Macroeconomic Dynamics of Monetary Unions

A Theoretical and Empirical Approach

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"EMU is a gamble, no doubt. [...]
But while EMU is a gamble, it is probably a gamble worth taking."

— *Barry Eichengreen*
The Finlay-O'Brien Lecture
University College, Dublin
October 7th, 1996

1. Introduction

It has been over a quarter of a century after signing the Treaty of Maastricht and the establishment of the Single Market[1], and twenty years[2] of a common currency in many of Europe's countries[3]. Since then, national monetary policies have been replaced by a common monetary policy (CMP) and we observe increasing interconnectedness of the European economies through the Single Market (European Commission, 2014).

Still, the plural – *economies* – is both intentional and appropriate, as it is not adequate to speak of one European economy, especially because of the low labour mobility (cf. Andor, 2014, Barslund and Busse, 2016, and Beyer and Smets, 2015) and also because of the lack of common economic and fiscal policies instead of national ones. However, the freedom of movement for goods, services, capital and people within Europe (the *Four Freedoms*) requires – it becomes "unavoidable" (Wyplosz, 1997: 3) – a common currency in order to protect the Single Market, see European Commission (2014), Eichengreen and Ghironi (1995), and Winkler (1996). Only a credible commitment to fixed exchange rates – a monetary union (MU) is a very credible commitment – precludes *beggar-thy-neighbour* policies in the presence of asymmetric economic shocks. That is, in order to protect the Single Market and the Four Freedoms from retaliatory duties and tariffs, devaluations have to be precluded[4]. MU prevents its members from mitigating the effects of an asymmetric shock at the expense of the other countries, i.e. preventing competitive devaluations and retaliatory constraints to free trade – if MU is done right. Eichengreen (2008) argues that the European Econonomic and Monetary Union (EEMU) did not repeat the mistakes of earlier attempts of establishing monetary union in Europe, and must therefore be seen as, in his words, "*sui generis EMU*". Of course, the EEMU

[1] Since January 1st, 1993, see European Commission (2014: 4).

[2] See `https://europa.eu/euroat20/`, last visited on January 28th, 2019.

[3] I use the term "Europe" rather loosely, mostly meaning the EU or EEMU or a certain subset of its members. The precise meaning is clear from the context, and especially in prose the word "Europe" is more easy to read than abbreviations.

[4] Eichengreen and Ghironi (1995) tell a tale of a California devaluating its fictional currency vis-à-vis the US Dollar after the recession of 1993 and the probable consequences of this beggar-thy-neighbour policy.

and all of the other MUs in history[5] and present are (were) more political projects than just mere necessities for a common market. Without political will (cf. Cobham, 1991 and Winkler, 1996), either for peaceful cooperation or for economic dominance, no MU would have been founded just for economic reasons, even if those economic reasons make the EEMU the "best possible economic solution" (Wyplosz, 1997: 18).

In order to retain the EEMU and with it all the economic advantages of protecting and nurturing the Single Market and the Four Freedoms, policy makers need to conduct sensible policies. The more we know about how MUs work, especially how it influences the behaviour of its members towards one another, the better these policies can be. This thesis aims to provide insight about these "inner workings" of an MU, i.e. the macroeconomic interactions of countries that share a common currency and an integrated market. Thus, in the words of Hamada and Porteous (1993), this thesis is about MUs "*among*"[6] nations[7]. Next, I will provide an outline of the thesis together with a description of the central concepts of the analysis and how the thesis connects to the literature.

1.1. Outline of the Thesis

This thesis is organised in five chapters, this introduction is the first one. The second chapter provides an empirical analysis of the impact of the crisis and the European Central Bank (ECB)'s CMP on six large and medium-sized economies of the EEMU, using a standard set of empirical tools, employed widely throughout the literature. In this chapter the connection of the members of the EEMU is considered only loosely, by being subject to the CMP and the ECB's reaction to the crisis. The analysis provides insights into the effects of both the crisis and the unconventional monetary policies by the ECB, operationalised by the "Whatever It Takes" announcement by ECB president Draghi in Summer 2012. In brief, the models highlight the differences of the EEMU member countries, both before the crisis and also in their reactions to the crisis and

[5]In particular, see Bergman (1999), and Bergman, Gerlach, and Jonung (1993) for the Scandinavian Monetary Union, and Timini (2018) for the Latin Monetary Union. Further, see Krämer (1970), Hamada and Porteous (1993), Bordo and Jonung (1999), and Ryan and Loughlin (2018) for a general overview on historical MUs. Other contemporaneous MUs, like the West African Economic and Monetary Union, West African Monetary Zone, the Central-African MU, the Eastern Caribbean Currency Union, or the Common Monetary Area in Southern Africa have received rather little attention from the literature, apart from a paragraph or two in the literature mentioned above.

[6]Although the US as a within-nation MU is used for comparison in chapter 4.

[7]Further, there is the notion of monetary unification within nations, often part of their becoming a nation or *political unificiation* (Krämer, 1970), cf. Handler (2013) and Hamada and Porteous (1993). Examples are the creation of the US Dollar in 1785, the Italian monetary unification of 1862, the founding of the German Empire in 1871 and the groundwork in the decades before (Keller and Shiue, 2008), or the German reunification of 1990.

to the unconventional monetary policy. In fact, the crisis – for all its negative impact on the lives of people – provides researchers a grand opportunity to quantify how similar countries react to a common economic shock and changes in a CMP. The results show that reactions across the countries vary strongly, not only quantitatively, but also qualitatively. The model works well to identify the impacts of the crisis and of the subsequent unconventional monetary policies, and is well established in the literature. However, it also lacks the means to deal with the direct macroeconomic interconnectedness and spillovers that are likely to occur in an economic area so closely connected as the EEMU.

Having identified the strengths and weaknesses of the model used and discussed in the second chapter, the third chapter introduces a theoretical model of a two-country MU, to mitigate or overcome these weaknesses. The key change is to include into the consumption decision of the consumers of one country a set of imperfectly substitutable goods from the other member country. This gives rise to two interconnected MU variants of an aggregate supply (AS) and an aggregate demand (AD) schedule for both countries, where magnitudes of the opposite country directly influence domestic magnitudes, instead of just indirectly via its influences on union-wide aggregates. Together with an interest rate rule, the model is a Dynamic Stochastic General Equilibrium (DSGE) model of an MU with two countries, national fiscal policies and a CMP, where the macroeconomic dynamics of prices and production are directly connected. As such the model describes a common general equilibrium setting not only for demand and supply, but also for both countries simultaneously. The model is, in a conceptual and technical manner, the two-country MU analogue to the standard New-Keynesian Model (NKM) discussed and employed widely in the macroeconomic literature. Thus both models share many properties and can be analysed, simulated and estimated in much the same ways and using the same techniques. Thus, I call the model the *Monetary-Union New-Keynsian Model*

Using the MU-NKM, the fourth chapter provides an empirical analysis of the interconnected AS schedules in Europe on the one hand, and in the US on the other hand. The major change as compared to the empirical analysis in the second chapter is the micro-founded introduction of a spillover parameter. Its estimate shows how much the inflation rate development comes from the macroeconomic developments of the other country, that is how foreign inflation and foreign costs influence domestic inflation. The model is estimated for two European countries, Germany and France, and additionally two of the four US census regions, North-East and South. The estimation results show that the MU-NKM does work reasonably well when fitted to data. Still, the limitation to only two countries or regions leaves room for improving the model by considering more countries.

The final chapter comments, concludes and gives an outlook to future areas of research. Given that the intermediate approach of treating MUs as something between a nation-economy and a fully integrated monolithic economy, is rather rare in the literature, there is much scope for follow-up work. I discuss several avenues of how to continue the analysis of MUs building upon this thesis.

Next, I describe the central concepts of the analyses in this thesis.

1.2. Monetary Union as a Set of Interacting Economies

Despite all the developments in the second half of the twentieth century and the twenty-first so far, the EEMU is still a set of *highly interconnected national economies* with a common currency and a common monetary policy – with numerous national idiosyncrasies, such as fiscal policies, wage bargaining traditions, institutional differences and other economic "baggage" coming from centuries as nation-economies.

In this sense, the EEMU is a very different MU from federally organised countries such as Germany, Austria, Switzerland or the US, because these countries are sovereign, whereas the European Union (EU) is not, but instead an association of sovereign countries, who cede certain parts of their sovereignty to the supranational level. Even the usual wording of "supranational" to describe the organisational level of the EU is witness to it being "non"-national, but encompassing the national levels of its members.

Precisely this nature of Europe, as an association of nations closely connected, but with all kinds of differences coming from the decisions of households and firms subject to different traditions, leads me to consider an economic analysis in regard to the three aspects: *asymmetry*, *direct spillover channels*, and *microeconomic foundations*. These aspects reflect that the members of the EEMU have national economic idiosyncrasies and show differences from one another, that any economic development in one country has likely direct effects on other members given the high degree of interconnectedness, and that macroeconomic dynamics in the end reflect microeconomic decisions. All of the aspects have been attributed to previous examinations of MUs in general and the EEMU in particular, however to the best of my knowledge, the present thesis is unique in that it takes all the three aspects simultaneously into consideration. In the following, I will describe these aspects in more detail, before turning to the related literature.

1.3. Three Central Aspects of the Analysis

1.3.1. Asymmetry

This thesis acknowledges the differences between the members of the EEMU from one another as well as from the union as a whole, and analyses the European economies without giving too much emphasis on either their common, interconnected or their national aspects. In short the thesis respects the "confederate" nature of the EEMU in the economic analysis. Paraphrasing the EU's official motto "*In varietate concordia*"[8], the analysis treats the economies as separate but strongly connected[9].

While interconnected through trade, finance, common policies and regulatory frameworks, the free movement of goods, services, people and capital, and through a common monetary policy, the single economies making up the EEMU show considerable asymmetries, both in the distribution of the shocks, and in their macroeconomic dynamics, i.e. the interplay of aggregate supply and aggregate demand. The latter sort of asymmetries are commonly referred to as *transmission asymmetries* (see e.g. Angelini et al., 2008; Clausen and Hayo, 2006; de Grauwe, 2000; Gros and Hefeker, 2002; 2007), as they affect the transmission or propagation of shocks through the economy, as well as the transmission of (monetary) policy.

A very broad range of differences in, for example, the structure of the economy, the political landscape, consumption preferences, industrial traditions, price setting behaviour, etc. means that even identically distributed idiosyncratic shocks or common shocks may have different effects on the EEMU's member countries. The thesis will empirically examine consequences of such differences in chapter 2.

In general, these differences are reflected in the macroeconomic dynamics of a given country, and thus affect the way how shocks propagate through the economy, from sector to sector, from prices to production and unemployment, or from policy to the decisions of households and firms. Given that changes in the policy stance of the central bank and the government can be seen as shocks, similar policies may have completely different outcomes in different countries. For that matter, in the EEMU – as in any other MU – there is only one *monetary* policy, and the decisions of the ECB affect each member country differently. It is established in the literature, that under certain circumstances, it can be welfare-enhancing for the common central bank (CCB) of an MU to take these asymmetries into account, see section 1.5.

[8] Latin for "United in diversity", see `https://europa.eu/european-union/about-eu/symbols/motto_en`, last visited on January 28th, 2019.

[9] The degree of interconnectedness varies throughout the thesis, but never is a single country analysed on its own, nor the EEMU as a whole.

Because of these differences and the profound role they play in the transmission of shocks and policy, it is necessary to incorporate them into the economic analysis. Only then, an economic model of the EEMU is able to produce meaningful policy analysis and thus can be used to provide insight and advice to policy makers.

1.3.2. Direct Spillover Channels

The common understanding throughout the established literature is the propagation of shocks, be it idiosyncratic ones, (e.g. Alesina and Barro, 2002; Alesina, Barro, and Tenreyro, 2002; Bayoumi and Eichengreen, 1992; de Grauwe and Sénégas, 2006; Mundell, 1961), or common ones originating at the centre (e.g. Carlino and DeFina, 1998; Clausen and Hayo, 2006). In these contributions, either sort of shock propagates through the whole union only via (the reaction of) a central institution, e.g. the CCB, by changing the *aggregate* magnitudes of, say, union-wide inflation or unemployment, or inducing changes of some common policy. These direct spillovers are an important additional layer of economic interaction, but it seems they did not yet receive the full attention of the literature. A notable exception, however, are the models[10] by Canzoneri and Henderson (1991), and a strand of literature focussing on spillovers via the terms-of-trade, i.e. movements of relative export and import prices. Examples of models exploring this channel are Benigno (2004), Beetsma and Jensen (2005), and Jang and Okano (2013).

To illustrate the importance of direct spillovers consider the following example. Suppose a setting of interacting economies – not necessarily an MU – that are in their long-run equilibrium. Then an idiosyncratic negative aggregate supply shock hits one country, resulting in a positive output gap, and ceteris paribus aggregate demand will not be completely satisfied and prices will rise. A direct spillover would now be that the firms in other countries increase production to cover the unmet demand in the country affected by the shock, because they anticipate profits or react to increased demand due to import increases from this country. Then, these other countries would also experience a positive output gap and an upward pressure on prices, while prices in the first country would not increase as much due to the rising imports, which is of course reflected in the terms of trade (and in the nominal and real exchange rates). Since the terms of trade are essentially a net magnitude, a more precise picture can be obtained by looking at the direct spillovers themselves, i.e. how changes in one country's prices are *directly* reflected in the output gap and inflation of another country. Since

[10] Still, the models are not made to analyse MUs – although one can modify them to this end –, they are not micro-founded, and interested mainly in monetary policy.

an obvious characteristic of MUs is the absence of nominal exchange rates between its members, this channel of adjustment is also absent, making the direct spillovers even more pronounced. Such direct spillover channels also work in a symmetric MU, but the general – and more interesting – case is when the member countries are asymmetric.

1.3.3. Microeconomic Foundations

In the macroeconomic analysis, the laws-of-motion of magnitudes like inflation, unemployment or production can simply be assumed, if the central interest is their effect and not their origin. Such *ad-hoc* models have the advantage of being the most parsimonious description of a given problem, and provide insights that are clear and tractable. Very often, such models are also rather light on mathematics and thus more accessible.

In the end, however, macroeconomic dynamics are the results of countless decisions of households and firms, based on their utility- or profit-maximising problems[11] and facing constraints and rigidities. If the researcher is not only interested in the effects of macroeconomic dynamics, but also in their *origins*, a different type of model is needed. In such models the aggregate dynamics are derived from the utility- and profit-maximising behaviour of households and firms, respectively, given the microeconomic constraints and rigidities, hence we call these models *micro-founded*. Then changes at the microeconomic level of households and firms, concerning e.g. preferences or pricing behaviour, directly change the way the macroeconomic magnitudes evolve and interact. Further and recalling the notion of spillovers from above, in multi-country models it is not only the interaction between macroeconomic magnitudes of the same country, but also across countries, that is in the end governed by the microeconomics of households and firms in all countries – whether they are symmetric or not.

Conversely and tying in to the aspect of asymmetry mentioned above, what is true for the macroeconomic dynamics of a single country based upon the microeconomics of its households and firms also applies to asymmetries, since the households and firms of another country probably have a different set of constraints and rigidities, even if the objectives are the same[12]. Thus, asymmetries, as touched upon earlier, can be assumed or, given appropriate models, derived from agents solving optimality problems. In a

[11] It is conceivable that not all decisions of economic agents are driven by (rational) utility or profit maximisation. Certainly, emotional, maybe irrational, responses are playing a non-negligible role. However, such decisions are notoriously hard to put into equations, thus economists usually settle for the optimisation of some objective function, be it utility, profit, policy compromises, re-election probability, etc. that is more easily quantifiable.

[12] Which does not need to be the case, but is often supposed.

large part of the literature these asymmetries are assumed to exist, because the central interest is their effect and not their origin, see section 1.5 for an overview.

The present thesis uses such micro-founded models throughout. Households and firms in different member countries of the examined MU face different microeconomic rigidities, thus inducing different macroeconomic (transmission) asymmetries, which will impact the shape of AS and AD, their evolution over time and the spillovers they induce to the other members.

In order to describe and explain asymmetric macroeconomic dynamics and how these affect monetary policy decisions, and spillovers to other countries, the obvious benefit of a micro-founded analysis is that it enables one to look beneath the macroeconomic behaviour, and examine the *reason* for it, i.e. the asymmetries in the underlying optimisation problems and/or in their constraints, for example pricing rigidities, consumption preferences, productivity, or influence on (monetary) policy decisions.

1.4. Operationalisation Using the New Phillips Curve

To analyse the interplay of AS and AD, we commonly suppose equations for each of them that describes their movements over time and their interactions. In principle the analysis of the macroeconomic dynamics of MUs is no different, albeit more complex, and even more so with respect to *asymmetry, direct spillovers* and *micro-foundations*, thus requiring appropriate models. To that regard, this thesis offers estimations of established models using new data, and a new model considering direct spillover channels, its theoretical predictions and its empirical application.

A common method is to model the interaction of inflation and capacity utilisation using a Phillips Curve which is micro-founded and forward-looking, commonly known as the *New Phillips Curve*. This class of models is both well established and researched, making such models an obvious choice for amending them in order to examine MUs along the lines described above. Hence, all the models in the present thesis fall into this class, whose micro-founded macroeconomic dynamics are captured by AS-schedules, the *New Phillips Curve*, which relates inflation to rational inflation expectations, along with distortions from the demand side. Alongside the AS-curve, there is of course an AD-schedule, the *Dynamic IS Curve*, derived from the consumption Euler-equation of the consumers.

