the euro area's core – maintains full employment and maximum TFP growth after the regime change. By contrast, F – the periphery – 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 F, the steady-state employment rate decreases by more than 6 percentage points, whereas steady-state employment in H remains unchanged. Regarding TFP growth, H's annual steady-state growth rate slightly increases after fixing the exchange rate, while F's growth rate decreases by about 0.3 percentage points. The decline in the F region's TFP growth rate implies a decline in the euro area's average TFP growth rate of 0.09 percentage points. Note that this decline in

[43] Appendix A describes the data we use in detail.

[44] Between 2012 and 2022 the ECB's main policy rate's reactivity was constrained by the zero lower bound (ZLB). While this may have contributed to actual inflation falling short of the union wide inflation target, and thus affected aggregate outcomes for the euro area as a whole, the difference in core and periphery wage Phillips curves implies that output divergence continues in a ZLB environment. Only if core and periphery wage Phillips curves happened to converge or diverge for low inflation levels would a ZLB episode alter the output divergence trend. Neither theory nor data suggest that there exists a relevant interaction between the ZLB and the output divergence dynamics we focus on.

Table 2: Steady states

	Employment		GDP growth		
	H	F	H	F	Whole area
	l	l^*	g	g^*	$\bar{g}$
Flexible	1.00	1.00	1.012	1.012	1.012
Fixed	1.00	0.94	1.012	1.009	1.011
Changes (ppt)	0	-6.31	0.04	-0.30	-0.09

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

TFP growth is reflected in correspondingly lower consumption growth rates in H as well as F.

Overall, the quantitative results of the model are comparable to that of the empirical analysis. Given F's long-run wage inflation fell by around 6 ppt upon adopting the euro, the empirical results in section 3 imply an increase in the unemployment rate of around six percentage points, similar to what the calibrated model implies. The empirical results also indicate that the TFP level shortfall cumulates to around 4.8% within ten years of fixing the exchange rate. The calibrated model generates a 3% TFP shortfall over the same time horizon, thus accounting for 60% of the empirical finding.

Table 3 displays the cumulative GDP effect that the steady state growth rate changes imply. Together with the level effect on GDP due to lower employment, small changes in steady-state growth rates can imply substantial output losses, when cumulated over the years. After 10 years, F's output under fixed exchange rates is around 9% lower than it would have been under flexible exchange rates. The annual output loss increases to 12% after 20 years, and almost 19% after 50 years. By contrast, fixing the exchange rate has a minimal effect on H's GDP. Even after 50 years, H's GDP is only about two percent higher under fixed exchange rates than under the flexible exchange rate counterfactual. Overall, average TFP in the euro area growth thus declines, resulting in a 5% loss of welfare, as measured by comparing certainty equivalent consumption on the BGP under fixed and flexible exchange rates.[45]

In sum, the growth 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 cost exceeds that implied by most existing analysis

[45]The welfare measure is computed as the percentage change in steady-state consumption that would make the household indifferent between the the initial steady-state under flexible exchange rates and the new steady state under fixed exchange rates. The welfare measure neglects the transition phase, because multiple transition paths may exist. Under the baseline calibration, with balanced external accounts, fixing the exchange rate has the same welfare effect in H and F, because both regions consume the same consumption bundle.

Table 3: GDP changes relative to flexible exchange rate baseline

Years after fixing	10	20	50
H	-0.05%	0.39%	1.75%
F	-8.78%	-11.52%	-19.25%

which focus on the volatility effects of fixing the exchange rate. Our analysis particularly cautions against pre-maturely fixing the exchange rate between regions whose structural wage inflation rates have not yet converged.

5.3. Policy discussion

5.3.1 Labor market convergence

Which economic policies are most promising in countering output divergence in the euro area? The (theoretically) trivial solution is to reduce the degree of labor market heterogeneity among member states. Therefore, this section analyzes how plausible alterations to the two Phillips curve parameters Π_w^*/Π_w (relative structural wage inflation) and μ^* (wage flexibility) influence output and welfare.

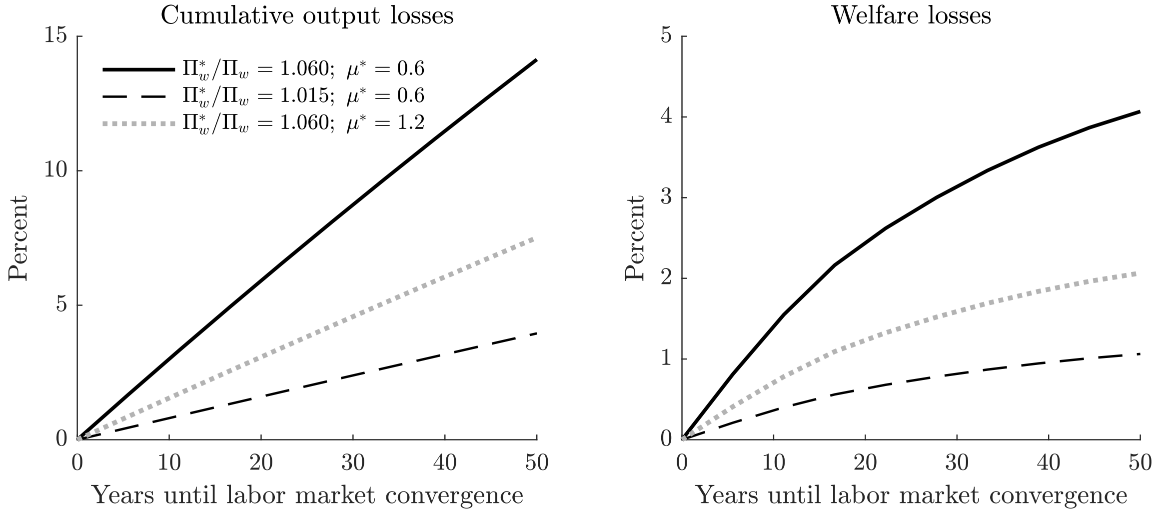
Figure 6 shows the output and welfare losses associated with different Phillips curve calibrations and varying labor market convergence horizons, ranging from 0 to 50 years. For example, the solid black lines, reflecting reference values produced by the baseline calibration, indicate that if labor market heterogeneity were to give way to labor market homogeneity after 20 years, the corresponding cumulated output and welfare losses would amount to around 5% and 2.5%, respectively. First, consider how an increase in F's wage flexibility affects output and welfare.[46] In principle, a steeper wage Phillips curve in F counters output divergence, because it implies that wage inflation equalization under a peg can be achieved through a wage adjustment rather than a quantity adjustment in the employment level. When we increase the steepness of F's Phillips curve from $\mu^* = 0.6$ to $\mu^* = 1.2$ – a value that corresponds to current best-practice estimates for the the slope of the Phillips curve in the U.S. (Barnichon and Mesters, 2021)[47] – the welfare cost of fixing the exchange rate is reduced by around half (gray dotted line).[48]

[46] The steepness of the H wage Phillips curve does not matter for our analysis, as H is at full employment under both exchange rate regimes (equation 13).

[47] Barnichon and Mesters (2021) estimate a price Phillips curve for quarterly frequency. We use their estimate at the 20-quarter horizon for the 1969Q1-1989Q4 sample as the wage Phillips curve slope for F. We multiply the quarterly frequency coefficient by 4 to translate it into an annual frequency coefficient.

[48] Note that when F's wage flexibility were to increase only H years after joining the peg, then for the initial $H-1$ years the solid black baseline lines give the correct loss values. Thereafter, output losses

Figure 6: Effect of labor market policies



Notes: solid line – result under baseline calibration. Dashed lines – result under alternative calibrations reflecting various labor market policy adjustments.

Next, consider how a decrease in the wage inflation differential Π_w^*/Π_w affects output and welfare losses. In particular, we consider a reform that decreases the relative structural wage inflation from the baseline value of 1.06 to 1.015 – a value that conforms with the Maastricht criteria's requirement that each euro area member's inflation rate remains within 1.5 ppt of the inflation rates of comparable member states with low inflation.[49] In this scenario, output and welfare losses would be cut to around one third of their values for the baseline calibration (dashed line in Figure 6). In this optimistic scenario, full labor market convergence after 20 years implies a comparatively small welfare loss of around 0.5%.[50]

would continue to increase, but at the slower rate represented by the slope of the gray dotted line.

[49] The Maastricht criteria's inflation criterion pertains to CPI inflation rather than wage inflation. However, in the model's steady state relative wage inflation equals relative CPI inflation.

[50] We have assumed that the long-run wage Phillips curve is invariant to changes in the exchange rate regime. However, joining the euro might itself have affected member states' Phillips curve parameters. According to Benigno and Ricci (2011) the position of the long-run wage Phillips curve is determined by firms' profit volatility and the degree of downward nominal wage rigidity. Therefore, to the extent that fixing the exchange rate alters macroeconomic volatility, the shape of the Phillips curve may alter too. For example, Devereux (2006) suggests that if a fixed exchange rate renders firm profits more volatile, this incentivizes firms to reduce nominal rigidity. More generally, the exchange rate regime's effect on macroeconomic volatility has long been discussed in the literature with ambiguous findings (Friedman, 1953; Baxter and Stockman, 1989; Duarte and Obstfeld, 2008; Aghion et al., 2009). To the extent that fixing euro area exchange rates did affect the shape of member states' Phillips curves, the alternative calibrations presented here can also be interpreted as optimistic lower bound estimates of the output and welfare losses associated with fixing exchange rates in the euro area.

5.3.2 Optimal common inflation target

According to the proposed model, an increase in the fixed exchange rate regime's common inflation target is another policy measure that counters output divergence. This is because the higher steady state inflation rate allows the high structural inflation region to achieve wage inflation equalization with a higher employment level, while the low structural inflation region maintains full employment. How high should the common inflation target optimally be? This depends on a comparison of the marginal benefit of closing the TFP growth gap with the marginal cost of higher steady state inflation. Since our model is silent on steady state inflation costs, we rely on the existing literature for guidance.

There exists a large empirical and theoretical literature quantifying the effect of inflation on output growth. The majority of papers finds a nonlinear relationship: the correlation between inflation and output growth is small or insignificant in the lower inflation range but unambiguously negative in the higher inflation range.[51] However, the identified threshold beyond which inflation negatively affects output growth, and the magnitude of the effect varies across studies. Given the 6 ppt observed structural inflation differential between the euro area's core and periphery, we focus on the growth effect of changes to the ECB's inflation target in the 2% to 8% range. Within this range, a 1 ppt increase in inflation has been found to be associated with a negative impact on output growth ranging from not significantly different from zero (Barro, 1995; Sarel, 1996; Bruno and Easterly, 1998) to 0.13 ppt (Fischer, 1993). Many studies report intermediate values, with a concentration towards the lower end of this range: 0.008 ppt (Arawatari et al., 2018), 0.04 to 0.05 ppt (Berentsen et al., 2012), and 0 to 0.05 (Khan and Senhadji, 2000).[52]

How does this compare to the model-derived marginal benefit of higher steady state inflation deriving from less output divergence? According to the model, a one percentage point increase in steady state inflation is associated with a 0.015 ppt higher output growth rate across the euro area as a whole.[53] This marginal benefit tends to be outweighed by the cost of inflation according to the majority of estimates cited above. Thus, increasing the common inflation target may not be optimal. A definite conclusion in this regard,

[51] See Arawatari et al. (2018) for a discussion of the literature.

[52] Another way in which higher inflation can affect welfare is through an increase in price dispersion that leads to inefficient production (Woodford, 2003). The evidence, however, does not support this notion for moderate levels of inflation ($< 20\%$ p.a.) (Burstein and Hellwig, 2008; Nakamura et al., 2018; Alvarez et al., 2019). Analogously, wage dispersion can also lead to inefficient production if wage setting is constrained by a Calvo-type nominal friction (Ascari et al., 2018; Phaneuf and Victor, 2019). If nominal wage rigidity takes the form of downward wage rigidity, however, wage dispersion is less of a concern.

