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Rebalancing the euro area: Is wage adjustment in Germany the answer?

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Non-technical summary

Research Question

Germany's trade and current account surplus have been the subject of much economic policy debate over recent years. In this respect, Germany has often been urged to stimulate domestic demand by lifting up, for example, wages to reduce global economic imbalances. In this paper we assess to what extent wage inflation policies in Germany could contribute to an economic rebalancing in the euro area and the rest of the world.

Contribution

To answer the question, we use an estimated three-country model for Germany in the euro area and the rest of the world. In particular, we analyze how a German nominal wage rise impacts on price inflation and the trade balance in Germany and the euro area. To account for the recent monetary policy stance in the euro area, we compare different potential monetary policy reactions to an increase of wages in Germany. More precisely, we assess the effects of different possible monetary policy scenarios. First, we assume that the euro area's monetary policy follows an interest rate rule. Second, we account for the situation of a constant interest rate policy by assuming that the monetary authority keeps the interest rate unchanged.

Results

We find that a rise in nominal wages has positive short-run effects on inflation and output in Germany and the rest of the euro area. The duration of constant interest rates and expectations about the monetary policy stance matter to the magnitude of the results obtained. We establish that the modelling of the trade relationships with the rest of the world is of particular importance, as it allows to capture the induced relative price movements and, hence, changes in competitiveness within the three regions. However, to obtain significant rebalancing effects for Germany and the rest of the euro area, very large wage increases in Germany are needed. Furthermore, the historical shock decomposition of aggregate German wage growth suggests that, in the past, wages were strongly driven by international supply and demand factors, so that the overall scope for influencing wages in Germany by domestic factors alone might be limited.

Nichttechnische Zusammenfassung

Fragestellung

Die deutschen Handels- und Leistungsbilanzüberschüsse haben in den vergangenen Jahren in der wirtschaftspolitischen Diskussion breiten Raum eingenommen. So wurde Deutschland oftmals aufgefordert, die Inlandsnachfrage beispielsweise durch Anhebung der Löhne anzukurbeln, um weltwirtschaftlichen Ungleichgewichten entgegenzuwirken. Die vorliegende Arbeit untersucht, inwieweit die Lohnpolitik in Deutschland zu einer (außen-) wirtschaftlichen Anpassung im Euro-Währungsgebiet und der übrigen Welt beitragen könnte.

Beitrag

Zur Beantwortung dieser Frage wird ein geschätztes Drei-Länder-Modell für Deutschland, den übrigen Euroraum und den Rest der Welt herangezogen. Dabei wird insbesondere analysiert, wie sich Nominallohnsteigerungen in Deutschland auf die Preisentwicklung und die Handelsbilanz im Inland und im Euroraum auswirken. Um den aktuellen geldpolitischen Kurs im Eurogebiet zu erfassen, werden verschiedene mögliche Reaktionen der Geldpolitik auf Lohnzuwächse in Deutschland miteinander verglichen. Konkret werden die Effekte verschiedener möglicher geldpolitischer Szenarien untersucht. Erstens wird angenommen, dass die Geldpolitik im Euro-Währungsgebiet einer Zinsregel folgt. Zweitens wird der Möglichkeit einer konstanten Zinspolitik Rechnung getragen.

Ergebnisse

Die Studie zeigt, dass sich eine Anhebung der Nominallöhne kurzfristig positiv auf die Inflation und Produktionsleistung in Deutschland und im übrigen Euroraum auswirkt. Entscheidend für die Höhe der Ergebnisse ist, wie lange die Zinssätze konstant gehalten werden und welche Erwartungen hinsichtlich des künftigen geldpolitischen Kurses bestehen. Der Modellierung der Handelsbeziehungen mit dem Rest der Welt kommt eine besondere Bedeutung zu, denn dadurch können die entstandenen Veränderungen der relativen Preise und damit der Wettbewerbsfähigkeit der drei Regionen erfasst werden. Um aber signifikante Anpassungseffekte in Deutschland und im übrigen Euroraum zu erzeugen, sind sehr hohe Lohnsteigerungen in Deutschland erforderlich. Zudem lässt die historische Schockzerlegung des aggregierten Lohnwachstums in Deutschland darauf schließen, dass die Löhne in der Vergangenheit stark durch globale angebots- und nachfrageseitige Faktoren bestimmt wurden. Somit könnte der Spielraum für eine Beeinflussung der Löhne in Deutschland ausschließlich durch inländische Faktoren insgesamt begrenzt sein.

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Rebalancing the Euro Area: Is Wage Adjustment in Germany the Answer?*

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Abstract

We assess to what extent wage inflation policies in Germany could contribute to an economic rebalancing in the euro area and the rest of the world. We find that a rise in nominal wage inflation has positive short-run effects on inflation and output in Germany and the rest of the euro area. The duration of constant interest rates and expectations about the monetary policy stance matter to the magnitude of the results obtained. We establish that the modelling of the trade relationships with the rest of the world is of particular importance, as it allows to capture the induced relative price movements and hence changes in competitiveness within the three regions. Our results are obtained from an estimated DSGE model which consists of Germany, the rest of the euro area, and the rest of the world.

Keywords: DSGE model, Bayesian estimation, Monetary policy, Trade balance

JEL classification:

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1 Introduction

Germany's trade and current account surpluses have been the subject of much economic policy debate over recent years.[1] The surpluses started to rise at the beginning of the 2000s with the launch of the euro and since then have increased steadily. In 2017 the German current account surplus stood at $287 billion. Thus, it was the highest in the world for the second year in a row, equating to around 8% of GDP.

The IMF (2018) argues that the persistent external imbalances in the surplus countries such as Germany reflect the possible lack of adjustment in relative prices in the euro area and the global economy as a whole, entailing the risk of moving towards more inward-oriented policies in countries such as the U.S. This could then dampen global trade and investment, thereby creating a drag on output growth and financial stability in advanced and emerging economies alike.[2] Recently, Obstfeld (2018) pointed out that in trade surplus countries such as Germany the IMF saw only "*hesitant measures, at best, to counteract the surplus*", even though the IMF and also the European Commission have long urged Germany to boost domestic demand by lifting, for example, wages to reduce what they call global economic imbalances.[3] Indeed, solving this issue involves realignments of relative prices to generate higher inflation in current account surplus countries, implemented for example through wage adjustments (see for example, IMF, 2019).[4]

In this paper we assess to what extent wage inflation policies in Germany could contribute to an economic rebalancing in the euro area and the rest of the world. In particular, we analyze how a German nominal wage rise impacts on price inflation and the current account in Germany and the euro area. To capture the nominal increase in German wages we focus in our model on a positive wage markup shock. To account for the recent monetary policy stance in the euro area, we compare three different potential monetary policy reactions to an increase in wages in Germany: In the first scenario we assume that the euro area's monetary policy follows a Taylor rule. We then investigate how the effects of the wage rise in Germany change when we account for the situation of a low interest rate environment, by assuming that the monetary authority keeps the interest rate constant for either one or two years. We find that the rise in nominal wage inflation has positive short-run effects on inflation and output in Germany and the rest of the euro area. The duration of constant interest rates and expectations about the monetary policy stance matter to the magnitude of the results obtained. We establish that the modelling of the trade relationships with the rest of the world is of particular importance, as it allows to capture the induced relative price movements and, hence, changes in competitiveness

[1] See the US Treasury (2013), the International Monetary Fund's (IMF) Executive Board statement, IMF (2013) and the European Commission (2013), as examples of relating the (German) current account surplus to concerns of a possible deflationary bias or the recovery of the euro area after the financial crisis.

[2] This view has been summarized by Obstfeld (2018): *"Germany's hesitancy to reduce its trade surplus is contributing to trade tension and adds to risks that could undermine global financial stability"*.

[3] However, it is worth highlighting that the so-called global economic imbalances are per se not inefficient "*...to the extent that global imbalances reflect the efficient allocation of capital and distribution of risk across countries, they support a well-functioning global economy...*", as Donald Kohn (Vice Chairman of the Federal Reserve, 2010) summarized it in Kohn (2010).

[4] Assessing the interaction between wage growth, the role of the exchange rate regime and, hence, the currency area for economic rebalancing traces back to Friedman (1953).

within the three regions, given the monetary policy within the euro area. However, to obtain significant rebalancing effects for Germany and the rest of the euro area, very large wage increases in Germany are needed. Furthermore, the historical shock decomposition of aggregate German wage growth suggests that in the past wages where strongly driven by international supply and demand factors, so that the overall scope of influencing wages in Germany by domestic factors alone might be limited.

Our results are obtained from an estimated Dynamic Stochastic General Equilibrium (DSGE) model which consists of Germany, the rest of the euro area and the rest of the world. In the estimation, the rest of the euro area consists of the current 19 member countries without Germany. The rest of the world is approximated on the basis of the 19 biggest trading partners of the Euro area.[5] The three regions in our model are linked internationally, given the exchange of traded goods and financial assets. The international trade in goods and financial assets is then mirrored by the countries' current account. There are exogenous shocks to preferences, technology and policy variables which alter the supply and demand conditions in markets for goods, capital, labor and financial assets in all three countries. In our simulation exercise, we focus on wage markup shocks originating in Germany. Given the importance of the export sector for the German economy, we explicitly aim to capture sectoral developments by allowing for traded and non-traded goods production. As an example, while the sectoral components of German GDP comoved up to the mid-2000s, the two sectors were de-coupling with the onset of the financial crisis. More precisely, the variations in the German non-traded GDP remained relatively stable, while the traded sector was affected very strongly during the financial crisis and the recovery thereafter. In our estimation, we therefore explicitly account for the sectoral time series of GDP for the German economy. The model is estimated by Bayesian methods using the endogenous prior approach by Del Negro and Schorfheide (2008) and Christiano, Trabandt, and Walentin (2011) . The time period of our estimation starts in 1995:Q2, ends in 2017:Q1, and it is based on seasonally adjusted data in quarterly growth rates.

While the focus of this paper is on the potential of wage inflation policies in Germany as a possible solution to European and global imbalances, it is related to a number of papers that have assessed the consequences of wage rigidity in currency unions, such as the work by Schmitt-Grohé and Uribe (2016), and Farhi, Gopinath, and Itskhoki (2013). The work closest to our is by Gali and Monacelli (2016). They assess the gains from wage adjustments within a small open economy model that is part of a currency union. In contrast to our analysis, the authors focus on the effects of greater wage flexibility as a way of insulating employment and output from shocks within a currency union. They find that the effectiveness of downward labor cost adjustments in stimulating employment is small in a currency union due to the lack of accounting for the small country within endogenous monetary policy response in the currency union. However, in our three-country model, Germany is a substantial part of the monetary reaction function within the euro area and any movements in German inflation and GDP will have a direct effect on the euro area's wide monetary policy. We show that this is of importance when assessing the relative price effects across countries and the induced re-channeling of trade flows in

[5]Those 19 countries comprising the rest of the world consist of the U.S., UK, Denmark, Norway, Sweden, Switzerland, Canada, Japan, Australia, Hong Kong, Korea, Singapore, Bulgaria, China, Czech Republic, Hungary, Croatia, Poland, and Romania.

response to higher wage inflation in Germany.

Other papers aimed at quantifying the contribution of German wage moderation policies on intra-European imbalances in two-country DSGE models (see, for example, Busl and Seymen, 2013; Gadatsch, Stähler, and Weigert, 2016; Dao, 2013a,b), but reach no consensus on the role they played for international imbalances. In contrast to those studies, we account for possible feedback coming from trade relationships of the euro area with the rest of the world. We highlight in our analysis the importance of those trade relationships, as they induce a main part of the international adjustment in relative prices via movements in the real exchange rate. In particular, the estimated moments within our three-country DSGE model are quite in line with the data, especially for variables like GDP growth and international linkages, such as net exports of Germany and the rest of the euro area, which are of first order importance in our simulation exercise. Furthermore, we find that prices of tradable goods are much more flexible than those of non-traded goods. Following the literature, this result indicates a higher competitiveness within the traded-goods sector, which then has also feedback effects on the relative price movements across countries.

In our attempt to analyze European imbalances in an estimated three-country DSGE model, the closest work to ours is Kollmann, Ratto, Roeger, in't Veld, and Vogel (2015). The authors investigate the main drivers of the German current account surplus. They find that the main factors influencing German trade flows were positive shocks to the German savings' rate as well as rest of the world's demand for German exports. In our historical shock decomposition of the German trade balance we also find a positive contribution of the German savings' rate and foreign demand factors. In addition, we find that particularly after the financial crisis, German wage developments contributed to the decline in the German external balance. In contrast to the work by Kollmann, Ratto, Roeger, in't Veld, and Vogel (2015), we utilize our estimated model to assess the possible gains from higher wage inflation in Germany in rebalancing the euro area and its main trading partners. In doing so, we allow explicitly for endogenous feedback which comes, on the one hand, from the relative monetary policy stance and, on the other hand, from the induced relative price movements and, hence, changes in competitiveness across the three trading regions.

In the following section, we give a detailed description of our model. In section 3, the Bayesian estimation procedure is laid out and the main estimation results are presented. A discussion on the model fit follows in section 4. In section 5, we address the question whether wage adjustment in Germany can help to rebalance the euro area and highlights the potential role of the monetary policy stance for relative price movements and competitiveness. Section 6 concludes.

2 Model

This section provides an outline of the three-country dynamic stochastic general equilibrium (DSGE) model, which is similar to those commonly used by many central banks and policy institutions.[6] Key to DSGE models are the microeconomic, choice-theoretic foundation of economic behavior, and the general equilibrium of these choices, given stochastic

[6]See, for example, Smets and Wouters (2003, 2007), Laxton (2008), and Pesenti (2008).

disturbances that perturb the economy away from its long-run steady state growth path.

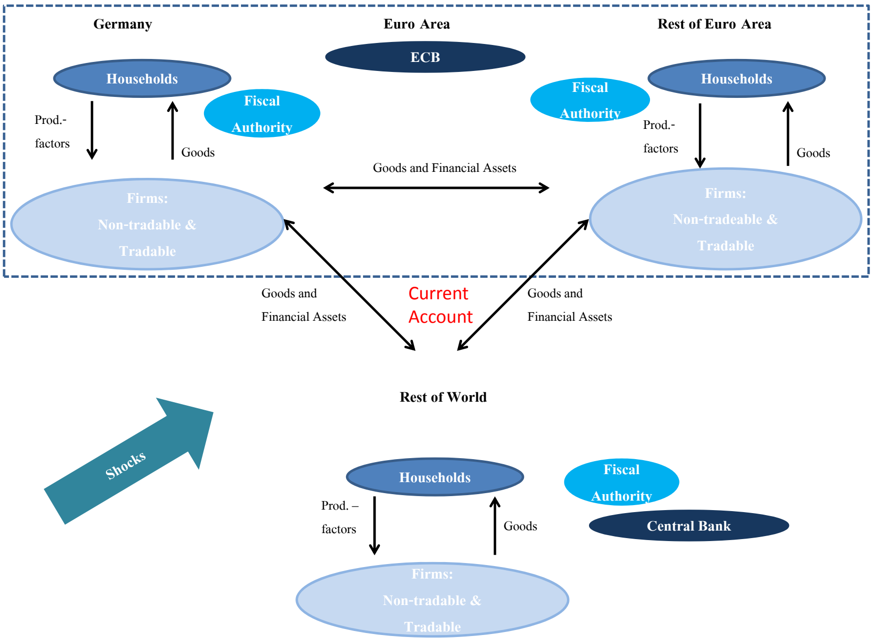


Figure 1: The model's graphical representation.

In the following we present the model's main properties. Figure 1 illustrates the countries' interplay. The theoretical world is made up of three countries, Germany, denoted below by a, the rest of the euro area, denoted by b, and the rest of the world, indexed by c. Each of the three countries has households, firms, and a government sector (i.e., a monetary and a fiscal authority). The government sector follows specific policy rules, while the behavior of firms and households derives from their maximization of profits and utility. More precisely, households consume and save and supply differentiated labor services to firms, subject to their budget constraints. Firms, in turn, combine capital and labor to produce differentiated goods sold in a monopolistically competitive product market. Investment adjustment and capital-utilization costs slow down the ability to adjust the capital stock. Both wage and price setting are subject to frictions which allow only a fraction of contracts to be reset each period. This generates real effects of monetary policy, which is determined so as to stabilize output and inflation fluctuations around their long-run trends.

The key assumption for the modelling of sticky prices and wages is that of monopolistic competition in product and labor markets, derived from preferences and technology. Households demand bundles of differentiated products, each produced by a specialized monopolistic producer. The producers thus face downward-sloping demand curves along which they choose an optimal price and quantity. In the presence of nominal price stickiness, firms' price decisions are forward-looking, that is they take future demand conditions into account when setting prices. This gives rise to the familiar New Keynesian Phillips curve. Similarly, firms' labor input is a bundle of differentiated labor services, so that a household supplying a particular variety faces a labor demand curve. Nominal wage stickiness implies that also the wage setting decision is forward-looking.

The three countries are linked internationally, given the exchange of goods and financial assets. International financial markets are incomplete and only nominal bonds are traded. The international trade in goods and financial assets is then mirrored by the countries' current account. There are exogenous shocks to preferences, technology and policy variables, which alter the supply and demand conditions in markets for goods, capital, labor and financial assets.

In the following, country-a-agents are indexed by numbers in the interval $[0;\mathcal{P}_a]$, b-agents are indexed in the interval $[0;\mathcal{P}_b]$, and c-agents reside on $[0;\mathcal{P}_c]$. Hence, the size of the world population is given by $\mathcal{P}_a+\mathcal{P}_b+\mathcal{P}_c$. All countries consist of two sectors: tradable and non-tradable. Goods from the tradable sector are supplied both domestically and internationally. Each economy specializes in the production of a certain traded (T) good, such that there are three final traded goods available in the global economy, namely goods of type a, b, and c. Each final good is an aggregate over a continuum of differentiated varieties z. Each variety is produced by a firm z which is owned by households in the respective country, using domestic capital and labor. Goods from the non-tradable sector (N) are supplied only domestically and are produced, similarly, with domestic capital and labor.

As outlined above, the countries a and b form a monetary union while the third country c has its own monetary policy. Country a represents Germany, and country b stands for the rest of the euro area. Country c then captures the rest of the world. In what follows, we discuss only country a in detail. Unless mentioned otherwise, the remaining countries b and c behave analogously to country a. We express aggregate variables in per capita terms.

2.1 Households

In country a lives a continuum of households, denoted by $[0;\mathcal{P}_a]$. We index the households by the subscript $h\in[0;\mathcal{P}_a]$. Each household h maximizes its utility,

$$\max_{C^a_{ht},I^a_{ht},K^a_{ht},u^a_{ht},\tilde{\Gamma}^a_{ht},M^a_{ht},B^{aa}_{ht},B^{ab}_{ht}} E_t\sum_{s=0}^{\infty}\beta_a^s\exp\left(\varepsilon^{\beta_a}_{t+s}\right)\cdot \tag{1}$$

$$\left[\frac{\left(C^a_{ht+s}-h_a\overline{C}^a_{t+s}\right)^{1-\sigma_a}-1}{1-\sigma_a}+\chi_a\frac{\left(M^a_{ht+s}/P^a_{t+s}\right)^{1-\zeta_a}-1}{1-\zeta_a}-\kappa_a\exp\left(\varepsilon^{N^a}_{t+s}\right)\frac{\left(N^a_{ht+s}\right)^{1+\psi_a}}{1+\psi_a}\right],$$

which depends on consumption C^a_{ht+s}, real-money balances M^a_{ht+s}/P^a_{t+s}, and hours worked N^a_{ht+s}, subject to three constraints that formalize the budget

$$\begin{aligned}&P^a_{t+s}C^a_{ht+s}+P^a_{t+s}I^a_{ht+s}+M^a_{ht+s}+B^{aa}_{ht+s}+S^{ab}_{t+s}B^{ba}_{ht+s}-B^{ac}_{ht+s} \\ &=\left(1-\tau^w_{at+s}\right)W^a_{ht+s}N^a_{ht+s}+\Upsilon^a_{ht+s}+P^a_{t+s}r^{ka}_{t+s}K^a_{ht+s-1}u^a_{ht+s}-P^a_{t+s}\tilde{\Gamma}^a_{ht+s}+M^a_{ht+s-1} \\ &+P^a_{t+s}d^a_{ht+s}-P^a_{t+s}\tau^k_{at+s}\left(r^{ka}_{t+s}K^a_{ht+s-1}u^a_{ht+s}-\tilde{\Gamma}^a_{ht+s}-\delta_aK^a_{ht+s-1}\right)+P^a_{t+s}T^a_{ht+s} \\ &+(1+i^a_{t+s-1})B^{aa}_{ht+s-1}+S^{ab}_{t+s}\left(1+i^{ba}_{t+s-1}\right)B^{ba}_{ht+s-1}-\left(1+i^{ac}_{t+s-1}\right)B^{ac}_{ht+s-1},\end{aligned} \tag{2}$$

as well as capital accumulation

$$K^a_{ht+s} = (1-\delta_a)K^a_{ht+s-1} + I^a_{ht+s}\left[1 - \frac{\upsilon_a}{2}\left(\frac{I^a_{ht+s}}{I^a_{ht+s-1}} - 1\right)^2\right]\exp\left(\varepsilon^{I^a}_{t+s}\right), \tag{3}$$

and capital-utilization costs

$$\tilde{\Gamma}^a_{ht+s} = \frac{r^{ka}}{\psi^k_a}\left[\exp\left(\psi^k_a\left(u^a_{ht+s} - 1\right)\right) - 1\right]K^a_{ht+s-1}. \tag{4}$$

Households discount the future by the factor β_a. Intertemporal decisions are, in addition, affected by the discount factor shock $\varepsilon^{\beta_a}_{t+s}$, which affects households' intertemporal substitution. The household is subject to external habit formation of the form $\overline{C}^a_{t+s} = C^a_{t+s-1}$, where C^a_{t+s-1} represents the previous period level of consumption per capita. $\varepsilon^{N^a}_{t+s}$ stands for a labor-supply shock, reflecting a disturbance to the marginal disutility of work. In quarter t, the household decides on consumption C^a_{ht}, investment I^a_{ht}, utilization rate of capital u^a_{ht}, nominal-money holdings M^a_{ht}, domestic bonds B^{aa}_{ht} (issued and held in country a, denominated in the currency of a), and international bonds B^{ab}_{ht} (issued from b to a, denominated in the currency of b, i.e. S^{ac}).[7] The remaining international bonds B^{ca}_{ht} (issued from a to c, denominated in the common currency of a and b) have a lump-sum character for the households in a—the households in c decide on B^{ca}_t. All final goods—private consumption, government consumption, investment, and capital-utilization costs—are sold at the same price P^a_{t+s}. To express the international bonds in the domestic currency, the household converts it by the nominal exchange rate S^{ac}. Every bond yields a corresponding nominal interest rate. The government taxes the nominal wage rate W^a_{ht+s} at rate τ^w_{at+s}. The nominal transfer Υ^a_{ht+s}, which the household takes as given, equalizes labor income among the households. Each unit of effective capital $K^a_{ht+s-1}u^a_{ht+s}$ earns the real return r^{ka}_{t+s}. However, the household has to bear the capital-utilization costs $\tilde{\Gamma}^a_{ht+s}$ and the capital tax rate τ^k_{at+s}, which the government imposes on the net return of capital. The physical capital K^a_{ht+s-1} depreciates at the rate δ_a. During the capital accumulation, the household encounters investment adjustment costs and the investment shock $\varepsilon^{I^a}_{t+s}$. Every household receives the same amount of dividends d^a_{ht+s}, lump-sum transfers T^a_{ht+s}, and bonds B^{ca}_{ht+s}.