The (New) Phillips Curve The central equations of the analyses in this thesis are variants of the Phillips Curve, juxtaposing the development of prices and capacity utilisation in the broadest sense.

Its original form, the *Traditional Phillips Curve*, was a strictly statistical relationship described by Phillips (1958) for the UK while analysing wage and unemployment data from the mid-19th to the mid-20th century[13]. Phillips' originally examined the relationship between wage growth rates and unemployment, using strictly contemporaneous figures, while the later incarnations added distinct sequences of events.

Lucas and Rapping (1969) recast the Phillips curve using "an aggregate labor supply function" (p. 343) in terms of contemporaneous deviations from natural magnitudes of employment, wages and prices, from the perspective of last period. In other words, the point-of-view chosen by Lucas and Rapping (1969) is that the relationship between unemployment and prices is driven by surprises, i.e. movements today that were unanticipated given the information available last period. This notion is usually called the *Classical Phillips Curve* (see e.g. Woodford, 2003).

However, since the late 1980s to mid-1990s, macroeconomic thinking emphasises both frictions, market imperfections and rigidities, and rational households and firms. The theoretical foundations for these models, and the models used in this thesis, are forward-looking macroeconomic dynamics that arise from firms maximising profits facing a sticky-price environment on the one hand, and on the other hand utility-maximising consumers that balance imperfectly substitutable goods against each other and against labour. The AS-schedule derived from such an environment, the *New Phillips Curve*, states that it is not inflation surprises as seen from last period's perspective that drives inflation, but rather (rational) expectations of the *next* period's inflation, together with contemporaneous, systematic distortions from the real economy (marginal costs of production, output gap, unemployment, etc.) and unsystematic random shocks. The New Phillips Curve kept the Keynesian[14] notion that inflation is also caused by all kinds

[13]Curiously, Phillips explains money wage rate growth (nominal wage inflation) with unemployment, and not the inflation rate as measured by the general price level as it is common now.

[14]"Keynesian" in this context means the presence of frictions that precludes prices and wages to immediately jump to their market clearing value after a shock. In contrast, Keynesian economic *policy* is not necessarily a warranted response when using these models to describe the macroeconomy of a country. Given rational expectations, the monetary authorities may be able to surprise the public once and create an inflationary over-utilisation of capacity for one period, but just as in the classical variant by Lucas, the public will internalise this behaviour of the authorities, rendering it ineffective.

Even more fundamental, the Lucas Critique (Lucas, 1976), states that basing policy on estimated models (necessarily using past values) is all but ineffective in anything longer than the very short term. Thus, trying to exploit relationships like the Phillips Curve has been falling out of fashion with both researchers and policy-makers.

of frictions and not only by monetary expansion, as the monetarists claimed. Thus, the supposed (short-term) relationship between prices and some measure of capacity utilisation, e.g. the output gap or excess unemployment, implies a trade-off between inflation and economic activity. Because of this, the New Phillips Curve is often called the New-Keynesian Phillips Curve (NKPC), a term which will be used in the remainder of this thesis. This *New Keynesian Macroeconomics* (Rotemberg, 1987, Mankiw, 1989, Roberts, 1995, Goodfriend and King, 1997, Clarida, Galí, and Gertler, 1999, and Woodford, 2003) is often the basis of workhorse-models for aggregate macroeconomic analysis used in research, central banks, treasuries and policy analyses, and is thus one of the currently dominant schools of thought.

Most of these workhorse-models are micro-founded, as required above, in particular the ones by Galí (2008), Clarida, Galí, and Gertler (1999), and Sbordone (2002; 2005) which are the basis of this thesis' examinations.

However, there are numerous relations to other contributions, especially regarding the analysis of MUs and the role of direct spillover channels, that are not necessarily New Keynesian. The following section gives an overview of the work related to the models used in this thesis.

1.5. Literature

This section gives a fairly encompassing overview of the literature on currency areas, monetary unions and related topics. Because the relevant body of literature is rather large, the selection shown here needs to be somewhat limited. Further, I have sorted the literature into several subcategories, although a clear distinction is not always possible.

1.5.1. Classic Treatments of MUs

The study of MUs begins when Mundell (1961) examines Optimal Currency Areas (OCAs), and whether or not it would make sense to have the eastern and western parts of the US and Canada share a currency, because the macroeconomic shocks to them were much more correlated, than the shocks between, say, Eastern and Western Canada. Two other studies are often cited alongside Mundell, namely McKinnon (1963) who makes the case for OCAs using trade openness as the central criterion, and Kenen (1969), using product diversification and industry specialisation. The common theme among these classic contributions is similarity and the ability to mitigate idiosyncratic shocks. It is supposed that the more similar countries or regions are, using various measures, the more likely they would favour a similar policy response to a certain shock – which would be the case if they shared a currency and thus a monetary policy. Further, the better a country or region is able to mitigate an idiosyncratic shock on its own without some policy response, the lower the costs from losing an independent monetary policy would become, thus increasing the relative worth of removing trade barriers such as exchange rates and separate currencies.

All of these early contributions are dealing with the question when such a union would be an OCA, and of course whether the established MUs (e.g. the US or then-West Germany, or later the countries of the Europen Communities) were optimal in the Mundellian sense (cf. Bayoumi and Eichengreen, 1996: 19). See especially Ishiyama (1975) for a more detailed overview.

The question is to determine whether the parts of those MUs experienced uncorrelated, idiosyncratic shocks or not, and whether internal flows of labour and capital could offset the shock discrepancies – in Mundell's words whether they had "internal factor mobility and external factor immobility" (Mundell, 1961: 664). In such a setting, the question of optimality is a cost-benefit analysis[15] (cf. Bayoumi and Eichengreen, 1996: 1), whether savings in transaction costs are larger than the adjustment costs of having a possibly regional suboptimal monetary policy (cf. Alesina and Barro, 2002). This trade-off is usually operationalised by comparing the gains from removing exchange rate fluctuations on the one hand, to the (lack of) correlation of idiosyncratic shocks (cf. Bayoumi and Eichengreen, 1996) on the other hand.

However, as Bayoumi and Eichengreen (1992; 1994; 1996) and Weber (1990) pointed out, the answer to this question was rather hard, because of the simplicity of the employed models, that could not distinguish between the shock itself, its effect on the macroeconomic magnitudes, and the effect of the policy reactions to the shock.

The classic contribution on OCA and MU have thus a different focus from the present thesis, which is concerned with the macroeconomic dynamics of MUs and the propagation of shocks within them, while taking their existence as given and remaining ignorant about their optimality (or their stability).

1.5.2. Renewed Interest Due To EEMU

In the beginning of the 1990s, the prospect of a common currency for the members of the then-European communities, rekindled also the academic interest in MUs, especially the

[15]Wyplosz (1997: 17) states that trying to measure the costs and benefits is a "useless" exercise, because of the large uncertainties involved and because economists miss a yardstick of alternative scenarios to compare the size of the costs and benefits to, if they were satisfiably calculable in the first place.

questions of whether the conditions for an OCA were endogenous, who should join in the first place, and of policy optimality and policy coordination. These contributions are surveyed by Cobham (1991), Bayoumi and Eichengreen (1996), and Dellas and Tavlas (2009). But even after the launch of the third stage of EEMU, researchers continue to evaluate the shock correlation and asymmetries using variants of these models. This is used both to assess the state of convergence among the full members of the EEMU and to examine whether prospective new members are ready for admission to the EEMU. Campos, Fidrmuc, and Korhonen (forthcoming) provide a meta-analysis of such studies.

In the 1990s EEMU was a possibility and researchers tried to examine whether it would "fly" (Pollard, 1995) or not – a question that has been answered by the continued existence and enlargement of the Euro Area. Still, these studies provide the fundament of analysing and understanding the macroeconomic dynamics of MUs in general and the EEMU in particular, and are thus highly relevant, despite their age[16]. In the following, I review some of these contributions sorted along the lines especially relevant for this thesis. Compared to these studies, the aim of this thesis is not, to keep Pollard's word, whether the EEMU will fly, but how and why it flies, and how this has changed over time.

1.5.3. Shock Asymmetries and Transmsission Asymmetries

As already touched upon in section 1.3.1 and as pointed out by e.g. Aksoy, de Grauwe, and Dewachter (2002), and Gros and Hefeker (2002) and others, there are asymmetries[17] among the members of an MU in the shocks and in the transmission mechanisms. The former – *shock asymmetries* – are usually described by the (lack of) correlation between the idiosyncratic events in the single countries, and the latter – *transmission asymmetries* – by differences in the way movements of magnitudes propagate through the economy of a single country, even if those movements are described using the same mechanism. Again the body of literature on both types of asymmetries is large, and in the following I discuss a selection of studies.

Theoretical Contributions Between the seminal works by Mundell (1961), McKinnon (1963), and Kenen (1969), and the treaty of Maastricht as the start for EEMU there is remarkably little literature on either OCAs or MUs, especially theoretical models.

[16]Some studies from the 1990s make for some very topical reading today, especially the one about the relationship between the EU and the United Kingdom (UK).

[17]It seems that in the literature the term *asymmetry* is more prevalent than *heterogeneity*. Although the terms are used interchangeably, I will stick to "asymmetry".

Bayoumi and Eichengreen based their voluminous work on the (unformalised) theory of Mundell, McKinnon and Kenen and came up with a rather ad-hoc econometric specification, as did Weber (1990). It seemed that only in the run-up of EEMU academic economics began to formalise the theory on MUs.

An early model of an OCA is provided by Bayoumi (1994), to formalise the optimality criteria by Mundell, McKinnon and Kenen into a setting with nominal rigidities, stochastic shocks, and asymmetries among them. Even earlier, Canzoneri (1982) examines exchange rate intervention policies and touched upon the topic of MU in this context, as an agreement to stabilise their exchange rate perfectly. Both contributions are not micro-founded and focus rather on the policy interactions of forming an MU.

Alesina and Barro (2002) provide a model of an MU to assess the viability of MUs given various asymmetries e.g. country size, output, distance and shocks. They use this model to discuss the incentives for countries to either form an MU or to give up their own currency and adopt a foreign one unilaterally. Their general result is that smaller, more internationally connected countries have a stronger incentive to share their currency with their neighbours.

Acknowledging the "permanent" nature (p. 29) of membership in an MU in general and the EEMU in particular, Hughes Hallett and Weymark (2002) consider the costs of adopting a common currency as changes in economic growth rates. They report that these costs can be potentially high as they accrue over time, for countries whose structure deviates more from the average. They clearly foresee the conflict between pressure to reform and increased redistribution, which is discussed in the EEMU for almost a decade now. Hughes Hallett and Weymark disregard *expressis verbis*, however, direct spillovers between the countries.

Empirical Contributions A large part of the body of literature in the run-up to EEMU empirically studied the asymmetries (and often indirectly also the spillovers) between the countries of the European Communities, in order to establish whether the OCA criteria were fulfilled. An early study is by Vaubel (1978), who applies real exchange rate changes to examine possible common currency areas in Europe.

Connecting the studies of the mid-1990s to the OCA work of the 1960s is the central concept of shocks and their correlation. Almost all widely cited econometric contributions in the run-up to EEMU attempt to estimate the correlation of idiosyncratic shocks between the European countries. Weber (1990) uses a time-series model to estimate the shocks and their correlations between European countries using a dataset from the 1970s through the 1980s, and to study the co-movements in European monetary policies.

Bayoumi and Eichengreen (1992) use a large scale econometric model and a dataset spanning 25 years and eleven countries of the then-European Communities (EC-11) to assess the transmission asymmetry. They identify a "core", where shocks are rather small and well correlated, and a "periphery" where this is not the case, in particular for supply shocks. Compared with the shocks in EC-11-countries, the shocks in US regions are smaller and less idiosyncratic, an observation Bayoumi and Eichengreen attribute to higher factor mobility between US regions. They conclude that the whole of the EC-11 would find it "more difficult to operate a monetary union than the United States" (Bayoumi and Eichengreen, 1992: 35), and "that Germany and its immediate EC neighbors come much closer than the Community as a whole to representing a workable monetary union along American lines" (Bayoumi and Eichengreen, 1992: 36). Bayoumi and Eichengreen (1994) confirmed their previous results, using the same econometric approach, with a slightly larger dataset for European countries (the 15 European OECD members instead of the EC-11, and spanning 30 years instead of 25), and further extended the analysis towards country groups in East Asia, South America and to the US regions.

The studies by Vaubel (1978) and von Hagen and Neumann (1994) use shocks to the real exchange rate to assess the viability of an MU and agree with other studies, that there is a core of European countries among which an MU would probably work, and a periphery whose correlations are too different from the core and from one another to make monetary unification viable.

Applying the Lucas critique, Frankel and Rose (1998) argue that all studies based on "historical" performance are "misleading" (p. 1010), because membership in the EEMU would accelerate convergence. They use a gravity-model of trade among industrialised countries to underscore their point, concluding that "a country is more likely to satisfy the criteria for entry into a currency union ex post than ex ante" (p. 1024).

The study by Clements, Kontolemis, and Levy (2001) find asymmetries in the responses to monetary policy, but attribute them to different policy rules, rather than to actual asymmetries in the transmsission mechanism.

Alesina, Barro, and Tenreyro (2002) use a model by Alesina and Barro (2002) (see above) to empirically study the formation of MUs, based on trade, output, country size, distance and correlation of shocks. Similarly, Barro and Tenreyro (2007) examine empirically the probability of an MU as the propensity to adopt another country's currency, depending on the similarity in socio-economic magnitudes such as population, trade but also the co-movement of shocks. They conclude that there is an area in Europe where monetary unification would be both viable and sensible, using data from 1960 through 1997.

The study by Ciccarelli and Rebucci (2002) uses a Bayesian framework to assess the temporal variability of transmission asymmetries. They report that there are transmission asymmetries, that are decreasing in the mid-1990s reinforcing the earlier arguments that homogeneity has increased in the run-up to EEMU, which reminds of Frankel and Rose's (1998) argument of endogenous OCA criteria.

Another approach is taken by Hughes Hallett and Piscitelli (1999; 2002), who use a calibrated multi-country model to simulate the effects of EEMU on the macroeconomic magnitudes.

Relatedly, Clausen and Hayo (2006) examine transmission asymmetries using data for Germany, France and Italy, and a Rudebusch and Svensson (1999)-type model. They confirm earlier results of transmission asymmetries across the European countries.

In contradiction to the results of other studies, Peersman (2004) estimates a large-scale econometric model with both EEMU-wide and national variables and reports similar effects of (common) monetary policy shocks across the countries of the EEMU, i.e. a rather low degree of transmission asymmetry.

The main difference between (most of) these studies and the empirical parts of this thesis is the aim of the analysis. While the majority of these studies are concerned with gauging the optimality of the EEMU as measured by the correlation of shocks, this thesis is more interested in the macroeconomic dynamics and their influence on each other. Still, especially the model developed in chapter 3 is simulated using a variety of common and idiosyncratic shocks. An estimated version of the model can thus be utilised to assess the degree of "Mundellian optimality" as operationalised by the correlation of shocks.

1.5.4. Optimal Monetary Policy

Within the strand of studies of asymmetries in MUs, especially the conduct of monetary policy by the CCB has received much attention from the literature. This literature focusses on the question whether regions prefer a different monetary policy from one another or from the MU as a whole, as measured by differences in some welfare function[18].

[18]While this is a common and sensible operationalisation seen throughout economics, it is worthwhile to mention that all notions of "optimality", of monetary policy, scope of currency areas, etc. depends ultimately on the model.

The basic notion in all of these studies is whether or not a degree of *regionality* should be used by the CCB, given that rational consumers form their inflation expectations including on the one hand the effects of idiosyncratic shocks to other countries to monetary policy and on the other hand the idiosyncratic reactions to a common shock.

Introducing direct spillovers into the models, could mean that idiosyncratic shocks or reactions could not be so idiosyncratic after all, thus mitigating both the problem of the CCB in conducting possibly regionally suboptimal monetary policy, and the "frustrations"[19] experienced by the individual members. Still, while this conjecture seems natural, investigating this question is beyond the scope of the present thesis. A proper welfare analysis along the lines of the contributions reviewed in this section is hence warranted, see also section 5.2.

Theoretical Contributions Von Hagen and Süppel (1994) employ a Barro/Gordon (1983)-type model to study the optimality of different central bank set-ups for MUs. They conclude that the CCB should be centrally organised ("governors") if the political power of the MU is more decentralised, and vice versa if the MU's political power is more centralised ("country representatives").

De Grauwe (2000) considers a stylised two-country MU with classical Phillips curves (see section 1.4 above) and finds that the stronger asymmetric shocks are correlated, the easier a CMP can mitigate them. Further, transmission asymmetries makes it harder for the CCB to stabilise. His findings thus reinforce the earlier arguments of optimality and similarity by Mundell in a more formalised setting using also a CCB, an improvement upon the earlier study by Bayoumi (1994).

The study by Gros and Hefeker (2002) addresses the same question, but more theoretically using a Barro/Gordon-type set-up of two countries in an MU. They examine the effect of asymmetries in shocks and distribution[20] on the welfare difference between a national view and an area-wide view on monetary policy. They find that area-wide stabilisation may be welfare-decreasing, because in that case the CCB does not take into account the adverse effects of over-stabilisation in countries that are more responsive to monetary policy, reinforcing the findings by de Grauwe and Piskorski (2001) and Aksoy, de Grauwe, and Dewachter (2002). In another study, Gros and Hefeker (2007) extend their earlier work by modelling explicitly a non-tradable goods sector to provide micro-foundations for the transmission asymmetries, and to account for the stronger

[19] Aksoy, de Grauwe, and Dewachter (2002) use this term to describe regional deviations of macroeconomic magnitudes from their optimum and/or target.