[53] This marginal benefit is close to linear in inflation (Appendix C.6). The model is recalibrated to target a steady state CPI inflation rate of 2% under the peg. The targeted nominal interest rates are adjusted accordingly to ensure that real interest rates remain unchanged. The recalibration does not affect the model steady states, as it leads to a proportional change in the long-run wage inflations and nominal interest rates, see eq. (39) – (42). Thus, the recalibration does not affect our baseline results.

however, is prevented by the finding that the benefits of higher steady state inflation are of a similar magnitude as the costs, and the fact that both estimates are shrouded in uncertainty.[54]

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 presented model provides a coherent account of the recent euro area experience. Upon irrevocably fixing exchange rates, euro area members experienced trend breaks in nominal and real variables that are in line with what the model predicts. In particular, nominal convergence in interest rates and wage growth was accompanied by real divergence in TFP and output growth. When calibrated to match euro area observables, the model implies a periphery shortfall in TFP and output amounting to 5% and 12%, respectively, explaining much of the observable TFP and output divergence within the euro area. Output divergence can be countered through reforms that promote labor market convergence among member states.

[54] This conclusion is robust to assuming that higher steady state inflation carries no cost for the periphery, where higher steady state inflation closes the gap between actual and structural inflation rates. This is equivalent to the assumption that inflation only is associated with a negative output growth effect once inflation exceeds the structural inflation rate. Under this assumption, all cited inflation cost estimates need to be scaled down by a factor of 0.6 (GDP share of H) to effectively set the periphery's inflation cost to 0.

References

Abadie, Alberto, Alexis Diamond, and Jens Hainmueller. 2010. Synthetic control methods for comparative case studies: estimating the effect of California's tobacco control program. *Journal of the American Statistical Association* 105(490): 493–505.

Abadie, Alberto, and Javier Gardeazabal. 2003. The economic costs of conflict: a case study of the Basque Country. *American Economic Review* 93(1): 113–132.

Abbritti, Mirko, Agostino Consolo, and Sebastian Weber. 2021. Endogenous growth, downward wage rigidities and optimal inflation. *IMF Working Paper* .

Aghion, Philippe, Philippe Bacchetta, Romain Ranciere, and Kenneth Rogoff. 2009. Exchange rate volatility and productivity growth: the role of financial development. *Journal of Monetary Economics* 56(4): 494–513.

Aghion, Philippe, and Peter Howitt. 1992. A model of growth through creative destruction. *Econometrica* 60: 323–351.

Aguiar, Mark, Manuel Amador, Emmanuel Farhi, and Gita Gopinath. 2014. Sovereign debt booms in monetary unions. *American Economic Review* 104(5): 101–06.

Akcigit, Ufuk, and William R. Kerr. 2018. Growth through heterogeneous innovations. *Journal of Political Economy* 126(4): 1374–1443.

Akerlof, George A., William T. Dickens, George L. Perry, Robert J. Gordon, and N. Gregory Mankiw. 1996. The macroeconomics of low inflation. *Brookings Papers on Economic Activity* 1996(1): 1–76.

Alvarez, Fernando, Martin Beraja, Martin Gonzalez-Rozada, and Pablo Andrés Neumeyer. 2019. From hyperinflation to stable prices: Argentina's evidence on menu cost models. *The Quarterly Journal of Economics* 134(1): 451–505.

Arawatari, Ryo, Takeo Hori, and Kazuo Mino. 2018. On the nonlinear relationship between inflation and growth: a theoretical exposition. *Journal of Monetary Economics* 94: 79–93.

Ascari, Guido, Louis Phaneuf, and Eric R. Sims. 2018. On the welfare and cyclical implications of moderate trend inflation. *Journal of Monetary Economics* 99: 56–71.

Babeckỳ, Jan, Philip Du Caju, Theodora Kosma, Martina Lawless, Julián Messina, and Tairi Rõõm. 2010. Downward nominal and real wage rigidity: survey evidence from European firms. *Scandinavian Journal of Economics* 112(4): 884–910.

Barnichon, Regis, and Geert Mesters. 2021. The Phillips multiplier. *Journal of Monetary Economics* 117: 689–705.

Barro, Robert J. 1995. Inflation and economic growth. *NBER Working Paper* .

Barro, Robert J, and Xavier I. Sala-i Martin. 2003. *Economic growth*. MIT press, 2nd ed. edition.

Bartelsman, Eric J., and Mark Doms. 2000. Understanding productivity: lessons from longitudinal microdata. *Journal of Economic Literature* 38(3): 569–594.

Baxter, Marianne, and Alan C. Stockman. 1989. Business cycles and the exchange-rate regime: some international evidence. *Journal of Monetary Economics* 23(3): 377–400.

Benigno, Gianluca, and Luca Fornaro. 2018. Stagnation traps. *The Review of Economic Studies* 85(3): 1425–1470.

Benigno, Pierpaolo, and Luca Antonio Ricci. 2011. The inflation-output trade-off with downward wage rigidities. *American Economic Review* 101(4): 1436–66.

Berentsen, Aleksander, Mariana Rojas Breu, and Shouyong Shi. 2012. Liquidity, innovation and growth. *Journal of Monetary Economics* 59(8): 721–737.

Bergin, Paul R, and Giancarlo Corsetti. 2020. Beyond competitive devaluations: the monetary dimensions of comparative advantage. *American Economic Journal: Macroeconomics* 12(4): 246–86.

Bianchi, Francesco, Howard Kung, and Gonzalo Morales. 2019. Growth, slowdowns, and recov-

eries. *Journal of Monetary Economics* 101: 47–63.
Bloom, Nicholas, Mirko Draca, and John Van Reenen. 2016. Trade induced technical change? The impact of Chinese imports on innovation, IT and productivity. *The Review of Economic Studies* 83(1): 87–117.
Bruno, Michael, and William Easterly. 1998. Inflation crises and long-run growth. *Journal of Monetary economics* 41(1): 3–26.
Burstein, Ariel, and Christian Hellwig. 2008. Welfare costs of inflation in a menu cost model. *American Economic Review* 98(2): 438–43.
Calvo, Guillermo. 2000. The case for hard pegs in the brave new world of global finance.
Canova, Fabio. forthcoming. Should we trust cross sectional multiplier estimates? *Journal of Applied Econometrics* .
Cavallo, Eduardo, Sebastian Galiani, Ilan Noy, and Juan Pantano. 2013. Catastrophic natural disasters and economic growth. *Review of Economics and Statistics* 95(5): 1549–1561.
Chen, Yao, Nuno Palma, and Felix Ward. 2022. American precious metals and the Rise of the West. Tinbergen Institute Discussion Paper TI 2022-063/VI.
Comin, Diego, and Mark Gertler. 2006. Medium-term business cycles. *American Economic Review* 96(3): 523–551.
Crucini, Mario J., and Mototsugu Shintani. 2008. Persistence in law of one price deviations: evidence from micro-data. *Journal of Monetary Economics* 55(3): 629–644.
Deutsche Bundesbank. 2016. Wage dynamics amid high euro-area unemployment. *Monthly Report* 33–55.
Devereux, Michael B. 2006. Exchange rate policy and endogenous price flexibility. *Journal of the European Economic Association* 4(4): 735–769.
Dickens, William T., Lorenz Goette, Erica L. Groshen, Steinar Holden, Julian Messina, Mark E. Schweitzer, Jarkko Turunen, and Melanie E. Ward. 2007. How wages change: micro evidence from the International Wage Flexibility Project. *Journal of Economic Perspectives* 21(2): 195–214.
Djankov, Simeon, Rafael La Porta, Florencio Lopez-de Silanes, and Andrei Shleifer. 2002. The regulation of entry. *The Quarterly Journal of Economics* 117(1): 1–37.
Dorn, David, Gordon H. Hanson, Gary Pisano, and Pian Shu. 2020. Foreign competition and domestic innovation: evidence from US patents. *American Economic Review: Insights* 2(3): 357–74.
Driscoll, John C., and Aart C. Kraay. 1998. Consistent covariance matrix estimation with spatially dependent panel data. *Review of Economics and Statistics* 80(4): 549–560.
Druant, Martine, Silvia Fabiani, Gabor Kezdi, Ana Lamo, Fernando Martins, and Roberto Sabbatini. 2009. How are firms' wages and prices linked: survey evidence in Europe. *National Bank of Belgium Working Paper* (174).
Duarte, Margarida, and Maurice Obstfeld. 2008. Monetary policy in the open economy revisited: the case for exchange-rate flexibility restored. *Journal of International Money and Finance* 27(6): 949–957.
Dubas, Justin, Byung-Joo Lee, and Nelson Mark. 2005. Effective exchange rate classifications and growth. *NBER Working Paper* .
Dunlop, John T., Mary L. Fledderus, and Mary van Kleeck. 1944. Wage determination under trade unions. *Science and Society* 8(4).
Fischer, Stanley. 1993. The role of macroeconomic factors in growth. *Journal of Monetary Economics* 32(3): 485–512.
Foster, Lucia, John C. Haltiwanger, and Cornell John Krizan. 2001. Aggregate productivity growth: lessons from microeconomic evidence. In *New developments in productivity analysis*, 303–372. University of Chicago Press.
Friedman, Milton. 1953. The case for flexible exchange rates. In *Essays in positive economics.*

Chicago: University of Chicago Press.

Garcia-Macia, Daniel, Chang-Tai Hsieh, and Peter J. Klenow. 2019. How destructive is innovation? *Econometrica* 87(5): 1507–1541.

Garga, Vaishali, and Sanjay R. Singh. 2021. Output hysteresis and optimal monetary policy. *Journal of Monetary Economics* 117: 871–886.

Ghosh, Atish R., Anne-Marie Gulde, Jonathan D. Ostry, and Holger Wolf. 1996. Does the exchange rate regime matter for inflation and growth? In *Economic Issues*, volume 2. International Monetary Fund.

Ghosh, Atish R., Anne-Marie Gulde, and Holger C. Wolf. 2003. *Exchange rate regimes: choices and consequences*, volume 1. MIT press.

Gopinath, Gita, Şebnem Kalemli-Özcan, Loukas Karabarbounis, and Carolina Villegas-Sanchez. 2017. Capital allocation and productivity in South Europe. *The Quarterly Journal of Economics* 132(4): 1915–1967.

Guerron-Quintana, Pablo A., and Ryo Jinnai. 2019. Financial frictions, trends, and the great recession. *Quantitative Economics* 10(2): 735–773.

Havránek, Tomáš. 2015. Measuring intertemporal substitution: the importance of method choices and selective reporting. *Journal of the European Economic Association* 13(6): 1180–1204.

Hodrick, Robert J., and Edward C. Prescott. 1997. Postwar US business cycles: an empirical investigation. *Journal of Money, Credit, and Banking* 1–16.

Holden, Steinar, and Fredrik Wulfsberg. 2008. Downward nominal wage rigidity in the OECD. *The BE Journal of Macroeconomics* 8(1).

Howitt, Peter. 2000. Endogenous growth and cross-country income differences. *American Economic Review* 90(4): 829–846.

Husain, Aasim M., Ashoka Mody, and Kenneth S. Rogoff. 2005. Exchange rate regime durability and performance in developing versus advanced economies. *Journal of Monetary Economics* 52(1): 35–64.

Ilzetzki, Ethan, Carmen M. Reinhart, and Kenneth S. Rogoff. 2019. Exchange arrangements entering the twenty-first century: which anchor will hold? *The Quarterly Journal of Economics* 134(2): 599–646.

Imbs, Jean M. 1999. Technology, growth and the business cycle. *Journal of Monetary Economics* 44(1): 65–80.

Jordà, Òscar. 2005. Estimation and inference of impulse responses by local projections. *American Economic Review* 95(1): 161–182.

Jordà, Òscar, Sanjay R. Singh, and Alan M. Taylor. 2020. The long-run effects of monetary policy. *NBER Working Paper* .

Kenen, Peter. 1969. The theory of optimum currency areas: an eclectic view. In *Monetary Problems in the International Economy*, edited by Mundell, R., and A. Swoboda. Chicago: University of Chicago Press.

Khan, Mohsin S., and Abdelhak S. Senhadji. 2000. Threshold effects in the relationship between inflation and growth. *IMF Working Paper* .