As in Erceg, Henderson, and Levin (2000), wages are assumed to be sticky in that each wage setter faces each period a fixed probability of not being able to change the wage for the respective labor input. Only a fraction of households can adjust their wage. With probability $1-\gamma^w_a$, the household chooses the optimal wage W^{*a}_{ht}. With probability γ^w_a, the household fully indexes its wage to past and trend CPI inflation: $W^a_{ht-1}\left(\pi^a_{t-1}\right)^{\xi^w_a}\left(\pi^a\right)^{1-\xi^w_a}$. The CPI inflation rate is defined as: $\pi^a_t = P^a_t/P^a_{t-1}$. The optimal wage W^{*a}_{ht} comes from the following optimization problem:

[7] Given the currency union between country a and b, monetary policy will ensure that ΔS^{ab} is constant.

$$\max_{W_{ht}^{*a}} E_t \sum_{s=0}^{\infty} \left(\beta_a \gamma_a^w\right)^s \cdot \left[\frac{\left(1-\tau_{at+s}^w\right) W_{ht}^{*a} \left[\prod_{j=0}^{s-1} \left(\pi_{t+j}^a\right)^{\xi_a^w} \left(\pi^a\right)^{1-\xi_a^w}\right] N_{ht+s}^a}{P_{t+s}^a} \lambda_{ht+s}^a \right. \tag{5}$$
$$\left. - \exp\left(\varepsilon_{t+s}^{\beta_a} + \varepsilon_{t+s}^{N^a}\right) \kappa_a \frac{\left(N_{ht+s}^a\right)^{1+\psi_a}}{1+\psi_a} \right]$$

subject to

$$N_{ht+s}^a = \left[\frac{W_{ht}^{*a} \prod_{j=0}^{s-1} \left(\pi_{t+j}^a\right)^{\xi_a^w} \left(\pi^a\right)^{1-\xi_a^w}}{W_{t+s}^a} \right]^{-\theta_a^w} N_{t+s}^a.$$

The shadow price of wealth λ_{ht+s}^a translates real labor income into utility. In the demand for the differentiated labor N_{ht+s}^a, the symbol W_{t+s}^a represents the aggregate nominal wage, and N_{t+s}^a represents the aggregate labor bundle. Thus, N_{ht+s}^a denotes the labor supplied in period $t+s$ for an optimal wage W_{ht}^{*a} set in period t. Implicit in this is the assumption that the household is committed to supply any amount of labor demanded at that wage. This is incentive-compatible as long as the wage is higher than the households' marginal rate of substitution, which we assume to be true for the magnitude of fluctuations considered. The transfer Υ_{ht+s}^a in (2) overcomes the heterogeneity of households that is caused by the Calvo wage setting. The households become identical—with the exception of wages W_{ht+s}^a and labor supply N_{ht+s}^a. Therefore, we can drop the subscript h in the following optimality conditions: The optimal real wage $w_t^{*a} = W_t^{*a}/P_t^a$ can be expressed by two auxiliary variables FW_t^a and HW_t^a:

$$w_t^{*a} = \left(\frac{\theta_a^w}{\theta_a^w - 1} \frac{FW_t^a}{HW_t^a} \right)^{\frac{1}{1+\theta_a^w \psi_a}}, \text{ with}$$

$$\begin{aligned} FW_t^a &= \exp\left(\varepsilon_t^{\beta_a} + \varepsilon_t^{N^a}\right) \kappa_a \left(N_t^a\right)^{1+\psi_a} \left(w_t^a\right)^{\theta_a^w(1+\psi_a)} \\ &\quad + \beta_a \gamma_a^w E_t \left[\frac{\pi_{t+1}^a}{\left(\pi_t^a\right)^{\xi_a^w} \left(\pi^a\right)^{1-\xi_a^w}} \right]^{\theta_a^w(1+\psi_a)} FW_{t+1}^a \text{ and} \\ HW_t^a &= \left(1-\tau_{at}^w\right) \left(w_t^a\right)^{\theta_a^w} N_t^a \lambda_t^a + \beta_a \gamma_a^w E_t \left[\frac{\pi_{t+1}^a}{\left(\pi_t^a\right)^{\xi_a^w} \left(\pi^a\right)^{1-\xi_a^w}} \right]^{\theta_a^w - 1} HW_{t+1}^a, \end{aligned}$$

where $w_t^a = W_t^a/P_t^a$ represents the real aggregate wage.

The shadow price of wealth equals the marginal utility:

$$\lambda_t^a = \exp\left(\varepsilon_t^{\beta_a}\right) \left(C_t^a - h_a C_{t-1}^a\right)^{-\sigma_a}.$$

We turn now to the behavior of the capital stock. When changing the amount of capital, households account explicitly for the adjustment costs borne when investing an additional unit of capital. This is reflected by Tobin's Q, which behaves according to

$$Q_t^a = E_t \beta_a \frac{\lambda_{t+1}^a}{\lambda_t^a} \left[(1-\delta_a) Q_{t+1}^a + r_{t+1}^{ka} u_{t+1}^a - \frac{\tilde{\Gamma}_{t+1}^a}{K_t^a} \right.$$
$$\left. -\tau_{at+1}^k \left(r_{t+1}^{ka} u_{t+1}^a - \frac{\tilde{\Gamma}_{t+1}^a}{K_t^a} - \delta_a \right) \right] \exp\left(\varepsilon_t^{Q^a}\right),$$

where $\varepsilon_t^{Q^a}$ captures a stochastic component. The shadow price relates the marginal product to the capital-utilization costs of adding one unit of capital. The households decide on investment and utilization by

$$1 - Q_t^a \left[1 - \frac{\upsilon_a}{2} \left(\frac{I_t^a}{I_{t-1}^a} - 1 \right)^2 - \upsilon_a \frac{I_t^a}{I_{t-1}^a} \left(\frac{I_t^a}{I_{t-1}^a} - 1 \right) \right] \exp\left(\varepsilon_t^{I^a}\right)$$
$$= E_t \beta_a \frac{\lambda_{t+1}^a}{\lambda_t^a} Q_{t+1}^a \upsilon_a \left(\frac{I_{t+1}^a}{I_t^a} \right)^2 \left(\frac{I_{t+1}^a}{I_t^a} - 1 \right) \exp\left(\varepsilon_{t+1}^{I^a}\right)$$

and the return on capital given by

$$r_t^{ka} = r^{ka} \exp\left(\psi_a^k \left(u_t^a - 1\right)\right).$$

The effective capital supplied by the households is demanded by firms in the tradable and non-tradable sector:

$$\mathcal{P}_a K_{t-1}^a u_t^a = \mathcal{P}_a K_t^{Ta} + \mathcal{P}_a K_t^{Na}.$$

The demand for real money $m_t^a = M_t^a / P_t^a$ has the form:

$$m_t^a = \left(\chi_a \left(C_t^a - h_a C_{t-1}^a \right)^{\sigma_a} \frac{1 + i_t^a}{i_t^a} \right)^{\frac{1}{\zeta_a}}.$$

The decisions on domestic bonds B_{ht}^{aa} and international bonds B_{ht}^{ab} result into two Euler equations:

$$\lambda_t^a = E_t \beta_a \lambda_{t+1}^a \frac{1 + i_t^a}{\pi_{t+1}^a} \text{ and } \lambda_t^a = E_t \beta_a \lambda_{t+1}^a \frac{\left(1 + i_t^{ab}\right) \Delta S_{t+1}^{ab}}{\pi_{t+1}^a} \exp\left(\varepsilon_t^{RP_{ab}}\right),$$

where $\Delta S_{t+1}^{ab} = S_{t+1}^{ab} / S_t^{ab}$ describes the change in the nominal exchange rate, and $\varepsilon_t^{RP_{ab}}$ stands for a risk-premium shock.[8]

2.2 Bundlers

2.2.1 The Labor Bundler

The labor supply of each household is aggregated into a composite labor input used in production, with an elasticity of substitution θ_a^w. The price-taking labor bundler combines

[8] Given the currency union between country a and b, monetary policy will ensure that ΔS^{ab} is constant.

the differentiated labor types N_{ht}^a and produces the bundle N_t^a:

$$\max_{N_t^a, N_{ht}^a \forall h \in [0;\mathcal{P}_a]} W_t^a \mathcal{P}_a N_t^a - \int_0^{\mathcal{P}_a} W_{ht}^a N_{ht}^a \, dh,$$

subject to

$$\mathcal{P}_a N_t^a = \left[\left(\frac{1}{\mathcal{P}_a} \right)^{\frac{1}{\theta_a^w}} \int_0^{\mathcal{P}_a} N_{ht}^{a \, \frac{\theta_a^w - 1}{\theta_a^w}} \, dh \right]^{\frac{\theta_a^w}{\theta_a^w - 1}}.$$

The resulting demand function reads

$$N_{ht}^a = \left(\frac{W_{ht}^a}{W_t^a} \right)^{-\theta_a^w} N_t^a \text{ with } W_t^a = \left(\frac{1}{\mathcal{P}_a} \int_0^{\mathcal{P}_a} \left(W_{ht}^a \right)^{1-\theta_a^w} \, dh \right)^{\frac{1}{1-\theta_a^w}}.$$

Since households follow Calvo wage setting, (5), we express the wage dynamics as

$$\left(w_t^a \right)^{1-\theta_a^w} = \left(1 - \gamma_a^w\right) \left(w_t^{*a} \right)^{1-\theta_a^w} + \gamma_a^w \left[w_{t-1}^a \frac{\left(\pi_{t-1}^a \right)^{\xi_a^w} \left(\pi^a \right)^{1-\xi_a^w}}{\pi_t^a} \right]^{1-\theta_a^w}.$$

The bundled labor is sold to firms in the tradable and non-tradable sector:

$$\mathcal{P}_a N_t^a = \mathcal{P}_a N_t^{Ta} + \mathcal{P}_a N_t^{Na}.$$

2.2.2 The Final Consumption Bundler

A representative bundler produces the final consumption C_t^a by combining the tradable consumption C_t^{Ta} with the non-tradable consumption C_t^{Na}. Then

$$\max_{C_t^a, C_t^{Ta}, C_t^{Na}} P_t^a \mathcal{P}_a C_t^a - P_t^{Ta} \mathcal{P}_a C_t^{Ta} - P_t^{Na} \mathcal{P}_a C_t^{Na},$$

subject to

$$\mathcal{P}_a C_t^a = \left[\mu_{at}^{\frac{1}{\theta_a}} \left(\mathcal{P}_a C_t^{Ta} \right)^{\frac{\theta_a - 1}{\theta_a}} + \left(1 - \mu_{at}\right)^{\frac{1}{\theta_a}} \left(\mathcal{P}_a C_t^{Na} \right)^{\frac{\theta_a - 1}{\theta_a}} \right]^{\frac{\theta_a}{\theta_a - 1}},$$

results into the following demand functions:

$$C_t^{Ta} = \mu_{at} \left(R_t^{Ta} \right)^{-\theta_a} C_t^a \text{ and } C_t^{Na} = \left(1 - \mu_{at}\right) \left(R_t^{Na} \right)^{-\theta_a} C_t^a,$$

where $R_t^{Ta} = P_t^{Ta}/P_t^a$ and $R_t^{Na} = P_t^{Na}/P_t^a$ represent relative prices and μ_{at} reflects the share of traded goods in overall consumption.[9] The conditions imply that relative prices equate to

$$1 = \mu_{at} \left(R_t^{Ta} \right)^{1-\theta_a} + \left(1 - \mu_{at}\right) \left(R_t^{Na} \right)^{1-\theta_a}.$$

[9]The share of traded goods μ_{at} will be calibrated based on German data, as outlined in section 3, where we assume the same share in consumption and investment.

Then we can express the CPI inflation in terms of the tradable, $\pi_t^{Ta} = P_t^{Ta}/P_{t-1}^{Ta}$, and non-tradable inflation, $\pi_t^{Na} = P_t^{Na}/P_{t-1}^{Na}$. Using the definition of relative prices results in

$$(\pi_t^a)^{1-\theta_a} = \mu_{at} \left(R_{t-1}^{Ta}\pi_t^{Ta}\right)^{1-\theta_a} + (1-\mu_{at}) \left(R_{t-1}^{Na}\pi_t^{Na}\right)^{1-\theta_a}.$$

Note also that identical bundlers exist in the model for the final investment I_t^a, final government consumption G_t^a, and final utilization costs $\tilde{\Gamma}_t^a$.

2.2.3 The Tradable Consumption Bundler

The tradable consumption C_t^{Ta} is produced by bundling tradable goods from countries a, b, and c. Maximizing

$$\max_{C_t^{Ta},C_t^{Taa},C_t^{Tba},C_t^{Tca}} P_t^{Ta}\mathcal{P}_a C_t^{Ta} - P_t^{Taa}\mathcal{P}_a C_t^{Taa} - P_t^{Tba}\mathcal{P}_a C_t^{Tba} - P_t^{Tca}\mathcal{P}_a C_t^{Tca}$$

subject to

$$\mathcal{P}_a C_t^{Ta} = \left[(n^{aa})^{\frac{1}{\eta_a}} \left(\mathcal{P}_a C_t^{Taa}\right)^{\frac{\eta_a-1}{\eta_a}} + \left(n^{ba}\right)^{\frac{1}{\eta_a}} \left(\mathcal{P}_a C_t^{Tba}\right)^{\frac{\eta_a-1}{\eta_a}} + (n^{ca})^{\frac{1}{\eta_a}} \left(\mathcal{P}_a C_t^{Tca}\right)^{\frac{\eta_a-1}{\eta_a}}\right]^{\frac{\eta_a}{\eta_a-1}},$$

results in the bundler demands for tradable goods from a, b, and c:

$$C_t^{Taa} = n^{aa} \left(R_t^{Taa}\right)^{-\eta_a} C_t^{Ta}, \quad C_t^{Tba} = n^{ba} \left(R_t^{Tba}\right)^{-\eta_a} C_t^{Ta}, \quad C_t^{Tca} = n^{ca} \left(R_t^{Tca}\right)^{-\eta_a} C_t^{Ta},$$

where the relative prices are defined as $R_t^{Taa} = P_t^{Taa}/P_t^{Ta}$, $R_t^{Tba} = P_t^{Tba}/P_t^{Ta}$, and $R_t^{Tca} = P_t^{Tca}/P_t^{Ta}$. The elasticity of substitution between tradable goods equals η_a. The share of goods consumed in a and produced by country $j = b, c$ is denoted by n^{ja}. Let us define all n^{ja}, using the fact that $n^{aa} + n^{ba} + n^{ca} = 1$:

$$n^{aa} = 1 - \frac{\vartheta^{ca}\mathcal{P}_c + \vartheta^{ba}\mathcal{P}_b}{\mathcal{P}_a + \mathcal{P}_b + \mathcal{P}_c}; \quad n^{ba} = \frac{\vartheta^{ba}\mathcal{P}_b}{\mathcal{P}_a + \mathcal{P}_b + \mathcal{P}_c}; \quad n^{ca} = \frac{\vartheta^{ca}\mathcal{P}_c}{\mathcal{P}_a + \mathcal{P}_b + \mathcal{P}_c}.$$

where $0 \le \vartheta^{ja} \le 1$ measures the degree of openness in traded goods between country a and country j. If $\vartheta^{ja} < 1$, there is a home bias in traded consumption, meaning that households potentially want to consume more local than foreign goods.[10] As above, the relative prices satisfy:

$$1 = n^{aa} \left(R_t^{Taa}\right)^{1-\eta_a} + n^{ba} \left(R_t^{Tba}\right)^{1-\eta_a} + n^{ca} \left(R_t^{Tca}\right)^{1-\eta_a}.$$

Aggregate tradable inflation obeys

$$\left(\pi_t^{Ta}\right)^{1-\eta_a} = n^{aa} \left(R_{t-1}^{Taa}\pi_t^{Taa}\right)^{1-\eta_a} + n^{ba} \left(R_{t-1}^{Tba}\pi_t^{Tba}\right)^{1-\eta_a} + n^{ca} \left(R_{t-1}^{Tca}\pi_t^{Tca}\right)^{1-\eta_a},$$

with $\pi_t^{Taa} = P_t^{Taa}/P_{t-1}^{Taa}$, $\pi_t^{Tba} = P_t^{Tba}/P_{t-1}^{Tba}$, and $\pi_t^{Tca} = P_t^{Tca}/P_{t-1}^{Tca}$. The bundlers of tradable investment I_t^{Ta}, tradable government consumption G_t^{Ta}, and tradable utilization costs $\tilde{\Gamma}_t^{Ta}$ behave in the same way.

[10] The degree of home bias in traded goods will be calibrated based on the inter-regional trade flows outlined in more detail in section 3.

2.2.4 The Tradable Sector Bundler

A continuum of firms $[0; \mathcal{P}_a]$ is active in the tradable sector. Each firm produces a differentiated good $Y_t^{Ta}(z)$. A profit-maximizing bundler combines the differentiated goods and supplies a tradable good Y_t^{Ta}, which is demanded by countries a, b, and c.

$$\max_{Y_t^{Ta}, Y_t^{Ta}(z) \forall z \in [0;\mathcal{P}_a]} P_t^{Taa} \mathcal{P}_a Y_t^{Ta} - \int_0^{\mathcal{P}_a} P_t^{Taa}(z) Y_t^{Ta}(z)\, dz$$

subject to

$$\mathcal{P}_a Y_t^{Ta} = \left[\left(\frac{1}{\mathcal{P}_a} \right)^{\frac{1}{\theta_a^T}} \int_0^{\mathcal{P}_a} \left(Y_t^{Ta}(z) \right)^{\frac{\theta_a^T - 1}{\theta_a^T}} dz \right]^{\frac{\theta_a^T}{\theta_a^T - 1}} .$$

Then the bundler buys the differentiated goods according to:

$$Y_t^{Ta}(z) = \left(\frac{P_t^{Taa}(z)}{P_t^{Taa}} \right)^{-\theta_a^T} Y_t^{Ta} \text{ with } P_t^{Taa} = \left(\frac{1}{\mathcal{P}_a} \int_0^{\mathcal{P}_a} \left(P_t^{Taa}(z) \right)^{1-\theta_a^T} dz \right)^{\frac{1}{1-\theta_a^T}} .$$

The producers of the differentiated goods $Y_t^{Ta}(z)$ adjust their prices according to Calvo pricing. With probability $1 - \gamma_a^T$, they re-optimize and set P_t^{*Taa}. With probability γ_a^T, they do not re-optimize and index their prices to past and trend inflation: $P_t^{Taa}(z) = P_{t-1}^{Taa}(z) \left(\pi^a\right)^{\xi_a^p} \left(\pi_{t-1}^a\right)^{1-\xi_a^p}$. Therefore, we can rewrite the price equation that determines P_t^{Taa}:

$$1 = \gamma_a^T \left[\frac{\left(\pi^a\right)^{\xi_a^p} \left(\pi_{t-1}^a\right)^{1-\xi_a^p}}{\pi_t^{Taa}} \right]^{1-\theta_a^T} + \left(1 - \gamma_a^T\right) \left(\frac{R_t^{*Taa}}{R_t^{Taa}} \right)^{1-\theta_a^T} ,$$

where $R_t^{*Taa} = P_t^{*Taa} / P_t^{Ta}$.