[20] But not in stabilisation preferences, as Gros and Hefeker explicitly point out. Thus, their results are independent of preferences.

Balassa-Samuelson-effect in the then-prospective new EEMU members from central and eastern Europe. They conclude that MUs with strong deviation between the inflation rates of tradable and non-tradable goods, may be welfare-better off when monetary policy has a more area-wide focus, instead of a national view.

Relatedly, Hefeker (2003) studies different set-ups of the governing body of the CCB and the associated welfare losses and thus what set-up any single region would prefer. In extension, this comparison of welfare losses determines which set-up the MU as a whole will adopt from the spectrum between a strongly centralised (the "Board") and strongly regionalised ("Regional Representatives") monetary policy, and an intermediate solution (the "Council") in-between.

De Grauwe and Sénégas (2006) study the effects of parameter uncertainty in a Barro/Gordon-type model, similar to the one used by Gros and Hefeker (2002), They find that in the investigated cases that uncertainty reinforces the argument to rely on national instead of union-wide data.

Benigno (2004) constructs a fully-fledged DSGE-model of a two-country MU, similar to the model developed in chapter 3, but with a focus on terms of trade spillovers. Further, he is more interested in optimal monetary policy and less in the interactions of the macroeconomic magnitudes of the MU's member countries. He finds that in general, the optimal monetary policy should assign a higher weight to the country with the higher price rigidity. Relatedly, Benigno and López-Salido (2006) use the model by Benigno (2004), augmented with inflation persistence to study optimal monetary policy. They confirm earlier findings that monetary policy which gives a higher weight to more price-rigid countries is welfare-better, because it exploits the higher degree of adjustments in the more flexible country.

Empirical Contributions The change from national to European monetary policies has also sparked a number of empirical studies about optimal monetary policy and changes in the conduct of monetary policy. In the following, I present a selection of these studies.

De Grauwe and Piskorski (2001), and Aksoy, de Grauwe, and Dewachter (2002) set up a large-scale state-space model of the eleven original members of the EEMU using ad-hoc classical Phillips curves and IS curves for the single countries and aggregate them. They then estimate the parameters and simulate the effects of shocks on the calibrated model. In order to assess the welfare implications of neglecting national information, they impose different monetary policy rules and calculate the welfare losses from shocks.

They find only small differences between the monetary policies for most countries, but substantial ones for others, where the reaction to monetary policy is more sluggish.

Altavilla and Landolfo (2005) estimate an ad-hoc auto-regressive model of the EEMU countries and use it to simulate the effects of idiosyncratic shocks and their transmission. They conclude that transmission asymmetries across the EEMU countries are only a minor concern and should further decrease over time.

Unlike most studies of asymmetries, McCallum and Smets (2007) are concerned rather with real wages, employment, and compensation, than with inflation or the output gap. They report "quite different" (p. 14) responses across the single countries.

The study by Hayo and Hofmann (2006) compares the monetary policy by the pre-EEMU Bundesbank and the ECB by estimating Taylor-rules and find that the ECB reacts similarly to inflation expectations but stronger to the output gap than the Bundesbank did.

Brissimis and Skotida (2008), and Lee (2009) impose quadratic loss functions on the CCB of an MU of two and twelve countries, respectively. The countries' macroeconomic dynamics are captured by New Phillips curves and Dynamic IS curves. Optimal monetary policy in the form of an interest rate rule is then derived as the solution to the loss minimisation problem. An estimation of their respective models with European data reinforces earlier results, that monetary policy using national instead of aggregate data seems to be welfare-better. Unlike earlier studies, Brissimis and Skotida (2008), and Lee (2009) conclude this from a micro-founded, New-Keynesian setting.

The general notion in all of these studies, regardless of the employed technique or data selection, is that asymmetries are present and that a CCB should incorporate disaggregate data into its monetary policy in order to increase welfare[21]. Still, almost all the contributions presented in this section use models without *direct* spillovers, with interaction only coming via the CMP or only indirectly via relative variables like the terms-of-trade. A logical extension to these models is the introduction of direct spillover channels to allow another way for shocks to propagate through the economies. Then, when idiosyncratic shocks are not only affecting one economy, but via the direct spillover

[21] Which leaves the obvious question whether an elusive concept such as *welfare* is adequately measured by linear-quadratic loss functions. However, given the mandate of most of the world's central banks' to keep prices stable and support the overall economy if that does not conflict with price stability, operationalising welfare in the form of linear-quadratic loss functions is at least sensible from a technical point-of-view.
There is however the notion of the linear-quadratic loss function in inflation and output gap, as a quadratic approximation of a common utility function used in these models, see Galí (2008), and Woodford (2003). Whether that particular function is an adequate measure of consumers' *utility* (another elusive concept), is better left to the microeconomists, however.

channels also the other economies, optimal monetary policy may look different to what we know so far. I believe it to be worthwhile to re-examine from this point-of-view the questions answered by the contributions presented in this section.

1.5.5. Interacting Economies

I the vast body of literature on MUs, the (direct) interactions between the countries themselves only rarely play a role. There are, however, a few exceptions.

Direct Interactions Canzoneri (1982) studies interactions of exchange rate intervention policies and acknowledges that being member of an MU is the strongest possible of such policy, i.e. perfect and instantaneous stabilisation. Canzoneri analyses then the effects of spillovers from one country to another in various settings, including an MU, and also from an MU to a third country. While these models are not micro-founded, they provide a robust framework for policy analysis and how these policies' effects propagate through the economies. In a similar three-country setting, Canzoneri and Gray (1982) study monetary policy interactions after unanticipated shocks.

Canzoneri and Henderson (1991) establish a simple yet powerful model, very similar in its function to the one developed in chapter 3 in this thesis, however they are not concerned with MUs but any two interacting economies. Still, the concept of an MU can be introduced in the Canzoneri/Henderson-model by requiring certain variables to take on identical values across the countries. In fact, the only two changes necessary concern monetary policy, which is centralised in an MU, and the exchange rate, which does not exist between the member countries of an MU – or is simply unity. Thus, setting the interest rates and money growth rates equal, as well as setting the nominal exchange rate to unity transforms their basic model into one consistent with the assumptions of chapter 3. The fundamental difference, though, is that the Canzoneri/Henderson-type models were designed to analyse monetary and fiscal policy interactions in the setting of interacting economies, while the MU-NKM of chapter 3 is designed to analyse macroeconomic interdependence, with the analysis of monetary policy as an afterthought. Hence, in the Canzoneri/Henderson-model, interaction terms are assumed, while they are derived from the micro-foundations in the MU-NKM.

Interactions Through the Terms-Of-Trade Quite a number of theoretical treatments of MUs consider the terms-of-trade in the context of MUs, as an important spillover channel. This notion is sensible, since the real exchange rate[22] is a measure of convergence and thus – in a way – a measure of the degree of optimality, cf. e.g. de Grauwe and Heens (1993), Schmitz et al. (2012), and Fidora, Giordano, and Schmitz (2018).

Beetsma and Jensen (2005) extend Benigno's (2004) model with fiscal authorities. They find that selecting proper fiscal policies, coordination and commitment leads to welfare improvements.

The model by Jang and Okano (2013) also studies a two-country New-Keynesian setting. Notable common features of their model and the MU-NKM are the relationship between producer prices and consumer prices, and the direct spillovers in the aggregate demand schedules. Apart from that, the spillovers also work through the terms-of-trade. Still, Jang and Okano (2013) study countries that are not bound by a CMP, so there is scope for policy interaction in the spirit of Canzoneri and Henderson (1991), which is, however not, explored in their paper.

Bhattarai, Lee, and Park (2015) construct a model of a two-country MU with financial frictions, nominal price rigidities and imperfect competition, and study the effect of a shock on the financial markets and how this affects optimal monetary policy. They report that the short term interest rate should also react to the interest rate spread and not only to inflation and the output gap. Similarly to the MU-NKM, the main laws-of-motion of their model also feature spillover channels, although they are indirect in the form of relative magnitudes, e.g. relative prices, the terms-of-trade.

The following chapters connect to the here presented literature in various ways. Additional relevant literature of a specific connection to the single chapters are reviewed at the beginning of each chapter separately.

[22]In an environment of fixed nominal exchange rate, the terms-of-trade are linear to the real exchange rate. In an MU where the nominal exchange rate is absent (or mathematically unity), the terms-of-trade and the real exchange rate are identical.

2. The Crisis, Unconventional Monetary Policy, and European Inflation Dynamics

An earlier version of this chapter has been published as: B. Schäfer (2018). "The Impact of the Crisis and Unconventional Monetary Policy on European Inflation Dynamics. Evidence from a Three-Period Structural Model and Six Countries". *Review of Economics* 69 (2): 87–110

EVER since after the financial crisis of 2008/09, the European debt crisis 2009/10, the subsequent individual economic problems (i.a. high unemployment in Spain, high debt and banks' instability in Italy, vast economic contraction in Greece) and the unprecedented monetary policy response following the "Whatever It Takes" (WIT) remark by European Central Bank (ECB) president Mario Draghi in summer 2012, inflation in Europe has been low (see appendix B.1.1). It seems that both events, crisis and reaction, had a profound impact on the levels of inflation. This harbours the question whether these impacts are of a transitory nature, i.e. a "shock", or whether they changed the underlying inflation dynamics. Under the assumption that the changes are not transitory, given the rather long time-frame, the motivation for the present study are, first, to try to quantify these impacts on the inflation dynamics, and second, to see whether these quantifications can help to explain why inflation rates remain low despite the ECB's monetary accomodation.

To this end, this chapter investigates empirically the economic activities of Austria, Germany, Spain, France, Italy, and The Netherlands, before, during, and after the crisis years. In particular, the study considers non-linear versions of an aggregate supply curve, colloquially known as the New (Keynesian) Phillips Curve (NKPC). Such an NKPC can be theoretically motivated by forward/backward-looking sticky-price models, so called *Hybrid New Keynesian Models*. Considering the non-linear version of the NKPC allows to estimate[1] the structural[2] (deep) parameters governing price stickiness, time preference and degree of forward and backward looking behaviour of price setters.

Related literature and my point of departure is described in the next section. The third section gives a brief introduction into the theoretical models. The fourth section presents the data in brief, and the estimation method and results are in the fifth section. The last section comments and concludes.

2.1. Literature Review

Empirical treatments of New-Keynesian Models (NKMs) were pioneered by Galí and Gertler (1999), and Galí, Gertler, and López-Salido (2001; 2005) who estimated their model using quarterly US and later European data and the Generalised Method of Moments (GMM). Their choice of data and methodology has since become very prevalent in the literature on estimated NKMs. Furthermore, Galí and Gertler (1999) and Fuhrer (1997) introduced the notion of a "hybrid" model, i.e. with a certain degree of backward-looking behaviour, to remedy the empirical short-comings of the purely forward-looking model. Another issue with the baseline model was the inadequacy of the output gap to capture capacity utilisation properly, Galí and Gertler (1999) suggest using a measure of marginal costs deviation. They suggest that the price setting behaviour, usually modelled by staggered pricing (e.g. following Calvo, 1983) is only partially able to link marginal costs deviations to movements in the output gap. Indeed using the deviation of marginal costs from their mean improves the NKM's fit considerably.

Regarding the estimation of European economies there are the studies by Rumler (2007), Brissimis and Skotida (2008), Angelini et al. (2008), and Lee (2009), of course given their publishing date, they cannot consider the crisis. Additionally, Boone (2002) considers the convergence of the European countries before European Econonomic and Monetary Union (EEMU) using the Kalman-filter to estimate time varying-parameters, however his model is not micro-founded.

A very recent contribution investigating the impact of unconventional monetary policy in Europe using a VARX approach and the ECB balance sheet is Elbourne, Ji, and Duijndam (2018). While their study is very broad, it lacks the theoretical underpinning

[1]In an earlier version of the paper this chapter is based on, I estimated a stacked *linear* model of the six countries, however it turned out that the single equation *non-linear* GMM presented later is much more sensitive than the stacked model. It seems that the efficiency gains by considering cross equation error correlations are not enough to make up the loss of degrees of freedom when estimating a simultaneous equation model with many more parameters.

[2]Structural parameters are non-composite (atomic) parameters of the underlying economic processes.

of a model such as the NKM. Studies by Łyziak and Mackiewicz-Łyziak (2014), Łyziak and Paloviita (2017), and Strohsal and Winkelmann (2015) look at if and how inflation expectations, i.e. the forward looking part of the Phillips curve has changed with the crisis. A common finding is variation across countries in the forward looking component, however they do not agree on whether inflation expectations have been de-anchored from the ECB's target or not. Contributions by Oinonen and Paloviita (2014), Riggi and Venditti (2015), and Bulligan and Viviano (2017) look at the Phillips curve in European economies or the EEMU. They agree that the Phillips curve has become steeper in Europe, i.e. the parameter for the driving variable became larger. Blanchard (2016), however reports opposite results for the US, with a flattening of the American Phillips curve.

2.2. Theory and Estimation Framework

The estimated model is a standard sticky-price, hybrid version of the Phillips curve, (see Galí and Gertler, 1999, and Galí, Gertler, and López-Salido, 2001; 2005). In particular, it arises from the optimal price-setting behaviour of firms with labour as the only input factor under monopolistic competition and subject to nominal price rigidities, facing iso-elastic demand curves.

The price rigidities in place are Calvo-pricing (Calvo, 1983) on the one hand, allowing only a subset $0 < (1-\theta) < 1$ of firms to readjust prices in any given firm, θ is the degree of nominal price rigidity or, more colloquially the *price stickiness*. Of these readjusting firms, only a fraction $0 < (1-\omega) < 1$ chooses the optimal price as a solution of the profit maximisation problem. The remaining firms set their price to the average of last period's prices corrected for last period's inflation rate. Thus, ω is the "degree of 'backwardness' in price setting" (Galí and Gertler, 1999: 211), or more colloquially the *pricing backwardness*.

Further, the labour share in the production function is governed by the parameter α and the elasticity of substitution between goods in the consumers' goods basket is ε, see Galí (2008) for an excellent theoretical treatment.

From this set-up, inflation can be modelled as depending on both inflation expectations and the inflation lag, as well as a driving variable from the real economy, making this a *Hybrid New-Keynesian Phillips Curve (HNKPC)*.

Following Galí (2008), Galí and Gertler (1999), Galí, Gertler, and López-Salido (2001; 2005), and Sbordone (2002), the HNKPC can be expressed with the marginal costs deviation from the steady state as the driving variable, which often improves the fit considerably as compared to using the output gap as the driving variable. With the production function used to derive the HNKPC in the first place, it follows also that marginal costs are just the labour income share of GDP, see appendix D.1 for the derivation.

The HNKPC is then the same as in section 4.1 of Galí, Gertler, and López-Salido (2001), and given by

$$\pi_t = \xi^f \mathrm{E}_t\{\pi_{t+1}\} + \xi^b \pi_{t-1} + \lambda \tilde{mc}_t, \tag{2.1}$$

with

$$\xi^f \equiv \beta\theta\phi^{-1} \qquad \xi^b \equiv \omega\phi^{-1} \qquad \lambda \equiv \phi^{-1}(1-\omega)(1-\theta)(1-\beta\theta)\Theta.$$

Further, notational shortcuts are[3]

$$\Theta \equiv (1-\alpha)/(1-\alpha+\alpha\varepsilon) \qquad \phi \equiv \theta + \omega(1-\theta(1-\beta)).$$

The magnitudes are the inflation rate π along with its one period lag and lead, and the deviation of marginal costs from its trend $\tilde{mc}$. Lastly, $\mathrm{E}_t\{\cdot\}$ denotes expectations formed in period t using all information available at this point, i.e. rational expectations.

This constitutes a non-linear model of five structural – or "deep" – parameters $\theta, \omega, \beta, \alpha, \varepsilon$ which can be estimated via GMM and instrumental variables, where β is the discount factor, α the production elasticity of capital, and ε is the elasticity of substitution in the consumer's goods basket. As stated above, θ and ω are, respectively, price stickiness and pricing backwardness.

Finally, the price stickiness parameter θ gives also a measure for the average price duration D in periods. Since any firm may re-optimise its price with a probability of $(1-\theta)$, the average time between two re-optimisation events (for forward-looking firms, as well as for rule-of-thumb firms) can be expressed as

$$D = \frac{1}{1-\theta}. \tag{2.2}$$

See appendix D.2 for the derivation.

[3]Observe that $\beta = 1 \Rightarrow \phi = \theta + \omega$.

2.3. Data

To estimate the model I make use of the usual data, most of the series are obtained from Eurostat, some from the ECB and from the OECD. The main variables are of course measures for inflation and marginal costs. The data are either monthly series or quarterly series that have been linearly interpolated to monthly frequency[4]. Still, the lag and lead structure is of quarterly frequency, that is every lag and lead step goes back or forth three months, i.e. one quarter. This helps to utilise the higher number of observations while keeping the usual calibrations and interpretations of quarterly models intact. An overview of the data used to capture the inflation rate, the marginal costs and the instruments is given in table A.1 in the appendix, see further appendix B for graphical representations of the time series.