Knoppik, Christoph, and Thomas Beissinger. 2009. Downward nominal wage rigidity in Europe: an analysis of European micro data from the ECHP 1994–2001. *Empirical Economics* 36(2): 321–338.

Kung, Howard, and Lukas Schmid. 2015. Innovation, growth, and asset prices. *The Journal of Finance* 70(3): 1001–1037.

Lentz, Rasmus, and Dale T. Mortensen. 2008. An empirical model of growth through product innovation. *Econometrica* 76(6): 1317–1373.

Levy-Yeyati, Eduardo, and Federico Sturzenegger. 2003. To float or to fix: evidence on the impact of exchange rate regimes on growth. *American Economic Review* 93(4): 1173–1193.

Lindbeck, Assar, and Dennis J. Snower. 1989. The insider-outsider theory of employment and unemployment. *MIT Press Books* .

Lo Duca, Marco, Anne Koban, Marisa Basten, Elias Bengtsson, Benjamin Klaus, Piotr Kusmierczyk, Jan Hannes Lang, Carsten Detken, and Tuomas A. Peltonen. 2017. A new database for financial crises in European countries: ECB/ESRB EU crises database. *ECB occasional paper* (194).

Mano, Rui C., Marola Castillo, and Steve Phillips. 2015. The level of productivity in traded and non-traded sectors for a large panel of countries. *IMF Working Papers* 2015(048).

McKinnon, Ronald I. 1963. Optimum currency areas. *American Economic Review* 53(4): 717–725.

Moran, Patrick, and Albert Queralto. 2018. Innovation, productivity, and monetary policy. *Journal of Monetary Economics* 93: 24–41.

Mundell, Robert A. 1961. A theory of optimum currency areas. *American Economic Review* 51(4): 657–665.

Mundell, Robert A. 2002. Exchange-rate systems and economic growth. In *Monetary Standards and Exchange Rates*, 27–52. Routledge.

Nakamura, Emi, Jón Steinsson, Patrick Sun, and Daniel Villar. 2018. The elusive costs of inflation: price dispersion during the US great inflation. *The Quarterly Journal of Economics* 133(4): 1933–1980.

Nickell, Stephen. 1997. Unemployment and labor market rigidities: Europe versus North America. *Journal of Economic Perspectives* 11(3): 55–74.

Oswald, Andrew J. 1986. Unemployment insurance and labor contracts under asymmetric information: theory and facts. *American Economic Review* 76(3): 365–377.

Palma, Nuno. 2021. The real effects of monetary expansions: evidence from a large-scale historical experiment. *Review of Economic Studies* .

Pesaran, M. Hashem. 2006. Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica* 74(4): 967–1012.

Phaneuf, Louis, and Jean Gardy Victor. 2019. Long-run inflation and the distorting effects of sticky wages and technical change. *Journal of Money, Credit and Banking* 51(1): 5–42.

Poole, William. 1970. Optimal choice of monetary policy instruments in a simple stochastic macro model. *The Quarterly Journal of Economics* 84(2): 197–216.

Reinhart, Carmen M., and Kenneth S. Rogoff. 2009. *This time is different.* Princeton University Press.

Reis, Ricardo. 2013. The Portuguese slump and crash and the euro crisis. *Brookings Papers on Economic Activity* 46: 143–193.

Rolnick, Arthur J., and Warren E. Weber. 1997. Money, inflation, and output under fiat and commodity standards. *Journal of Political Economy* 105(6): 1308–1321.

Sarel, Michael. 1996. Nonlinear effects of inflation on economic growth. *IMF Staff Papers* 43(1): 199–215.

Schmitt-Grohé, Stephanie, and Martın Uribe. 2003. Closing small open economy models. *Journal of International Economics* 61(1): 163–185.

Schmitt-Grohé, Stephanie, and Martin Uribe. 2016. Downward nominal wage rigidity, currency pegs, and involuntary unemployment. *Journal of Political Economy* 124(5): 1466–1514.

Shister, Joseph. 1943. The theory of union wage rigidity. *The Quarterly Journal of Economics* 57(4): 522–542.

Stock, James H., and Mark W. Watson. 2018. Identification and estimation of dynamic causal effects in macroeconomics using external instruments. *The Economic Journal* 128(610): 917–948.

Thomson, Russell. 2017. The effectiveness of R&D tax credits. *Review of Economics and Statistics* 99(3): 544–549.

Tobin, James. 1972. Inflation and unemployment. *American Economic Review* 62(1): 1–18.
Woodford, Michael. 2003. *Interest and prices.* Princeton University Press Princeton.

Appendix

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

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Contents

A. Data

A.1. Utilization-adjusted TFP

We adjust the 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 as[3]

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

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, υ 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 $\delta = 0.08, r = 0.04, \alpha = 0.33, \upsilon = 1$, 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.

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

A.2. 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 (USD)	GDP at constant 2015 USD	World Bank
Nominal GDP	in local currency unit; calculated as real GDP per capita in local currency * GDP deflator	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 (%); the series is extended backwards using the human capital index from Penn World Table	World Bank
Total factor productivity	unadjusted	AMECO database, the European Commission, Bergeaud et al. (2016)
Goods import (from the world and China)[a]	in mil. USD	IMF
Nominal exchange rate	units of national currency per USD	Penn World Table 10.0 (PWT) (Feenstra et al., 2015)
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 sources for individual items
Human capital index	based on years of schooling and returns to education	PWT
Capital stock	at constant 2017 national prices (in mil. 2017USD)	PWT
Real GDP (national price)	at constant 2017 national prices (in mil. 2017USD)	PWT
Real GDP - PPP	at chained PPPs (in mil. 2017USD)	PWT
Average annual hours worked	by persons engaged	PWT
Number of persons engaged	in millions	PWT

[a]For missing values, we linearly interpolated the series if the gap is less than four years.

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

Variable	Detailed description	Source
Population	total population	United Nations
Service share	% of total value added; calculated as the sum of gross value added from (1) other Activities (ISIC J-P) (2) transport, storage and communication (ISIC I) (3) wholesale, retail trade, restaurants and hotels (ISIC G-H) to total gross value added	United Nations
Manufacturing share	% of total value added; calculated as the gross value added from manufacturing (ISIC D) to total gross value added	United Nations
Unemployment rates[a]	% of total labor force	OECD, World Bank
Gross domestic spending on R&D as percentage of GDP[b]		OECD
Real private sector R&D spending[b]	Annual R&D expenditure performed by business enterprises, in millions constant (2015 PPP) US Dollar	OECD
Real R&D spending per capita	calculated as real GDP - PPP * Gross domestic spending on R&D as percentage of GDP/population	see sources for individual items
Implied tax subsidy rates on R&D expenditure	for SME and large firms (percentage points)	OECD
Total labor compensation of employees[c]	in local currency	OECD
Average hourly nominal wage	calculated as total labor compensation of employees/(average annual hours worked per worker *number of persons engaged)	see sources for individual items
Crisis dummy	= 1 for a systemic crisis	Reinhart and Rogoff (2009) and Lo Duca et al. (2017) until 2016; 2017-2019= 0
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) up to 2016[d]
Base country		Ilzetzki et al. (2019)[e]
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)

[a] We use OECD harmonized unemployment rates when available. We use World Bank (national estimates) to extend the OECD series to earlier periods by means of splicing.

[b] For missing values, we linearly interpolated the series if the gap is less than four years.

[c] Compensation of employees includes gross wages and salaries payable in cash or in kind, and the value of social contributions payable by employers.

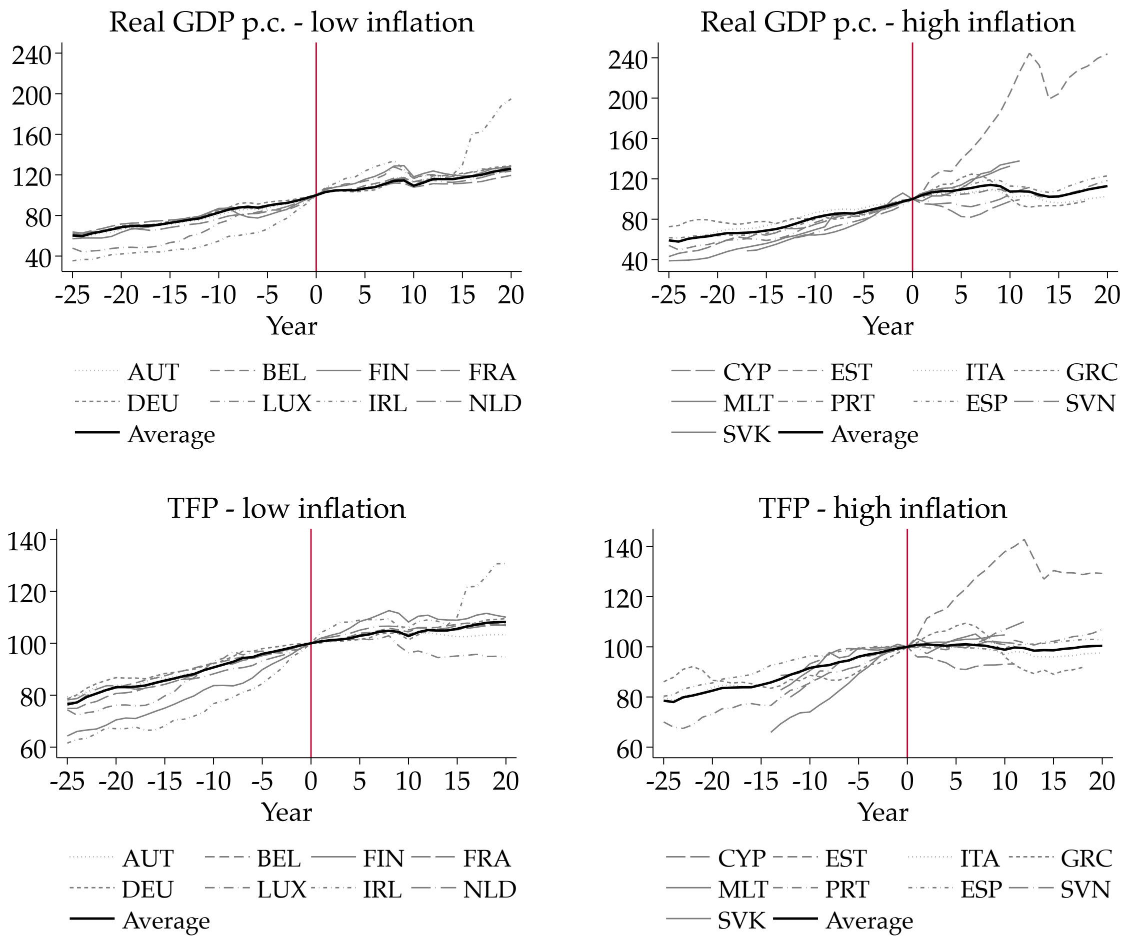
[d] Ilzetzki et al. (2019) classify Greece as "no separate legal tender" starting from 1999. However, Greece only officially joined the euro area in 2001. Thus, we classify Greece as non-peg before 2001 and as peg afterward. The Ilzetzki et al. (2019) data set is available up to year 2016. We extend the data to 2019 while assuming no further change in the exchange rate regime after 2016.

[e] The Ilzetzki et al. (2019) data set is available up to year 2015. We extend the data to 2019 while assuming no further change in the base country after 2015.

B. Empirical analysis: additional results

B.1. GDP per capita and TFP: individual country time series

Figure B.1: Divergence in the euro area: individual country time series



Notes: All series are indexed to 100 in year 0. Year 0 denotes the year of joining the euro.