The tradable good Y_t^{Ta} is sold to bundlers from a, b, and c that produce tradable consumption, tradable investment, tradable government consumption, and tradable utilization costs:

$$\begin{aligned} \mathcal{P}_a Y_t^{Ta} = {} & \mathcal{P}_a C_t^{Taa} + \mathcal{P}_a I_t^{Taa} + \mathcal{P}_a G_t^{Taa} + \mathcal{P}_a \tilde{\Gamma}_t^{Taa} \\ & + \mathcal{P}_b C_t^{Tab} + \mathcal{P}_b I_t^{Tab} + \mathcal{P}_b G_t^{Tab} + \mathcal{P}_b \tilde{\Gamma}_t^{Tab} \\ & + \mathcal{P}_c C_t^{Tac} + \mathcal{P}_c I_t^{Tac} + \mathcal{P}_c G_t^{Tac} + \mathcal{P}_c \tilde{\Gamma}_t^{Tac}. \end{aligned}$$

The law of one price holds. The prices of the tradable good Y_t^{Ta} in countries b and c equal $P_t^{Tab} = P_t^{Taa} S_t^{ba}$ and $P_t^{Tac} = P_t^{Taa} S_t^{ca}$. The corresponding relative prices can be written as:

$$R_t^{Tab} = R_t^{Taa} \mathcal{E}_t^{ba} \frac{R_t^{Ta}}{R_t^{Tb}} \text{ and } R_t^{Tac} = R_t^{Taa} \mathcal{E}_t^{ca} \frac{R_t^{Ta}}{R_t^{Tc}},$$

where $\mathcal{E}_t^{ba} = S_t^{ba} \left(P_t^a / P_t^b \right)$ and $\mathcal{E}_t^{ca} = S_t^{ca} \left(P_t^a / P_t^c \right)$ represent the real exchange rates. The tradable PPI inflation π_t^{Taa} and aggregate tradable inflation π_t^{Ta} are linked by

$$\pi_t^{Taa} = \pi_t^{Ta} \frac{R_t^{Taa}}{R_{t-1}^{Taa}}.$$

The inflation rates of the tradable good from a comove across countries:

$$\pi_t^{Tab} = \frac{\pi_t^{Taa}}{\Delta S_t^{ab}} \text{ and } \pi_t^{Tac} = \frac{\pi_t^{Taa}}{\Delta S_t^{ac}}.$$

2.2.5 The Non-Tradable Sector Bundler

A representative bundler buys differentiated goods $Y_t^{Na}(z)$ from the non-tradable sector and produces the aggregate non-tradable good Y_t^{Na} by

$$\max_{Y_t^{Na}, Y_t^{Na}(z) \forall z \in [0;\mathcal{P}_a]} P_t^{Na}\mathcal{P}_a Y_t^{Na} - \int_0^{\mathcal{P}_a} P_t^{Na}(z) Y_t^{Na}(z)\, dz$$

subject to

$$\mathcal{P}_a Y_t^{Na} = \left[\left(\frac{1}{\mathcal{P}_a}\right)^{\frac{1}{\theta_a^N}} \int_0^{\mathcal{P}_a} \left(Y_t^{Na}(z)\right)^{\frac{\theta_a^N - 1}{\theta_a^N}} dz \right]^{\frac{\theta_a^N}{\theta_a^N - 1}}.$$

Then the demand of the bundler reads

$$Y_t^{Na}(z) = \left(\frac{P_t^{Na}(z)}{P_t^{Na}}\right)^{-\theta_a^N} Y_t^{Na} \text{ with } P_t^{Na} = \left(\frac{1}{\mathcal{P}_a}\int_0^{\mathcal{P}_a} \left(P_t^{Na}(z)\right)^{1-\theta_a^N} dz\right)^{\frac{1}{1-\theta_a^N}}.$$

Similarly to the tradable sector, firms in the non-tradable sector set prices à la Calvo. The non-tradable firms set the optimal price P_t^{*Na} with probability $1-\gamma_a^N$. They index to trend and past CPI inflation with probability γ_a^N: $P_t^{Na}(z) = P_{t-1}^{Na}(z)\left(\pi^a\right)^{\xi_a^p}\left(\pi_{t-1}^a\right)^{1-\xi_a^p}$. Consequently, the price equation that determines P_t^{Na} can be written as:

$$1 = \gamma_a^N \left[\frac{\left(\pi^a\right)^{\xi_a^p}\left(\pi_{t-1}^a\right)^{1-\xi_a^p}}{\pi_t^{Na}}\right]^{1-\theta_a^N} + \left(1-\gamma_a^N\right)\left(\frac{R_t^{*Na}}{R_t^{Na}}\right)^{1-\theta_a^N},$$

where $R_t^{*Na} = P_t^{*Na}/P_t^a$. The following relation describes the linkage between the overall CPI inflation π_t^a and the non-tradable inflation π_t^{Na}:

$$\pi_t^{Na} = \pi_t^a \frac{R_t^{Na}}{R_{t-1}^{Na}}.$$

The aggregate non-tradable good Y_t^{Na} is sold to bundlers from a that produce the final consumption C_t^a, the final investment I_t^a, the final government consumption G_t^a, and the final utilization costs $\tilde{\Gamma}_t^a$:

$$\mathcal{P}_a Y_t^{Na} = \mathcal{P}_a C_t^{Na} + \mathcal{P}_a I_t^{Na} + \mathcal{P}_a G_t^{Na} + \mathcal{P}_a \tilde{\Gamma}_t^{Na}.$$

2.3 Firms

Firms in the traded and non-traded goods sector hire capital and labor inputs in an economy-wide rental market and are subject to price adjustment frictions in the fashion of Calvo (1983). That is, just as wage setters, firms are allowed to change their price only with a certain probability each period, so that the optimal price choice must take into account the fact that it may not be adjusted for a number of periods.

2.3.1 Firms in the Tradable Sector

Firms in the tradable sector face two productivity shocks: an economy-wide productivity shock A_t^a and a sector-specific shock A_t^{Ta}. Each firm $z \in [0; \mathcal{P}_a]$ produces a differentiated good according to a Cobb-Douglas production function:

$$Y_t^{Ta}(z) = \left(A_t^a A_t^{Ta}\right)^{1-\alpha_a^T} \left(K_t^{Ta}(z)\right)^{\alpha_a^T} \left(N_t^{Ta}(z)\right)^{1-\alpha_a^T},$$

which transforms effective capital $K_t^{Ta}(z)$ and bundled labor $N_t^{Ta}(z)$ into output $Y_t^{Ta}(z)$. The government requires the firms in the tradable sector to pay a revenue tax τ_{at}^{Tv}. In every quarter, the firms have to satisfy the demand for their products. Each firm wants to produce the demanded amount $\bar{Y}_t^{Ta}(z)$ as cheaply as possible:

$$\min_{K_t^{Ta}(z), N_t^{Ta}(z)} r_t^{ka} K_t^{Ta}(z) + w_t^a N_t^{Ta}(z)$$

subject to

$$Y_t^{Ta}(z) = \left(A_t^a A_t^{Ta}\right)^{1-\alpha_a^T} \left(K_t^{Ta}(z)\right)^{\alpha_a^T} \left(N_t^{Ta}(z)\right)^{1-\alpha_a^T} \text{ and } Y_t^{Ta}(z) \geq \bar{Y}_t^{Ta}(z).$$

The total factor demand in the tradable sector is expressed as $\int_0^{\mathcal{P}_a} K_t^{Ta}(z)\, dz = \mathcal{P}_a K_t^{Ta}$ for capital, and $\int_0^{\mathcal{P}_a} N_t^{Ta}(z)\, dz = \mathcal{P}_a N_t^{Ta}$ for labor, so that the optimal input mix then reads:

$$\frac{r_t^{ka}}{w_t^a} = \frac{\alpha_a^T}{1-\alpha_a^T} \frac{N_t^{Ta}}{K_t^{Ta}}.$$

The production function ensures that all firms have the same marginal costs $mc_t^{Ta} = MC_t^{Ta}/P_t^a$:

$$mc_t^{Ta} = \frac{\left(r_t^{ka}\right)^{\alpha_a^T} \left(w_t^a\right)^{1-\alpha_a^T}}{\left(A_t^a A_t^{Ta}\right)^{1-\alpha_a^T} \left(\alpha_a^T\right)^{\alpha_a^T} \left(1-\alpha_a^T\right)^{1-\alpha_a^T}}.$$

With probability $1-\gamma_a^T$, the firm z re-optimizes its price. The firm selects the optimal price P_t^{*Taa} by maximizing its expected profits.

$$\max_{P_t^{*Taa}} E_t \sum_{s=0}^{\infty} \left(\gamma_a^T \beta_a\right)^s \frac{\lambda_{t+s}^a}{\lambda_t^a} \frac{P_t^a}{P_{t+s}^a} \left[\left(1-\tau_{at+s}^{Tv}\right) P_t^{*Taa} \left(\prod_{j=0}^{s-1} \left(\pi^a\right)^{\xi_a^p} \left(\pi_{t+j}^a\right)^{1-\xi_a^p}\right) Y_{t+s}^{Ta}(z) \right.$$
$$\left. - MC_{t+s}^{Ta} Y_{t+s}^{Ta}(z)\right]$$

subject to

$$Y_{t+s}^{Ta}(z) = \left[\frac{P_t^{*Taa} \left(\prod_{j=0}^{s-1} \left(\pi^a\right)^{\xi_a^p} \left(\pi_{t+j}^a\right)^{1-\xi_a^p}\right)}{P_{t+s}^{Taa}}\right]^{-\theta_a^T} Y_{t+s}^{Ta}.$$

Then, the following condition specifies the optimal price in the tradable sector:

$$R_t^{*Taa} R_t^{Ta} = \frac{\theta_a^T}{\theta_a^T - 1} \frac{KN_t^{Ta}}{KD_t^{Ta}},$$

where the auxiliary variables KN_t^{Ta} and KD_t^{Ta} are defined as:

$$KN_t^{Ta} = \lambda_t^a mc_t^{Ta} Y_t^{Ta} + \gamma_a^T \beta_a E_t \left(\frac{\pi_{t+1}^{Taa}}{(\pi^a)^{\xi_a^p} (\pi_t^a)^{1-\xi_a^p}} \right)^{\theta_a^T} KN_{t+1}^{Ta},$$

$$KD_t^{Ta} = \lambda_t^a \left(1 - \tau_{at}^{Tv}\right) Y_t^{Ta} + \gamma_a^T \beta_a E_t \left(\frac{\pi_{t+1}^{Taa}}{(\pi^a)^{\xi_a^p} (\pi_t^a)^{1-\xi_a^p}} \right)^{\theta_a^T} \frac{(\pi^a)^{\xi_a^p} (\pi_t^a)^{1-\xi_a^p}}{\pi_{t+1}^a} KD_{t+1}^{Ta}.$$

Since we know the optimal input mix and the demand for $Y_t^{Ta}(z)$, we can integrate over z and obtain the aggregate production function of the tradable sector:

$$Y_t^{Ta} \frac{1}{\mathcal{P}_a} \int_0^{\mathcal{P}_a} \left(\frac{P_t^{Taa}(z)}{P_t^{Taa}} \right)^{-\theta_a^T} dz = \left(A_t^a A_t^{Ta}\right)^{1-\alpha_a^T} \left(K_t^{Ta}\right)^{\alpha_a^T} \left(N_t^{Ta}\right)^{1-\alpha_a^T}.$$

2.3.2 Firms in the Non-Tradable Sector

The environment of the non-tradable sector resembles the environment of the tradable sector. A firm $z \in [0; \mathcal{P}_a]$ from the non-tradable sector has also a Cobb-Douglas production function:

$$Y_t^{Na}(z) = \left(A_t^a A_t^{Na}\right)^{1-\alpha_a^N} \left(K_t^{Na}(z)\right)^{\alpha_a^N} \left(N_t^{Na}(z)\right)^{1-\alpha_a^N},$$

where A_t^{Na} denotes the productivity shock that is specific to the non-tradable sector.

The firm z is confronted with the demand $\bar{Y}_t^{Na}(z)$. To produce the amount of goods demanded, the firm has to decide how much effective capital $K_t^{Na}(z)$ and bundled labor $N_t^{Na}(z)$ to hire by

$$\min_{K_t^{Na}(z), N_t^{Na}(z)} r_t^{ka} K_t^{Na}(z) + w_t^a N_t^{Na}(z)$$

subject to

$$Y_t^{Na}(z) = \left(A_t^a A_t^{Na}\right)^{1-\alpha_a^N} \left(K_t^{Na}(z)\right)^{\alpha_a^N} \left(N_t^{Na}(z)\right)^{1-\alpha_a^N} \text{ and } Y_t^{Na}(z) \geq \bar{Y}_t^{Na}(z).$$

We express the optimal choice of labor and capital in aggregate terms:

$$\frac{r_t^{ka}}{w_t^a} = \frac{\alpha_a^N}{1-\alpha_a^N} \frac{N_t^{Na}}{K_t^{Na}},$$

where $\mathcal{P}_a K_t^{Na} = \int_0^{\mathcal{P}_a} K_t^{Na}(z)\, dz$ and $\mathcal{P}_a N_t^{Na} = \int_0^{\mathcal{P}_a} N_t^{Na}(z)\, dz$. All firms in the non-tradable sector share the same marginal costs $mc_t^{Na} = MC_t^{Na}/P_t^a$:

$$mc_t^{Na} = \frac{\left(r_t^{ka}\right)^{\alpha_a^N} \left(w_t^a\right)^{1-\alpha_a^N}}{\left(A_t^a A_t^{Na}\right)^{1-\alpha_a^N} \left(\alpha_a^N\right)^{\alpha_a^N} \left(1-\alpha_a^N\right)^{1-\alpha_a^N}}.$$

The firm z re-optimizes its price with probability $1-\gamma_a^N$. The re-optimized price P_t^{*Na} maximizes the stream of expected profits, which are lowered by the revenue tax τ_{at}^{Nv}:

$$\max_{P_t^{*Na}} E_t \sum_{s=0}^{\infty} \left(\gamma_a^N \beta_a\right)^s \frac{\lambda_{t+s}^a}{\lambda_t^a} \frac{P_t^a}{P_{t+s}^a} \left[\left(1-\tau_{at+s}^{Nv}\right) P_t^{*Na} \left(\prod_{j=0}^{s-1} \left(\pi^a\right)^{\xi_a^p} \left(\pi_{t+j}^a\right)^{1-\xi_a^p}\right) Y_{t+s}^{Na}(z) \right.$$
$$\left. - MC_{t+s}^{Na} Y_{t+s}^{Na}(z)\right]$$

subject to

$$Y_{t+s}^{Na}(z) = \left[\frac{P_t^{*Na}\left(\prod_{j=0}^{s-1} \left(\pi^a\right)^{\xi_a^p} \left(\pi_{t+j}^a\right)^{1-\xi_a^p}\right)}{P_{t+s}^{Na}}\right]^{-\theta_a^N} Y_{t+s}^{Na}.$$

Then, the re-optimized price takes the form:

$$R_t^{*Na} = \frac{\theta_a^N}{\theta_a^N - 1} \frac{KN_t^{Na}}{KD_t^{Na}},$$

where the auxiliary variables KN_t^{Na} and KD_t^{Na} follow:

$$KN_t^{Na} = \lambda_t^a mc_t^{Na} Y_t^{Na} + \gamma_a^N \beta_a E_t \left(\frac{\pi_{t+1}^{Na}}{\left(\pi^a\right)^{\xi_a^p} \left(\pi_t^a\right)^{1-\xi_a^p}}\right)^{\theta_a^N} KN_{t+1}^{Na},$$

$$KD_t^{Na} = \lambda_t^a \left(1-\tau_{at}^{Nv}\right) Y_t^{Na} + \gamma_a^N \beta_a E_t \left(\frac{\pi_{t+1}^{Na}}{\left(\pi^a\right)^{\xi_a^p} \left(\pi_t^a\right)^{1-\xi_a^p}}\right)^{\theta_a^N} \frac{\left(\pi^a\right)^{\xi_a^p} \left(\pi_t^a\right)^{1-\xi_a^p}}{\pi_{t+1}^a} KD_{t+1}^{Na}.$$

Integrating over the demand for $Y_t^{Na}(z)$ results into the aggregate production function of the non-tradable sector:

$$Y_t^{Na} \frac{1}{\mathcal{P}_a} \int_0^{\mathcal{P}_a} \left(\frac{P_t^{Na}(z)}{P_t^{Na}}\right)^{-\theta_a^N} dz = \left(A_t^a A_t^{Na}\right)^{1-\alpha_a^N} \left(K_t^{Na}\right)^{\alpha_a^N} \left(N_t^{Na}\right)^{1-\alpha_a^N}.$$

2.4 Monetary Policy

The central bank of the monetary union (countries a and b) conducts its policy according to a simple rule:

$$\ln\left(\frac{1+i_t^{mu}}{1+i^{mu}}\right) = \rho_{mu}^i \ln\left(\frac{1+i_{t-1}^{mu}}{1+i^{mu}}\right) + \left(1-\rho_{mu}^i\right) \phi_{mu}^{\pi} \left[\frac{\mathcal{P}_a}{\mathcal{P}_a+\mathcal{P}_b} \ln\left(\frac{\pi_t^a}{\pi^a}\right) + \frac{\mathcal{P}_b}{\mathcal{P}_a+\mathcal{P}_b} \ln\left(\frac{\pi_t^b}{\pi^b}\right)\right]$$
$$+ \left(1-\rho_{mu}^i\right) \phi_{mu}^{y} \left[\frac{\mathcal{P}_a}{\mathcal{P}_a+\mathcal{P}_b} \ln\left(\frac{Y_t^a}{Y_{t-1}^a}\right) + \frac{\mathcal{P}_b}{\mathcal{P}_a+\mathcal{P}_b} \ln\left(\frac{Y_t^b}{Y_{t-1}^b}\right)\right] + \nu_t^{i^{mu}}.$$

The bank smoothes its policy rate i_t^{mu} and responds to the average CPI inflation and the average output growth in the monetary union. The monetary shock $\nu_t^{i^{mu}}$ allows for deviations from the strict rule. To be precise, the symbol Y_t^a denotes the CPI-deflated

GDP per capita:

$$Y_t^a = R_t^{Taa} R_t^{Ta} Y_t^{Ta} + R_t^{Na} Y_t^{Na}.$$

The following relation transmits the common monetary policy to countries a and b:

$$\ln\left(\frac{1+i_t^{mu}}{1+i^{mu}}\right) = \frac{\mathcal{P}_a}{\mathcal{P}_a+\mathcal{P}_b}\ln\left(\frac{1+i_t^a}{1+i^a}\right) + \frac{\mathcal{P}_b}{\mathcal{P}_a+\mathcal{P}_b}\ln\left(\frac{1+i_t^b}{1+i^b}\right).$$

The nominal exchange rate between the countries that constitute the monetary union does not alter:

$$\Delta S_t^{ab} = \frac{S_t^{ab}}{S_{t-1}^{ab}} = \frac{1}{1} = 1.$$

Similarly to the monetary union, the central bank of country c sets the policy rate i_t^c by a simple rule with smoothing:

$$\ln\left(\frac{1+i_t^c}{1+i^c}\right) = \rho_c^i \ln\left(\frac{1+i_{t-1}^c}{1+i^c}\right) + \left(1-\rho_c^i\right)\phi_c^\pi \ln\left(\frac{\pi_t^c}{\pi^c}\right) + \left(1-\rho_c^i\right)\phi_c^y \ln\left(\frac{Y_t^c}{Y_{t-1}^c}\right) + \nu_t^{ic}.$$

Changes in the interest rates lead to changes in the monetary base, which represent seigniorage for the governments.