Inflation Measures The European Union (EU) and its member states measure their price levels via a system of harmonised goods baskets. The index of these prices is the Harmonised Index of Consumer Prices (HICP), which is published monthly by the statistical authorities of the member states and collected at Eurostat. The usual inflation measure, and also the one guiding the ECB's monetary policy, is the monthly annualised rate of change of the HICP, or simply the *HICP inflation rate* or *consumer price inflation rate*. A second, often employed measure of price movements is the annualised rate of change of the ratio of nominal and real GDP, the *GDP Deflator*, measuring the prices of domestically produced goods, i.e. "goods [. . .] purchased by consumers, businesses, government, and foreigners, but not importers." (Church, 2016), or simply the *domestic goods price inflation rate*. It is available at quarterly frequency at Eurostat. Figure 2.1 shows the series for Germany, the series for the other countries of the sample are shown in appendix B.1.1.

Marginal Costs It is a well-known notion in the literature of empirical treatments of NKMs that the deviations of marginal costs from their steady state value often outperform the output gap as the driving variable of the HNKPC, see e.g. Galí and Gertler (1999), Galí, Gertler, and López-Salido (2001; 2005), and Sbordone (2002; 2005). Further, using marginal costs deviations does not require a formal assumption on the consumers' utility function, as the output gap would do. For these reasons I will stick to marginal costs deviations as the driving variable.

[4]Alternative estimations using quarterly data, and monthly data aggregated to quarterly frequency showed poorer, less sensitive results than with (interpolated) monthly data.

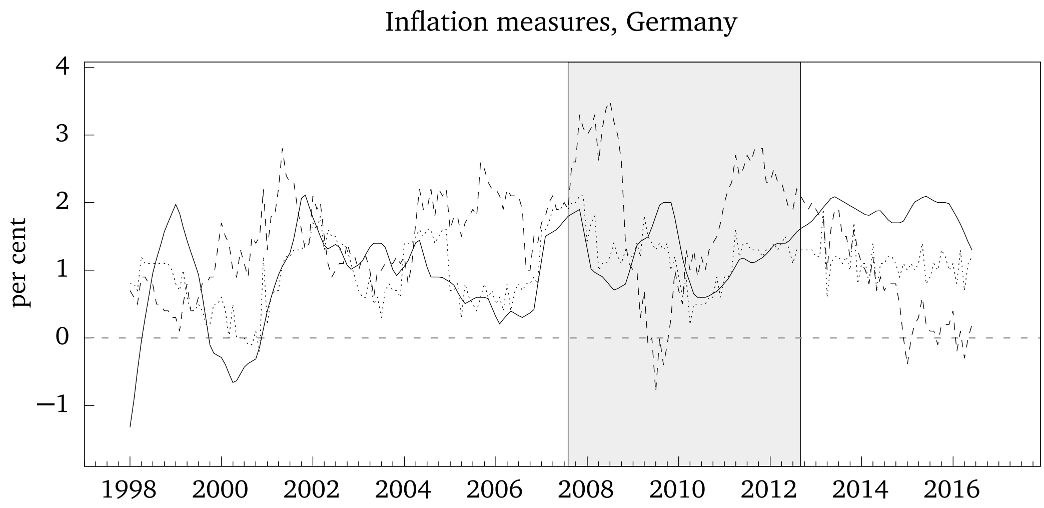

Figure 2.1.: Germany, monthly, annualised rates of change of the GDP Deflator (interpolated, solid), HICP (dashed) and Core HICP (dotted). Shaded region is the crisis period. *Source: Eurostat, own calculations and illustration*.

Using the production function to derive the HNKPC, marginal costs can be expressed as unit labour costs or equivalently as the labour income share, see appendix D.1 or Galí, Gertler, and López-Salido (2001), and Galí and Gertler (1999) and references in these studies for details.

Applying the HP-filter to the series of labour income share gives an estimate of marginal costs deviation from the steady state in percent as the filter's cyclical component. Figure 2.2 shows this filtered series for Germany, the series for the other countries are shown in the appendix.

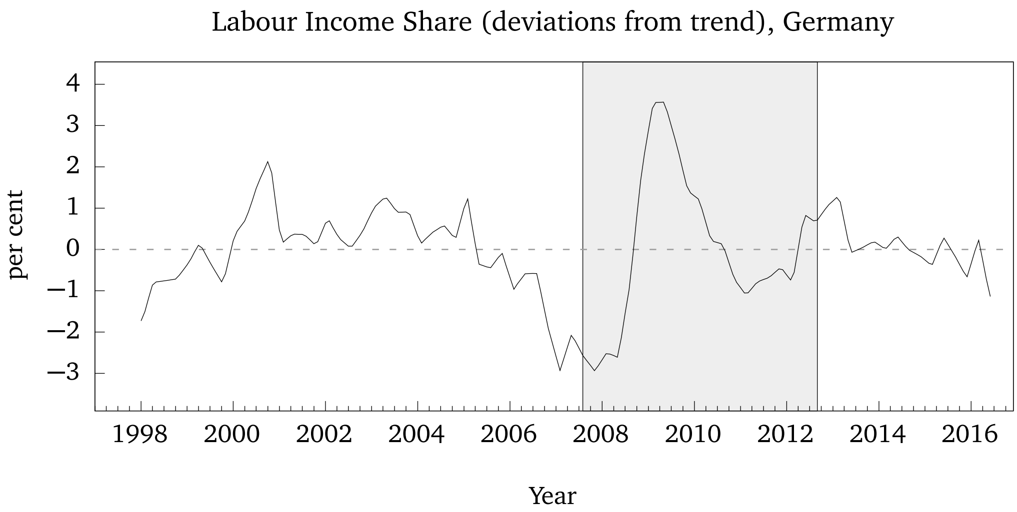

Figure 2.2.: Marginal costs deviation from steady state, expressed as cyclical component of HP-filtered labour income share (monthly), Germany. Shaded region is the crisis period.
Source: Eurostat and own calculations.

Parameter Calibrations Finally, to calibrate the parameter α, ε, and thus Θ, I use data from the European Commission's AMECO database, namely the adjusted wage share at factor prices (following Raurich, Sala, and Sorolla, 2011). Following Galí, Gertler, and López-Salido (2001), I use the average value[5] to pin down the production elasticity[6] of labour:

$$1 - \alpha_k = \frac{S_k}{\mu} \tag{2.3}$$

where S_k is the average adjusted wage share at factor prices in country k and μ is an estimate of the economies' average price mark-up over marginal costs. Then, of course, $1 - \alpha_k$ is the production elasticity of labour.

[5]Earlier studies found a persistent decline in the labour income share, see e.g. Grömling (2010), ILO and OECD (2015), and Krämer (2011). However, the trend is no longer visible in the adjusted wage share series of AMECO over the period investigated in the present study. Only the series for Spain shows a significant negative drift in an ARMA-fit, all the other series seem to be stationary, judging from this simple analysis. Still, the adjusted wage share is far from constant, thus calibrating the model like this has to be done cautiously.

[6]Since the models used in this thesis and in the related literature are usually expressed in logs, so is the production function, turning the multiplicative Cobb-Douglas structure into a sum, with *constant* (not varying with the production-level) coefficients. Since by definition they add up to unity, the production function is homogenous of first degree, and thus α_k and $1 - \alpha_k$ can also be thought of as the shares of input factors capital and labour in the creation of the GDP, and also (via the income approach) as the distribution of GDP among workers and capital owners. This is also the usual wording of these magnitudes, especially for $1 - \alpha_k$, the *labour share*.

I take[7] $\mu = 1.1$ from Galí, Gertler, and López-Salido (2001). By theory, the elasticity of substitution is

$$\varepsilon = \frac{\mu}{\mu - 1} = 11 \tag{2.4}$$

Since $1 - \alpha_k = S_k / \mu$ is a sample average scaled by a constant, its associated standard error is simple to calculate. The estimates of $1 - \alpha_k$ and of the shortcut Θ_k together with their standard errors are presented in table 2.1, and in figure 2.3. The standard errors of Θ are calculated using error propagation, see appendix C.

$k =$	AT	DE	ES	FR	IT	NL
$1 - \alpha_k$	0.5684	0.5675	0.5709	0.5932	0.5471	0.5935
	(0.0136)	(0.0122)	(0.0114)	(0.0114)	(0.0104)	(0.0108)
Θ_k	0.1069	0.1066	0.1079	0.1171	0.0989	0.1172
	(0.0053)	(0.0047)	(0.0045)	(0.0049)	(0.0037)	(0.0046)

Table 2.1.: Estimates and standard errors of the labour share $1 - \alpha$ and the shortcut Θ. *Source: European Commission, AMECO database, and own calculations.*

Notably, Italy has a rather low labour share, while France and The Netherlands have a rather high labour share. Austria, Germany and Spain are in the middle.

2.4. Estimation

Estimation is performed with GMM and instrumental variables using R (R Core Team, 2017) and the gmm package (Chaussé, 2010). Using GMM allows to estimate the structural, non-linear HNKPC, while the instruments solve the endogeneity problem. The instrumented structural HNKPC provides a straightforward[8] set of moment conditions:

$$\mathrm{E}_t \left\{ \mathbf{z} \times \left(\pi_t - \beta\theta\phi^{-1}\pi_{t+1} - \omega\phi^{-1}\pi_{t-1} - \phi^{-1}(1-\omega)(1-\theta)(1-\beta\theta)\Theta \tilde{mc}_t \right) \right\} = 0 \tag{2.5}$$

where $\mathbf{z}$ is a collection of instrumental variables dated $t-1$ or earlier. In contrast to Galí, Gertler, and López-Salido (2001), I only consider calibrations where the discount factor β is fixed at unity, as commonly done in the empirical literature on the HNKPC. With

[7] Following Galí, Gertler, and López-Salido (2001), μ is assumed to be known with certainty.

[8] Galí and Gertler (1999), and Galí, Gertler, and López-Salido (2001) note that GMM is unstable with respect to the formulation of the moment conditions and suggesting two mathematically equivalent sets of conditions. I have estimated the model with both sets as suggested by Galí, Gertler, and López-Salido (2001), however only the one presented here produces reasonable results.

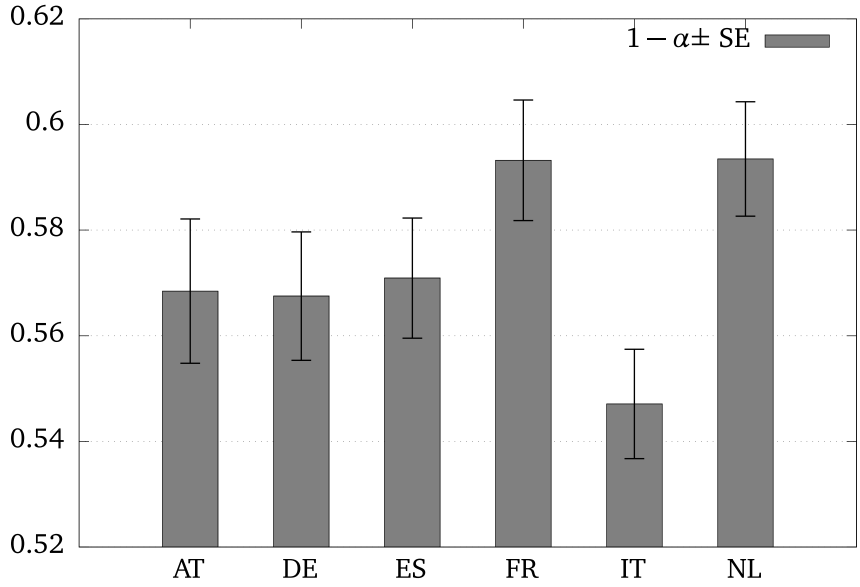

Figure 2.3.: Estimated average production elasticities of labour and their SEs, selected European countries. Source: AMECO, 1998-2016, annual figures, own calculation.

this, the forward and backward looking reduced coefficients ξ_f and ξ_b add up to one, making the interpretation more straightforward. Further, since α and ε are calibrated, also the parameter Θ is fixed at the values obtained in section 2.3.

I estimate the models with two different inflation measures, the HICP annualised inflation rate, and the GDP Deflator annualised rate, for all six countries, Austria, Germany, Spain, France, Italy and The Netherlands, and for the three periods, *pre-crisis* from 1999-1 to 2007-7, the *crisis* period from 2007-8 to 2012-8, and the "*Whatever-It-Takes*"[9] (WIT) period from 2012-9 to 2016-6[10].

The standard errors of the structural parameters are calculated with a Newey/West heteroscedasticity and autocorrelation robust (HAC) variance-covariance estimator with 12 lags (following Galí and Gertler, 1999) from the `sandwich` package for R (see Zeileis, 2004; 2006). In contrast, the standard errors of the implied (reduced form) coefficient

[9] See the announcement by ECB president Draghi, at `https://www.ecb.europa.eu/press/key/date/2012/html/sp120726.en.html` for a verbatim of the speech. Curiously enough, he also touches the topic of intra-EEMU divergences, hinting that the ECB is aware of the fact that the EEMU is not (yet) a fully integrated an economic area, although the ECB's mandate cleary requires policy to be based on developments of the whole of the EEMU.

[10] I have cut the sample rather early to avoid the end-point problem of the HP-Filter.

estimates are calculated via error propagation, namely the delta method, see appendix C, and Shalizi (2017: appendix G).

2.4.1. Instruments

The instrument set contains two lags of respectively, the inflation rate measure, the marginal cost deviations, the wage inflation rate. Further, two lags of respectively, the survey based inflation expectations, the output gap[11], and the interest rate spread[12]. The notable difference is Spain in the WIT period, here the instrument set contains additionally a third lag of the GDP Deflator, when this is the inflation measure. When using the HICP as the inflation rate measure, two lags of the unemployment rate are added to the instrument set. All instruments are series from the country in question, no series from other countries[13] are used.

Appropriateness Regarding the specification or the appropriateness of the instrument set, one usually employs the Sargan/Hansen J-Test with the null hypothesis of a correctly specified model, hence we would like a low, statistically insignificant J-statistic. However, the literature suggests that with large sample length T (the following estimations have $T \approx 100$ or more), and with thus many moment conditions, the J-Test has very little power in detecting mis-specification of the model, or instrument appropriateness, see Andersen and Sørensen (1996) and Bowsher (2002). In fact, I could almost always "create" a non-rejection of the J-Test's null hypothesis of model appropriateness by using a rather low (three or four) number of arbitrary instrumental variables. This leaves serious doubt about the effectiveness of the J-Test. Unfortunately, there are scarcely alternatives for gauging the model specification, except for "selected instrument reduction"[14] (Bowsher, 2002). I thus rely on a very conservative first-stage F-test, in the spirit of Olea and Pflueger (2013), Pflueger and Wang (2015), Stock, Wright, and Yogo (2002), and Stock and Yogo (2005) and require the OLS regression of the endogeneous variables against the instrument set to have an F-statistic of at least 30, which is admittedly ad-hoc, but more than required by these authors. All null hypotheses of no explanatory power can be rejected[15] at very high significance.

[11] Cyclical component of HP-filtered real GDP.

[12] The difference between the yield of a 10-year sovereign bond and the Euro Overnight Index Average (EONIA).

[13] I found that their explanatory power is very limited, due to variations across countries.

[14] Basically an ad-hoc method of trial-and-error removing instruments and see if and by how much the fit improves

[15] Not reported in the text, see the output of the provide R code.

Dep. var.	GDP Deflator			HICP		
	Pre-Crisis	Crisis	WIT	Pre-Crisis	Crisis	WIT
Price Stickiness θ	0.472*** (0.038)	0.530*** (0.013)	0.450*** (0.089)	0.628*** (0.013)	0.567*** (0.025)	0.714*** (0.246)
Pricing backwardness ω	0.609*** (0.081)	0.430*** (0.024)	0.566*** (0.194)	0.334*** (0.022)	0.356*** (0.044)	0.419 (0.345)
Inflation expectation ξ^f	0.437*** (0.053)	0.552*** (0.020)	0.443*** (0.133)	0.653*** (0.020)	0.615*** (0.040)	0.630** (0.273)
Inflation inertia ξ^b	0.563*** (0.053)	0.448*** (0.020)	0.557*** (0.133)	0.347*** (0.020)	0.385*** (0.040)	0.370 (0.273)
MC deviation λ	0.012*** (0.001)	0.013*** (0.000)	0.014*** (0.002)	0.010*** (0.000)	0.013*** (0.001)	0.005 (0.006)
Avg. Price Duration D	1.895*** (0.137)	2.128*** (0.060)	1.818*** (0.293)	2.690*** (0.098)	2.310*** (0.131)	3.497 (3.015)

Coefficient restriction $\beta = 1$ for all models, Θ is calibrated as shown in table 2.1. Upper panel shows the GMM estimates of the structural (deep) parameters, HAC-robust SEs in parentheses. Lower panel shows the reduced form coefficients based on the structural parameter estimates. SEs of the reduced form estimates are calculated via error propagation.
Significance: $p < 0.01$ ***, $p < 0.05$ **, $p < 0.1$ *.

Table 2.2.: Non-linear hybrid NKPC, Austria. GDP Deflator (monthly, annualised rate of change), HICP (monthly, annualised rate of change), Log labour income share (monthly, HP-filtered).