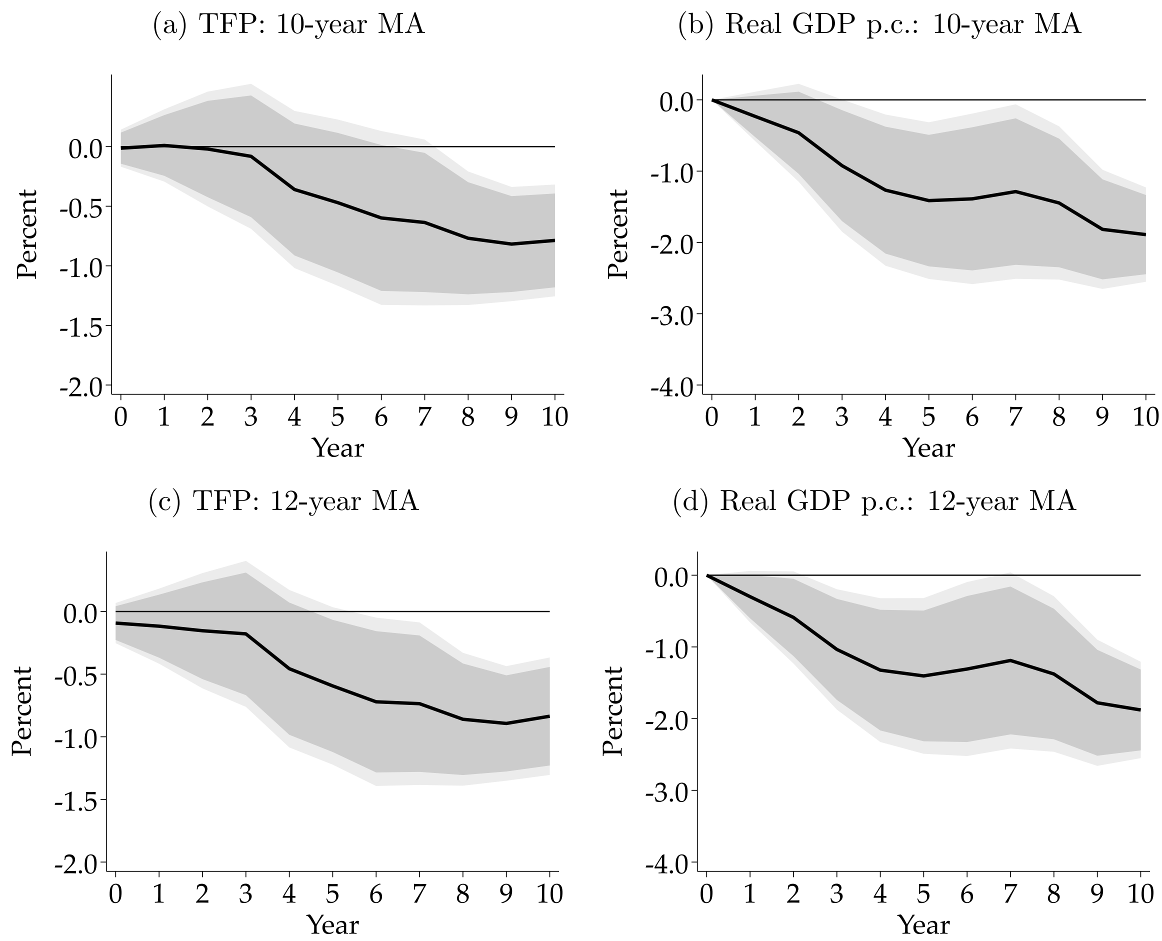
B.2. Alternative measures of relative structural wage inflation

To see whether the baseline findings are robust to the measurement of relative structural inflation, we repeat the analysis for three different measurement approaches. First, we vary the pre-peg time window used for calculating structural inflation (section B.2.1). Second, we replace the structural wage inflation differential with an underlying labor market characteristic – the degree of downward nominal wage rigidity (DNWR) (section B.2.2). Finally, we calculate relative structural inflation based on the pre-peg exchange rate depreciation trend vis-à-vis the base country currency (section B.2.3).

B.2.1 Alternative moving average time windows

The baseline analysis uses a 15-year backward looking moving average to calculate the structural wage inflation differential. Here, we vary the moving average time window from 15 years to 12 and 10 years. Figure B.2 shows that corresponding IRF estimates are very similar to the baseline results.

Figure B.2: Productivity and output trajectories after pegging with a nominal wage inflation differential of +1 ppt

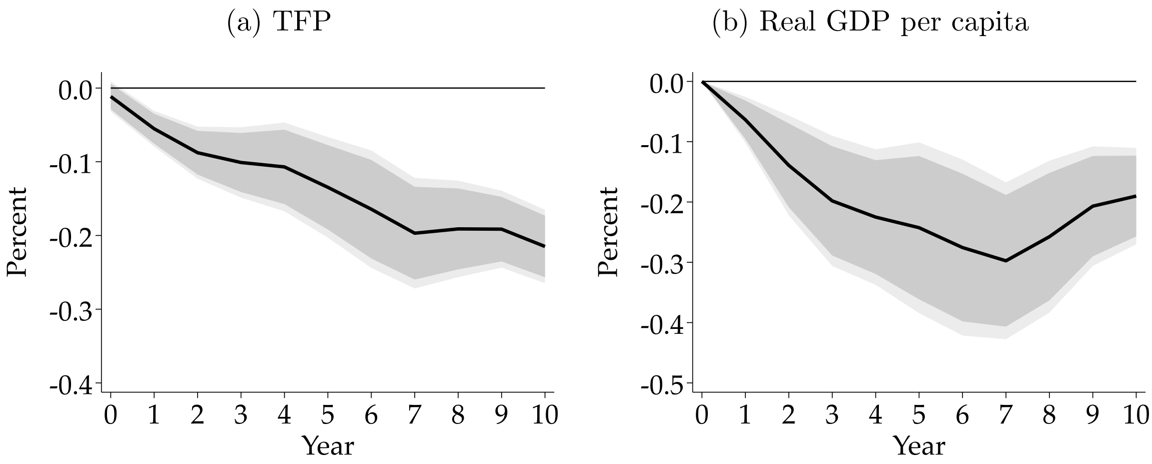


Notes: Black solid line – mean estimate. Dark shaded area – 90% confidence interval. Light shaded area – 95% confidence interval.

B.2.2 Downward nominal wage rigidity

Different degrees of downward nominal wage rigidity (DNWR) are a prominent candidate for cross-country differences in structural wage inflation rates. Here, we analyze whether the IRF estimates are robust to replacing the relative structural wage inflation measure with an indicator that measures the degree of DNWR (Knoppik and Beissinger, 2009). For a given level of macroeconomic volatility, more DNWR requires a higher steady state

Figure B.3: Productivity and output trajectories after pegging with a +1 ppt higher degree of DNWR



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

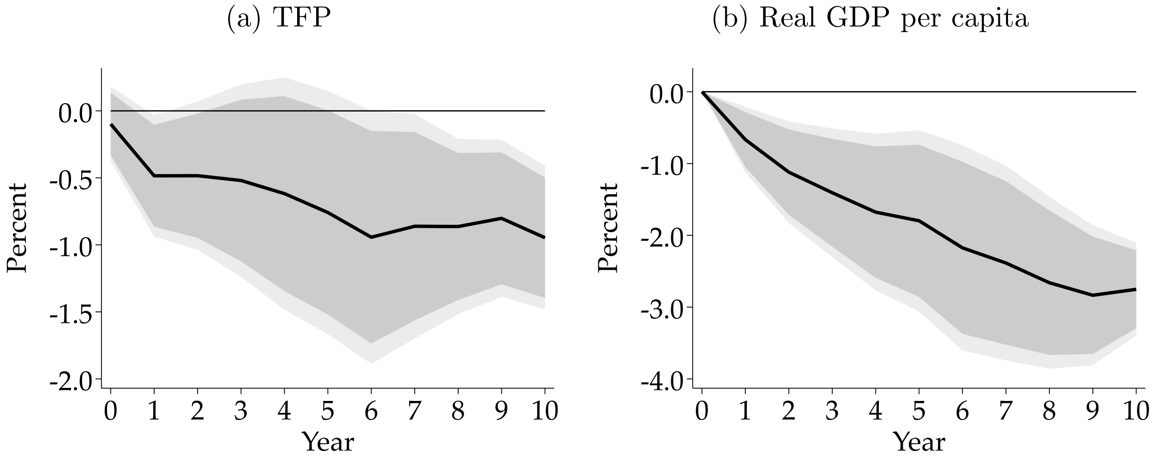
wage inflation rate to support full employment (Benigno and Ricci, 2011). Thus, countries with a high degree of DNWR prior to pegging should experience slower TFP growth after pegging. The IRF estimates depicted Figure B.3 are consistent with this line of reasoning: a higher pre-peg DNWR level is associated with lower post-peg TFP and output growth.[4]

B.2.3 Exchange rate depreciation rate

The depreciation rate against the base country currency is another suitable measure 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. There are, however, two main drawbacks of using depreciation rates. First, exchange rate fluctuations are much more volatile than nominal wage fluctuations, making it more difficult to derive the long-run depreciation trend from the data. Second, the exchange rate movements of countries joining the euro were explicitly constrained by the Maastricht treaty already two years before pegging. Despite these drawbacks, we find similar results when measuring a country's relative structural inflation by its pre-peg exchange rate depreciation. Country's with higher depreciation rates have a slower TFP and output growth in the aftermath of pegging (Figure B.4).

[4]The DNWR indicator by Knoppik and Beissinger (2009) measures the fraction of negative wage adjustments that were prevented by downward nominal wage rigidity. The IRF depicted in panel (c) of Figure 4 presents the shortfall of TFP growth in a country with a 1 ppt higher DNWR. The sample size for this robustness check is about 50% smaller than the baseline sample, owing to the less extensive country-coverage of the DNWR measures provided by Knoppik and Beissinger (2009). To account for cross-country differences in macroeconomic volatility we include the 15-year backward looking moving standard deviation of real GDP per capita growth to the control vector.

Figure B.4: Productivity and output trajectories after pegging with a nominal exchange rate depreciation trend of +1% per year



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

B.3. Accounting for dynamic heterogeneity

As our baseline empirical strategy replies on cross-sectional variation to identify the impact of joining the euro, our estimate of interest may not be capturing the actual average dynamic effect if countries react differently to fixing the exchange rate.[5] An often used alternative to the pooled estimate is the mean group estimate, which estimates the effect unit-by-unit and is consistent despite spatial heterogeneity. However, as our sample is short (about 15 observations per country) and there is very limited variation of the explanatory variable of interest within each unit (each country became pegged only once), the mean group estimate is not suitable for the application at hand. Instead, we conduct two alternative exercises to analyze dynamic heterogeneity. First, we pool countries into different subgroups – core vs. periphery, high vs. low structural wage inflation – and run the regressions for each of these subgroups (section B.3.1). Second, we employ an approach that estimates treatment effects for each euro area country individually before averaging across core and periphery countries: the synthetic control method (SCM) proposed by Abadie and Gardeazabal (2003) and Abadie et al. (2010) (section B.3.2).[6]

[5] See Pesaran (2006) and Canova (forthcoming) for a discussion of the potential bias due to dynamic and cross-sectional heterogeneity.

[6] The main drawback of using SCM is that other treatments might have coincided with the time when a country fixed the exchange rate. While it is straightforward to control for these other treatments in a LP setup, it is not possible to isolate a specific mechanism from the alternatives in the SCM setup.

B.3.1 Partially pooled estimates

In this subsection we pool countries into different groups – euro area core vs. periphery, high vs. low structural wage inflation – and run the regressions for each of the groups to analyze the potential bias due to dynamic heterogeneity in our baseline estimate. The euro area core group includes Austria, Belgium, Denmark, France, Finland, Germany, Luxembourg, and the Netherlands. The euro area periphery group includes Greece, Italy, Portugal, Spain. We use the median structural wage inflation in the year of pegging to separate countries into a high and low structural inflation group. The low structural inflation group includes Austria, Belgium, Denmark, France, Finland, Germany, Ireland, Luxembourg, and the Netherlands. The high structural wage inflation group includes Cyprus, Estonia, Greece, Italy, Latvia, Malta, Portugal, Slovakia, Slovenia, and Spain.

We also drop countries that did not enter a peg during our sample period (Australia, Canada, Japan, New Zealand, United States, United Kingdom, and Switzerland). By pooling countries into different groups, the number of observations decreases substantially compared to our baseline regression. Thus, we implement a parsimonious regression specification that, besides the interaction term between the exchange rate regime and relative structural wage inflation, only includes two lags of TFP growth, the exchange rate regime indicator, and the relative structural wage inflation rate among the explanatory variables.