2.5 Fiscal Policy

The government consumption G_t^a follows a stochastic process:

$$G_t^a = G^a \exp\left(\varepsilon_t^{Ga}\right).$$

The fiscal budget equalizes expenditures with revenues:

$$\begin{aligned}\mathcal{P}_a P_t^a T_t^a + \mathcal{P}_a P_t^a G_t^a &= \mathcal{P}_a M_t^a - \mathcal{P}_a M_{t-1}^a + \mathcal{P}_a \tau_{at}^w W_t^a N_t^a \\ &+ \mathcal{P}_a P_t^a \tau_{at}^k \left(r_t^{ka} K_{t-1}^a u_t^a - \tilde{\Gamma}_t^a - \delta_a K_{t-1}^a\right) \\ &+ \mathcal{P}_a \tau_{at}^{Tv} P_t^{Taa} Y_t^{Ta} + \mathcal{P}_a \tau_{at}^{Nv} P_t^{Na} Y_t^{Na}.\end{aligned}$$

The income of the government comes from seigniorage, wage tax, capital tax, and revenue tax. The government spends the income on transfers and consumption. The privately organized transfers Υ_{ht}^a result in each household receiving the average after-tax labor income. Consequently, the transfers Υ_{ht}^a sum to zero:

$$\int_0^{\mathcal{P}_a} \Upsilon_{ht}^a \, dh = 0.$$

2.6 International Linkages

The real exchange rate of country a against country b equals the inverse of the real exchange rate of country b against country a:

$$\mathcal{E}_t^{ab} = S_t^{ab} \frac{P_t^b}{P_t^a} = \frac{1}{\mathcal{E}_t^{ba}}.$$

Similarly, the real exchange rate of country a against country c equals the inverse of the real exchange rate of country c against country a:

$$\mathcal{E}_t^{ac} = S_t^{ac}\frac{P_t^c}{P_t^a} = \frac{1}{\mathcal{E}_t^{ca}}.$$

Changes in nominal exchange rates can be expressed as changes in real exchange rates that are adjusted for inflation:

$$\Delta S_t^{ab} = \frac{S_t^{ab}}{S_{t-1}^{ab}} = \frac{\mathcal{E}_t^{ab}}{\mathcal{E}_{t-1}^{ab}}\frac{\pi_t^a}{\pi_t^b} \text{ and } \Delta S_t^{ca} = \frac{S_t^{ca}}{S_{t-1}^{ca}} = \frac{\mathcal{E}_t^{ca}}{\mathcal{E}_{t-1}^{ca}}\frac{\pi_t^c}{\pi_t^a}.$$

We introduce net exports into the model by the following equations:

$$\begin{aligned} NX_t^a = & R_t^{Taa}R_t^{Ta}\frac{\mathcal{P}_b}{\mathcal{P}_a}\left(C_t^{Tab} + I_t^{Tab} + G_t^{Tab} + \tilde{\Gamma}_t^{Tab}\right) \\ & + R_t^{Taa}R_t^{Ta}\frac{\mathcal{P}_c}{\mathcal{P}_a}\left(C_t^{Tac} + I_t^{Tac} + G_t^{Tac} + \tilde{\Gamma}_t^{Tac}\right) \\ & - \mathcal{E}_t^{ab}R_t^{Tbb}R_t^{Tb}\left(C_t^{Tba} + I_t^{Tba} + G_t^{Tba} + \tilde{\Gamma}_t^{Tba}\right) \\ & - \mathcal{E}_t^{ac}R_t^{Tcc}R_t^{Tc}\left(C_t^{Tca} + I_t^{Tca} + G_t^{Tca} + \tilde{\Gamma}_t^{Tca}\right). \end{aligned}$$

The net exports NX_t^a are deflated by the CPI and expressed in per capita terms. Additionally, we define net foreign assets nfa_t^a—again CPI-deflated and in per capita terms:

$$nfa_t^a = \mathcal{E}_t^{ab}\frac{\mathcal{P}_b}{\mathcal{P}_a}b_t^{ab} - b_t^{ca}.$$

The bonds b_t^{ab} issued from b to a are deflated by the CPI of b and are expressed in per capita terms of b; the bonds b_t^{ca} issued from a to c are deflated by the CPI of a and are expressed in per capita terms of a. The domestic bonds stay in zero net supply:

$$\int_0^{\mathcal{P}_a} B_{ht}^{aa}\, dh = 0.$$

By modelling risk premia, we follow Adolfson, Laséen, Lindé, and Villani (2008). The risk premia depend on the amount of bonds in circulation and on the expected change in the nominal exchange rate:

$$1 + i_t^{ca} = (1 + i_t^a)\exp\left(-\omega^b\left[\mathcal{E}_t^{ca}b_t^{ca} - \mathcal{E}^{ca}b^{ca}\right] - \omega^s\left[E_t\Delta S_{t+1}^{ca}\Delta S_t^{ca} - (\Delta S^{ca})^2\right]\right).$$

The structure of risk premia rules out explosive behavior of bonds and results into a hump-shaped response of the real exchange rate after a monetary shock. A similar condition holds with respect to the interest rate $1 + i_t^{ab}$, except that the change in the nominal exchange rate is constant between country a and country b, so that the last term in the above equation would disappear. If one combines the fiscal budget with the household budget, and one realizes that dividends d_t^a can be written as:

$$\mathcal{P}_a P_t^a d_t^a = \mathcal{P}_a \left(1 - \tau_{at}^{Tv}\right) P_t^{Taa} Y_t^{Ta} + \mathcal{P}_a \left(1 - \tau_{at}^{Nv}\right) P_t^{Na} Y_t^{Na} - \mathcal{P}_a W_t^a N_t^a - \mathcal{P}_a P_t^a r_t^{ka} K_{t-1}^a u_t^a,$$

one can then obtain the aggregate resource constraint:

$$Y_t^a + \mathcal{E}_t^{ab} \frac{1 + i_{t-1}^{ab}}{\pi_t^b} \frac{\mathcal{P}_b}{\mathcal{P}_a} b_{t-1}^{ab} + b_t^{ca} = C_t^a + I_t^a + G_t^a + \tilde{\Gamma}_t^a + \mathcal{E}_t^{ab} \frac{\mathcal{P}_b}{\mathcal{P}_a} b_t^{ab} + \frac{1 + i_{t-1}^{ca}}{\pi_t^a} b_{t-1}^{ca}.$$

This closes the description of our three-country DSGE model of Germany, the rest of the euro area and the rest of the world.

3 Data and Estimation

Having outlined the micro foundations of our three-country DSGE model, we now turn to the estimation of the model. In this section we describe the data used and discuss the Bayesian procedure to estimate the three-country model outlined in section 2.

3.1 Data

The data for Germany (GER) are obtained from the Bundesbank's statistics department, while all time series for the rest of the euro area (RoE) are calculated from original Eurostat data and are measures of the current 19 EMU-member countries without Germany. The precise time series we use for both areas are data on nominal GDP, consumption, investment, nominal wages, CPI deflator, population, and employment. While for Germany these data are available from 1991 onward, time series for RoE start from 1995 or even later. For example, the time series for CPI is available from 1996 onwards, but series for wages and employment start in 2000. To this end, we follow the approach by Gadatsch, Hauzenberger, and Stähler (2016) and use a subset of eight countries to extend the aforementioned time series back to 1995.[11] To distinguish between the tradable and non-tradable sector in Germany we decompose the German GDP accordingly by using German GDP by industry data. Therefore, we group industries like *manufacturing*, *information and communication*, *financial and insurance services*, and *business activities* as tradable goods and the remaining industries like *agriculture, forestry and fishing*, *construction*, *real estate activities*, *trade, transport, accommodation and food services*, *public services, education and health*, and *other services* into the group of non-traded goods. Of course, this classification is ad hoc and for some industries, especially, like *trade, transport, accommodation and food services* a stricter separation would be appreciated but is not accomplishable at this aggregate level. Hence, on average, we treat 45% of German GDP as coming from tradable goods sector. Figure 2 shows the year-to-year real growth rate of the constructed time series with each series deflated by overall CPI.

The figure highlights the profound role of Germany's tradable goods sector after the financial crisis. While before and later both time series comove very closely, the deep

[11] As discussed in Gadatsch, Hauzenberger, and Stähler (2016), the subset of countries includes Austria, Belgium, Finland, France, Italy, the Netherlands, and Spain, which together with Germany cover roughly 90% of euro area's GDP.

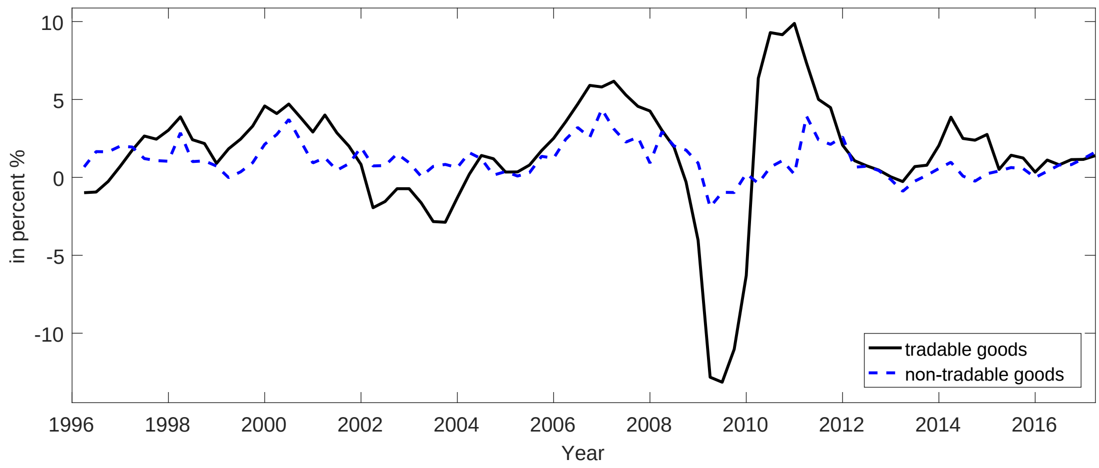
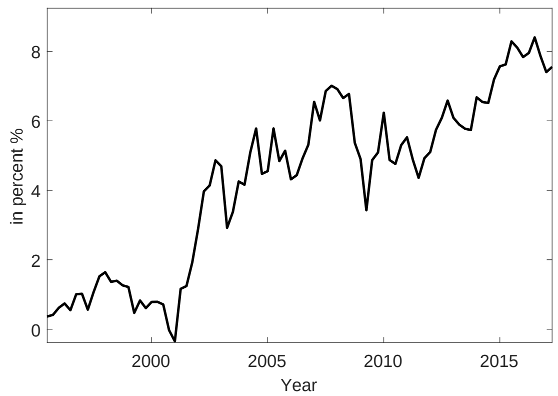


Figure 2: Year-on-year growth of German GDP decomposed into tradable and non-tradable goods.

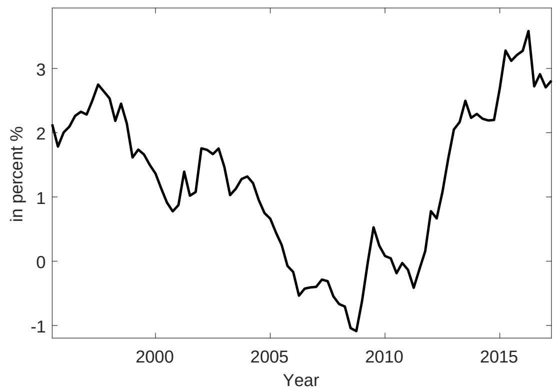
recession in the aftermath of the financial crisis mainly shows up in Germany's tradable goods sector.

We decompose the German PPI deflator into traded and non-traded goods. Note that in our model the PPI deflator of non-tradable goods is equivalent to the CPI deflator of non-tradable goods, which is also used for our estimation below.

We follow Kollmann, Ratto, Roeger, in't Veld, and Vogel (2015) by using nominal trade balances available for Germany and the euro area to derive the RoE's trade balance given the regional configuration of the model. Figures 3(a) and 3(b) show the time series for net exports over GDP for Germany and RoE, respectively. Figure 3(a) illustrates the substantial and persistent increase of Germany's net exports relative to GDP at the beginning of the 2000s. Before that time span, the German trade balance was close to balance. The German net exports in percent of GDP reached around 7% in 2007 before the financial crisis, followed by an abrupt decrease to 4%-5% in the global recession of 2008-09, and continuously increased afterwards to almost 8% in 2015-17, as highlighted in the introduction.



(a) Germany



(b) Rest of Euro Area

Figure 3: Net exports over GDP for Germany and rest of euro area between 1995:Q1 and 2017:Q1

For the estimation we approximate the rest of the world (RoW) by the 19 biggest trading partners of the euro area.[12] RoW's nominal GDP is calculated as the sum of nominal GDP for the 19 countries converted into US dollar. To do so, we use data from the Bundesbank's statistics department as well as the IMF's International Financial Statistics (IFS) database. Figure 4 shows the average contribution of the different countries to RoW's nominal GDP. In particular, the U.S. accounts for around 44% of RoW's nominal GDP, while China accounts for around 12%. These time-varying weights for each of the

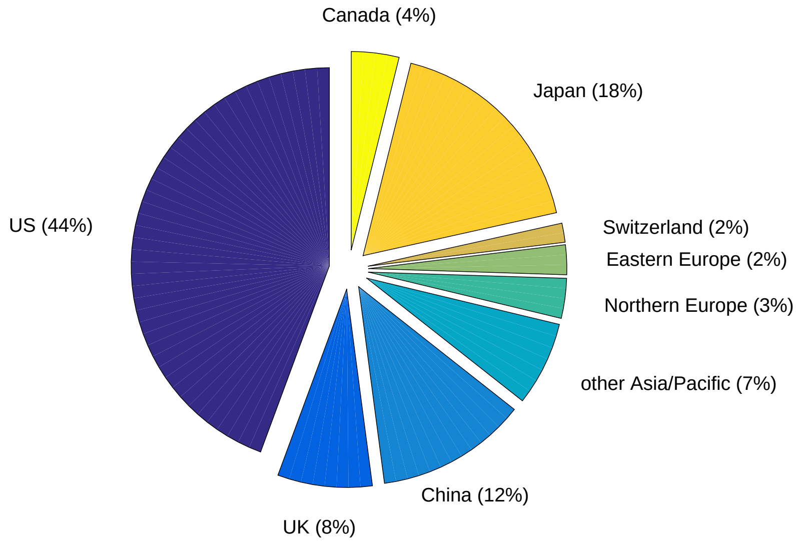


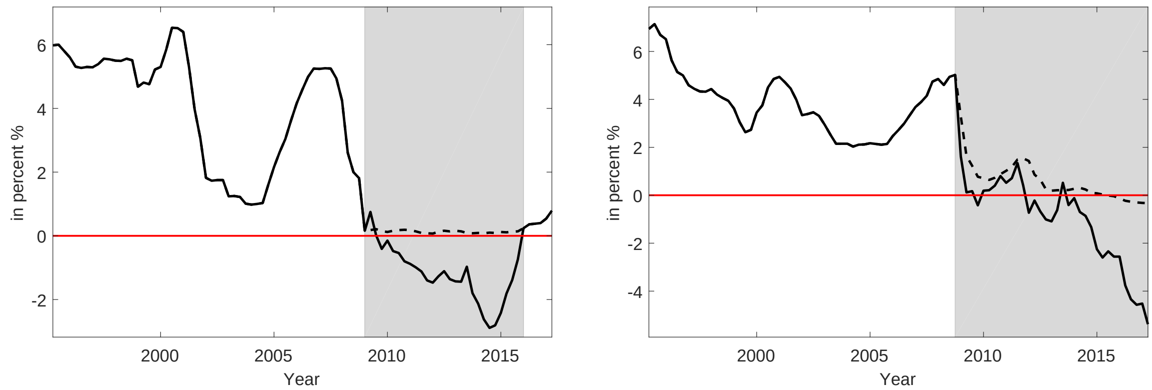
Figure 4: Average geographical decomposition of the RoW's nominal GDP.

19 countries are also used to calculate the CPI deflator for the RoW block in our model. Moreover, the use of time-varying weights accounts for the increasing relative economic weight of emerging economies over our sample period. Finally, we use the US interest rate as a proxy for the RoW nominal interest rate. Due to the currency transformation into U.S. dollar, price inflation in the RoW is defined in U.S. dollar terms and includes real exchange rate movements between the RoW members. Therefore, the use of U,S, dollar prices is consistent with the U.S. interest rates in the RoW monetary policy rule (see Kollmann, Ratto, Roeger, in't Veld, and Vogel, 2015).

In the aftermath of the financial crisis the euro area as well as the U.S. experienced a prolonged time of nominal interest rates close to or below zero accompanied by various measures of unconventional monetary policy. However, it is beyond the scope of the present model to capture the zero lower bound of interest rates or unconventional monetary policy measures like quantitative easing. Hence, to cover the accommodative monetary policy over the last few years to some extent, we use the shadow short rates as postulated by Wu and Xia (2016, 2017). In particular, until 2008:Q3 we use the effective federal funds rate and the Euribor as measures for the nominal interest rate for RoW and the euro area, respectively. Afterwards, we use the corresponding shadow short rates for the U.S. until 2015:Q3 and until the end of the sample for the euro area. Additionally, because the Euribor starts in 1999, we extend the time series back to 1995 by using

[12] The 19 countries are: the U.S., United Kingdom, Denmark, Norway, Sweden, Switzerland, Canada, Japan, Australia, Hong Kong, Korea, Singapore, Bulgaria, China, Czech Republic, Hungary, Croatia, Poland, and Romania.

the short-term interest rate of Fagan, Henry, and Mestre (2005) or Warne, Coenen, and Christoffel (2008). Figure 5(a) and 5(b) illustrates the aforementioned transformation of the nominal interest rates and shadow rates due to episodes of unconventional monetary policy.



(a) U.S.

(b) Euro Area

Figure 5: Nominal policy rate in the U.S. and Euro Area between 1995:Q1 and 2017:Q1. The dashed lines represent the effective federal funds rate and Euribor for the U.S. and Euro area, respectively, while the solid lines include the shadow short rates by Wu and Xia (2016, 2017) during the episodes of unconventional monetary policy in the aftermath of the financial crisis (shaded areas).

We estimate the three-country model with quarterly data from 1995:Q2 to 2017:Q1. All time series are transformed into real and per capita terms as necessary. Altogether, we use 20 time series, where nine time series are related to Germany, seven time series are related to the rest of the euro area as well as the euro area policy rate, while three time series cover the rest of the world. Appendix A.1 reports more details about the source and transformation of all data and the set of corresponding observable variables in the model.

3.2 Bayesian Estimation

In this subsection, we present the prior choices for the estimated parameters as well as the calibration of the remaining parameters. We calibrate several parameters of the model. In all regions, the discount factor β and the steady state inflation rate π imply annual nominal interest rate of 3.9% in the steady state. We set the steady state velocity of the monetary base to 14% and the steady state government consumption to 25% of GDP. In the steady state, the households spend 33% of their time working. The depreciation rates of capital δ equal 2.5% per quarter; the capital share α in both sectors—tradable and non-tradable— is equal to 33%. The tradable sector exhibits price elasticity θ^T of 6. The non-tradable sector, where firms face less intensive competition, exhibits price elasticity θ^N of 4. We set the wage elasticity θ^w to a conservative value of 6. The elasticity between home and foreign tradables η is calibrated to 1.5 following, for example, Mendoza (1992). We calibrate θ, the elasticity between tradables and non-tradables, to 0.9, which is smaller than in Obstfeld and Rogoff (2007) but higher than in Mendoza (1992) or Stockman and

Tesar (1995). We choose the weights of the home and foreign tradables n to match the inter-regional trade flows, which we report in Table 1.

	Exports from i to j in % of i GDP			Imports to i from j in % of i GDP		
$i\backslash j$	*GER*	*RoE*	*RoW*	*GER*	*RoE*	*RoW*
GER	—	14.8	23.1	—	14.8	23.1
RoE	4.9	—	17.4	4.9	—	17.4
RoW	0.9	2.1	—	0.9	2.1	—

Table 1: Steady State Trade Matrix.

The elasticity between the aggregate tradable and the aggregate non-tradable good θ is 0.9. The weight of the aggregate tradable good μ ensures that the size of the tradable production corresponds to 45% of the total GDP, in line with the data. We normalize the German population $\mathcal{P}_a$ to 1. Consequently, we express the populations of the remaining regions $\mathcal{P}_b$ and $\mathcal{P}_c$ in relative terms to Germany. Table 2 in the appendix gives a complete overview of the calibrated values. The remaining parameters of the model are estimated.

The focus of the paper is to explain key business cycle facts of the German economy, including those which reflect the international linkages. We therefore pay special attention to selected second moments when estimating the DSGE model. In particular, we use the second moments of macroeconomic variables, about which we have a priori knowledge, to inform our prior distribution and apply the method of Christiano, Trabandt, and Walentin (2011). Their approach is conceptually similar to the one proposed by Del Negro and Schorfheide (2008), but differs in some important respects. Specifically, Del Negro and Schorfheide (2008) focus on the model-implied p-th order vector autoregression, which implies that the likelihood of the second moments is known exactly conditional on the DSGE model parameters and requires no large-sample approximation, in contrast to the approach by Christiano, Trabandt, and Walentin (2011). Yet, the latter approach is more flexible when focusing on the statistics (S) to be targeted. More precisely, let S be a column vector containing the second moments of interest, then, as shown by Christiano, Trabandt, and Walentin (2011) under the assumption of a large sample, the estimator of S is

$$\hat{S} \sim N\left(S^0, \frac{\hat{\Sigma}_S}{T}\right) \tag{6}$$

with S^0 the true value of S, T the sample length, and $\hat{\Sigma}_S$ the estimate of the zero-frequency spectral density. Now, let $S_M(\theta)$ be a function which maps our DSGE model parameters θ into S. Then, for n targeted second moments and sufficiently large T, the density of $\hat{S}$ is given by

$$p\left(\hat{S}|\theta\right) = \left(\frac{T}{2\pi}\right)^{\frac{n}{2}} \left\|\hat{\Sigma}_S\right\|^{-\frac{1}{2}} \exp\left\{-\frac{T}{2}\left(\hat{S} - S_M(\theta)\right)' \hat{\Sigma}_S^{-1} \left(\hat{S} - S_M(\theta)\right)\right\} . \tag{7}$$

In our application, S is a set of variances of macroeconomic variables (German GDP growth, German investment growth, German consumption growth, German inflation, German net exports over GDP, and the euro area policy rate). In sum, the overall endogenous prior distribution takes the following form

$$p\left(\theta|\hat{S}\right) = C^{-1}p\left(\theta\right)p\left(\hat{S}|\theta\right) \ , \tag{8}$$

where $p\left(\theta\right)$ is the initial prior distribution and C a normalization constant. Two points are noteworthy. First, while the initial priors are independent across parameters, as is typical in Bayesian analysis, the endogenous prior is not independent across parameters. Second, the normalization constant C is necessary for, e.g., posterior odds calculation but not for estimating the model. Accordingly, we do not calculate this constant, which has otherwise to be approximated (see, for example, Del Negro and Schorfheide, 2008). Thus, the posterior distribution is given by

$$p\left(\theta|X,\hat{S}\right) \propto p\left(\theta|\hat{S}\right)p\left(X|\theta\right) \tag{9}$$

with $p\left(X|\theta\right)$ the likelihood of the data conditional on DSGE model parameters θ. Table 4 in the appendix summarizes the initial prior distributions of the estimated parameters.