2.4.2. Austria

Consider the estimation results for Austria as presented in table 2.2. First, the estimates using the GDP Deflator as the inflation rate. The estimates of the structural parameters for price stickiness $\hat{\theta}$ are 0.47, 0.53 and 0.45, respectively, and the estimates for pricing backwardness $\hat{\omega}$ are 0.61, 0.43 and 0.57, respectively. This shows that domestic goods prices are more sticky and less backward-looking during the crisis. In the WIT period, both price stickiness and pricing backwardness fall to (slightly) below their pre-crisis levels.

The reduced coefficient estimates for inflation expecation $\hat{\xi}^f$ and inflation inertia $\hat{\xi}^b$ mirror this pattern. The estimated shares of GDP Deflator inflation rate accounted for by inflation expectations are 0.44, 0.55 and 0.44, respectively in the three periods. Accordingly, the estimated shares accounted for by inflation inertia are 0.56, 0.45 and 0.56, respectively. This shows that Austrian domestic goods prices before the crisis are rather backward-looking than forward-looking, and again so in the WIT period. This pattern flips during the crisis period. The estimated influence of marginal costs deviations $\hat{\lambda}$ increases slightly, from 0.012 to 0.013 and 0.014. Reflecting the price stickiness, the estimated average domestic goods price durations $\hat{D}$ are 1.9, 2.1 and 1.8 quarters, respectively in the three periods.

Consider now the estimates using the HICP as the inflation rate. The estimates of price stickiness $\hat{\theta}$ are 0.63, 0.57 and 0.71, respectively. This shows that consumer prices are less sticky during the crisis but even more so in the WIT period, suggesting that disinflationary pressure reduces price stickiness in the crisis period, but pricing stabilise again in the WIT period. The values for pricing backwardness $\hat{\omega}$ are 0.33 and 0.36, respectively. The estimate for the WIT period is insignificant, due to a large increase in the associated standard error.

Pricing backwardness increases a bit during the crisis but becomes very different among firms in the WIT period such that there is too much variation to estimate it.

The reduced coefficient estimates for the share of consumer price inflation accounted for by inflation expectations $\hat{\xi}^f$ are 0.65, 0.62 and 0.63, respectively. Accordingly, the estimates for the shares accounted for by inflation inertia $\hat{\xi}^b$ are 0.35 and 0.38, respectively for the pre-crisis and the crisis periods. The estimate for the WIT period is insignificant, again because the associated standard error is too large. For the pre-crisis and crisis period the estimated influence of marginal costs deviations $\hat{\lambda}$ are 0.01 and 0.013, respectively, the estimate for the WIT period is insignificant. Reflecting the price stickiness, the estimated average consumer price durations $\hat{D}$ are 2.7 and 2.3 quarters, respectively in the the pre-crisis and the crisis periods, the estimate for the WIT period is insignificant.

The insignificance of many of the WIT period estimates can be attributed to the large standard errors of the structural estimates. This documents that firms in Austria experience no clear pattern of the pricing environment, and are further not in agreement whether past prices carry information for current prices.

Aside from the HICP estimates in the WIT period, all estimates are highly statistically significant.

2.4.3. Germany

Turn next to Germany, the results are presented in table 2.3. Beginning with the GDP Deflator, the structural estimates for the WIT period are not statistically significant. Still some reduced parameters are significant, but those should be taken with a grain of salt.

Aside from the WIT period, estimated price stickiness $\hat{\theta}$ decreases strongly in the crisis period from 0.61 to 0.46. Conversely, estimated pricing backwardness $\hat{\omega}$ increases, from 0.4 to 0.59 suggesting that uncertainty lead to more rule-of-thumb pricing than optimal pricing, although prices became less sticky, reflecting disinflationary pressure. In the WIT

Dep. var.	GDP Deflator			HICP		
	Pre-Crisis	Crisis	WIT	Pre-Crisis	Crisis	WIT
Price Stickiness θ	0.611***	0.455***	0.127	0.692***	0.472***	0.608***
	(0.015)	(0.016)	(0.224)	(0.018)	(0.009)	(0.045)
Pricing backwardness ω	0.396***	0.593***	0.875	0.277***	0.519***	0.416***
	(0.024)	(0.034)	(1.763)	(0.026)	(0.020)	(0.073)
Inflation expectation ξ^f	0.607***	0.434***	0.127	0.714***	0.476***	0.594***
	(0.021)	(0.023)	(0.418)	(0.025)	(0.014)	(0.060)
Inflation inertia ξ^b	0.393***	0.566***	0.873*	0.286***	0.524***	0.406***
	(0.021)	(0.023)	(0.418)	(0.025)	(0.014)	(0.060)
MC deviation λ	0.010***	0.013***	0.010	0.007***	0.014***	0.010***
	(0.000)	(0.000)	(0.138)	(0.001)	(0.000)	(0.001)
Avg. Price Duration D	2.570***	1.833***	1.145***	3.245***	1.893***	2.553***
	(0.099)	(0.054)	(0.293)	(0.192)	(0.033)	(0.293)

Coefficient restriction $\beta = 1$ for all models, Θ is calibrated as shown in table 2.1. Upper panel shows the GMM estimates of the structural (deep) parameters, HAC-robust SEs in parentheses. Lower panel shows the reduced form coefficients based on the structural parameter estimates. SEs of the reduced form estimates are calculated via error propagation.
Significance: $p < 0.01$ ***, $p < 0.05$ **, $p < 0.1$ *.

Table 2.3.: Non-linear hybrid NKPC, Germany. GDP Deflator (monthly, annualised rate of change), HICP (monthly, annualised rate of change), Log labour income share (monthly, HP-filtered).

period, both structural parameters are estimated to be statistically insignificant, mainly because the associated standard errors increased by orders of magnitude, although $\hat{\theta}$ is very low on its own.

The reduced coefficients show the usual pattern before the crisis. An estimated share of 0.61 of the GDP Deflator changes can be attributed to inflation expectations $\hat{\xi}^f$, and accordingly 0.39 to estimated inflation inertia $\hat{\xi}^b$. This picture flips during the crisis period, estimated shares are now 0.43 and 0.57 for inflation expectations and inertia, respectively. After the WIT remark, estimated inflation expectations are insignificant but estimated inflation inertia increases further to 0.87, suggesting that the HNKPC was completely backward-looking – note that the estimate is only weakly significant. The influence of marginal cost deviations $\hat{\lambda}$ increases in the crisis period, from 0.01 to 0.13, and is insignificant after WIT, again because the implied standard error is so large. Still, the result for the WIT period is that the GDP Deflator measured inflation rate is decoupled from its expectations and the real economy and resembles more of an auto-regressive process. The estimated average duration of domestic goods prices $\hat{D}$ decreases, estimated at 2.6, 1.8 and 1.1 quarters, respectively.

Turning to the HICP inflation rate, we see a similar picture, however now also the estimates for the WIT period are highly statistically significant. Here, estimates of price stickiness $\hat{\theta}$ and pricing backwardness $\hat{\omega}$ show qualitatively the same pattern in the pre-crisis to the crisis periods as for the GDP Deflator, with price stickiness decreasing from 0.7 to 0.47 and increasing again to 0.61 in the WIT period. An explanation may be that disinflationary pressure during the crisis period decreases the price stickiness and stabilising inflation expectations in the WIT increased it again. Pricing backwardness increases from 0.28 to 0.52 and then declines again to 0.42, still substantially higher than its pre-crisis level. This pattern suggests that firms used more rule-of-thumb pricing in the crisis period and that uncertainty is still higher than it was in the pre-crisis period.

Consider now the reduced coefficients. The estimated shares of the HICP inflation rate accounted for by inflation expectations $\hat{\xi}^f$ are 0.71, 0.52 and 0.6, respectively for the three periods. Accordingly, the shares accounted for by inflation inertia $\hat{\xi}^b$ are estimated at 0.29, 0.48 and 0.4, respectively. The pattern of estimated influences of the marginal cost deviations $\hat{\lambda}$ is similar to the estimates using the GDP Deflator, aside from the insignificance of the estimate in the WIT period. The estimates are 0.007, 0.014 and 0.01, respectively. The estimated average duration of consumer prices $\hat{D}$ decreases in the crisis period but increases again after the WIT remark, at 3.2, 1.9 and 2.6 quarters, respectively, i.e. consumer prices are stickier than domestic goods prices.

The HNKPC becomes steeper during the crisis and then flatter again after WIT, however not as flat as before the crisis in the case of HICP. The statistically insignificant coefficients in the WIT period for the GDP Deflator as the inflation measure is due to a strong increase of the standard errors of the structural estimates as compared to the preceding periods. That means that firms face very different pricing environments throughout Germany, some may be able to pass cost developments on to prices very well, others rather poorly. Given that the magnitude of the estimate did not change much after WIT, but the standard error did, we should not necessarily conclude that prices in Germany are no longer influenced by costs but that there is a lot of difference among firms making it hard to identify a clear pattern.

2.4.4. Spain

Consider now the results for Spain (table 2.4). The estimation of the Spanish HNKPC for the WIT period requires an instrument set augmented with an additional lag of the GDP Deflator when using this as the inflation rate measure, and two lags of the unemployment rate when using the HICP. With the standard set of instruments, the F-statistic criterion for valid instruments was not fulfilled, see section 2.4.1.

Dep. var.	GDP Deflator			HICP		
	Pre-Crisis	Crisis	WIT	Pre-Crisis	Crisis	WIT
Price Stickiness θ	0.535*** (0.007)	0.938*** (0.193)	0.542*** (0.004)	0.398*** (0.019)	0.425*** (0.042)	0.650*** (0.035)
Pricing backwardness ω	0.468*** (0.013)	0.255 (0.207)	0.000 (0.014)	0.602*** (0.047)	0.545*** (0.099)	0.275*** (0.053)
Inflation expectation ξ^f	0.534*** (0.010)	0.787*** (0.171)	1.000*** (0.026)	0.398*** (0.030)	0.439*** (0.069)	0.703*** (0.051)
Inflation inertia ξ^b	0.466*** (0.010)	0.213 (0.171)	0.000 (0.026)	0.602*** (0.030)	0.561*** (0.069)	0.297*** (0.051)
MC deviation λ	0.012*** (0.000)	0.000 (0.002)	0.023*** (0.000)	0.016*** (0.001)	0.016*** (0.001)	0.010*** (0.001)
Avg. Price Duration D	2.152*** (0.032)	16.258 (51.108)	2.184*** (0.021)	1.660*** (0.051)	1.741*** (0.128)	2.855*** (0.284)

Coefficient restriction $\beta = 1$ for all models, Θ is calibrated as shown in table 2.1. Upper panel shows the GMM estimates of the structural (deep) parameters, HAC-robust SEs in parentheses. Lower panel shows the reduced form coefficients based on the structural parameter estimates. SEs of the reduced form estimates are calculated via error propagation.
Significance: $p < 0.01$ ***, $p < 0.05$ **, $p < 0.1$ *.

Table 2.4.: Non-linear hybrid NKPC, Spain. GDP Deflator (monthly, annualised rate of change), HICP (monthly, annualised rate of change), Log labour income share (monthly, HP-filtered).

Consider first the GDP Deflator as the inflation measure. The structural estimates of price stickiness $\hat{\theta}$ and $\hat{\omega}$ are peculiar, especially in the crisis and WIT periods. The degrees of price stickiness are estimated at 0.54, 0.94 and 0.54, respectively. An interpretation of the unusually high price stickiness in the crisis period would be that firms anticipated the disinflation and tried to hold on to higher prices for as long as they could to support revenues. Estimated pricing backwardness[16] is only significant in the pre-crisis period, at 0.47.

Interestingly, while in Germany and Austria, insignificant results are mainly driven by large standard errors, the standard error associated with Spain's pricing backwardness in the WIT period is on the level of the pre-crisis period, i.e. here the HNKPC actually seems to degenerate into the purely forward-looking NKPC, as past prices hold no information about how to re-optimise once a firm may do so. Still, for the crisis period the standard error of $\hat{\omega}$ is quite large and suggests that there was no clear pattern for firms whether to use past prices or not.In fact, since pricing backwardness is estimated to be zero in the WIT period with a standard error in the order of magnitude of the pre-crisis estimate, the interpretation has some merit that pricing backwardness was

[16]Since the estimate of pricing backwardness in the WIT period is at the lower parameter boundary, the results for this period are to be taken with a grain of salt .

zero already in the crisis. Still, the estimate of pricing backwardness in this period is at the lower parameter boundary, making the results for the WIT period questionable at best.

Of the reduced form coefficients, only the estimates of inflation expectations $\hat{\xi}^f$ are significant in all periods, at 0.53, 0.79 and 1.0. Estimates for inflation inertia $\hat{\xi}^b$ are only significant in the pre-crisis period at 0.47, the estimate in the crisis period has a large standard error. In the WIT period, the structural estimate of pricing backwardness of zero drives the results. The influence of marginal cost deviations $\hat{\lambda}$ is estimated at 0.012, 0.0 and 0.023, respectively – with the estimate in the crisis period of course insignificant. All estimates have rather low associated standard errors, suggesting that the HNKPC is completely flat in the crisis period, but becomes almost twice as steep in the WIT period as compared to the pre-crisis period. Since prices are no longer backward-looking, marginal cost deviations are passed onto every price, thus steepening the NKPC. Finally, the estimated average domestic goods price durations $\hat{D}$ are 2.2 quarters in both the pre-crisis and the WIT periods, but insignificant in the crisis period due to the large standard error.

Consider now the HICP inflation rate. Here the estimates for price stickiness $\hat{\theta}$ are 0.4, 0.43 and 0.65, respectively for the three periods, i.e. increasing. Estimated pricing backwardness $\hat{\omega}$ is falling however, the values are 0.6, 0.55 and 0.28. These estimates suggest that consumer prices are becoming stickier and and the same time less backward-looking.

Turn to the reduced parameters. Reflecting the development of the structural parameter estimates, the shares of consumer price inflation accounted for by inflation expectations $\hat{\xi}^f$ increase and accordingly the shares accounted for by inflation inertia $\hat{\xi}^b$ decline. The estimates for the three periods are 0.4, 0.44 and 0.7 for inflation expectations, and respectively for inflation inertia 0.6, 0.56 and 0.3.

The influence of marginal cost deviations on consumer prices $\hat{\lambda}$ are estimated at 0.016, 0.016 and 0.01, respectively for the three periods. Estimated average consumer price durations are 1.7, 1.7 and 2.9 quarters. All parameter estimates for the HICP are highly statistically significant.

The results suggest that the crisis and the ECB's monetary policy reaction has an enormous effect on Spain's domestic goods prices, especially the collapse of the backward-looking component and the strong increase in the cost-channel suggest that Spain's domestic goods price inflation dynamics have profoundly changed. A *very* tentative interpretation could be that the crisis had a cathartic effect on the pricing dynamics

Dep. var.	GDP Deflator			HICP		
	Pre-Crisis	Crisis	WIT	Pre-Crisis	Crisis	WIT
Price Stickiness θ	0.624***	0.319***	0.496***	0.640***	0.449***	0.451***
	(0.008)	(0.032)	(0.131)	(0.023)	(0.034)	(0.085)
Pricing backwardness ω	0.374***	0.646***	0.517*	0.366***	0.555***	0.391**
	(0.014)	(0.102)	(0.268)	(0.036)	(0.076)	(0.187)
Inflation expectation ξ^f	0.625***	0.331***	0.490**	0.637***	0.447***	0.536***
	(0.012)	(0.057)	(0.196)	(0.031)	(0.053)	(0.166)
Inflation inertia ξ^b	0.375***	0.669***	0.510**	0.363***	0.553***	0.464**
	(0.012)	(0.057)	(0.196)	(0.031)	(0.053)	(0.166)
MC deviation λ	0.010***	0.019***	0.014***	0.010***	0.016***	0.021***
	(0.000)	(0.004)	(0.000)	(0.001)	(0.001)	(0.000)
Avg. Price Duration D	2.658***	1.469***	1.985***	2.781***	1.816***	1.823***
	(0.060)	(0.069)	(0.517)	(0.178)	(0.112)	(0.283)

Coefficient restriction $\beta = 1$ for all models, Θ is calibrated as shown in table 2.1. Upper panel shows the GMM estimates of the structural (deep) parameters, HAC-robust SEs in parentheses. Lower panel shows the reduced form coefficients based on the structural parameter estimates. SEs of the reduced form estimates are calculated via error propagation.
Significance: $p < 0.01$ ***, $p < 0.05$ **, $p < 0.1$ *.

Table 2.5.: Non-linear hybrid NKPC, France. GDP Deflator (monthly, annualised rate of change), HICP (monthly, annualised rate of change), Log labour income share (monthly, HP-filtered).

in Spain by breaking up old monopolies[17]. On the consumer prices side, we see the magnitudes of the structural estimates and of the expectations/inertia channel flip from the pre-crisis and crisis periods to the WIT period. The HICP based HNKPC in the WIT period resembles the usual estimates in the literature much more than in the periods before.

2.4.5. France

For France (table 2.5) the general results do not differ much between the two inflation measures.

Consider first the GDP Deflator. Here the structural parameter estimates change strongly in the crisis period and do not completely recovere in the WIT period. Price stickiness $\hat{\theta}$ is estimated at 0.62, 0.32 and 0.5, respectively. An explanation may be that disinflationary pressure during the crisis period decreases the price stickiness and stabilising inflation expectations in the WIT increased it again. Pricing backwardness $\hat{\omega}$

[17]This however at the cost of a severe recession, high and persistent (youth) unemployment, a lost decade and the upending of people's lifetime plans.

is estimated at 0.37, 0.65 and 0.52, suggesting that firms rely more on rule-of-thumb pricing during the uncertainty of the crisis period.