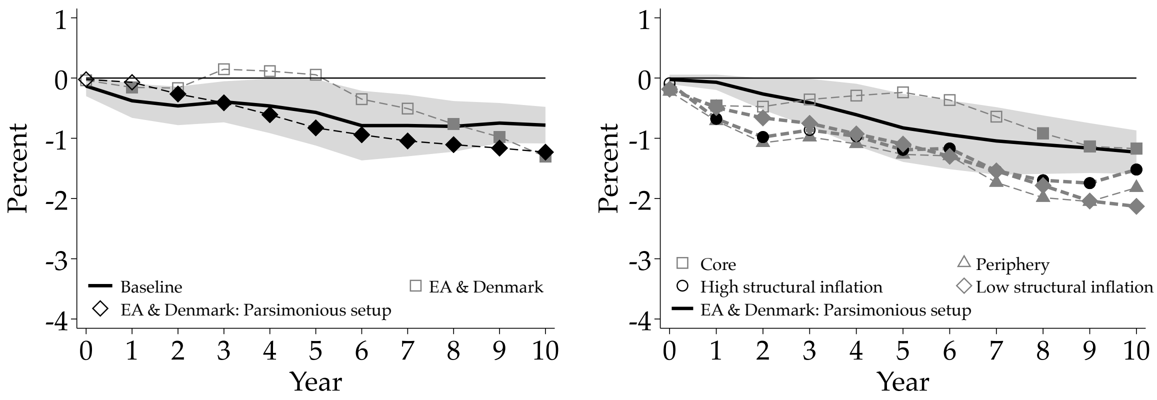
Figure B.5a compares our baseline result (using the full set of controls and the full sample) with the results we obtain when restricting the sample to countries that joined a peg during the sample period, i.e. euro area members & Denmark (square markers). The TFP effect is initially less pronounced, but converges with the baseline effect size towards the end of the projection horizon. The results for the more parsimonious specification are very similar to the baseline results throughout (diamond markers).

We continue to estimate the effect of pegging with a +1 ppt structural wage inflation differential for the four subgroups using the parsimonious setup. Figure B.5b displays the IRF estimates. For three of the four subgroups the effect size is somewhat larger than in the pooled estimate (solid line). The only exception is the euro area core region, which exhibits a smaller TFP decline before converging to the baseline effect size after about seven years.[7] Overall, the magnitude of the differences in effect size across subgroups is modest, indicating only a small potential bias due to dynamic heterogeneity.

[7] Possibly this reflects the considerably lower inflation rate dispersion within the euro area's core region, which renders identification within this group difficult.

Figure B.5: Productivity and output trajectories after pegging with a nominal wage inflation differential of +1 ppt

(a) Baseline vs. parsimonious setup (b) Partially pooled estimates



Notes: Black solid line – mean estimate using the baseline specification. Dark shaded area – 90% confidence interval. Dashed line with markers – mean estimate under alternative specifications. Solid markers – significance at the 10% level. Hollow markers – no significance at the 10% level.

B.3.2 Synthetic control methods

The Synthetic Control Method (SCM) evaluates the treatment effect by comparing the time path of an outcome variable in the treated unit to the same outcome variable for a synthetic control group (the counterfactual). The synthetic control group combines several unaffected units (the donor group) using a data-driven procedure. Different weights are applied to the donor units such as to approximate the treated unit in terms of a set of predictors observed before the treatment. Using the SCM, we can compare the effects of pegging for our two groups of interest – the group of countries with high structural wage inflation and the group with low structural wage inflation.[8]

We use the median structural wage inflation rate in the year of pegging to separate countries into a high and low structural inflation group. The structural wage inflation rates are measured as backward looking moving averages of nominal wage trend growth, as described in the main text. The outcome variable is ln(TFP). The predictors include the 20-years pre-peg averages of ln TFP, the real GDP per capita growth rate in USD, and the TFP growth rate.[9] We set the treatment year to the year in which a country's exchange rate was fixed.

The implementation of the SCM requires a strongly balanced sample, sufficient data pre- and post-treatment for each unit, and a donor group that was never treated, i.e., never pegged. Thus, several adjustments to the sample are necessary. First, we exclude

[8] Abadie (2021) provides a detailed methodological description.
[9] Our results stay virtually unaffected when additional predictors are included.

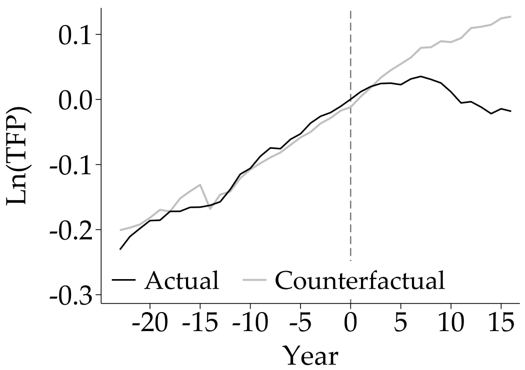
the years 1970 to 1974 to eliminate periods when some donor countries were still pegged, e.g., as members of the Bretton Woods System. Second, we also drop Switzerland from the donor group because it classifies as a peg between 2012 and 2014. Second, several euro area countries were dropped from the sample because of insufficient pre- or post-treatment data. We drop Estonia, Latvia, and Ireland because they pegged their currencies multiple times during the sample period, resulting in a limited amount of pre-treatment data. We drop Slovenia, Slovakia, Malta, and Cyprus because their TFP series cover only a short time period. After sample adjustments, the high structural inflation group consists of Spain, Greece, Italy, and Portugal. The low structural inflation group consists of Austria, Belgium, Germany, Denmark, Finland, France, Luxembourg, the Netherlands. The donor group includes Australia, Canada, Japan, New Zealand, the U.K. and the U.S.

Figure B.6 shows the result for the group of countries with high structural wage inflation, and Figure B.7 the result for countries with low structural wage inflation. Panel (a) on each figure compares the actual average ln(TFP) with the non-peg counterfactual. Panel (b) shows the average effect of becoming pegged, which is the difference between the actual ln(TFP) and its counterfactual from panel (a). Panel (c) reports the corresponding standardized p-values. After becoming pegged for ten years, the high structural inflation group has an average TFP that is about 0.8% lower than in the non-peg counterfactual scenario. Similarly so, the low structural inflation group has a 0.5% lower TFP level after ten years compared to its non-peg counterfactual. Both effects have a near zero probability of being generated by chance.

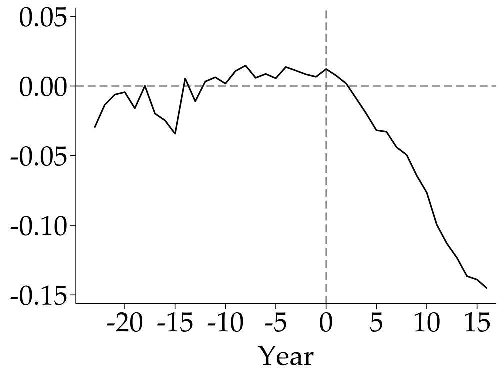
To make the SCM results comparable to our baseline LP result, we subtract the TFP effect of pegging in the low inflation group from that in the high inflation group and divide it by the structural inflation difference that existed between these groups in the year the exchange rate was fixed. The thus obtained result indicates that a one percentage point higher structural wage inflation is associated with an around 0.8% lower TFP level ten years after fixing the exchange rate – similar to the baseline LP result.

Figure B.6: TFP effect of joining the euro: countries with high structural inflation

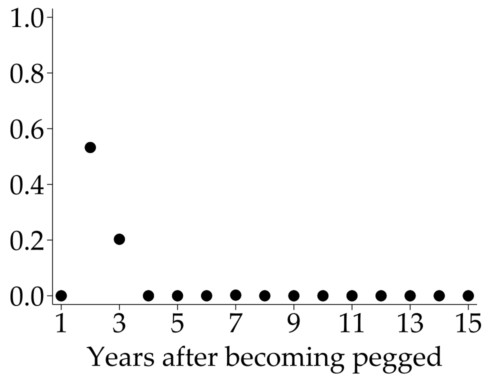
(a) Actual vs. counterfactual



(b) Effect of pegging

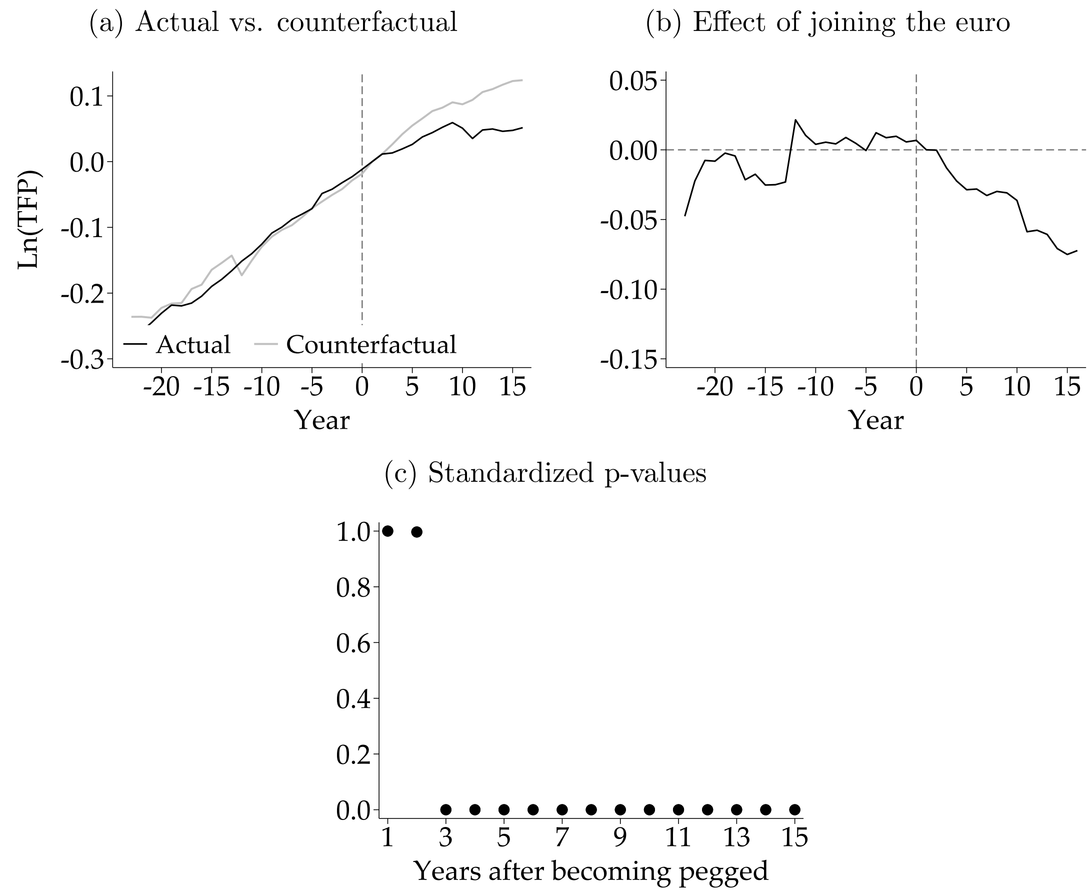


(c) Standardized p-values



Notes: Year 0 – exchange rate fixed. The group of countries with high structural wage inflation includes Spain, Greece, Italy, and Portugal.

Figure B.7: TFP effect of joining the euro: countries with low structural inflation



Notes: Year 0 – exchange rate fixed. The group of countries with low structural wage inflation includes Austria, Belgium, Germany, Denmark, Finland, France, Luxembourg, the Netherlands.