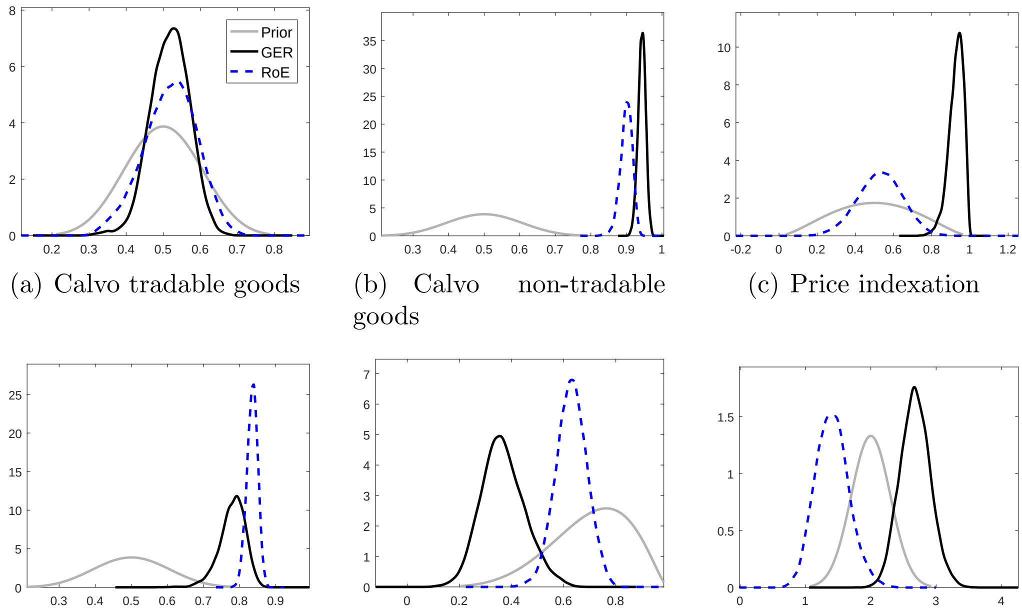
4 Estimation Results and Model Fit

In the following subsection, we present parameter estimates and business cycle statistics to evaluate our estimated three-country model. We apply standard Bayesian techniques to estimate the model using the 20 time series listed above between 1995:Q2 to 2017:Q1. In particular, we estimate the posterior mode of the distribution and employ a random walk Metropolis-Hasting algorithm to simulate the posterior distribution of the parameters and to quantify the uncertainty of our estimates of the same. In particular, we run 10 chains, each with one million parameter vector draws, where the first 50% have been discarded, with a draw acceptance rate of about 1/4.

4.1 Parameter Estimates

Tables 4 and 5 in the appendix provide posterior statistics of the estimated parameters, e.g., the posterior mode, posterior mean and the 90% posterior credible set. The results indicate that the posterior distributions of all structural parameters are well approximated and differ from the initial prior distribution.

In the following, we discuss some key parameters in greater detail. Figure 6 illustrates the posterior distribution of key parameters in comparison to its initial prior distribution. We find strong heterogeneities between the tradable goods and non-tradable goods sector within each country, but also differences across countries. In particular, we find that prices of tradable goods are much more flexible than non-traded goods. Following the literature, this result indicates a greater competitiveness within the traded goods sector. For example, Rotemberg and Saloner (1987) find that the cost of having the wrong price is bigger for duopolists than for monopolists, and Carlton (1986) provides empirical support showing that less competitive industries have more rigid prices. Regarding the flexibility of wages, we find a similar but less pronounced result, with less flexible wages in the rest of the euro area compared to Germany. Together with the differences in price indexation in both areas, the model points to heterogeneous inflation dynamics. Additionally, the differences in the preference parameters (e.g. habit formation and consumption elasticity) point to different output-interest rate elasticities in both regions via the IS curve. Together, these findings illustrate the necessity to carefully evaluate the effects of a common monetary policy across countries and sectors.



(a) Calvo tradable goods (b) Calvo non-tradable goods (c) Price indexation

(d) Calvo wages (e) Habit formation (f) Consumption elasticity

Figure 6: Prior and Posterior distribution for selected model parameters. The gray line indicates the prior while the black line and the blue dashed line represent the posterior for GER parameters and RoE parameters, respectively.

4.2 Second Moments

In this subsection we perform a posterior analysis with respect to the predicted second moments of the model as shown in Figure 7. As the predicted moments from the model are population moments, we compare them with second moments predicted by a Bayesian vector autoregression model (BVAR) with two lags.[13] The results are based on 1,200 parameter vector draws from the respective posterior distribution. For the real variables, the DSGE model's predicted distribution of standard deviations incorporates for most of the variables the standard deviations of the actual data (red solid line). Especially for GDP growth, consumption growth, and investment growth, a strong alignment between the predicted distribution of the DSGE model and the BVAR can be seen from Figure 7. When focusing on the international linkages, such as net exports of Germany and the rest of the euro area, the DSGE model is also quite in line with the data. Regarding the nominal variables, Figure 7 shows that the DSGE (and also the BVAR to some extent) predicts a much higher standard deviation of CPI inflation for Germany and rest of euro

[13] We fit a BVAR(2) to the observables by assuming a weak Normal-Wishart prior for the coefficients.

area than observed in the data. These discrepancies may result from the weak inflation observed in the aftermath of the financial crisis. For example, Blanchard, Cerutti, and Summers (2015) argue that the Phillips curve has flattened and so the connection between inflation and domestic real activity has weakened too. In this respect, the fixed slope of the Phillips curve in our model can be a source for the discrepancies, especially regarding the sample standard deviation. However, the endogenous prior approach used in the estimation has been an important factor in achieving model predictions which reasonably match those of the BVAR model, and limits the discrepancies to the observed moments in the data.

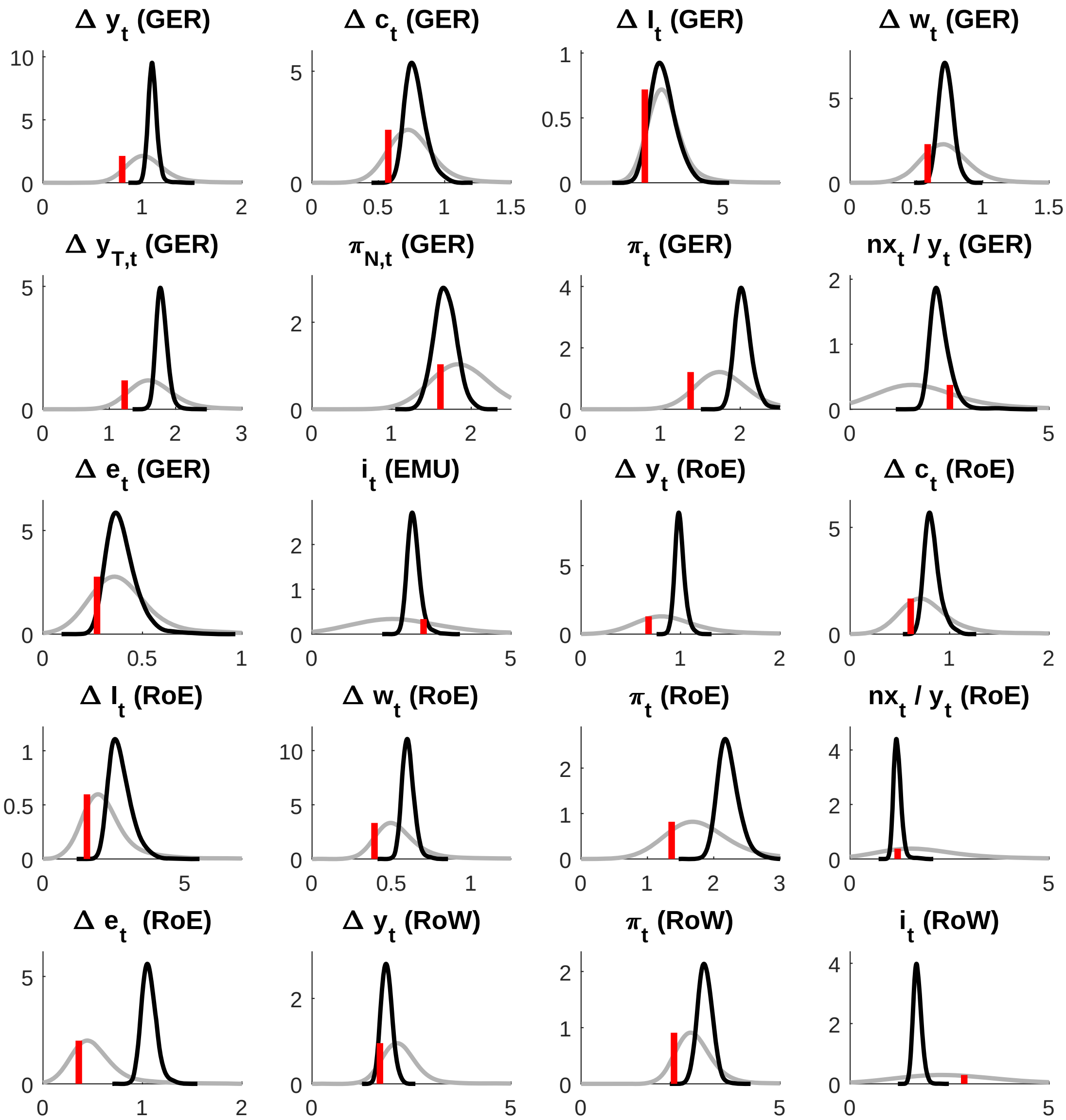


Figure 7: Predicted standard deviation of observable variables by DSGE model (black line) and BVAR(2) (gray line), the red line shows the standard deviation from the data.

To further investigate the dynamics of key German variables, Figures 8 and 9 present the predicted autocorrelations and cross-correlations implied by the model in comparison to the model-implied correlations of a BVAR(2). In particular, the figures compare model-based correlations of hp-filtered variables. While the DSGE model-based correlations show, in general, a very tight distribution they are, with few exceptions, part of the 90% probability bands of BVAR model-implied correlations. However, for some leads and lags around zero, the predicted cross-correlations between consumption and net exports as well as between investment and tradable-goods sector GDP show stronger discrepancies between both models. Nevertheless, the overall finding is again that the estimated DSGE model matches reasonably well the fluctuations of endogenous variables of interest.

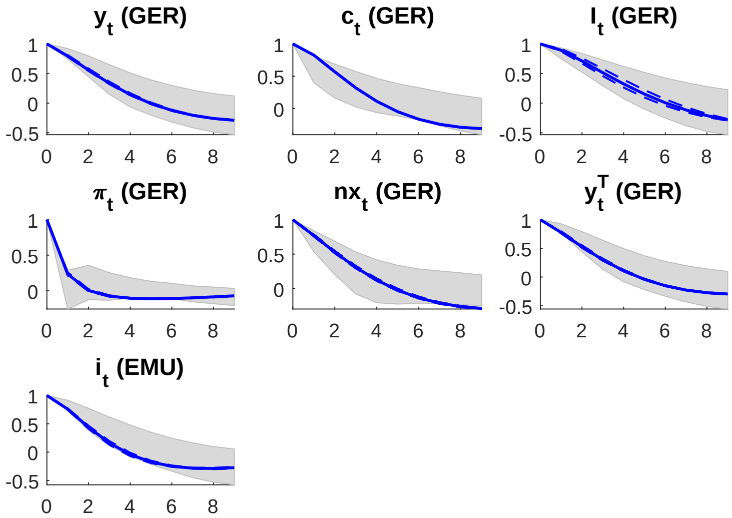


Figure 8: Predicted autocorrelation of selected hp-filtered variables by DSGE model (blue lines) and BVAR(2) (gray area).

5 Rebalancing the Euro Area: Is Wage Adjustment in Germany the Answer?

Based on the estimation results, we now assess how a nominal wage adjustment in Germany can contribute to an economic rebalancing of the euro area and the rest of world. The motivation for focusing on wage adjustment is based on the economic policy discussions regarding the gains in German economic competitiveness. In particular, it has often been argued that Germany's trade and current account surplus started increasing initially in the beginning of the 2000s, when employers and unions agreed to contain wage growth. The mitigated wage growth then caused an internal devaluation of Germany within the euro area, making German products more competitive. This induced increase in competitiveness triggered a rise in exports and, hence, a trade surplus in Germany, which was mirrored in Germany's current account, and, hence, trade surplus. Therefore, in the first step we revisit the effects of wage markup shocks on wage dynamics and the German trade balance from an historical perspective. In a second step, we assess how a German nominal wage rise impacts on price inflation and the current account in Germany, the euro area and the rest of the world.

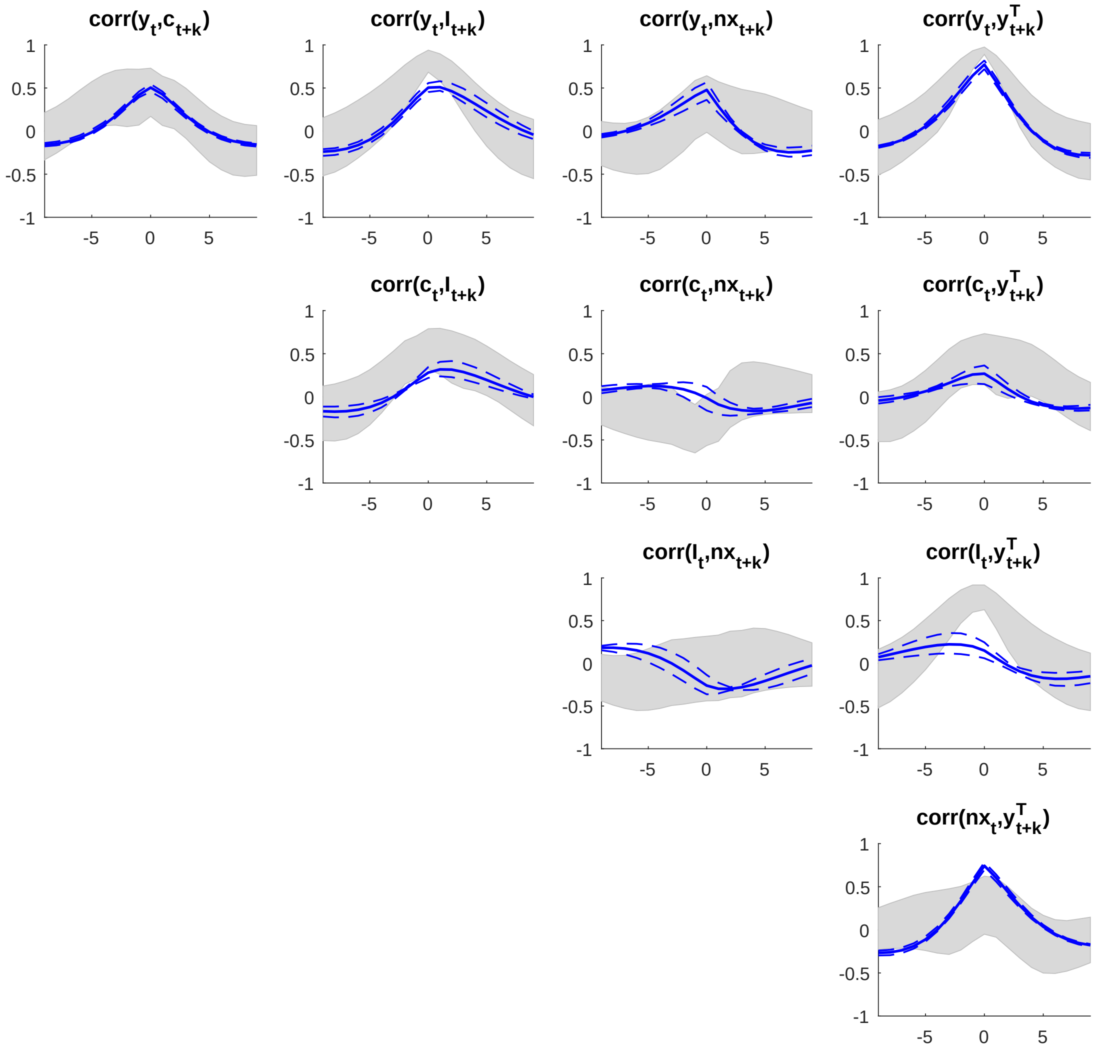


Figure 9: Predicted cross-correlation of selected hp-filtered variables by DSGE model (blue lines) and BVAR(2) (gray area).

5.1 Historical shock decomposition

The following two figures outline the main determinants of real wages and trade balance developments in Germany from an historical perspective over our estimation horizon 1995 up to 2017. The colored bars in the historical shock decompositions show the contribution of the most important shocks, while the solid black line shows the de-trended evolution of the variable of interest. Figure 10 shows the annual real wage growth developments for Germany from 1996 onwards.

The figure shows that in the recent past wages were mainly held down by international factors, while it was price markup developments and, to a smaller extent German wage markup shocks that contributed positively to real wage growth in Germany together with monetary policy innovations.

Figure 11 mirrors the historical shock decomposition of the German trade balance. Wage markup shocks only contributed to a small extent to German trade balance developments, especially in the aftermath of the financial crisis. Thus, from an historical

Figure 10: Historical decomposition of German annual real wage growth.

perspective, wage developments were not the main factor in explaining the German external surplus. It was mainly a combination of German supply and demand conditions together with international factors which affected the German trade balance positively.

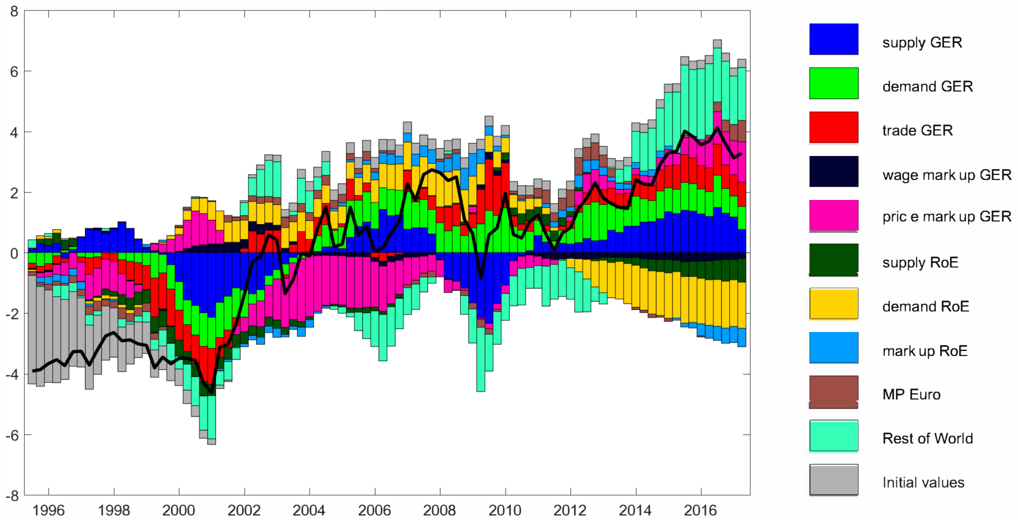


Figure 11: Historical decomposition of German trade balance.

5.2 Simulating the consequences of a German wage rise

The historical shock decompositions of the previous section, however, do not imply that higher wage markup shocks could not contribute positively to the rebalancing of the

German current account. We therefore assess the effects of an exogenous, unexpected German wage rise on the internal revaluation, inflation and the German current account. To that end, we present an impulse response analysis to a wage markup shock in Germany for selected macro variables. The starting point of the simulations is an exogenous increase in nominal wages of a magnitude representative of what we observed in Germany over our sample, as portrayed in the historical shock decompositions.

We will present three scenarios, characterizing different potential and relevant monetary policy reactions in the euro area to an increase of wages in Germany. In the first scenario we assess impulse responses after a wage markup shock when the monetary authority is assumed to follow the estimated historical policy rule of section 2 for the euro area. Most likely, knowing the potential of such a wage adjustment policy in re-balancing the euro area, the monetary policy authority should be accommodative. We thus analyze how the effects differ when the nominal interest rate is announced to be kept constant for one year or two years after the wage markup shock occurred in scenarios 2 and 3. In all three scenarios, it is assumed that the central bank in the rest of the world follows the policy rule outlined in section 2, when setting monetary policy abroad.

Figure 12 shows the consequences of a wage markup shock for euro area's monetary policy. In all the scenarios, wages are assumed to increase by about 2.5 percentage points from the steady state. A wage markup shock leads to a rise in nominal and real wages, which causes marginal costs to increase. This translates into higher prices. In scenario 1 (i.e. the historical policy rule), the red solid line, the monetary authority will counteract the increase in inflation by raising the nominal interest rate in the euro area.

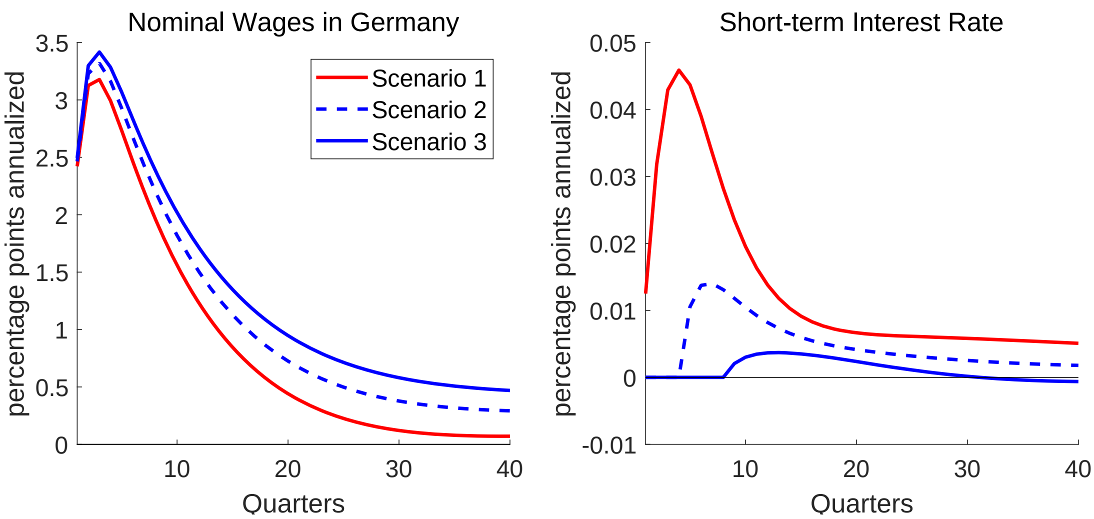


Figure 12: Wage inflation and monetary policy

In scenarios 2 and 3 respectively, the blue dashed and solid lines, the monetary authority credibly commits to keeping the euro area's short-term interest rate constant for one and two years. Agents thus know that monetary policy will be accommodative and expansionary, so that the nominal interest rate does not rise. As we show next, this will have strong effects on how the wage markup shock translates to the real exchange rate, the trade balance as well as inflation and output in Germany and the rest of the euro area. Thereby, all variables responses are reported as percentage deviations from steady state, except inflation and the interest rates, which are expressed in annualized absolute deviations.