The reduced coefficients show accordingly a similar picture. The share of the GDP Deflator inflation rate accounted for by inflation expectations $\hat{\xi}^f$ declines in the crisis from 0.63 to 0.33 and recovers to 0.49 in the WIT period. Accordingly, the shares accounted for by inflation inertia $\hat{\xi}^b$ are estimated at 0.37, 0.67 and 0.51.

The influence of marginal cost deviations $\hat{\lambda}$ is estimated at 0.01, 0.019 and 0.014, i.e. the HNKPC is much steeper in the crisis period at still not as flat in the WIT period as it was before the crisis. Estimated average domestic goods price durations $\hat{D}$ are 2.7, 1.5 and 2.0 quarters, respectively.

Turning to the HICP based estimations, the picture is similar. Structural estimates of price stickiness $\hat{\theta}$ are 0.64, 0.45 and 0.45, respectively and the estimates of pricing backwardness are 0.37, 0.55 and 0.39, respectively.

The reduced coefficients for inflation expectations $\hat{\xi}^f$ and inflation inertia $\hat{\xi}^b$ show the same pattern as with the GDP Deflator, but not as strong. Inflation expectations are estimated to account for shares of 0.64, 0.45 and 0.54 of consumer price inflation, respectively. Accordingly, the estimated shares accounted for by inflation inertia are 0.36, 0.55 and 0.46, respectively. The influence of marginal cost deviations $\hat{\lambda}$ is estimated at 0.01, 0.016 and 0.021, respectively, i.e. the HNKPC is becoming steeper in the crisis period and again in the WIT period. Estimated average consumer price durations $\hat{D}$ are 2.8, 1.8 and 1.8 quarters, respectively.

The estimates for France show that during times of uncertainty, pricing becomes more backward-looking, and thus inflation carries more inertia. Further, we see a pattern reversal with the onset of the crisis and a return to pre-crisis levels after WIT, which can be interpreted as a recovery from the crisis. All estimates are highly statistically significant.

2.4.6. Italy

The results for Italy (table 2.6) differ not much across inflation rate measures, however there is a lot of sharply increased uncertainty in the WIT period when using the GDP Deflator, resulting in many estimates being statistically insignificant. Although they look very much like their counterparts in the HICP based estimations, we cannot interpret them any different than zero.

Consider first the GDP Deflator. Price stickiness $\hat{\theta}$ is estimated at 0.6, 0.49 and 0.73, respectively. Pricing backwardness $\hat{\omega}$ is estimated at 0.39 and 0.51, in the pre-crisis and crisis periods respectively, but due to its large standard error is insignificant in the WIT

Dep. var.	GDP Deflator			HICP		
	Pre-Crisis	Crisis	WIT	Pre-Crisis	Crisis	WIT
Price Stickiness θ	0.600***	0.493***	0.727**	0.535***	0.477***	0.703***
	(0.015)	(0.027)	(0.313)	(0.008)	(0.049)	(0.075)
Pricing backwardness ω	0.389***	0.513***	0.443	0.460***	0.546***	0.364***
	(0.025)	(0.055)	(0.431)	(0.015)	(0.103)	(0.107)
Inflation expectation ξ^f	0.607***	0.490***	0.622*	0.538***	0.466***	0.659***
	(0.021)	(0.041)	(0.330)	(0.012)	(0.073)	(0.090)
Inflation inertia ξ^b	0.393***	0.510***	0.378	0.462***	0.534***	0.341***
	(0.021)	(0.041)	(0.330)	(0.012)	(0.073)	(0.090)
MC deviation λ	0.010***	0.012***	0.004	0.012***	0.012***	0.006**
	(0.000)	(0.000)	(0.006)	(0.000)	(0.000)	(0.002)
Avg. Price Duration D	2.502***	1.972***	3.664	2.151***	1.913***	3.368***
	(0.094)	(0.106)	(4.207)	(0.036)	(0.179)	(0.851)

Coefficient restriction $\beta = 1$ for all models, Θ is calibrated as shown in table 2.1. Upper panel shows the GMM estimates of the structural (deep) parameters, HAC-robust SEs in parentheses. Lower panel shows the reduced form coefficients based on the structural parameter estimates. SEs of the reduced form estimates are calculated via error propagation.
Significance: $p < 0.01$ ***, $p < 0.05$ **, $p < 0.1$ *.

Table 2.6.: Non-linear hybrid NKPC, Italy. GDP Deflator (monthly, annualised rate of change), HICP (monthly, annualised rate of change), Log labour income share (monthly, HP-filtered).

period. Still, it shows the pattern of an increase in the crisis as rising uncertainty made firms rely more on rule-of-thumb pricing than optimal pricing.

The reduced form coefficient estimates are also fully significant only for the pre-crisis and crisis periods. In the WIT period only inflation expectations are weakly significant. The shares of domestic goods price inflation accounted for by inflation expectations $\hat{\xi}^f$ are estimated at 0.61, 0.49 and 0.62, respectively. Accordingly, the shares accounted for by inflation inertia $\hat{\xi}^b$ are estimated at 0.39 and 0.51. The estimate for the WIT period is insignificant. The estimates of influence of marginal cost deviations $\hat{\lambda}$ are 0.01 and 0.012, the third estimate is again insignificant. Lastly, estimated average domestic goods price durations are 1.8 and 1.6 quarters, and the estimate for the WIT period is insignificant. We see a pattern of reversal after the crisis, however given the large standard errors of the structural and reduced parameter estimates in the WIT period, the results should be taken with a grain of salt. It seems that it is rather hard to identify a clear pattern in that period.

Now consider the HICP based estimation. The basic pattern is very similar to the GDP Deflator base estimation, but here also the estimates for the WIT period are significant. The degrees of price stickiness $\hat{\theta}$ are estimated at 0.54, 0.48 and 0.7, respectively.

The estimates for pricing backwardness $\hat{\omega}$ are 0.46, 0.55 and 0.36. We see here the same pattern, that prices become less sticky due to disinflationary pressure and more backward-looking in the uncertainty of the crisis period, and later stabilising in the WIT period.

The reduced parameters also show a similar pattern to the estimates using the GDP Deflator. The shares of consumer price inflation accounted for by inflation expectations $\hat{\xi}^f$ are estimated at 0.54, 0.47 and 0.66, respectively in the three periods. Accordingly, inflation inertia $\hat{\xi}^b$ accounts estimatedly for a share of 0.46, 0.53 and 0.34, respectively, of consumer price inflation. Here again the dominance of backward-looking behaviour in the crisis period is apparent. The influence of marginal costs deviations $\hat{\lambda}$ is estimated at 0.012, 0.012 and 0.006, i.e. the firms were less able to pass cost changes onto consumer prices after the WIT remark, due to the higher price stickiness $\hat{\theta}$ in that period. The estimated average duration of consumer prices are 2.1, 1.9 and 3.4 quarters, respectively.

In Italy, we see a similar picture both qualitatively and quantitatively in the pre-crisis and crisis periods, that prices become more backward-looking and the HNKPC retains its slope in marginal costs developments. An explanation may be that disinflationary pressure during the crisis period decreases the price stickiness and stabilising inflation expectations in the WIT increased it again. However in the WIT period, the HNKPC does not seem to be an appropriate model to describe the movements of domestic goods prices. Still for consumer prices, the HNKPC captures the price movements very well and suggests that Italy's consumer price dynamics have stabilised after the WIT remark.

2.4.7. The Netherlands

Finally, consider The Netherlands (table 2.7). Here the both structural and reduced form estimates are almost identical in the pre-crisis period across both inflation measures. However, for the crisis and the WIT period the results differ markedly.

Start with the GDP Deflator as the inflation measure. Here estimated price stickiness $\hat{\theta}$ decreases in the crisis but more than doubled again in the WIT period. The estimates are 0.46, 0.37 and 0.84, respectively. An explanation may be that disinflationary pressure during the crisis period decreases the price stickiness and stabilising inflation expectations in the WIT increased it again. Estimated pricing backwardness $\hat{\omega}$ decreases in the crisis and then again a little bit in the WIT period, different from e.g. Italy. Estimates are 0.55, 0.4 and 0.36, respectively. Perhaps Dutch firms anticipate future disinflations during the crisis period better than firms in other countries where uncertainty increases the pricing backwardness.

Dep. var.	GDP Deflator			HICP		
	Pre-Crisis	Crisis	WIT	Pre-Crisis	Crisis	WIT
Price Stickiness θ	0.459***	0.373***	0.842***	0.455***	0.684***	0.626***
	(0.007)	(0.026)	(0.175)	(0.005)	(0.030)	(0.040)
Pricing backwardness ω	0.546***	0.404***	0.362*	0.546***	0.245***	0.174***
	(0.016)	(0.068)	(0.208)	(0.012)	(0.044)	(0.064)
Inflation expectation ξ^f	0.456***	0.480***	0.699***	0.455***	0.736***	0.782***
	(0.011)	(0.060)	(0.165)	(0.008)	(0.043)	(0.073)
Inflation inertia ξ^b	0.544***	0.520***	0.301*	0.545***	0.264***	0.218**
	(0.011)	(0.060)	(0.165)	(0.008)	(0.043)	(0.073)
MC deviation λ	0.016***	0.028***	0.002	0.016***	0.009***	0.014***
	(0.000)	(0.001)	(0.004)	(0.000)	(0.001)	(0.002)
Avg. Price Duration D	1.847***	1.594***	6.313	1.835***	3.166***	2.671***
	(0.025)	(0.067)	(6.979)	(0.018)	(0.298)	(0.288)

Coefficient restriction $\beta = 1$ for all models, Θ is calibrated as shown in table 2.1. Upper panel shows the GMM estimates of the structural (deep) parameters, HAC-robust SEs in parentheses. Lower panel shows the reduced form coefficients based on the structural parameter estimates. SEs of the reduced form estimates are calculated via error propagation.
Significance: $p < 0.01$ ***, $p < 0.05$ **, $p < 0.1$ *.

Table 2.7.: Non-linear hybrid NKPC, The Netherlands. GDP Deflator (monthly, annualised rate of change), HICP (monthly, annualised rate of change), Log labour income share (monthly, HP-filtered).

The reduced form coefficient estimates only weakly track the pattern of the structural parameters. The shares of domestic goods price inflation accounted for by inflation expectations $\hat{\xi}^f$ are estimated at 0.46, 0.48 and 0.7. Accordingly, the shares accounted for by inflation inertia $\hat{\xi}^b$ are estimated at 0.54, 0.52 and 0.3, respectively. The influence of marginal cost deviations are significant only in the pre-crisis and crisis periods, estimates at 0.016 and 0.028, i.e. becoming steeper in the crisis period. However, in the WIT period, domestic goods prices and marginal cost developments seem to have decoupled. Note that the insignificance does not come from a large standard error, but from the collapse of the parameter estimate by an order of magnitude. Finally, estimated average domestic goods price durations are 1.8 and 1.6 quarters, in the pre-crisis and crisis periods respectively. The estimate for the WIT period is insignificant, due to the large standard error, i.e. the fit was unable to identify a clear pattern.

Turn now to the HICP based estimations. Here all estimates are significant. First, consider the structural parameters. Price stickiness $\hat{\theta}$ is estimated at 0.46, 0.68 and 0.63, respectively, and pricing backwardness $\hat{\omega}$ is estimated at 0.55, 0.25 and 0.17. We see a strong increase in price stickiness but an even stronger decline in pricing backwardness, that is consumer prices last longer and firms rely more and more on optimal pricing than on rule-of-thumb pricing.

Consider now the reduced parameters. Inflation expectations $\hat{\xi}^f$ account for the following estimated shares of consumer price inflation, 0.45, 0.73 and 0.78, respectively. Accordingly, the shares accounted for by inflation inertia $\hat{\xi}^b$ are estimated at 0.55, 0.26 and 0.22. This reflects the structural estimates well, we see a strong increase in forward-looking and a strong decrease in backward-looking components in the HNKPC. Marginal cost deviation influences $\hat{\lambda}$ are estimated at 0.016, 0.009 and 0.014, we see a recovery from the flattening of the HNKPC in the crisis period. Finally, estimated average durations of consumer prices are estimated at 1.8, 3.2 and 2.7 quarters.

The results suggest that, like in other countries of the sample, domestic goods prices and consumer prices are on rather different dynamics after the crisis.

2.5. Conclusion

This chapter estimated non-linear structural Hybrid New-Keynesian Phillips Curves (HNKPCs) for six large and medium-sized European countries in three distinct periods, the pre-crisis period, the acute crisis and the "Whatever-It-Takes" period started with the ECB's credible commitment to preserve the EEMU. The estimates were obtained using GMM and instrumental variables.

Throughout all estimations, most results are well in line with theory and other results established in the literature. However, exceptions did occur, most notably strong increases in the standard errors with the associated detrimental effects on significance. Further, the estimates revealed a considerable amount of disagreement between estimates using the GDP-Deflator or the HICP as the inflation rate measure, mainly in the crisis and the WIT periods. A reason for this dichotomy could be that (unconventional) monetary policy had very different effects on the domestic prices and the prices as measured by a goods basket. Further, oil prices (see B.3) have been strongly falling in the later part of the sample, and energy price inflation has been low and negative as well (see B.11). Since oil is not a domestically produced good in the countries of the sample, its price developments only show up in the HICP but not in the GDP deflator.

The results highlight that the crisis and the ECB's response had and probably still have a profound impact on European price and inflation dynamics. In fact, more often than not, the results in the final period were markedly different from the pre-crisis period, suggesting a permanent change in the dynamics. The low degree of inflation can be attributed to the disinflationary effects of the crisis and the rather high price stickiness parameter estimates in the WIT period, especially for consumer prices. Still, the HNKPCs show a significant slope in the real marginal costs deviations, i.e. labour costs. Thus, policy measures and/or economic developments that increase wages should also increase inflation, i.e. the basic relationship of the Phillips curve seems to be intact. Such policies, however, are not within the possibilities of the ECB but require action by the governments of the EEMU members.

Further, the study shows that the crisis and the ECB's response affected the countries of the EEMU very differently, highlighting the need for cautious monetary policy on the one hand, and the still low degree of economic convergence on the other hand. However, we do see some (qualitative) similarities, such as the increased reliance on rule-of-thumb-pricing during the crisis observed in Germany, France, and Italy. Still, since each member of the EEMU experienced the effects of the crisis differently, and indeed faces different economic challenges, it is not surprising to see these differences manifested in the estimation results. In order to decrease "frustrations" (Aksoy, de Grauwe, and Dewachter, 2002) and to make monetary policy easier to conduct, governments of the member countries of the EEMU should focus on increasing economic convergence by eliminating national idiosyncrasies. Further, both the similarity of the inflation measures before the crisis and their dissimilarity during and after the crisis, highlight that the ECB needs to have a whole set of price measures under scrutiny in order to gauge the environment for monetary policy correctly, and that no one inflation measure tells the whole story of price developments.

Methodologically, the study of the HNKPC could be accompanied by the estimation of a Dynamic IS curve, capturing the aggregate demand side of the economy. However, this would require imposing further assumptions about the utility function and the relation of marginal costs and production. Further, the analysis of the (hybrid) NKPC of countries in a monetary union like the EEMU may be improved by considering a model that takes into account the high degree of economic interconnectedness. Such a model is developed and simulated in the next chapter.

3. A Two-Country Model of a Monetary Union With Direct Spillover Channels

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"Same-same. But different. But still same."

— *James Franco as Dave Skylark in "The Interview" (2014)*

UNTIL now, theoretical treatments of the macroeconomics of monetary unions (MUs) remain by and large variants of international economics models, where one or several small open economies are influenced by aggregate magnitudes. Then cross-country[1] spillovers are modelled by asymmetric shocks to one country, which influences then the outcomes in the other countries via the shocks' effect on the aggregate magnitudes[2]. This approach is sensible from a modelling point of view, by simplifying the formal presentation and also from an economic point of view, since of course any asymmetric shock influences the other countries via its effect on the aggregates but these spillovers are of an indirect nature.

However, the huge amount of interaction *inside* the MU, from firms' cross-border supply chains to the increased availability of foreign goods from other member countries suggest that the cross-country spillovers are only insufficiently modelled by asymmetric shocks and their influence on and through union-wide aggregates. Instead, I find it more appropriate to see how the countries themselves influence each other directly and

[1] Since this chapter was written with the European Econonomic and Monetary Union (EEMU) in mind – an MU "among nations" (Hamada and Porteous, 1993) – the wording is "countries" as the constituents of the MU. "Regions" would be an equivalent term, applicable e.g. for the US (see chapter 4) or pre-Euro Germany.

[2] A notable exception are the models used by Canzoneri and Gray (1982) and Canzoneri and Henderson (1991), who employ direct spillovers, however not in a micro-founded environment. See also section 1.5, especially section 1.5.5.

how (asymmetric) shocks run through these direct channels. Hence, the basic difference in the line of thought of this chapter as compared to the literature is one of perspective: Not at all is an MU an economic entity of its own that influences its members; instead, the countries themselves are the MU, influencing each other due to the large extent of economic interconnectedness.

The presence of a common monetary policy (CMP) conducted by a supranational common central bank (CCB) does not mean that this set of interconnected economies, all of a sudden transform into a nation-like entity, thus justifying the study of aggregate developments. A common currency merely acts as a device to coordinate monetary policies[3] by replacing the perhaps imperfectly coordinated, national policies by a CMP.