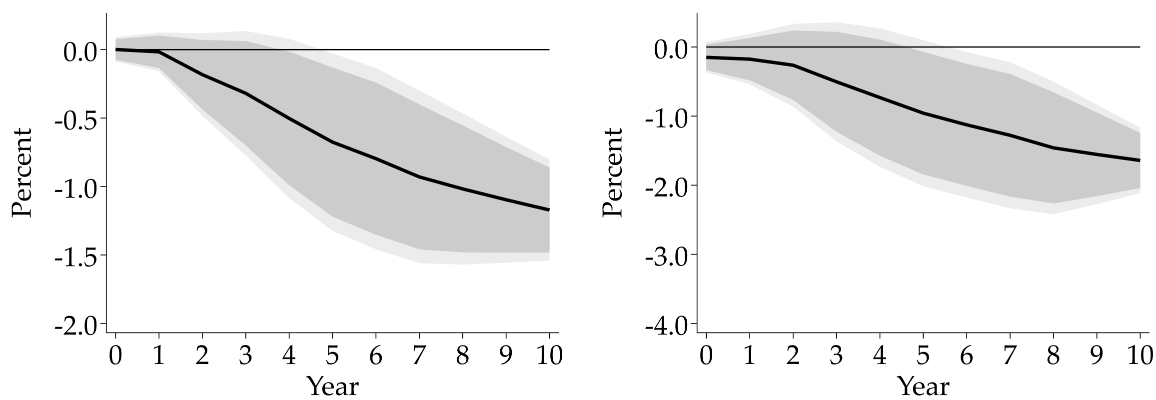
B.4. Other robustness checks

B.4.1 Parsimonious specification

Figure B.8 shows the TFP and output result for a parsimonious specification that, besides the interaction term between the exchange rate regime and relative structural wage inflation, only includes two lags of the dependent variable's growth rate, the exchange rate regime indicator, and the relative structural wage inflation rate among the explanatory variables.

Figure B.8: Productivity and output trajectory after pegging with a nominal wage inflation differential of +1 ppt

(a) TFP (b) Real GDP per capita

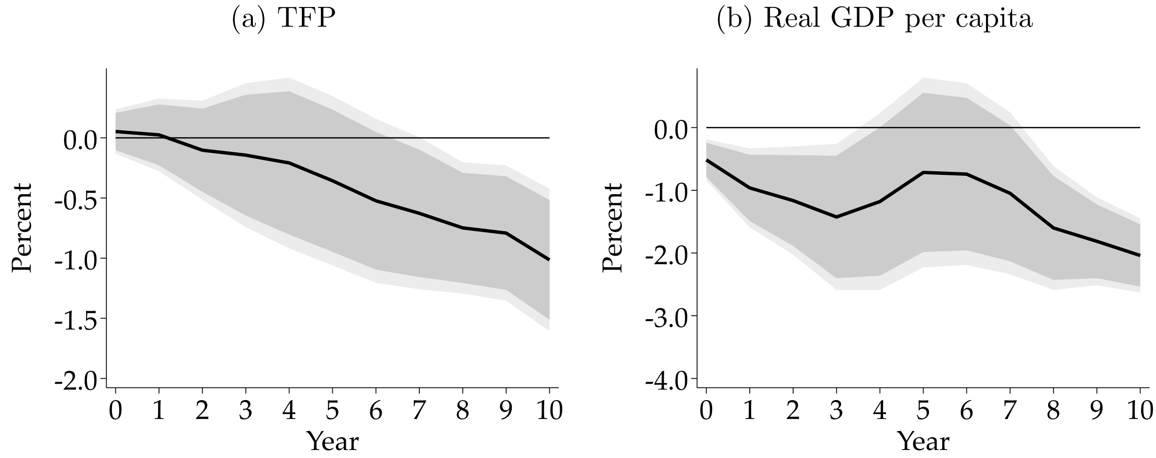


Notes: Black solid line – mean estimate. Dark shaded area – 90% confidence interval. Light shaded area – 95% confidence interval.

B.4.2 Excluding contemporaneous control variables

Figure B.9 shows the TFP and output result when all control variables from the baseline specification are lagged by one period, thereby excluding contemporaneous control variables.

Figure B.9: Productivity and output trajectory after pegging with a nominal wage inflation differential of +1 ppt

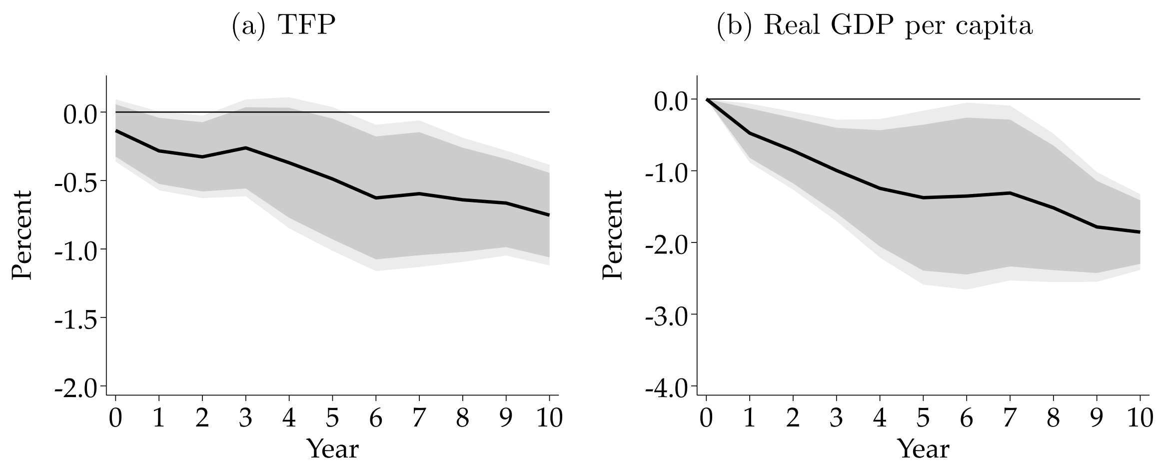


Notes: Black solid line – mean estimate. Dark shaded area – 90% confidence interval. Light shaded area – 95% confidence interval.

B.4.3 Controlling for lead crises

By using utilization-adjusted TFP, our result is less sensitive to the impact of economic crises during the regression horizon than the unadjusted TFP series. Nevertheless, to see to which extent the Global Financial Crisis and the euro area debt crisis affect our baseline findings, we also add leads of the cumulative change of a financial crisis indicator to the set of controls. For each country, the financial crisis indicator is set to 0 at the beginning of the sample. The indicator then increases by 1 unit for each year that a country subsequently finds itself in a financial crisis as defined by Reinhart and Rogoff (2009) and Lo Duca et al. (2017). By thus tracing the total number of years a country spent in financial crisis, we can use the cumulative change in this variable between t and $t + h$ to control for financial crisis effects throughout the projection horizon. Figure B.10 shows that our results remain robust to the inclusion of the crisis indicator.

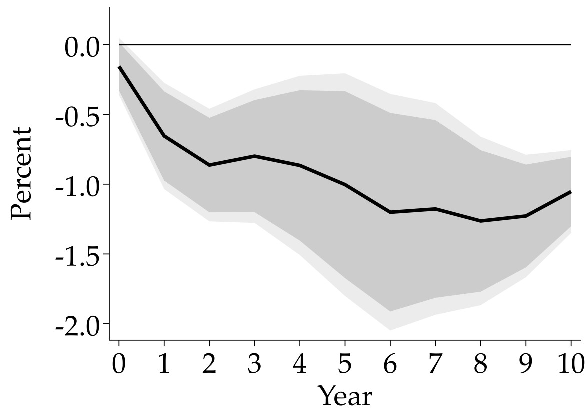
Figure B.10: Productivity and output trajectory after pegging with a nominal wage inflation differential of +1 ppt



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

B.4.4 Non-adjusted TFP

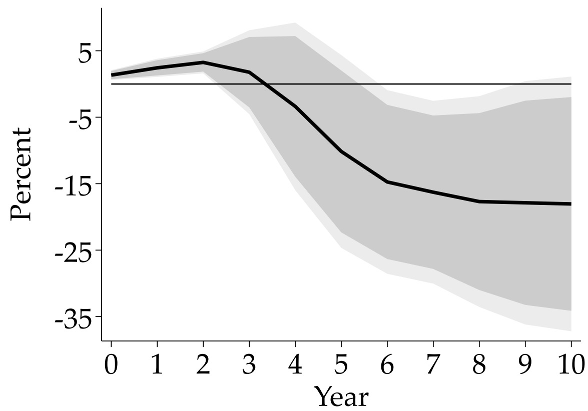
Figure B.11: TFP (non-adjusted) trajectory after pegging with a nominal wage inflation differential of +1 ppt



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

B.4.5 Private sector performed R&D

Figure B.12: Private sector performed real R&D p.c. trajectory after pegging with a nominal wage inflation differential of +1 ppt



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

C. Model: details and additional results

C.1. System of nonlinear equations

This section lays out the system of nonlinear equations that determines the model equilibrium.

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, $\tilde{P}_{F,t} \equiv \frac{P^*_{F,t}}{P^*_t}\left(\frac{A_{F,t}}{A_{H,t}}\right)^{1-\theta}$.

The complete set of nonlinear equations is listed below. Here, we make use of $\Pi_{H,t} = \Pi^*_{H,t}\Pi_{e,t}, \Pi_{F,t} = \Pi^*_{F,t}\Pi_{e,t}$, and $\Pi_t = \Pi^*_t\Pi_{e,t}$, which follows from the law of one price and Assumption **??**. 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.12) describe the nominal wage and price inflation. (C.13) - (C.14) follow from the definition of variables $\tilde{P}_H, \tilde{P}_F$. (C.15) - (C.16) result from the optimal investment in the intermediate goods sector. (C.17) - (C.20) describe the innovation processes. (C.21) - (C.22) are the monetary policy rules. (C.23) - (C. 25) show the market clearing conditions. Finally, (C.26) defines the average TFP growth rate.

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

$$\tilde{c^*}_t^{(-\sigma)} = \mathbb{E}_t\left[\frac{\Pi_{e,t+1}\,\beta\,\rho^*\,{R^*}_t\,\left(\tilde{c^*}_{t+1}\,\bar{g}_{t+1}\right)^{(-\sigma)}}{\Pi_{t+1}}\right] \tag{C.2}$$

$$\tilde{c}_t + \frac{\tilde{b}_{H,t}}{R_t} + \frac{\tilde{b}_{F,t}}{R_t^*} = \frac{\tilde{b}_{H,t-1}}{\Pi_t\,\bar{g}_t} + \frac{\tilde{b}_{F,t-1}\Pi_{e,t}}{\Pi_t\,\bar{g}_t} + \Psi\,\tilde{P}_{H,t}\,l_t - \tilde{P}_{H,t}\,Z_t \tag{C.3}$$

$$\tilde{c}_t^* + \frac{\tilde{b}_{F,t}^*}{R_t^*} + \frac{\tilde{b}_{H,t}^*}{R_t} = \frac{\tilde{b}_{F,t-1}^* \Pi_{e,t}}{\Pi_t \, \bar{g}_t} + \frac{\tilde{b}_{H,t-1}^*}{\Pi_t \, \bar{g}_t} + \Psi^* \, \tilde{P}_{F,t} \, l_t^* - \tilde{P}_{F,t} \, Z_t^* \tag{C.4}$$

$$R_t \mathbb{E}_t \frac{\tilde{c}_{t+1}^{-\sigma}}{\Pi_{t+1}} = R_t^* \frac{1}{1 + K(\tilde{b}_{F,t} - o)} \mathbb{E}_t \frac{\tilde{c}_{t+1}^{-\sigma}}{\Pi_{t+1}} \frac{e_{t+1}}{e_t} \tag{C.5}$$

$$R_t^* \mathbb{E}_t \frac{\tilde{c^*}_{t+1}^{-\sigma}}{\Pi_{t+1}^*} = R_t \frac{1}{1 + K^*(\tilde{b}_{H,t}^* - o^*)} \mathbb{E}_t \frac{\tilde{c^*}_{t+1}^{-\sigma}}{\Pi_{t+1}^*} \frac{e_t}{e_{t+1}} \tag{C.6}$$