Figure 13 mirrors the consequences of the wage hike in Germany for inflation, the real interest rate, and output for Germany and the rest of the euro area. A rise in the markup on wages increases the cost of production, causes a rise in inflation, and has negative effects on German output, as shown in the left panel of Figure 13. In the rest of the euro area, the right panel, the response by the monetary authority acts like a contractionary monetary policy shock, causing inflation and output in the euro area to decline. However, when the central bank commits to keeping the policy rate constant for one as well as two years (scenarios 2 and 3, respectively) the effects are reversed.

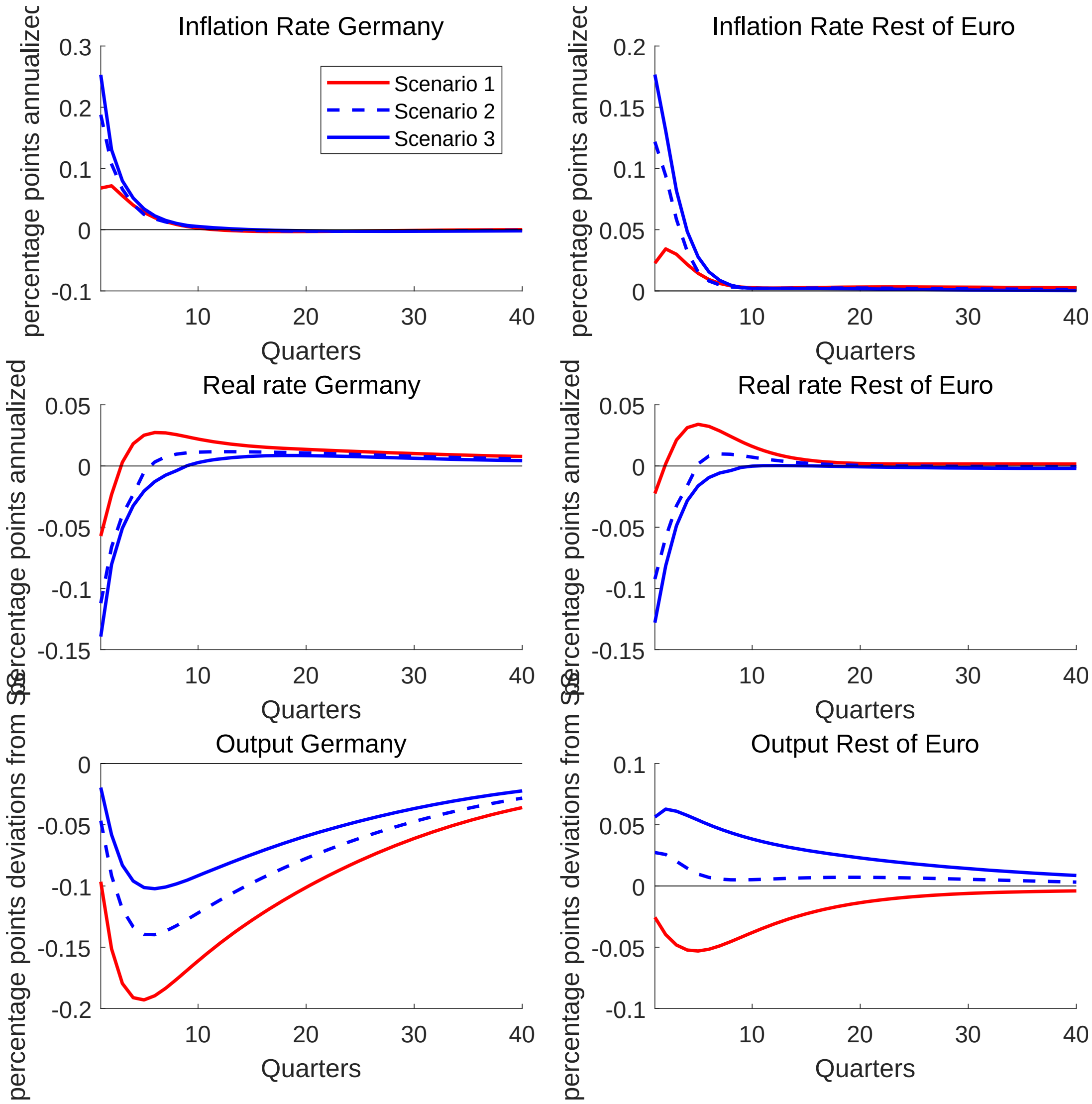


Figure 13: Inflation and output developments

More precisely, in scenario 2, the blue dashed line in Figure 13, the euro area's monetary authority commits to keeping the nominal interest rate constant for one year. The accommodative response by the monetary authority leads to higher German inflation and a decline in the (expected) real interest rate, making consumption and investment relatively more attractive today. Consequently (relative) output in Germany increases, as shown by the left panel. In the rest of the euro area, the right panel, the constant interest rate policy has expansionary effects, causing inflation to increase and output to improve in comparison to scenario 1.

When looking at scenario 3, the solid blue line, we see that the longer the European central bank holds the policy rate constant, the stronger is the real interest rate effect and the more positive are the inflation and output responses for both Germany and the rest of the euro area. Comparing the cumulated output growth effects, they are slightly positive for the euro area as a whole, in comparison to what they would be in scenario 1. The overall effect on euro area inflation is positive throughout all three scenarios, with a higher rise in inflation in Germany compared to the rest of the euro area. This will have implications for the relative competitiveness, as is shown next.

Figure 14 shows the responses of net exports (NX/GDP) and the real exchange rate (RER) to a positive wage markup shock in Germany for the three scenarios considered.

The real exchange rate response for Germany, shown in the middle right and bottom left of Figure 14, shows a real appreciation in scenario 1 vis á vis the rest of the euro area and the rest of the world, given the rise in German inflation. As a consequence, the German trade balance initially deteriorates. The induced gain in relative competitiveness in the rest of the euro area causes its trade balance to improve. However, the nominal interest rate response by the European Central Bank is sufficiently large in scenario 1, so that the real exchange rate of the rest of the euro area appreciates initially against the rest of the world. It follows that the overall trade balance in the rest of the Euro area improves only modestly.

However, when the European Central Bank accommodates the rise in German wages by holding the nominal interest rate constant (i.e. scenarios 2 and 3), the results look different. Then, Germany's and the rest of the euro area's real exchange rates depreciate against the rest of the world, as shown by the two bottom panels of Figure 14. The reason is that the implied higher inflation rates in the euro area raise import prices in the rest of the world. This causes upward pressure on overall inflation abroad. The central bank counteracts this increase in inflation by raising interest rates abroad. Given the constant interest rate policy within the euro area, a depreciation of the currency union's real exchange rates follows. Consequently, there is now an expenditure switching within the rest of the world towards euro area products, compared to scenario 1. This mitigates the effect the wage hike has on the German trade balance deficit, while the trade surplus in the rest of the euro area improves even further. The two opposing effects in scenarios 2 and 3 moderate the overall rebalancing of the euro area's trade balance. In summary, Figure 14 shows that the effects on the German trade balance are not that large and even positive in the medium-run, suggesting that the increase in wages needs to be relatively large to obtain a sufficient rebalancing of the German external balance.

After having outlined the main mechanism at work, we now turn to assessing the robustness of our findings. Given the importance of the monetary policy stance, we analyze to what extent the announcement to keep the monetary policy accommodative after a wage hike in Germany affects our results. We then assess the role of wage flexibility in Germany for the rebalancing of the euro area.

So far, we have investigated the role of monetary policy, contrasting two main scenarios

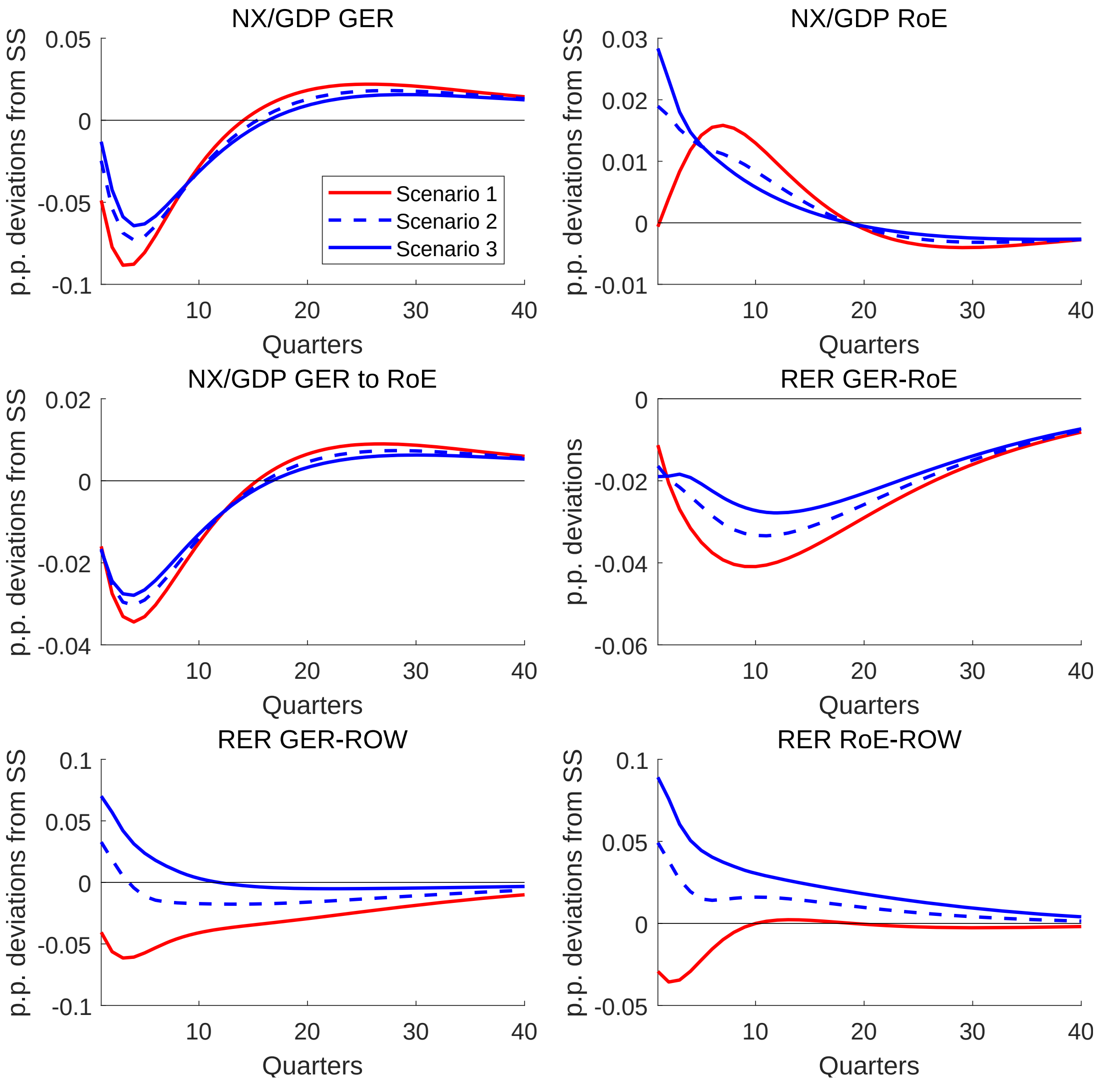


Figure 14: Net exports and real exchange rate developments

where the nominal interest rate was governed by the estimated Taylor Rule and where it was announced to be kept constant by the monetary policy authority, following the wage inflation shock. In the latter case, the responses are partly driven by a mechanism known as the forward guidance channel. Forward guidance aims at announcing a level of the nominal interest rate lower, here constant, than it should be if responding to the shocks in the economy. After our wage inflation shock, this raises expected inflation and thus current inflation with a resulting larger fall of the real interest rate and increased economic activity compared to a situation without announcements of future interest policies. To assess the quantitative importance of this assumption, Figure 15 reports the dynamics of our baseline scenario when the nominal interest rate is announced to be kept constant and its equivalent policy purged from its announcements' effects. In other words, this alternative scenario is implemented with a sequence of unexpected monetary policy shocks.

Removing the forward guidance channel as described above has mainly two noticeable effects. The first is that the rebalancing vis á vis the rest of the euro area and the rest of

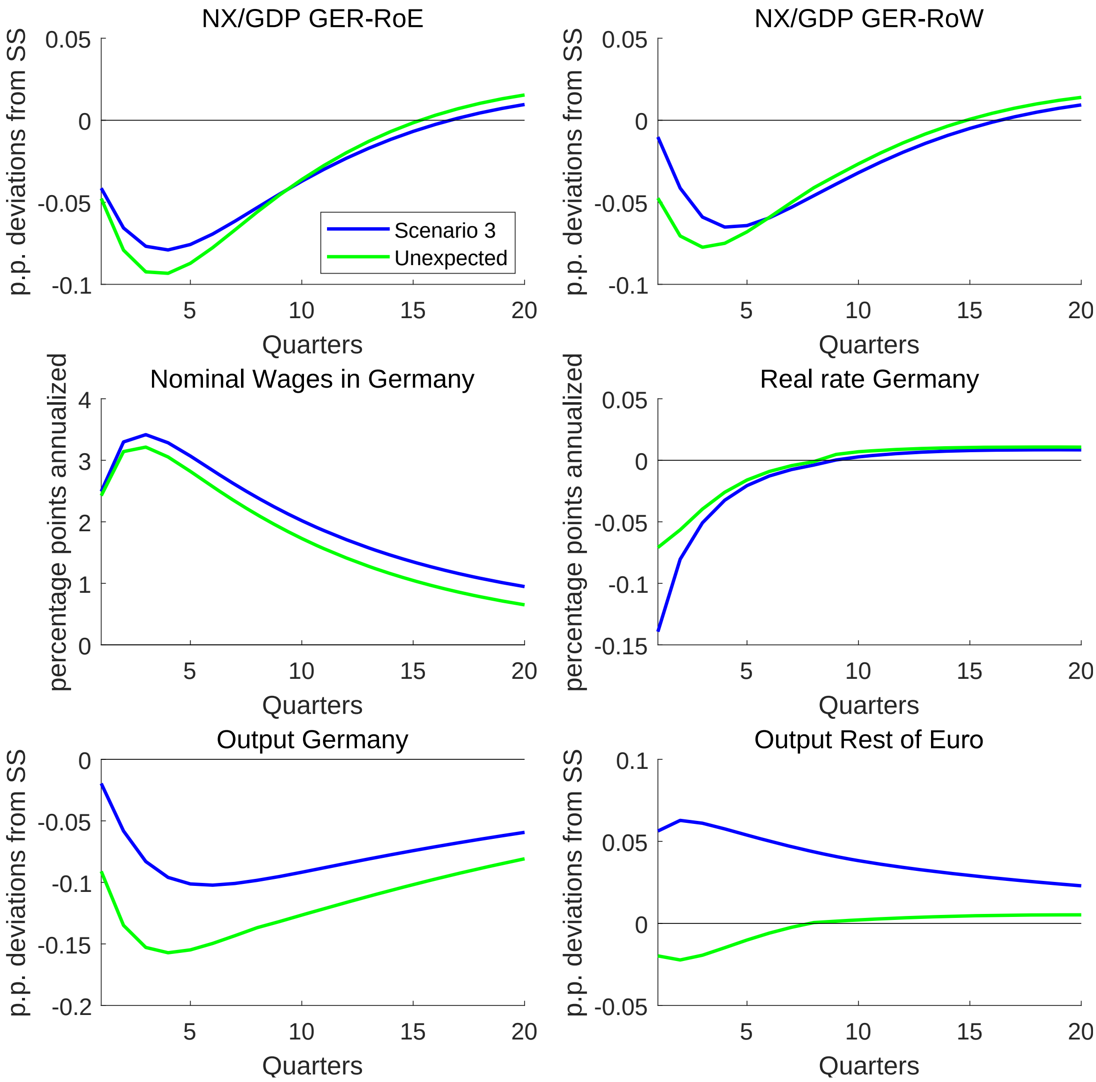


Figure 15: The effect of monetary policy announcement

the world is similarly enhanced. The second is the large difference in output dynamics, especially for the rest of the euro area. As the stimulative effect of forward guidance are absent the positive effect of increasing European inflations expectations largely disappears implying as, for Germany in all scenarios, a fall in output in the rest of the euro area.

To complete our results, we now explore the quantitative sensitivity of the net exports and some other selected variable to variations in the parameter governing wage rigidity in Germany. To make our point clear, we consider a rather extreme parameter change for which the degree of wage flexibility increases substantially. Indeed, we assume that the average duration of wage contracts drops from five quarters, as estimated, to two and a half quarters, implying a Calvo wage parameter of 0.6 for Germany. All the other structural parameters as well as the Taylor rule coefficients are kept constant at the posterior mean of their respective estimation. We also adjust the size of the shock to nominal wages such that it implies a 2.5 per cent increase in nominal wages on impact, as in the previous exercises.

Figure 16 reports the dynamics of selected variables for this new parameter configuration and for the first and third scenarios described earlier in this section.

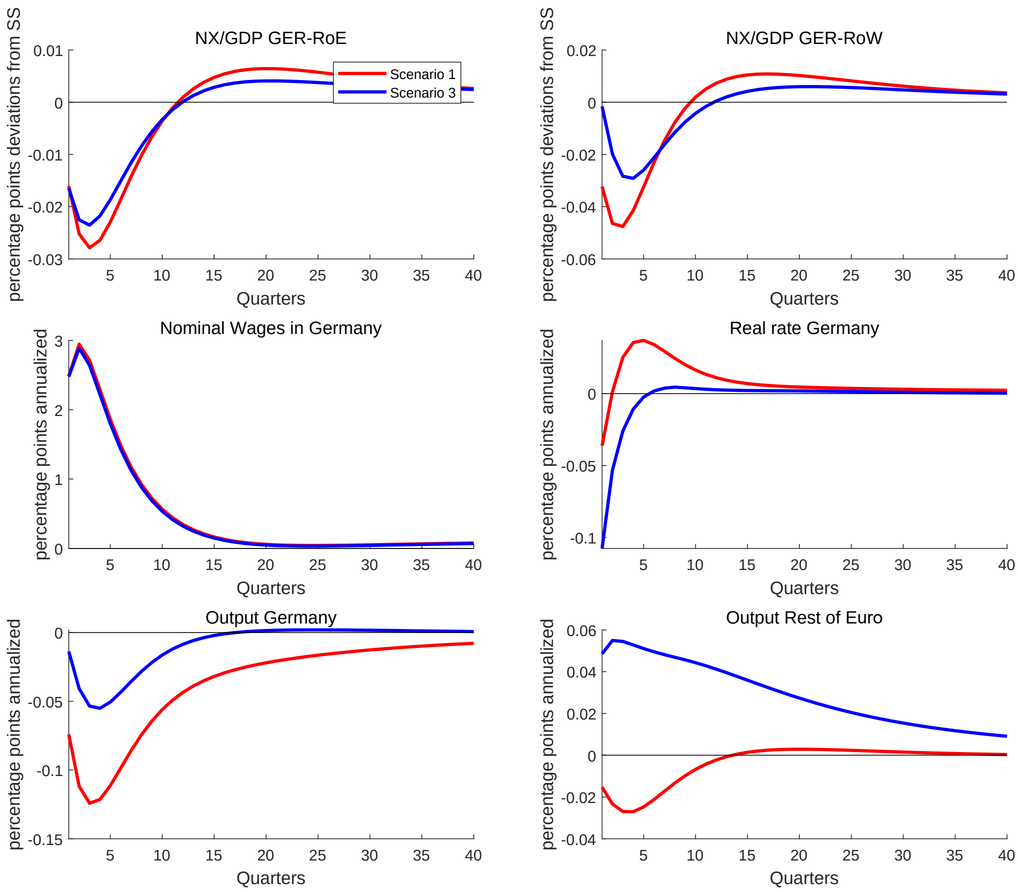


Figure 16: The role of wage flexibility

On impact, the increase in nominal wages is now mitigated, implying a lower response of inflation and thus a lower fall of the real interest rate compared to our baseline scenarios. The output adjustments are also mitigated in both regions, but especially in Germany and under the constant interest rate policy. The negative real effects of increasing nominal wages are substantially reduced.

Moving to the effect of wage flexibility on international rebalancing, one also observes a dampening. While the trade rebalancing is almost unaffected on impact, its persistence is significantly lowered. Overall, an increasing degree of wage flexibility in Germany impairs significantly the ability of a relative price adjustment, via a wage increase, to rebalance the economy.

6 Conclusion

Over the last few years, Germany's trade and current account surplus have been the subject of much economic policy debate. In particular, Germany was urged by many institutions like the IMF and the European Commission to boost domestic demand by lifting, for example, wages to reduce what they call global economic imbalances.

We assess to what extent nominal wage increases could contribute to an economic rebalancing within the euro area and the rest of the world. Our findings show that higher German wages cause short-run effects on the trade balance, inflation and output, but the monetary policy stance matters for the magnitude of the results obtained. In particular, the duration of zero interest rates and expectations about monetary policy are very important for the re-balancing effects obtained within the euro area. At constant euro area interest rates, the higher German wage growth will have greater inflationary effects, while the output effects in the overall euro area remain relatively small. The higher German wage growth causes, however, only a mild German trade balance deficit. The latter result occurs due to the induced changes in competitiveness with the rest of the world, given the euro area's monetary policy of constant interest rate.