However, it is well known[4] that such CMPs cannot accommodate all members of an MU equally well and the short-run trade-off between unemployment and inflation extends across countries. While this is true even for identical economies, if a single country of the MU is hit by asymmetric shocks, the literature[5] has stressed that countries have all kinds of asymmetries and idiosyncrasies. Since members of an MU are not only connected via a CMP but also via trade and commerce, idiosyncratic events in one country likely have *direct* repercussions on the economies of its fellow members. Moreover, global events that affect all members of an MU in the same way or affect the institutions of the MU, may have very different direct and indirect effects on the single countries, depending on their relative economic exposure to each other, in terms of size, trade volume, rigidity of prices, wages and labour markets or preferences for imports or for leisure over consumption. A CMP reacting to such events affects the economies in different ways, perhaps not only in magnitude but also in direction. These different real developments in turn should have different *direct* repercussions on the other members – a mechanism largely absent from the literature. All these asymmetries, be it due to asymmetric shocks or structural differences, make again the case against studying an MU's aggregates, but instead the countries themselves, as profound movements in the single countries might cancel out in the aggregate.

In the spirit of this perspective, this chapter offers a treatment of the macroeconomics of the members of an MU and, in turn, of the MU as a whole, without losing the view on its constituents: the single, asymmetric countries. To this end, I derive a sticky

[3]See e.g. Alesina, Barro, and Tenreyro (2002), Cooper and Kempf (2003), and Eichengreen (1992; 1993).

[4]As early as Mundell (1961). See also Debrun, Masson, and Pattillo (2005) and Lane (2000). Colourfully, Aksoy, de Grauwe, and Dewachter (2002) use the term "frustration" for regionally suboptimal outcomes of a common monetary policy. See also section 1.5.4.

[5]To name but a few, Benigno (2004) offers a theoretical treatment and Lee (2009) an empirical one. See further sections 3.1 and 1.5.3 for a more detailed view on the literature.

price, forward-looking model of a two-country-MU, following the presentation and notation of the baseline model by Galí (2008) and incorporates features also used by i.a. Beetsma and Jensen (2005), Benigno (2004), and Lombardo (2006). However the result differs from most of the existing contributions by introducing hitherto unexplored, micro-founded, direct spillover channels, via the output gaps.

This chapter is structured as follows: The next section reviews the relevant literature and explains where the analysis of this chapter fits in. In the third section I state the assumptions and structure of the economies and derive the central laws-of-motion. There will be structurally symmetric aggregate supply and aggregate demand curves for each of the two countries as well as an interest rate rule to describe the CMP of the CCB and hence close the model. Next, I analyse the policy parameters space that yields saddlepath-stable behaviour and present simulations of the model's equilibrium dynamics when the MU is hit by a global monetary shock, and by idiosyncratic shocks to, respectively, productivity and inflation of one of the countries. I find that common shocks are easily absorbed by the MU, while idiosyncratic shocks, due to the direct spillovers, lead to heavily oscillating behaviour, making stabilisation by the CCB much harder, a result that obviously has policy implications. The last section concludes.

3.1. Literature Review

The inquiry into the nature of the macroeconomic dynamics of an MU has produced a vast number of contributions. Most of the contributions are variants of international economics models, focussing on member countries whose behaviour is influenced by union-wide aggregate magnitudes, essentially using the rationale of the single member country being like a small open economy and the MU acting like the "rest of the world".

This chapter abandons this prevailing approach by modelling direct and explicit spillover channels, without resorting to union-wide aggregate magnitudes. This allows to track more easily the source and cause for a certain movement, as there is no "black box" of an MU lumping all developments together and as such shrouding the ways the single economies influence each other. Of course, movements in one country do influence the aggregate magnitudes, so the results of previous analyses remain by all means relevant for policy analysis; this chapter however adds more detail in how exactly a single member country influences its fellows, by shedding more light on the asymmetries in the spillover channels. To this end, I model the spillovers directly via the main variables of the model, i.e. inflation rates and output gaps.

The structure of the model follows the baseline sticky-price, forward-looking macroeconomic model as laid out by i.a. Galí (2008), Walsh (2010), and Woodford (2003), thus modelling an MU “from scratch”. Technically and notationally, the model is most closely related to the baseline model by Galí (2008). However, it also incorporates elements that are similarly found in contributions by i.a. Beetsma and Jensen (2005), Benigno (2004), and Lombardo (2006). Further, i.a. since Basse (2014), Bayoumi and Eichengreen (1992), Belke, Beckmann, and Verheyen (2013), and Giannone, Lenza, and Reichlin (2010) and others have shown that there are in fact structural differences and asymmetries among the members of the EEMU, the present model will also allow for such asymmetries.

Benigno (2004) sets up a two-country model and finds that an inflation targeting policy that is close to optimal policy can be established, by giving more weight to the more price rigid country. His modelling approach focuses more on the influences of differences in the terms-of-trade, and makes different assumptions about the savings technology that is available to the agents. Beetsma and Jensen (2005) also develop a model very similar to the one by Benigno (2004), where the equilibrium dynamics feature spillovers via union-wide magnitudes. They use it to study the interaction of fiscal policy makers and the central bank and find that fiscal stabilization and commitment benefits the MU. Also similar is a model by Lombardo (2006) who extends Benigno’s analysis by allowing for a distorted steady state and finds the opposite of Benigno, namely that the more flexible country should have more weight, if the countries are differently competitive. Ferrero (2009) sets up a model similar to mine, however without explicit spillovers and focusses more on the stabilisation via fiscal policy, an aspect not present in my model.

Empirical attempts to model MUs as sticky-price models come from Angeloni and Ehrmann (2007), Brissimis and Skotida (2008), and Lee (2009), who consider the individual countries as sticky-price, forward-looking economies, tied together by a CCB. Angeloni and Ehrmann (2007) estimate a stylised twelve-country model along the lines of the hybrid model by Galí and Gertler (1999), but also featuring spillovers via the nominal and real effective exchange rates, much like the terms-of-trade gap emphasised by Benigno (2004). However, the approaches of Brissimis and Skotida (2008) and Lee (2009) do not consider any spillovers apart from monetary policy.

Another set of contributions is similar from a modelling point of view, but these models were not designed to study MUs but to answer trade-related questions. Clarida, Galí, and Gertler (2002) develop a two-country model with international consumption, sticky prices and international bond markets to study the welfare gains from monetary policy cooperation. Another sticky-price, forward-looking trade model comes from da Silveira (2006) to study fluctuations of the real exchange rate in the small open economy case induced by frictions in the terms of trade. Jang and Okano (2013) study the effects of asymmetric shocks in a model of two trading countries.

3.2. The Model

I consider an MU of two countries, each inhabited by an infinitely lived, utility maximising representative household, which consumes goods from its own country and from the other country. Each country produces a distinct continuum of differentiated goods, which are not perfectly substitutable, this is reflected in the Cobb-Douglas-type consumption function. Labour is assumed to be immobile[6] across countries and the capital stock is fixed. The countries are linked by a common monetary policy, conducted by a CCB that uses the short-term interest rate as its policy instrument. Further, there is a savings technology that allows intertemporal trade in the form of a risk-free one-period bond. The basic structure closely follows chapters 2 and 3 of Galí (2008). More detailed derivations are collected in appendix D.

Notation In the following derivation, countries are indexed by $k = A, B$, where $-k$ denotes the respective other country. Magnitudes may have subscripts denoting country and period and also superscripts denoting origin of a certain good. For example, the magnitude $C^{k}_{-k,t}$ denotes country $-k$'s consumption of country k-made goods in period t and $C^{-k}_{k,t}$ is country k's consumption of goods from country $-k$ in period t. Further, in general lower-case variables denote the natural logarithm of capital-letter variables, e.g. $x_t \equiv \ln(X_t)$.

3.2.1. Household

Each country is inhabited by a representative household that consumes goods from both countries and supplies labour to the country's firms. The household aims to maximise the stream of discounted period utility. Utility is increasing in total consumption $\frac{\partial U_k}{\partial C_{k,t}} > 0$ and falling in hours worked $\frac{\partial U_k}{\partial N_{k,t}} < 0$.

$$E_0 \sum_{t=0}^{\infty} \beta^t U_k(C_{k,t}, N_{k,t}) \tag{3.1}$$

[6]See e.g. Andor (2014), Barslund and Busse (2016), and Beyer and Smets (2015).

where $0 < \beta < 1$ is the discount factor and the same for both countries.

The household consumes a basket of goods from both countries, given by a Cobb-Douglas consumption function:

$$C_{k,t} = {C_{k,t}^{k}}^{\gamma_k} C_{k,t}^{-k(1-\gamma_k)} \tag{3.2}$$

where $C_{k,t}^{k}, C_{k,t}^{-k}$ are Dixit/Stiglitz-type (CES) consumption indices, with $\varepsilon > 1$ as the elasticity of substitution, which is the same for goods from both countries.

$$C_{k,t}^{k} = \left(\int_0^1 C_{k,t}^{k}(i)^{\frac{\varepsilon-1}{\varepsilon}} \, di \right)^{\frac{\varepsilon}{\varepsilon-1}} \qquad C_{k,t}^{-k} = \left(\int_0^1 C_{k,t}^{-k}(i)^{\frac{\varepsilon-1}{\varepsilon}} \, di \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{3.3}$$

Imposing the standard expenditure constraints and intertemporal budget constraint gives the usual consumer problem of finding the optimal combination of consumption and leisure, see appendix D.3. The solution to this problem is the (log-linear) consumption Euler equation:

$$\begin{aligned} \gamma_k c_{k,t}^{k} + (1-\gamma_k) c_{k,t}^{-k} = \mathrm{E}_t \left\{ \gamma_k c_{k,t+1}^{k} + (1-\gamma_k) c_{k,t+1}^{-k} \right\} \\ - \frac{1}{\sigma_k} \left(i_t - \gamma_k \mathrm{E}_t \left\{ \pi_{t+1}^{k} \right\} - (1-\gamma_k) \mathrm{E}_t \left\{ \pi_{t+1}^{-k} \right\} - \rho \right) \end{aligned} \tag{3.4}$$

where i_t denotes the nominal interest rate, ρ the time preference and π_t^k the rate of change for k-good prices. Note that this is conceptually different from the consumer price inflation rate in country k, $\breve{\pi}_{k,t}$, which is a consumption-weighted average of both price rates of change.

Equation (3.4) is the central building-block of the economy's demand side. It states that optimal consumption today is a function of optimal consumption tomorrow and of the real interest rate, i.e. it is the log-linear version of the optimality condition for consumption and saving. Together with the conditions of goods markets clearing, it will later become the output gap dynamics equation.

3.2.2. Output, Costs and Prices

In both countries there is a continuum of country-wise symmetric firms subject to monopolistic competition, indexed i, with the following production functions[7]:

$$Y_t^k(i) = A_{k,t} N_{k,t}(i)^{1-\alpha} \tag{3.5}$$

Production depends only on the country's own technology and labour as assumed at the beginning of this section. Capital is assumed to be constant and normalised to unity.

Staggered price setting as suggested by Calvo (1983) and monopolistic competition implies the usual relationship between prices[8], price expectations and real marginal costs deviations[9]:

$$\pi_t^k = \beta \mathrm{E}_t \left\{ \pi_{t+1}^k \right\} + \lambda_k \tilde{mc}_t^k \tag{3.6}$$

where

$$\lambda_k \equiv \Theta \frac{(1-\beta\theta_k)(1-\theta_k)}{\theta_k} \qquad \text{and} \qquad \Theta \equiv \frac{1-\alpha}{1-\alpha+\alpha\varepsilon}.$$

Since goods are only produced with domestic labour, this relationship is conceptually the same as the one for the closed economy, as shown in Galí (2008: 46-47). Thus, the deviation of real marginal costs from their steady state value can be obtained (see appendix D.6) similar to the closed-economy model. However, since the goods are consumed in *both* countries, the market clearing condition (see appendix D.5) contains the whole MU and in turn, unlike in the closed economy setting, marginal cost deviations can be related to both countries' output gaps.

$$\tilde{mc}_t^k = \left(\sigma_k \gamma_k + \frac{\varphi_k + \alpha}{1-\alpha} \right) \tilde{y}_t^k + \sigma_k (1-\gamma_k) \tilde{y}_t^{-k}. \tag{3.7}$$

Here $\tilde{y}_t^k \equiv y_t^k - y_t^{n,k}$ and $\tilde{y}_t^{-k} \equiv y_t^{-k} - y_t^{n,-k}$ denote the *output gaps*, the deviation of actual output from its natural level in both countries.

[7]The super script k in $Y_t^k(i)$ denotes that the firm produces a "k-good". By definition, this firm is located in country k.

[8]Like in (3.4), the magnitudes π_t^k and $\mathrm{E}_t \left\{ \pi_t^k \right\}$ denote the (expected) rate of change of k-made goods and not the consumer price inflation rate.

[9]I reserve the notation of $\hat{z}$ for estimated magnitudes, here of a general variable z. To denote deviations from a "natural" value or a steady-state value, I use the notation $\tilde{z}$. Thus the real marginal costs deviations from their steady-state value are denoted $\tilde{mc}$, much like the output gap, i.e. the deviation of observed from natural output is denoted by $\tilde{y}$. This is a bit different from the notation Galí (2008) uses, however I find it both more stringent and less prone to confusion.

This natural output level, i.e. the output level if prices were fully flexible, can be shown to be a positive function of technology and a negative function of the opposite country's production technology:

$$y_t^{n,k} = \frac{\psi_k}{1-\chi_k\chi_{-k}} a_{k,t} - \frac{\psi_{-k}\chi_k}{1-\chi_k\chi_{-k}} a_{-k,t} - \frac{\chi_k\vartheta_{-k} - \vartheta_k}{1-\chi_k\chi_{-k}} \tag{3.8}$$

where parameters $\psi_k, \chi_k, \vartheta_k$ consist of exogenous parameters (see appendix D.7). The negative sign with which the opposite country's technology enters the equation can be interpreted as a crowding-out effect: Higher productivity of the opposite country's firms enables them to serve a greater share of overall demand, thus lowering k-firms' natural output.

Using (3.7) in (3.6) yields a forward-looking law of motion for the price dynamics of k-goods:

$$\pi_t^k = \beta \mathrm{E}_t \left\{\pi_{t+1}^k\right\} + \lambda_k \left[\left(\sigma_k\gamma_k + \frac{\varphi_k + \alpha}{1-\alpha}\right)\tilde{y}_t^k + \sigma_k(1-\gamma_k)\tilde{y}_t^{-k}\right] \tag{3.9}$$

The evolution of k-good prices depends on the expected prices of k-goods and on positive influences of both countries' output gaps. For a discussion of the coefficients see the derivation of the inflation dynamics in the next subsection.

3.2.3. The Laws-Of-Motion

Inflation Dynamics Given the Cobb-Douglas structure of consumption, country k's consumer price inflation rate is the consumption elasticity-weighed average of the price dynamics of both countries[10]:

$$\breve{\pi}_{k,t} = \gamma_k\pi_t^k + (1-\gamma_k)\pi_t^{-k} \tag{3.10}$$

Equation (3.10) has the straight-forward interpretation that country k's consumer price inflation rate $\breve{\pi}_{k,t}$ is a positive function of the respective price evolutions for k- and $-k$-goods, π_t^k and π_t^{-k}.

Using (3.9) for both k- and $-k$-goods in (3.10) and collecting terms yields the consumer price inflation rate as a function of the expected consumer price inflation rate and the output gaps:

$$\breve{\pi}_{k,t} = \beta \mathrm{E}_t \left\{\breve{\pi}_{k,t+1}\right\} + \kappa_k\tilde{y}_t^k + \eta_k\tilde{y}_t^{-k} \tag{3.11}$$

[10] See appendix D.4 for the derivation.

where κ_k, η_k are the slopes in the country's own and in the opposite country's output gap defined as

$$\kappa_k \equiv \gamma_k \lambda_k \left(\sigma_k \gamma_k + \frac{\varphi_k + \alpha}{1-\alpha} \right) + (1-\gamma_k)\lambda_{-k}\sigma_{-k}(1-\gamma_{-k})$$
$$\eta_k \equiv (1-\gamma_k)\lambda_{-k} \left(\sigma_{-k} \gamma_{-k} + \frac{\varphi_{-k} + \alpha}{1-\alpha} \right) + \gamma_k \lambda_k \sigma_k (1-\gamma_k)$$

Equation (3.11) is called the MU-NKPC and describes the behaviour of aggregate supply near the steady state. While it has the notion of a positive relationship between the inflation rate and the output gap, as usual in sticky-price, forward-looking monetary models, this relationship is also there for the output gap of the opposite country. Additional demand in the other country, via the direct link between production and consumption, will exert additional upward pressure on consumer prices. This effect comes from a higher demand for both countries' goods, whose price developments enter consumer prices according to the preference parameter γ_k. Hence, unlike other forward-looking, sticky-price aggregate supply curves, (3.11) has explicit spillover effects and does not relate price developments to a union-wide aggregate. It is worth emphasising that via the use of the consumer price inflation rate, price developments in the opposite country are very much present in (3.11)[11].