$$\Pi_{H,t} = \frac{\Pi_{w,t}}{g_t} \tag{C.7}$$

$$\frac{\Pi_{F,t}}{\Pi_{e,t}} = \frac{\Pi_{w,t}^*}{g_t^*} \tag{C.8}$$

$$\Pi_t = \Pi_{H,t}^{1-\theta} \, \Pi_{F,t}^{\theta} \tag{C.9}$$

$$\Pi_t = \Pi_t^* \, \Pi_{e,t} \tag{C.10}$$

$$\Pi_{w,t} = \check{\Pi}_w \; \exp\left(1 - l_t\right)^{-\mu} \; \mathbb{E}_t \Pi_{t+1}^{\psi} \tag{C.11}$$

$$\Pi_{w,t}^* = \check{\Pi}_w^* \; \exp\left(1 - l_t^*\right)^{-\mu^*} \; \mathbb{E}_t {\Pi_{t+1}^*}^{\psi^*} \tag{C.12}$$

$$\frac{\tilde{P}_{H,t}}{\tilde{P}_{H,t-1}} = \frac{\Pi_{H,t}}{\Pi_t} \; \left(\frac{g_t}{g_t^*}\right)^{\theta} \tag{C.13}$$

$$1 = \tilde{P}_{H,t}^{1-\theta} \, \tilde{P}_{F,t}^{\theta} \tag{C.14}$$

$$\begin{aligned} &\mathbb{E}_t \left(\frac{\Pi_{H,t+1} \, \left(\bar{g}_t \, \frac{\tilde{c}_{t+1}}{\tilde{c}_t}\right)^{(-\sigma)}}{\Pi_{t+1}} \, \left(\Omega \, Z_t^{\kappa-1} \, l_{t+1} \right.\right. \\ &\left.\left. + \rho \, \beta \, \left(1 - \eta\right) \, \left(\left(\frac{Z_t}{Z_{t+1}}\right)^{\kappa-1} + \left(\gamma - 1\right) \, \left(1 - \kappa\right) \, \chi \, g_t \, Z_{t+1} \right) \right) \right) = 1 \end{aligned} \tag{C.15}$$

$$\mathbb{E}_t \left(\frac{\Pi_{F,t+1} \left(\bar{g}_t \frac{\tilde{c}^*_{t+1}}{\tilde{c}^*_t} \right)^{(-\sigma)}}{\Pi_{t+1}} \left(\Omega^* Z_t^{*\kappa-1} l^*_{t+1} \right.\right.$$

$$\left.\left. + \rho \beta \left(1 - \eta^*\right) \left(\left(\frac{Z^*_t}{Z^*_{t+1}} \right)^{\kappa-1} + \left(\gamma^* - 1\right) \left(1 - \kappa\right) \chi^* g^*_t Z^*_{t+1} \right) \right) \right) = 1 \tag{C.16}$$

$$Z_t = \left(\frac{q_t}{\chi} \right)^{\frac{1}{\kappa}} \tag{C.17}$$

$$Z^*_t = \left(\frac{q^*_t}{\chi^*} \right)^{\frac{1}{\kappa}} \tag{C.18}$$

$$q_t \left(\gamma - 1\right) = g_{t+1} - 1 \tag{C.19}$$

$$q^*_t \left(\gamma^* - 1\right) = g^*_{t+1} - 1 \tag{C.20}$$

$$R_t = \begin{cases} \Upsilon \, l_t^{\phi}, \text{ if flexible exchange rates} \\ \Upsilon^u \left(l_t^{\tau} \, l_t^{*1-\tau} \right)^{\phi}, \text{ if fixed exchange rates} \end{cases} \tag{C.21}$$

$$R^*_t = \begin{cases} \Upsilon^* \, l_t^{*\phi^*}, \text{ if flexible exchange rates} \\ \text{a rate that ensures } \Pi_{e,t} = 1, \text{ if fixed exchange rates} \end{cases} \tag{C.22}$$

$$\Psi \, l_t = Z_t + \frac{\tilde{c}_t \left(1 - \theta\right)}{\tilde{P}_{H,t}} + \frac{\tilde{c}^*_t \left(1 - \theta\right)}{\tilde{P}_{H,t}} \tag{C.23}$$

$$\Psi^* \, l^*_t = Z^*_t + \frac{\tilde{c}_t \, \theta}{\tilde{P}_{F,t}} + \frac{\tilde{c}^*_t \, \theta}{\tilde{P}_{F,t}} \tag{C.24}$$

$$\tilde{b}_{H,t} + \tilde{b}^*_{H,t} = 0 \tag{C.25}$$

$$\bar{g}_t = g_t^{1-\theta} \, g_t^{*\theta} \tag{C.26}$$

C.2. Balanced growth path

In this section we derive equations (39) - (42), 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.7), 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:

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

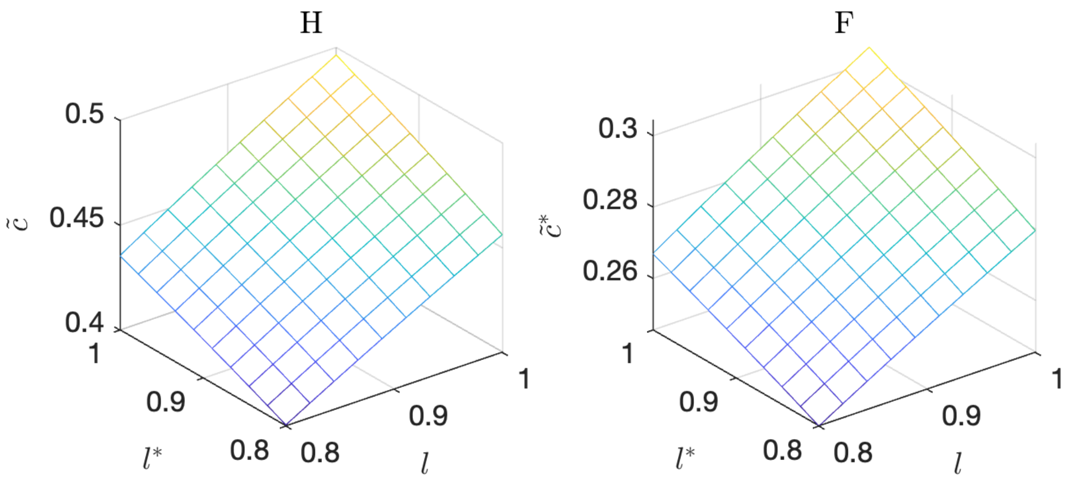
It also follows that $\Pi_F = \Pi_w/g^*$. Using (C.7) and (C.9), we have $\Pi = \Pi_w/\bar{g}, \Pi_H/\Pi = \bar{g}/g, \Pi_F/\Pi = \bar{g}/g^*$. (39) follows from (C.1), as $\tilde{c}$ is constant at the steady state. We can derive (40) analogously. To derive (41), we evaluate (C.15) at the steady state, replace Z, Z^* with q, q^* using (C.17) and (C.18), and then replace q, q^* with g, g^* using (C.19) and (C.20). 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. The relationship between employment gap and welfare

The monetary policy rule in our baseline model aims to maximize the employment level. In principle, maximizing employment, which maximizes TFP and output growth, may not maximize welfare. This is because the level of welfare, measured as the discounted total utility from consumption, is determined by both the growth rate of consumption as well as the steady state productivity-normalized level of consumption. While the growth rate of consumption is maximized at a maximal level of output growth, the steady state productivity-normalized level of consumption, $\tilde{c}$ and $\tilde{c}^*$, may not be if the level of investment is sub-optimal. An increase in employment is associated with an increase in both output and investment, and thus the consumption level may go up or down (equations (C.23) - (C.24)). In this subsection, we show that, under our baseline calibration, investment increases are slower than the output increases. Thus, consumption is increasing in the employment level in H and F.

Figure (C.1) shows the steady-state levels of $\tilde{c}$ and $\tilde{c}^*$ 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. Under fixed exchange rates, steady states are constrained to combinations of l, l^* that satisfy (12). Since $\tilde{c}$ and $\tilde{c}^*$ 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 achieves the maximum average employment level, also obtains the maximum average welfare.[10]

Figure C.1: Consumption and employment



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

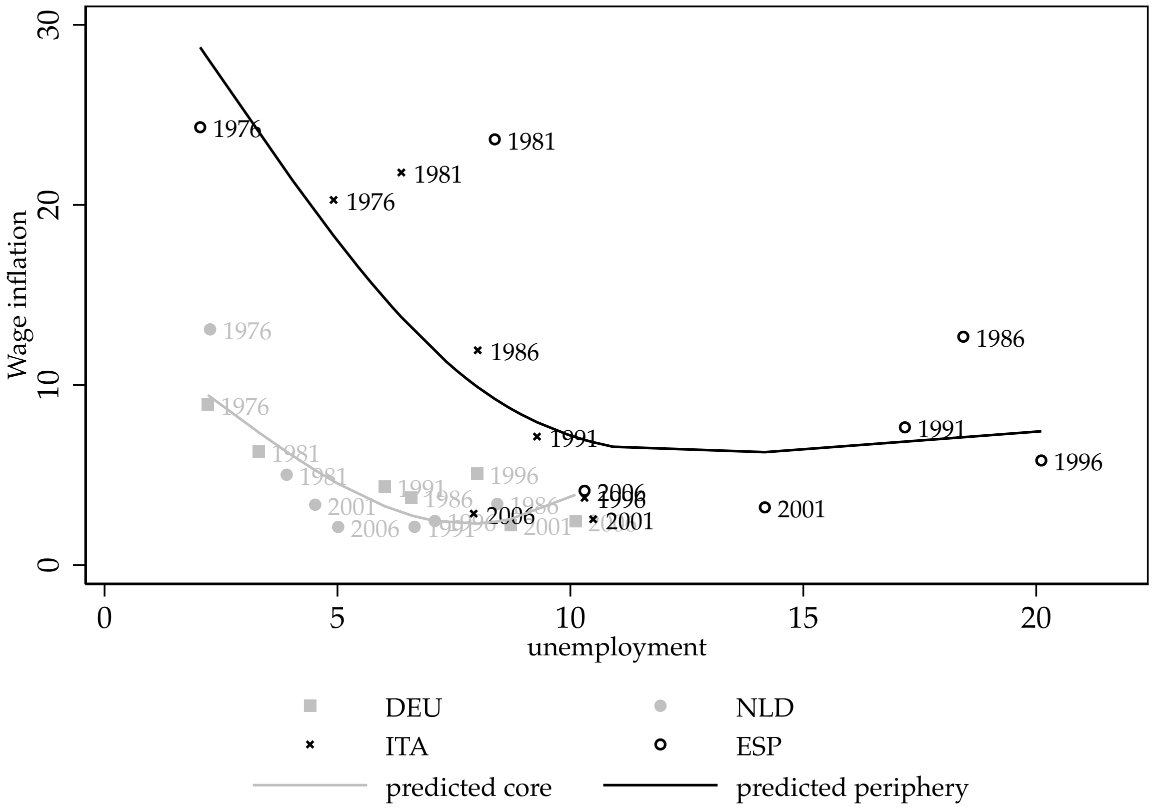
In our model, the effect of the exchange rate regime on TFP growth depends on the long-run tradeoff between wage inflation and employment. This long-run tradeoff is graphically reflected in a non-vertical (downward sloping) long-run wage Phillips curve. As a result of the downward sloping wage Phillips 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 employment 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.[11] The theoretical literature has pointed out that the long-run wage Phillips curve is nonlinear (Akerlof et al., 1996; Benigno and Ricci, 2011).[12] Thus, following Byrne and Zekaite (2020), we fit a non-linear model to the data using a restricted

[10] This holds for any weight used to calculate the average utility and the average employment level.
[11] Appendix A provides a detailed data description.
[12] For related non-linear short-run Phillips curve estimates for the euro area see Moretti et al. (2019); Nickel et al. (2019).

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.