Thus, in summary, we find that shocks to nominal wages are rather unlikely to reduce the German trade balance by a quantitatively meaningful amount. Therefore, solely promoting wage hikes to reduce imbalances in the future is a too simple answer; as it is to pointing to negative wage shocks in the past as the origin of German trade balance surpluses.

A Appendix

A.1 Data

We use several international time series. Especially, the construction of time series for the rest of world (RoW) and trade balances for Germany and the rest of the euro area needs a more detailed discussion. Altogether, we use 20 times series which will be discussed below.

A.1.1 Germany

The data for Germany are based on quarterly and seasonal adjusted time series which were provided by the Bundesbank's statistics department. The raw data cover the time span between 1991:Q1 and 2017:Q2. If necessary the data are transformed into per capita terms by using the quarterly time series for overall German population.

Inflation $\pi^{obs}_{GER,t}$: Log-First differences and demeaned series of the overall consumer price index (CPI) (quarterly, seasonal and working day adjusted).

$$\pi^{obs}_{GER,t} = (\pi^a_t - \pi^a) \cdot 400$$

Real GDP growth $\Delta y^{obs}_{GER,t}$: Real GDP is calculated as nominal total GDP (quarterly, seasonal and working day adjusted) divided by population and CPI series. The growth rate is calculated by log-first differences and afterwards demeaned.

$$\Delta y^{obs}_{GER,t} = \log\left(y^a_t / y^a_{t-1}\right) \cdot 100$$

Real consumption growth $\Delta c^{obs}_{GER,t}$: Nominal private consumption (quarterly, seasonal and working day adjusted) divided by population and CPI series. The growth rate is calculated by log-first differences and afterwards demeaned.

$$\Delta c^{obs}_{GER,t} = \log\left(c^a_t / c^a_{t-1}\right) \cdot 100$$

Real investment growth $\Delta I^{obs}_{GER,t}$: Nominal gross fixed investment (quarterly, seasonal and working day adjusted) divided by population and CPI series. The growth rate is calculated by log-first differences and afterwards demeaned.

$$\Delta I^{obs}_{GER,t} = \log\left(I^a_t / I^a_{t-1}\right) \cdot 100$$

Employment growth $\Delta E^{obs}_{GER,t}$: Total working population (quarterly, seasonal and working day adjusted). The growth rate is calculated by log-first differences and afterwards demeaned. We follow Smets and Wouters (2003) and make use of an auxiliary equation to link the number of total employed people with hours worked.

$$E^a_t = \beta E^a_{t+1} + \frac{\left(1-\beta\gamma^E_a\right)\left(1-\gamma^E_a\right)}{\gamma^E_a}\left(\log\left(N^a_t / N^a\right) - E^a_t\right)$$
$$\Delta E^{obs}_{GER,t} = E^a_t / E^a_{t-1} \cdot 100$$

Real wage growth $\Delta w^{obs}_{GER,t}$: Nominal salaries and wages (quarterly, seasonal and working day adjusted) divided by total working population and CPI series. The growth rate is calculated by log-first differences and afterwards demeaned.

$$\Delta w^{obs}_{GER,t} = \log\left(w^a_t / w^a_{t-1}\right) \cdot 100$$

To distinguish between the tradable- and non-tradable goods sector in Germany we decompose the German GDP accordingly by using German GDP by industry data. Therefore, we group industries like *manufacturing*, *information and communication*, *financial and insurance services*, and *business activities* as tradable goods and the remaining industries like *agriculture, forestry and fishing*, *construction*, *real estate activities*, *trade, transport, accommodation and food services*, *public services, education and health*, and *other services* into the group of non-traded goods. The difference between those sums and the overall measure of GDP is evenly assigned to both groups.

real GDP (tradable goods) growth $\Delta y^{obs}_{GER,T,t}$**:** Total nominal GDP of tradable goods is the sum of the aforementioned subgroups at industry level. Afterwards, the series is divided by population and overall consumer price index to get real per capita terms. Finally, the growth rate is calculated by log-first differences and afterwards demeaned.

Inflation (non-tradable goods) $\pi^{obs}_{GER,N,t}$**:** The price deflator for non-traded goods is calculated as the ratio between nominal and real GDP of non-traded goods. Finally, the series is transformed into growth rates (by log-First differences) and afterwards demeaned series.

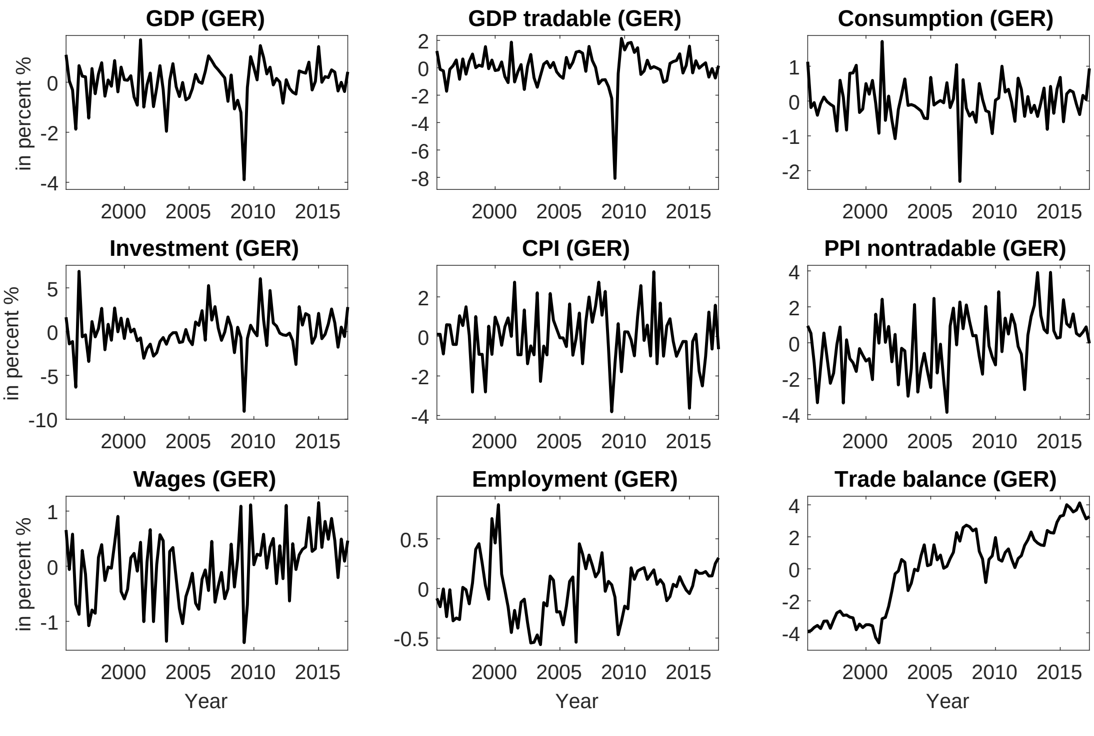


Figure 17: Observed variables for Germany

A.1.2 Rest of Euro Area

The data for the rest of euro area region are based on the 19 member countries of the euro area without Germany. Similarly, all data based on quarterly and seasonal adjusted time series which were provided by the Bundesbank's statistics department. If necessary the data are transformed into per capita terms by using the quarterly time series for overall population of the artificial region. While most of the raw data cover the time span between 1995:q1 and 2017:q2, some of the raw data are just available from a later starting point (CPI: 1996:q1, nominal wages: 2000:q1, employment: 2000:q1). To this end, we use the growth rate of the corresponding data by Gadatsch, Hauzenberger, and Stähler (2016) to extrapolate the missing values.[14]

Inflation $\pi^{obs}_{RoE,t}$: Log-First differences and demeaned series of the overall consumer price index (CPI) (quarterly, seasonal and working day adjusted).

$$\pi^{obs}_{RoE,t} = \left(\pi^b_t - \pi^b\right) \cdot 400$$

Real GDP growth $\Delta y^{obs}_{RoE,t}$: Real GDP is calculated as nominal total GDP (quarterly, seasonal and working day adjusted) divided by population and CPI series. The growth rate is calculated by log-first differences and afterwards demeaned.

$$\Delta y^{obs}_{RoE,t} = \log\left(y^b_t / y^b_{t-1}\right) \cdot 100$$

Real consumption growth $\Delta c^{obs}_{GER,t}$: Nominal private consumption (quarterly, seasonal and working day adjusted) divided by population and CPI series. The growth rate is calculated by log-first differences and afterwards demeaned.

$$\Delta c^{obs}_{RoE,t} = \log\left(c^b_t / c^b_{t-1}\right) \cdot 100$$

Real investment growth $\Delta I^{obs}_{GER,t}$: Nominal gross fixed investment (quarterly, seasonal and working day adjusted) divided by population and CPI series. The growth rate is calculated by log-first differences and afterwards demeaned.

$$\Delta I^{obs}_{RoE,t} = \log\left(I^b_t / I^b_{t-1}\right) \cdot 100$$

Employment growth $\Delta E^{obs}_{GER,t}$: Total working population (quarterly, seasonal and working day adjusted). The growth rate is calculated by log-first differences and afterwards demeaned. We follow Smets and Wouters (2003) and make use of an auxiliary equation to link the number of total employed people with hours worked.

$$E^b_t = \beta E^b_{t+1} + \frac{\left(1-\beta\gamma^E_b\right)\left(1-\gamma^E_b\right)}{\gamma^E_b}\left(\log\left(N^b_t / N^b\right) - E^b_t\right)$$
$$\Delta E^{obs}_{RoE,t} = E^b_t / E^b_{t-1} \cdot 100$$

Real wage growth $\Delta w^{obs}_{RoE,t}$: Nominal salaries and wages (quarterly, seasonal and working day adjusted) divided by total working population and CPI series. The growth rate is calculated by log-first differences and afterwards demeaned.

$$\Delta w^{obs}_{RoE,t} = \log\left(w^b_t / w^b_{t-1}\right) \cdot 100$$

[14] Gadatsch, Hauzenberger, and Stähler (2016) approximate the euro area without Germany by the group of the 11 initial member states which corresponds to around 90% of GDP

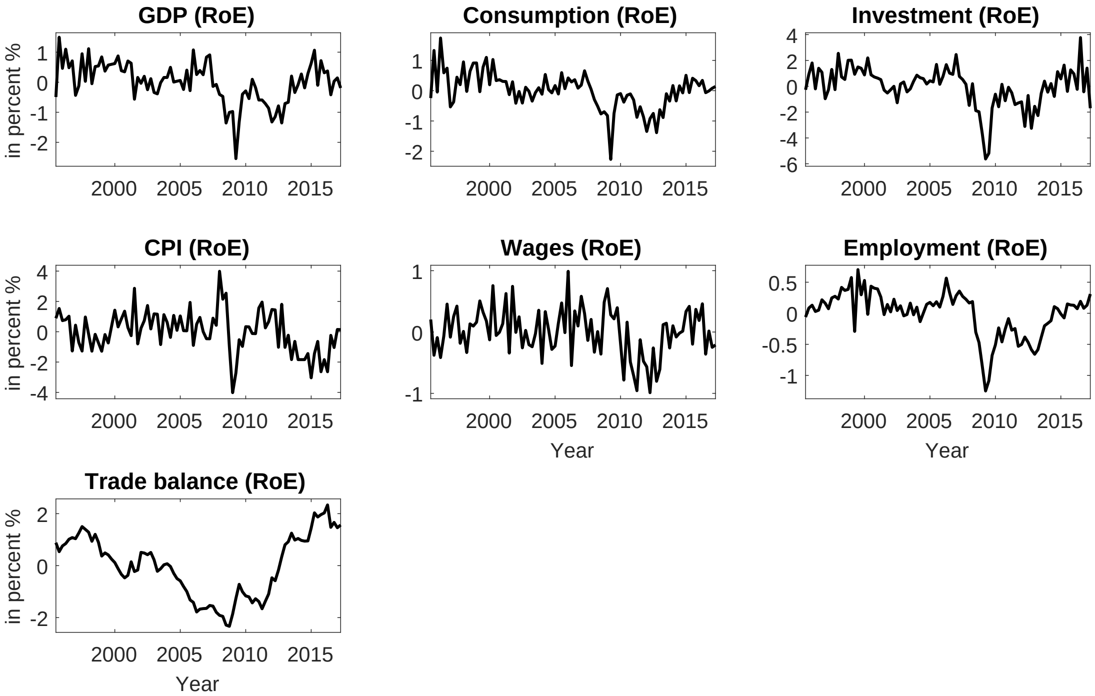


Figure 18: Observed variables for the rest of euro area.

A.1.3 Rest of World and Aggregates

The data for the rest of the world (RoW) are constructed following Kollmann, Ratto, Roeger, in't Veld, and Vogel (2015). In particular, we approximate RoW on the basis of the 19 biggest trading partners of the euro area. The 19 countries are: USA, United Kingdom, Denmark, Norway, Sweden, Switzerland, Canada, Japan, Australia, Hong Kong, Korea, Singapore, Bulgaria, China, Czech Republic, Hungary, Croatia, Poland, and Romania.

RoW's nominal GDP is calculated as sum of nominal GDP for the 19 countries converted into US dollar. Therefore, we use data from the Bundesbank's statistic department as well as the IMF's International Financial Statistics (IFS) database. Because not all time series were available at quarterly frequency over the full time span (e.g. Bulgaria, Croatia, Poland, and Czech Republic), we extended the available quarterly time series with growth rates based on annual data transformed into quarterly frequency. The series is transformed into per capita terms by using the sum of 19 countries population, which were transformed into quarterly frequency. This aggregation considers time-varying weights to account for the gain in relative economic weight of emerging economies over the sample period. RoW's CPI is calculated as sum of CPI for the 19 countries weighted with the time-varying weights GDP weights.

As pointed out by Kollmann, Ratto, Roeger, in't Veld, and Vogel (2015), due to the currency transformation into US-dollar, price inflation in the RoW is defined in US-dollar terms and includes REER movements between the RoW members. Therefore, the use of US-dollar prices is consistent with using the Euro/US-dollar exchange rate in trade equations of the model and US interest rates in the RoW monetary policy rule.

The RoW's nominal policy rate is the quarterly U.S. effective federal funds rate. To cover the accommodating monetary policy over last years to some extent, we use the shadow short rates as postulated by Wu and Xia (2016) for the time between 2008:Q4 and 2015:Q3. The EMU nominal policy rate is measured by the Euribor. Because the Euribor starts in 1999 we extend the time series back to 1995 by using the short-term interest rate of Fagan, Henry, and Mestre (2005) or Warne, Coenen, and Christoffel (2008). Moreover, for the time from 2008:Q4 onwards we use the shadow short rate by Wu and Xia (2017).

Inflation $\pi^{obs}_{RoW,t}$: RoW's CPI is calculated as sum of individual CPIs for the 19 countries which are weighted with the time-varying GDP weights. Afterwards, we calculate log-first differences and demeaned series of the CPI.

$$\pi^{obs}_{RoW,t} = (\pi^c_t - \pi^c) \cdot 400$$

Real GDP $\Delta y^{obs}_{RoW,t}$: real GDP is calculated as nominal total GDP (see above) divided by population and CPI series. The growth rate is calculated by log-first differences and afterwards demeaned.

$$\Delta y^{obs}_{RoW,t} = \log\left(y^c_t / y^c_{t-1}\right) \cdot 100$$

Nominal policy rate $i^{obs}_{RoW,t}$: the nominal policy rate is the effective fed funds rate together with the shadow short rate from Wu and Xia (2016), constructed as described before and afterwards demeaned.

$$i^{obs}_{RoW,t} = (i^c_t - i^c) \cdot 400$$

Nominal policy rate $i^{obs}_{EMU,t}$: the nominal policy rate is the Euribor together with the shadow short rate from Wu and Xia (2017), constructed as described before and afterwards demeaned.

$$i^{obs}_{EMU,t} = \left(i^{EMU}_t - i^{EMU}\right) \cdot 400$$

We use time series for Germany (NX^{GER}_t) and EMU (NX^{EMU}_t) net export from the Bundesbank's statistical department. Given the configuration of our model the RoE values can be derived implicitly:

$$NX^{RoW}_t = -NX^{EMU}_t$$
$$NX^{RoE}_t = -(NX^{RoE}_t - NX^{RoW}_t)$$

Trade balance $TB^{obs}_{GER,t}$: Ratio of German net exports over GDP.

$$TB^{obs}_{GER,t} = NX^a_t / y^a_t \cdot 100$$

Trade balance $TB^{obs}_{RoE,t}$: Ratio of RoE net exports over GDP.

$$TB^{obs}_{RoE,t} = NX^b_t / y^b_t \cdot 100$$

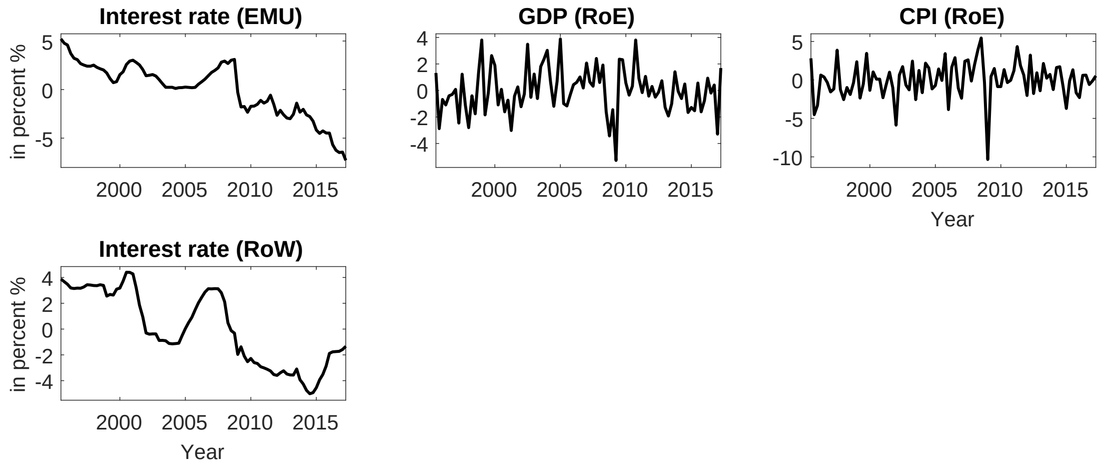


Figure 19: Observed variables for the rest of the world and euro-wide aggregates.

A.2 Supplementary Material

A.2.1 Parameters

Parameter	Description	Value
β_a, β_b, β_c	discount factor	0.9950
ζ_a, ζ_b, ζ_c	inverse of money-demand elasticity	1.0000
δ_a, δ_b, δ_c	depreciation rate of capital	0.0250
α_a^N, α_b^N, α_c^N	capital share in non-tradable sector	0.3300
α_a^T, α_b^T, α_c^T	capital share in tradable sector	0.3300
θ_a^N, θ_b^N, θ_c^N	price elasticity in non-tradable sector	4.0000
θ_a^T, θ_b^T, θ_c^T	price elasticity in tradable sector	6.0000
θ_a^w, θ_b^w, θ_c^w	wage elasticity	6.0000
η_a, η_b, η_c	elasticity between home and foreign tradables	1.5000
n^{ba}	weight in a of tradable b	0.3310
n^{ca}	weight in a of tradable c	0.5172
n^{aa}	weight in a of tradable a	$1 - n^{ba} - n^{ca}$
n^{ab}	weight in b of tradable a	0.1103
n^{cb}	weight in b of tradable c	0.3879
n^{bb}	weight in b of tradable b	$1 - n^{ab} - n^{cb}$
n^{ac}	weight in c of tradable a	0.0207
n^{bc}	weight in c of tradable b	0.0466
n^{cc}	weight in c of tradable c	$1 - n^{ac} - n^{bc}$
θ_a, θ_b, θ_c	elasticity between tradables and non-tradables	0.9000
μ_a, μ_b, μ_c	weight of aggregate tradable good	0.4500
$\mathcal{P}_a$	population of a	1.0000
$\mathcal{P}_b$	population of b	3.0000
$\mathcal{P}_c$	population of c	25.0000
τ_a^w, τ_b^w, τ_c^w	steady-state labor tax	0.4000
τ_a^k, τ_b^k, τ_c^k	steady-state capital tax	0.2000
τ_a^v, τ_b^v, τ_c^v	steady-state revenue tax	0.1500
ι_2^a, ι_2^b, ι_2^c	forward-looking employment	β_a, β_b, β_c
π^a, π^b, π^c	steady-state inflation	1.0045
m^a/Y^a, m^b/Y^b, m^c/Y^c	inverse of money velocity	0.0700
G^a/Y^a, G^b/Y^b, G^c/Y^c	government consumption to GDP	0.2500
N^a, N^b, N^c	steady-state hours	0.3300
b^{ab}	steady-state bond between a and b	0.0000

Table 2: Calibrated Parameters

Name	Symbol	Domain	Density	Para(1)	Para(2)
Model parameter					
Preference consumption	σ_i	$\mathbb{R}$	Normal	2.00	0.30
Habit formation	h_i	$[0,1)$	Beta	0.70	0.15
Price stickiness (tradable)	γ_i^T	$[0,1)$	Beta	0.50	0.10
Price stickiness (non-tradable)	γ_i^N	$[0,1)$	Beta	0.50	0.10
Wage stickiness	γ_i^w	$[0,1)$	Beta	0.50	0.10
Capacity util. cost	ψ_i^k	$[0,1)$	Beta	0.50	0.20
Investment adjustment cost	υ_i	$\mathbb{R}^+$	Gamma	4.00	1.50
Employment stickiness	γ_i^E	$[0,1)$	Beta	0.50	0.20
Price indexation	ξ_i^p	$[0,1)$	Beta	0.50	0.20
Wage indexation	ξ_i^w	$[0,1)$	Beta	0.50	0.20
AR Taylor rule (EMU)	ϕ_{MU}^i	$[0,1)$	Beta	0.50	0.20
Inflation Taylor rule (EMU)	ϕ_{MU}^π	$\mathbb{R}^+$	Gamma	1.50	0.15
Output Taylor rule (EMU)	ϕ_{MU}^y	$\mathbb{R}$	Normal	0.12	0.05
Risk premium parameter	ω_i	$\mathbb{R}^+$	InvGam	0.02	4
Risk premium parameter	ω_S	$[0,1)$	Beta	0.50	0.20
autoregressive parameter and s.d. of shocks					
AR technology	ρ_i^A	$[0,1)$	Beta	0.70	0.10
AR preference	ρ_i^β	$[0,1)$	Beta	0.80	0.10
AR investment efficiency	ρ_i^I	$[0,1)$	Beta	0.80	0.10
AR government spending	ρ_i^G	$[0,1)$	Beta	0.50	0.15
AR markup (tradable)	ρ_i^T	$[0,1)$	Beta	0.50	0.15
AR markup (non-tradable)	ρ_i^N	$[0,1)$	Beta	0.50	0.15
AR markup (wages)	ρ_i^w	$[0,1)$	Beta	0.50	0.15
AR risk premium	ρ_{ca}^{RA}	$[0,1)$	Beta	0.75	0.15
AR trade preference	ρ_a^μ	$[0,1)$	Beta	0.50	0.15
AR trade preference	ρ_c^μ	$[0,1)$	Beta	0.50	0.15
S.d. technology	σ_i^A	$\mathbb{R}^+$	InvGam	0.01	4
S.d. preference	σ_i^β	$\mathbb{R}^+$	InvGam	0.01	4
S.d. investment efficiency	σ_i^I	$\mathbb{R}^+$	InvGam	0.01	4
S.d. government spending	σ_i^G	$\mathbb{R}^+$	InvGam	0.01	4
S.d. markup (tradable)	σ_i^T	$\mathbb{R}^+$	InvGam	0.01	4
S.d. markup (non-tradable)	σ_i^N	$\mathbb{R}^+$	InvGam	0.01	4
S.d. markup (wages)	σ_i^w	$\mathbb{R}^+$	InvGam	0.01	4
S.d. risk premium	σ_{ca}^{RP}	$\mathbb{R}^+$	InvGam	0.01	4
S.d. trade preference	σ_a^μ	$\mathbb{R}^+$	InvGam	0.01	4
S.d. trade preference	σ_c^μ	$\mathbb{R}^+$	InvGam	0.01	4

Table 3: Initial prior distribution. Para(1) and Para(2) correspond to means and standard deviations for the Beta, Gamma, Inverted Gamma, and Normal distributions.

		Germany			Rest of Euro Area		
Parameter	Symbol	Posterior	HPD		Posterior	HPD	
		Mean	5%	95%	Mean	5%	95%
Model parameter							
Preference consumption	σ_i	2.68	2.29	3.05	1.41	0.97	1.81
Habit formation	h_i	0.37	0.23	0.51	0.63	0.53	0.73
Price stickiness (tradable)	γ_i^T	0.52	0.43	0.60	0.52	0.40	0.64
Price stickiness (non-tradable)	γ_i^N	0.94	0.93	0.96	0.90	0.87	0.93
Wage stickiness	γ_i^w	0.78	0.72	0.84	0.83	0.81	0.86
Capacity util. cost	ψ_i^k	0.56	0.28	0.82	0.83	0.69	0.97
Investment adjustment cost	υ_i	9.09	6.54	11.56	4.88	3.01	6.75
Employment stickiness	γ_i^E	0.87	0.85	0.89	0.58	0.54	0.64
Price indexation	ξ_i^p	0.93	0.87	0.99	0.53	0.34	0.72
Wage indexation	ξ_i^w	0.22	0.07	0.37	0.09	0.02	0.16
autoregressive parameter and s.d. of shocks							
AR technology	ρ_i^A	0.83	0.76	0.89	0.95	0.93	0.96
AR preference	ρ_i^β	0.87	0.81	0.93	0.89	0.84	0.93
AR investment efficiency	ρ_i^I	0.37	0.26	0.48	0.80	0.72	0.88
AR government spending	ρ_i^G	0.94	0.91	0.96	0.93	0.90	0.96
AR markup (tradable)	ρ_i^T	0.28	0.17	0.39	0.23	0.11	0.34
AR markup (non-tradable)	ρ_i^N	0.96	0.95	0.98	0.42	0.26	0.57
AR markup (wages)	ρ_i^w	0.41	0.23	0.58	0.14	0.05	0.22
S.d. technology	$100\sigma_i^A$	3.78	2.89	4.62	1.53	1.30	1.76
S.d. preference	$100\sigma_i^\beta$	2.47	1.88	3.09	2.17	1.52	2.80
S.d. investment efficiency	$100\sigma_i^I$	13.77	9.33	18.38	2.34	1.42	3.22
S.d. government spending	$100\sigma_i^G$	2.57	2.25	2.90	1.27	1.10	1.44
S.d. markup (tradable)	$100\sigma_i^T$	0.27	0.23	0.31	0.54	0.46	0.63
S.d. markup (non-tradable)	$100\sigma_i^N$	0.97	0.55	1.40	1.96	1.38	2.52
S.d. markup (wages)	$100\sigma_i^w$	0.47	0.37	0.58	0.38	0.33	0.44

Table 4: MCMC Results.

Parameter	Symbol	Posterior Mean	HPD 5%	HPD 95%
MODEL PARAMETER				
AR Taylor rule (EMU)	ϕ^i_{MU}	0.70	0.66	0.75
Inflation Taylor rule (EMU)	ϕ^π_{MU}	2.31	2.09	2.53
Output Taylor rule (EMU)	ϕ^y_{MU}	0.24	0.16	0.31
Risk premium parameter	ω_a	0.01	0.00	0.01
Risk premium parameter	ω_b	0.04	0.01	0.07
Risk premium parameter	ω_c	0.05	0.02	0.07
Risk premium parameter	ω_S	0.49	0.24	0.75
AUTOREGRESSIVE PARAMETER AND S.D. OF SHOCKS				
AR technology (RoW)	ρ^A_c	0.92	0.88	0.96
AR government (RoW)	ρ^G_c	0.88	0.83	0.94
AR markup (RoW)	$\rho^{T,N}_c$	0.13	0.05	0.21
AR risk premium	ρ^{RA}_{ca}	0.98	0.96	1.00
AR trade preference	ρ^μ_a	0.90	0.86	0.94
AR trade preference	ρ^μ_c	0.91	0.87	0.95
S.d. technology (RoW)	$100\sigma^A_c$	1.11	0.78	1.45
S.d. government spending (RoW)	$100\sigma^G_c$	7.38	6.44	8.32
S.d. markup (price RoW)	$100\sigma^T_c$	0.66	0.58	0.74
S.d. monetary policy (EMU)	$100\sigma^i_{MU}$	0.22	0.19	0.25
S.d. monetary policy (RoW)	$100\sigma^i_c$	0.16	0.15	0.18
S.d. risk premium	$100\sigma^{RP}_{ca}$	0.43	0.24	0.61
S.d. trade preference	$100\sigma^\mu_a$	2.36	1.91	2.83
S.d. trade preference	$100\sigma^\mu_c$	1.00	0.87	1.13

Table 5: MCMC Results - continued.

A.2.2 Variance decomposition

	supply GER	demand GER	trade GER	markup GER	supply RoE	demand RoE	markup RoE	Monetary policy EMU	Rest of world
Δ GDP (GER)	21.34	12.69	11.17	10.96	4.05	0.1	2.67	4.48	32.54
Δ Consump. (GER)	5.96	57.51	0.71	4.13	6.49	0.79	2.72	3.2	18.49
Δ Investment (GER)	73.78	0.96	0.35	8.48	4.17	0.72	0.61	0.97	9.96
Δ Wages (GER)	1.05	0.62	0.35	74.07	1.29	0.06	4.94	2.23	15.41
Δ GDP-tradable (GER)	20	0.18	2.21	11.13	2.62	0.26	2.97	5.3	55.35
Inflation non-tradable (GER)	4.03	0.17	0.14	85.33	4.23	1.1	1.5	0.49	2.99
CPI Inflation (GER)	5.5	0.16	0.57	15.96	4.41	1.02	17.6	7.68	47.11
Net Exports / GDP (GER)	18.85	10.31	8.5	7.24	3.17	2.52	1.07	0.86	47.48
Δ Employment (GER)	16.67	9.13	0.69	66.06	0.95	0.08	1.04	1.54	3.86
Policy rate (EMU)	3.69	0.47	0.03	1.85	16.41	3.66	26.94	7.21	39.73
Δ GDP (RoE)	0.94	0.05	0.42	0.53	30.42	7.53	30.43	6.07	23.61
Δ Consump. (RoE)	1.49	0.12	0	0.77	25.66	42.48	14.11	4.14	11.23
Δ Investment (RoE)	1.94	0.17	0	0.86	65.56	3.81	14.04	2.53	11.05
Δ Wages (RoE)	0.94	0.02	0.02	0.7	11.68	0.37	66.33	2.28	17.68
CPI Inflation (RoE)	1.77	0.14	0.07	1.34	9.75	1.23	51.61	4.9	29.2
Net Exports / GDP (RoE)	2.27	1.92	1.47	0.78	14.21	6.75	13.44	1.28	57.89
Δ Employment (RoE)	0.22	0.02	0.39	0.3	12.22	5.04	49.89	10.56	21.37
Δ GDP (RoW)	0	0	0	0	0.01	0	0.04	0.01	99.93
CPI Inflation (RoW)	0.08	0	0	0.04	0.15	0.01	0.28	0.04	99.41
Policy rate (RoW)	0.06	0	0	0.04	0.12	0.01	0.1	0.01	99.66

Table 6: Variance decomposition.

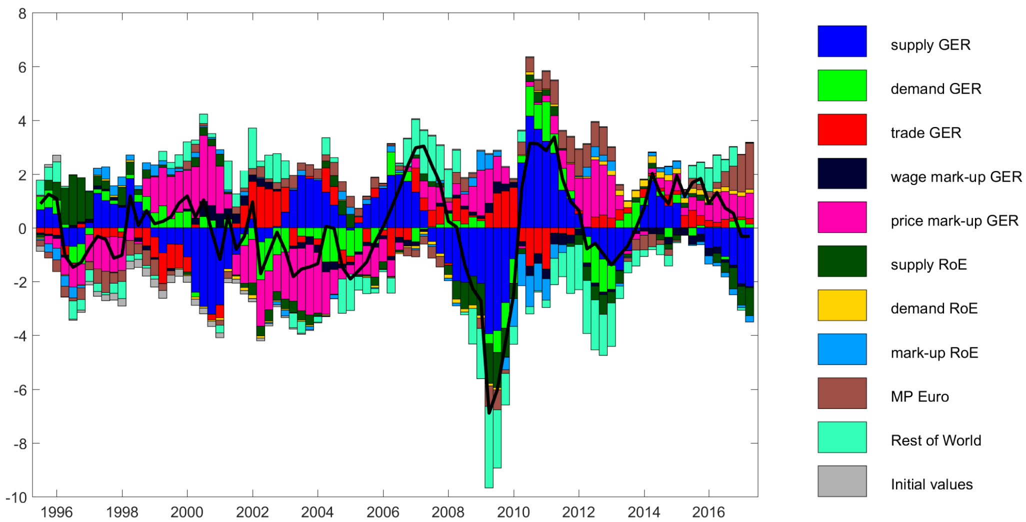
	supply GER	demand GER	trade GER	markup GER	supply RoE	demand RoE	markup RoE	Monetary policy EMU	Rest of world
Δ GDP (GER)	19.91	13.28	12.21	9.37	3.74	0.09	1.93	4.94	34.51
Δ Consump. (GER)	5.84	59.44	0.73	3.97	6.33	0.77	2.02	3.6	17.3
Δ Investment (GER)	89.63	0.22	0.12	3.24	1.58	0.3	0.1	0.58	4.23
Δ Wages (GER)	0.69	0.26	0.01	75.77	0.2	0	5.12	1.83	16.13
Δ GDP-tradable (GER)	18.4	0.18	2.5	10.1	2.56	0.24	2.38	5.72	57.94
Inflation non-tradable (GER)	1.81	0.02	0.02	97.66	0.12	0.03	0.09	0.06	0.18
CPI Inflation (GER)	3.93	0.02	0.71	17.53	0.08	0.01	18.28	9.81	49.62
Net Exports / GDP (GER)	14.29	10.01	15.71	4.69	0.52	0.48	1.25	2.52	50.54
Δ Employment (GER)	15.64	9.61	0.52	67.52	0.76	0.08	0.95	1.46	3.49
Policy rate (EMU)	1.3	0.19	0.01	0.73	0.86	0.5	34.34	21.97	40.1
Δ GDP (RoE)	0.79	0.03	0.51	0.43	24.89	7.78	30.21	7.61	27.75
Δ Consump. (RoE)	1.26	0.13	0.01	0.68	22.53	47.46	13.03	5.82	9.09
Δ Investment (RoE)	1.82	0.14	0	0.77	67.86	2.26	15.18	3.39	8.58
Δ Wages (RoE)	0.55	0	0.03	0.4	4.31	0.15	76.36	2.52	15.67
CPI Inflation (RoE)	0.97	0.01	0.08	0.7	3.73	0.05	60.88	6.29	27.29
Net Exports / GDP (RoE)	0.13	0.46	1.22	0.05	7.02	3.7	24.56	3.71	59.15
Δ Employment (RoE)	0.17	0.03	0.44	0.28	9.17	5.44	49.04	11.87	23.53
Δ GDP (RoW)	0	0	0	0	0	0	0.03	0.01	99.97
CPI Inflation (RoW)	0.06	0	0	0.02	0.11	0	0.29	0.06	99.45
Policy rate (RoW)	0.02	0	0	0.01	0.04	0	0.1	0.02	99.81

Table 7: Conditional Variance decomposition - 1 Quarter.

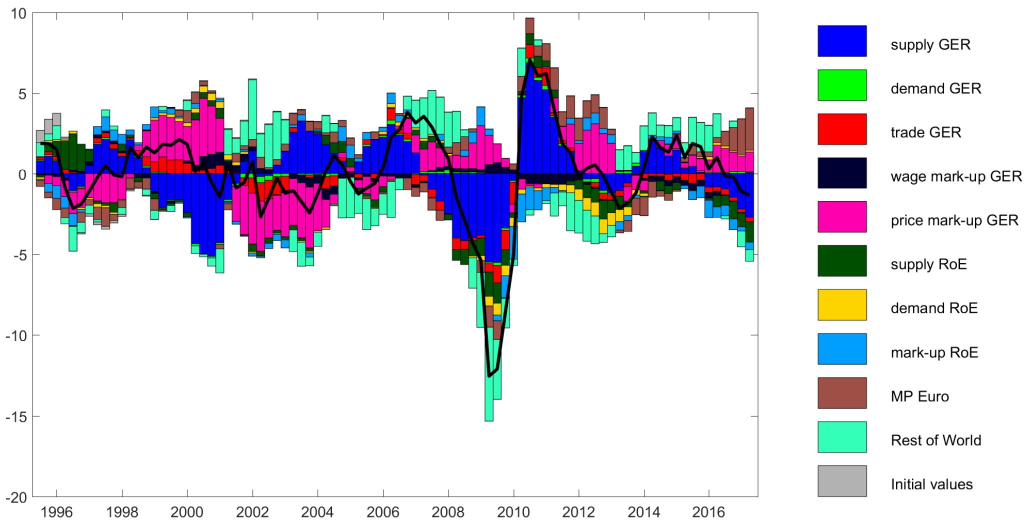
	supply GER	demand GER	trade GER	markup GER	supply RoE	demand RoE	markup RoE	Monetary policy EMU	Rest of world
Δ GDP (GER)	21.38	12.74	11.21	10.85	3.97	0.09	2.67	4.49	32.63
Δ Consump. (GER)	5.94	57.57	0.71	4.14	6.46	0.79	2.72	3.2	18.47
Δ Investment (GER)	76.16	0.82	0.31	7.59	3.77	0.68	0.54	0.92	9.21
Δ Wages (GER)	1.01	0.57	0.33	74.19	1.15	0.05	5	2.24	15.48
Δ GDP-tradable (GER)	20.01	0.18	2.2	11.11	2.57	0.26	2.98	5.3	55.42
Inflation non-tradable (GER)	4.23	0.15	0.11	89.19	1.69	0.61	1.21	0.5	2.3
CPI Inflation (GER)	5.64	0.14	0.57	16.22	2.74	0.77	17.88	7.87	48.16
Net Exports / GDP (GER)	19.46	9.14	9.09	7.91	2.21	2.56	1.06	0.97	47.6
Δ Employment (GER)	16.7	9.12	0.68	66.11	0.89	0.08	1.04	1.54	3.83
Policy rate (EMU)	3.78	0.39	0.02	1.9	13.27	3.12	28.43	7.56	41.55
Δ GDP (RoE)	0.95	0.05	0.42	0.53	29.83	7.59	30.7	6.12	23.8
Δ Consump. (RoE)	1.5	0.12	0	0.78	25.28	42.63	14.22	4.18	11.27
Δ Investment (RoE)	2.01	0.17	0	0.89	65.42	3.51	14.39	2.58	11.04
Δ Wages (RoE)	0.93	0.02	0.02	0.7	10.93	0.31	67	2.3	17.8
CPI Inflation (RoE)	1.74	0.11	0.07	1.32	9.3	1.13	52.05	4.92	29.35
Net Exports / GDP (RoE)	2	1.62	1.43	0.69	13.6	6.88	15.3	1.47	57
Δ Employment (RoE)	0.21	0.02	0.4	0.3	12.07	5.03	49.99	10.59	21.39
Δ GDP (RoW)	0	0	0	0	0.01	0	0.04	0.01	99.93
CPI Inflation (RoW)	0.08	0	0	0.04	0.15	0.01	0.28	0.04	99.4
Policy rate (RoW)	0.06	0	0	0.04	0.12	0.01	0.1	0.01	99.67

Table 8: Conditional Variance decomposition - 20 Quarter.

A.2.3 Historical shock decomposition



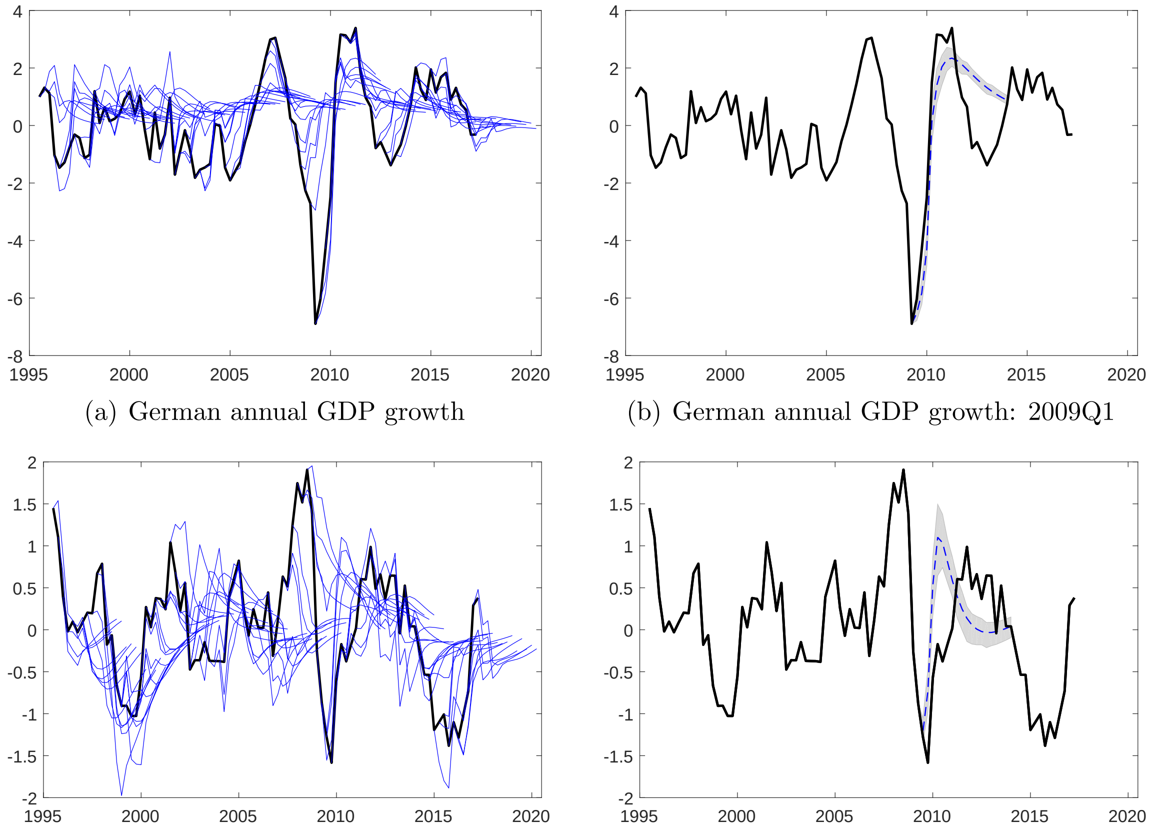
(a) German annual GDP growth



(b) German annual GDP growth (tradeable goods)

Figure 20: Historical decomposition of selected variables.

A.2.4 Filtered variables



(a) German annual GDP growth

(b) German annual GDP growth: 2009Q1

(c) German annual inflation

(d) German annual inflation: 2009Q1

Figure 21: Smoothed variable (black solid line) and 1-step to 20-step ahead filtered variables. The gray area in the right panel reflects the 90% parameter probability.

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