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



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

Reduced-form Phillips curve estimates, however, have several drawbacks that have been extensively discussed in the literature (McLeay and Tenreyro, 2020; Hazell et al., 2022). 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, our simple reduced-form Phillips curve estimates do not account for CPI indexation in wage determination. 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.[13] 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 even then intra-European exchange rate fluctuations were constrained by the European Monetary System (EMS) and the Exchange Rate Mechanism (ERM) – occasionally binding target zone regimes. 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 between 1972 and the entry into euro area for the group of countries with high structural wage inflation as identified in section 3.[14] We estimate the wage inflation Phillips multiplier over a ten-year horizon while controlling for expected CPI inflation and two lags of the unemployment rate.[15] We furthermore control for contemporaneous world real GDP growth as in Jordà et al. (2020b) to capture changes in the base country's interest rate

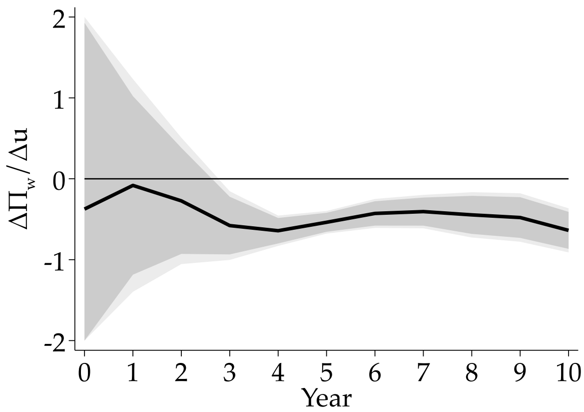
[13] Gabriel (2022) estimates the wage Phillips curve for the euro area as a whole using a similar method.

[14] Within this group, the Trilemma IV is available only for Italy, Spain, and Portugal. Together, these three countries account for 85% of the total population of the high structural wage inflation group.

[15] Absent survey data on CPI inflation expectations for our sample, we rely instead on the linear trend of CPI inflation as a proxy for inflation expectations. Before the introduction of the euro, CPI inflation among high structural wage inflation countries followed linear downward trends. After entering the eurozone, further declines in CPI inflation rates along the same downward trends were thus unlikely to surprise. Accordingly, we extrapolate the pre-euro linear CPI inflation trend and use it as a proxy for expected future inflation. However, our Wage Phillips multiplier result is robust to using a lagged linear trend instead.

that are driven by global factors that affect many countries simultaneously. The wage Phillips multipliers that result from a panel regression are shown in Figure C.3.

Figure C.3: Wage Phillips multiplier



Notes: Black 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 0.6 percentage points. The point estimates are also fairly stable over the 4 to 10 year horizon. We use the point estimate at year 10 to calibrate the model's long-run wage Phillips curve.[16]

C.5. Cross-border technology spillovers

In our baseline model, we assume no cross-border technology spillovers. This section describes an extended model that allows for such spillovers. To account for technology spillovers, the extended model's probability of discovery also depends on foreign innovation:

$$\begin{aligned} q_{j,t} &= \min\left[\chi\left(\frac{I_{j,t}}{A_{j,t}}\right)^{\kappa}\left(\frac{I^*_{j,t}}{A^*_{j,t}}\right)^{\upsilon}, \quad 1\right] \\ &= \min\left[\chi Z^{\kappa}_{j,t} Z^{*\ \upsilon}_{j,t}, \quad 1\right], \quad Z_{j,t} \equiv \frac{I_{j,t}}{A_{j,t}},\ Z^*_{j,t} \equiv \frac{I^*_{j,t}}{A^*_{j,t}}. \end{aligned} \tag{C.27}$$

υ quantifies the spillover effect of foreign R&D investment into the corresponding local industry's discovery probability.[17] If $\upsilon > 0$, there is a positive technological spillover:

[16] Moretti et al. (2019) and Eser et al. (2020) report short-run euro area Phillips curve slopes that are similarly sized to our short-run estimate, but more precisely estimated.

[17] This modeling of cross-border technological spillover follows Abbritti and Weber (2019).

higher R&D in F increases the probability of discovery in H. If $\upsilon < 0$, 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. The monopolist chooses the amount of investment $I_{j,t}$ to maximize the expected return from such an investment:

$$\max_{I_{j,t}} q_{j,t} \left[V_t(\gamma A_{j,t}) - V_t(A_{j,t})\right] - P_{H,t} I_{j,t}, \quad s.t. \quad (C.27)$$

Consequently, (26) is replaced by (C.28):

$$\begin{aligned} 1 = \quad & Z_t^{\kappa-1} Z_t^{*\upsilon} \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \Pi_{H,t+1} [\Omega l_{t+1} \\ & + (1-\eta)\beta\rho [\frac{1}{Z_{t+1}^{\kappa-1} {Z_{t+1}^{*}}^{\upsilon}} + (\gamma - 1)\,(1-\kappa)\,\chi\, g_t\, Z_{t+1}]] \end{aligned} \tag{C.28}$$

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 two technological spillover scenarios: $\upsilon = \upsilon^* = 0.05$ and $\upsilon = \upsilon^* = -0.05$ – both sizable degrees of spillover compared to the domestic elasticity of discovery probability.[18] The corresponding steady state and welfare effects of fixing the exchange rate under the two spillover scenarios are shown in Tables C.1 and C.2.

A positive technology spillover exacerbates the welfare losses brought about by fixing the exchange rate. This is because, as the negative TFP effect of pegging spills over from F to H, the H growth rate decreases by more than the F growth rate increases relative to baseline. 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 at the same time as the TFP growth gap between H and F increases.

[18] To ensure comparability of the results, for each alternative calibration of υ, we recalibrate the parameters χ, χ^* to target the same TFP growth rate in H and F under flexible exchange rates as in the baseline calibration.

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

		Employment		GDP growth		
		H	F	H	F	Whole area
		l	l^*	g	g^*	$\bar{g}$
Baseline (ppt)		0.00	-6.31	0.04	-0.30	-0.09
Positive spillover (ppt)	$\upsilon = 0.05$	0.00	-6.31	-0.03	-0.29	-0.13
Negative spillover (ppt)	$\upsilon = -0.05$	0.00	-6.31	0.15	-0.35	-0.04

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

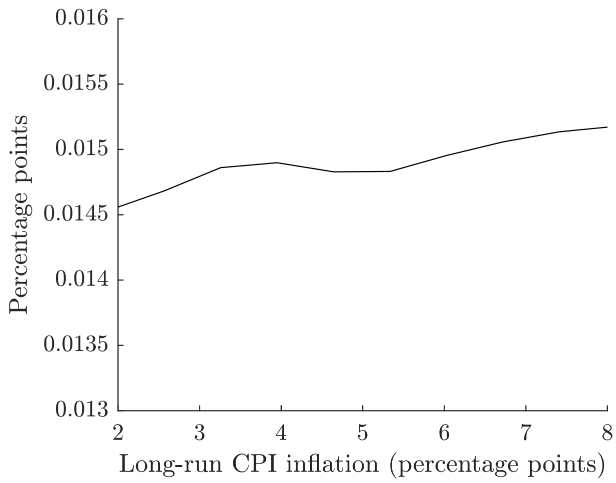
Table C.2: Welfare change relative to flexible exchange rate baseline

		Labor market convergence		
		Never	after 50 years	after 20 years
Baseline		-5.10%	-4.07%	-2.45%
Positive tech. spillover	$\upsilon = 0.05$	-6.33%	-5.03%	-3.02%
Negative tech. spillover	$\upsilon = -0.05$	-3.77%	-3.02%	-1.83%

Notes: Welfare is measured in certainty equivalent consumption. Changes are expressed as the percentage change of the steady state value under fixed exchange rates relative the steady state value under flexible exchange rates.

C.6. Benefits of inflation

Figure C.4: Marginal effect of long-run wage inflation on output growth



References

Abadie, Alberto. 2021. Using synthetic controls: feasibility, data requirements, and methodological aspects. *Journal of Economic Literature* 59(2): 391–425.

Abadie, Alberto, Alexis Diamond, and Jens Hainmueller. 2010. Synthetic control methods for comparative case studies: estimating the effect of California's tobacco control program. *Journal of the American Statistical Association* 105(490): 493–505.

Abadie, Alberto, and Javier Gardeazabal. 2003. The economic costs of conflict: a case study of the Basque Country. *American Economic Review* 93(1): 113–132.

Abbritti, Mirko, and Sebastian Weber. 2019. Market regulation, cycles and growth in a monetary union. *IMF Working Paper* .

Akerlof, George A., William T. Dickens, George L. Perry, Robert J. Gordon, and N. Gregory Mankiw. 1996. The macroeconomics of low inflation. *Brookings Papers on Economic Activity* 1996(1): 1–76.

Barnichon, Regis, and Geert Mesters. 2021. The Phillips multiplier. *Journal of Monetary Economics* 117: 689–705.

Benigno, Pierpaolo, and Luca Antonio Ricci. 2011. The inflation-output trade-off with downward wage rigidities. *American Economic Review* 101(4): 1436–66.

Bergeaud, Antonin, Gilbert Cette, and Rémy Lecat. 2016. Productivity trends in advanced countries between 1890 and 2012. *Review of Income and Wealth* 62(3): 420–444.

Byrne, David, and Zivile Zekaite. 2020. Non-linearity in the wage Phillips curve: euro area analysis. *Economics Letters* 186: 108521.

Canova, Fabio. forthcoming. Should we trust cross sectional multiplier estimates? *Journal of Applied Econometrics* .

Eser, Fabian, Peter Karadi, Philip R. Lane, Laura Moretti, and Chiara Osbat. 2020. The Phillips curve at the ECB. *The Manchester School* 88: 50–85.

Feenstra, Robert C., Robert Inklaar, and Marcel P. Timmer. 2015. The next generation of the Penn World Table. *American Economic Review* 105(10): 3150–82, available for download at www.ggdc.net/pwt.

Gabriel, Ricardo Duque. 2022. Monetary Policy and the Wage Inflation-Unemployment Tradeoff. *unpublished manuscript* .

Hazell, Jonathon, Juan Herreno, Emi Nakamura, and Jón Steinsson. 2022. The slope of the Phillips Curve: evidence from US states. *The Quarterly Journal of Economics* 137(3): 1299–1344.

Ilzetzki, Ethan, Carmen M. Reinhart, and Kenneth S. Rogoff. 2019. Exchange arrangements entering the twenty-first century: which anchor will hold? *The Quarterly Journal of Economics* 134(2): 599–646.

Imbs, Jean M. 1999. Technology, growth and the business cycle. *Journal of Monetary Economics* 44(1): 65–80.

Jordà, Òscar, Moritz Schularick, and Alan M. Taylor. 2020a. The effects of quasi-random monetary experiments. *Journal of Monetary Economics* 112: 22–40.

Jordà, Òscar, Sanjay R. Singh, and Alan M. Taylor. 2020b. The long-run effects of monetary policy. *NBER Working Paper* .

Knoppik, Christoph, and Thomas Beissinger. 2009. Downward nominal wage rigidity in Europe: an analysis of European micro data from the ECHP 1994–2001. *Empirical Economics* 36(2): 321–338.

Lo Duca, Marco, Anne Koban, Marisa Basten, Elias Bengtsson, Benjamin Klaus, Piotr Kusmierczyk, Jan Hannes Lang, Carsten Detken, and Tuomas A. Peltonen. 2017. A new database for financial crises in European countries: ECB/ESRB EU crises database. *ECB occasional paper* (194).

McLeay, Michael, and Silvana Tenreyro. 2020. Optimal inflation and the identification of the Phillips curve. *NBER Macroeconomics Annual* 34(1): 199–255.

Moretti, Laura, Luca Onorante, and Shayan Zakipour-Saber. 2019. Phillips curves in the euro area. ECB Working Paper Series No 2295.

Nickel, Christiane, Elena Bobeica, Gerrit Koester, Eliza Lis, and Mario Porqueddu. 2019. Understanding low wage growth in the euro area and European countries. ECB Occasional Paper Series No 232.

Pesaran, M. Hashem. 2006. Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica* 74(4): 967–1012.

Reinhart, Carmen M., and Kenneth S. Rogoff. 2009. *This time is different.* Princeton University Press.

Schularick, Moritz, Lucas Ter Steege, and Felix Ward. 2021. Leaning against the wind and crisis risk. *American Economic Review: Insights* 3(2): 199–214.