Recall that λ_k collects terms of the degree of price stickiness θ_k and the discount factor β as a measure of consumers' impatience and falls with rising θ_k and β. Regarding the slope κ_k then, via λ_k, the higher the degree of price stickiness and the discount factor is, the weaker is the output gap's influence on today's consumer price inflation rate. The interpretation is straight-forward and analogous to the closed economy setting: a higher degree of price stickiness dampens the price adjustments due to changes in the production, in turn dampening inflation. As a corollary, higher price stickiness also slows the economy's return to equilibrium after a shock. Further, κ_k depends positively on the consumer's dislike for labour φ_k and the elasticity of labour in production α. The stronger the consumer likes consumption (higher σ_k) and/or dislikes labour (higher φ_k), the higher are real marginal costs via the real wage, which results from the solution[12] to

[11]In fact, using a consumption basket-like structure as in equation (3.10) resembles closely the structure in the EEMU. Here the European Central Bank (ECB) also uses the Harmonised Index of Consumer Pricess (HICPs) of the member countries that by their very definition include imports from other EEMU members. The ECB's preferred measure for the inflation rate is a consumption share-weighted average of the countries' HICP, but not an aggregate inflation rate that treats the whole EEMU as an integrated economy, as would be suggested by conventional treatments of MU economics. See also `https://www.ecb.europa.eu/stats/prices/hicp/html/index.en.html`

[12]See equation (D.6) in the appendix.

the consumer's problem of balancing consumption and leisure at the margin. A higher[13] degree of diminishing returns to labour in the production function, $1-\alpha$, increases real marginal costs as well, due to its dampening influence on the marginal product of labour. The effect of the consumption elasticity of domestic goods γ_k is ambiguous, however for the baseline calibration (see table 3.1) the effect is positive. Via the trade connection between the countries, a similar interpretation holds for the parameters of the opposite country, i.e. for the preference of k-goods in country $-k$, denoted by $1-\gamma_{-k}$, the price stickiness and discount parameter λ_{-k} and the preference for consumption σ_{-k}. Further, the interpretation for the slope in the opposite country's output gap η_k is of course analogous.

Output Gap Dynamics Consider the log-linearised consumption Euler equation (3.4) together with goods market clearing (D.14). Add $\gamma_k \mathrm{E}_t \left\{\Delta y_{t+1}^{n,k}\right\} + (1-\gamma_k)\mathrm{E}_t \left\{\Delta y_{t+1}^{n,-k}\right\}$ to arrive at the output gap dynamics, describing the behaviour of aggregate demand around the steady state:

$$\tilde{y}_t^k = \mathrm{E}_t \left\{\tilde{y}_{t+1}^k\right\} - \Gamma_k \tilde{y}_t^{-k} + \Gamma_k \mathrm{E}_t \left\{\tilde{y}_{t+1}^{-k}\right\} - \frac{1}{\sigma_k \gamma_k}\left(i_t - \mathrm{E}_t \left\{\breve{\pi}_{k,t+1}\right\} - r_t^{n,k}\right) \qquad (3.12)$$

where $r_t^{n,k} \equiv \rho + \sigma_k \gamma_k \mathrm{E}_t \left\{\Delta y_{t+1}^{n,k}\right\} + \sigma_k (1-\gamma_k)\mathrm{E}_t \left\{\Delta y_{t+1}^{n,-k}\right\}$ is the natural real interest rate and $\Gamma_k \equiv \frac{1-\gamma_k}{\gamma_k}$.

Like in traditional sticky price, forward-looking models, the output gap is largely driven by expectations of the output gap in the next period and the real interest rate, but also positively by the expected change in the output gap of the opposite country. The expectation of higher production, income and consumption tomorrow, increases these magnitudes already today.

Monetary Policy Rules Equations (3.11) and (3.12) pin down the movements of the consumer price inflation rate and the output gap in both countries, depending only[14] on the path of the nominal interest rate i_t. In other words, since the movements of the real

[13] Recall that in equation (3.5), the elasticity of labour is $1-\alpha$, i.e. the parameter α governs the complement degree of diminishing returns. The higher α, the lower is the marginal product of labour.

[14] There are additionally the Total Factor Productivitys (TFPs) as an exogenous variable. As usual in this type of models, the path of the TFP is assumed to follow an AR-process and is not chosen by some institution or affected by the movements of the endogenous variables. See section 3.3.3 for the consequences of an unanticipated movement in the productivity. Put differently, the TFPs (and hence natural interest rates and natural output levels) are state variables and the nominal interest rate is a control variable.

variables are affected by the choice of the nominal interest rate, monetary policy is not neutral and the model dynamics depend on the CCB's choice of an interest rate rule.

There are numerous variants of monetary policy rules to close a model where the movement of the nominal interest rate matters[15]. One class of the most widely used simple[16] rules are the Taylor Rules[17] relating the development of the nominal interest rate to the contemporaneous inflation rate and output gap in a positive way, i.e. raising the nominal interest rate when either or both the inflation rate or the output gap are above target (here zero), thus tightening monetary policy to cool the economy. While Taylor considered only a closed economy version of the interest rate rule, the rules below depend on the inflation rate and output gap of both countries. I consider a Taylor-like rule where the weights[18] of the countries in the CMP may be different:

$$i_t = \rho + \phi_\pi(\omega\breve{\pi}_{k,t} + (1-\omega)\breve{\pi}_{-k,t}) + \phi_y(\omega\tilde{y}_t^k + (1-\omega)\tilde{y}_t^{-k}) + \nu_t \tag{3.13}$$

where ω denotes the weight[19] of country k in the decision making process.

Moreover, the rule has an additive term ν_t, representing an interest rate shock, i.e. an unsystematic, unanticipated development of the nominal interest rate. Since the consumers in both countries know the interest rate rule of the CCB, they can perfectly anticipate the rational nominal interest rate response to inflation rates and output gaps. Such rule-governed responses are called systematic monetary policy. The consumers cannot, however, anticipate any deviations of the CCB from this rule, i.e. unsystematic monetary policy. Such unsystematic, ad-hoc interest rate movements could be either mistakes by the CCB or over-zealous reaction to inflation or any other behaviour that cannot be explained by the rule. Another interpretation would be that the CCB is unable to control the nominal interest rate perfectly, then ν_t is an exogenous shock to nominal lending conditions that does not originate from the CCB[20].

[15] See Galí (2008), chapter 4 for an overview.

[16] "Simple" means that the rule may be suboptimal but is implementable, since it only depends on measurable magnitudes, as contrasted to "Optimal Rules" that usually depend on unobservable magnitudes like the natural rate of interest.

[17] After the empirical specification used by Taylor (1993). This specification was also simultaneously proposed by Henderson and McKibbin (1993).

[18] An alternative interpretation would be the voting powers the CCB assigns to the countries.

[19] This is a generalised weight and can be interpreted as e.g. voting power, economic size, population, political clout, etc.

[20] Such shocks may include new lending/borrowing technology ("fintech") or changes due to other global events such as geopolitical tensions.

3.2.4. Discussion

The model outlined above describes the economic dynamics of a two-country MU in a way consistent with the idea that conventional MU-models that only look at aggregate magnitudes, do not fully capture the dynamics inside the MU. Since models of the conventional sort are abundant in the literature and I would like to keep the exposition of an MU's inner dynamics as tractable as possible, I restrict the formal analysis to idiosyncratic spillovers and abstract from economic interaction via the aggregates. The model is by no means a replacement for the existing analyses but a complement.

Further, again for the sake of tractability, I restrict the analysis to a two-country setting. Obvious extensions of the model include the addition of a third country to analyse cross-spillovers and secondary spillovers. From an econometric point-of-view, an n-country version would be desirable, to estimate the model for all 19 members of the EEMU. Both extensions are left for future research, see also section 5.2.

3.3. Monetary Policy and Stability

This section presents the reaction of the model to a global and common shock in monetary policy, and to idiosyncratic shocks in the technology level (total factor productivity) and the inflation rate of one of the countries. The model will be calibrated to feature one parameter difference at a time, to see how any single heterogeneity affects the path of the economy as compared to a baseline calibration. For the sake of brevity, the analysis is restrained[21] to variations in the price rigidities (Calvo parameters θ_k) and the relative weight of the countries ω. Hence all other parameters will be set equal for the purpose of this analysis, formally assume $\gamma_k = \gamma_{-k} = \gamma, s_k = s_{-k} = s, \sigma_k = \sigma_{-k} = \sigma, \varphi_k = \varphi_{-k} = \varphi$.

Backward Looking Behaviour As Fuhrer (1997), Galí and Gertler (1999), and Galí, Gertler, and López-Salido (2001) and numerous others have shown, inflation and output dynamics are empirically not completely forward looking. Instead agents show varying amounts of backward-looking behaviour when determining the inflation and output expectations. To this end, I amend[22] the model by introducing lags, similar to the proposition of Clarida, Galí, and Gertler (1999) and Galí and Gertler (1999). Note that the introduction of lags here is ad-hoc, but having lags is firmly rooted in theory (rule-of-thumb-pricing, adaptive expectations, etc.) and econometric practice. Let

[21] Further analysis can easily be conducted by using the provided Dynare code.

[22] A fully-fledged micro-foundation of the lags is desirable and – for the sake of brevity – left for future research.

$\xi, \zeta > 0$ denote[23] the relative strength of backward-looking behaviour as compared to the forward-looking behaviour. Then the laws of motion of the MU can be represented by the following equations:

$$\breve{\pi}_{k,t} = \xi \breve{\pi}_{k,t-1} + \beta \mathrm{E}_t \left\{ \breve{\pi}_{k,t+1} \right\} + \kappa_k \tilde{y}_t^k + \eta_k \tilde{y}_t^{-k} + u_t \tag{3.14}$$

$$\begin{aligned} \tilde{y}_t^k = \zeta \tilde{y}_{t-1}^k + \mathrm{E}_t \left\{ \tilde{y}_{t+1}^k \right\} - \Gamma_k \tilde{y}_t^{-k} + \Gamma_k \mathrm{E}_t \left\{ \tilde{y}_{t+1}^{-k} \right\} \\ - \frac{1}{\sigma_k \gamma_k} \left(i_t - \mathrm{E}_t \left\{ \breve{\pi}_{k,t+1} \right\} - r_t^{n,k} \right) \end{aligned} \tag{3.15}$$

The original model can be recovered by setting the parameters $\xi = \zeta = 0$.

3.3.1. Baseline Calibration

First consider a baseline calibration, against which the later variations in the parameters can be compared. The baseline calibration is given by the parametrisation[24] (following Galí, 2008) given in table 3.1. The baseline calibration considers a symmetric MU where both countries have the same price rigidities and size. All parameters are calibrated such that the model's periods are quarters.

Parameter	Value	Parameter	Value
α	0.333	β	0.99
ε	6	γ	0.6
θ_A	0.667	θ_B	0.667
σ	2	φ	2
s	0.3	ξ	0.6
ζ	0.6	ω	0.5
ϕ_π	1.9	ϕ_y	0.125

Table 3.1.: Baseline parameter calibration

[23] I assume that the strength of the backward-looking behaviour is identical across the countries. The provided source code has two of each parameters, to allow for heterogeneities, which will not be discussed in the paper.

[24] With these numbers, the shortcuts take on the following values: $\rho = 0.0101$, $\mu = -0.1823$, $\Theta = 0.25$, $\Gamma = 0.6667$, $\kappa_A = 0.1335$, $\kappa_B = 0.1335$, $\lambda_A = 0.0425$, $\lambda_B = 0.0425$, $\eta_A = 0.0799$, $\eta_B = 0.0799$, $\psi = 0.9575$, $\chi = 0.1702$, $\vartheta = 0.1053$, $K = -0.3127$.

Policy Space Under the baseline calibration above, figure 3.1 shows the policy parameters ϕ_π, ϕ_y that give saddlepath-stable behaviour[25]. It shows that monetary policy by the CCB must adhere to the Taylor principle of aggressive reaction to inflation deviations from the steady state, i.e. increasing the nominal interest rate more than one-for-one to a rise in the (average) inflation rate. Interestingly, the CCB must not react too strongly to deviations in the (average) output gap in order to keep the inflation reaction rather low. This can be interpreted as an inherent aversion to output stabilisation, since the dynamics of the MU become unstable if the CCB cares too much about output without taking a very aggressive stance on inflation at the same time. This peculiar feature of the CCB reaction is due to the output spillovers that introduce a negative contemporaneous and a positive forward-looking element into the output dynamics and thus also into the inflation rate dynamics. Trying to stabilise both contemporaneous and expected output in both countries is not possible for two reasons, a lack of policy instruments and the simple contemporaneous structure of the interest rate rule. However, the CCB might try to employ a more elaborate interest rate rule, e.g. with interest rate inertia or forward-looking commitment, or a rule that reacts to changes in the output gap to aim at deviation stabilisation. These possible alternative specifications[26] of monetary policy are beyond the scope of this chapter and left to future research.

[25]The graphic is created by running the model for different combination of the policy parameters in a nested loop. Dynare reports whether the Blanchard/Kahn conditions (Blanchard and Kahn, 1980, proposition 1) are satisfied, i.e. whether exactly one steady state exists. If they are, the associated combination of the policy parameters is stored, else they are discarded. The resolution is 0.05 in both parameters, meaning that every loop, one of the parameters is increased by 0.05. The the ranges of $1.5 \leq \phi_\pi \leq 4$ and $0 \leq \phi_y \leq 1.8$ are chosen after experimenting with the model.

[26]While elaborate rules may be "better" from a theoretical point of view, they are also harder to implement and – more importantly – harder to explain to the general public, thus possibly weakening the CCB's credibility.

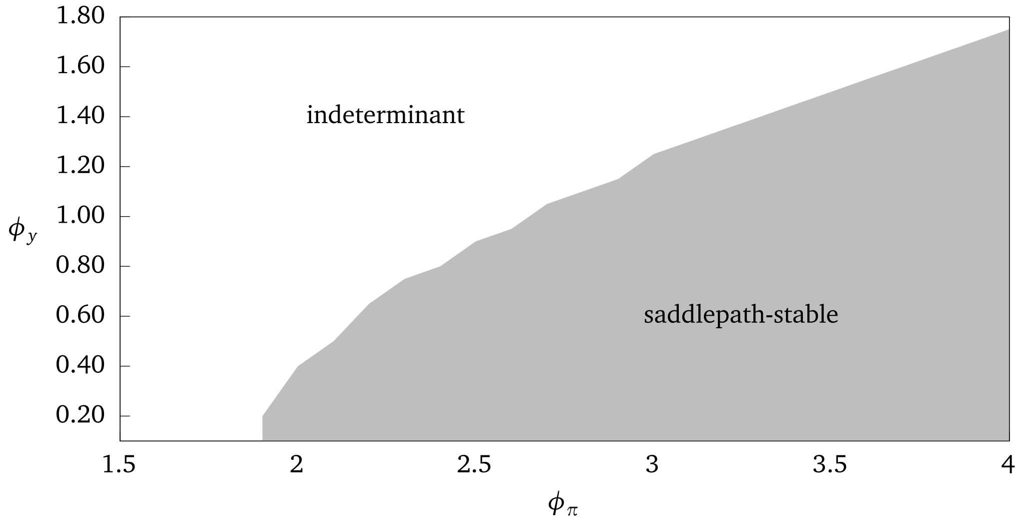

Figure 3.1.: Estimated policy space under baseline calibration. Gray area denotes saddlepath-stable behaviour. Resolution is 0.05 in both parameters.

3.3.2. Monetary Policy Shock

Assume that there is a common monetary policy shock ν_t that follows an AR(1) process:

$$\nu_t = \rho_\nu \nu_{t-1} + \varepsilon_t^\nu, \qquad \text{with: } \rho_\nu \in [0; 1) \text{ and } \varepsilon_t^\nu \text{ is white noise} \tag{3.16}$$

We can interpret this shock as unsystematic monetary policy, e.g. policy makers deliberately stray from the interest rate rule, say for stabilisation purposes. Since then part of monetary policy is not guided by a rule but by personal judgement of the policy makers, this latter part is unsystematic and unexpected. Another interpretation is that the nominal interest rate is only partly controlled by the CCB and the shock accounts for changes in the global lending environment.

A simulation of the model in the baseline calibration with Dynare (Adjemian et al., 2011) shows the reaction to a contractionary monetary policy shock of 25 basis points. The Impulse-Response-Functions (IRFs) are shown in figure 3.2.

The contractionary monetary policy shock increases the nominal interest rate, however not one to one, since the central bank also reacts to lower output and inflation, putting downward pressure on the nominal interest rate. The persistence makes the output gap react only very little in the quarter of the shock. A similar argument holds for the inflation rates, that stay negative throughout and almost identical in the quarter of the shock and one after. This prompts the CCB to not only correct the shock but also stimulate the economy in the second quarter by lowering the interest rates below its steady state value. Output gaps become immediately positive but due to persistence they reach peak only in the third quarter, the same is true for employment. Since the natural levels of output are not affected by monetary policy, actual output levels must fall by the same amount as the output gaps.

Different Price Rigidities Consider next an MU where the countries have different price rigidities as reflected by the Calvo parameters. Set $\theta_A = 1/2$, while the price rigidity of B remains at $\theta_B = 2/3$, which means[27] an average price duration of 2 quarters in A and 3 quarters in B, meaning that country A is less price rigid than country B. Figure 3.3 shows the IRFs.

Qualitatively, the results are as in the symmetric baseline case above. However, A's less rigid prices result in both a stronger reaction to the initial shock via the stronger reaction of the inflation rate, and in smaller responses to the CCB's rebound.

[27] The probability that any given firm may reset its price after n periods is geometrically distributed with parameter $1-\theta_k$, $k = A, B$. The expected value is $D = \frac{1}{1-\theta_k}$ periods. See appendix D.2.

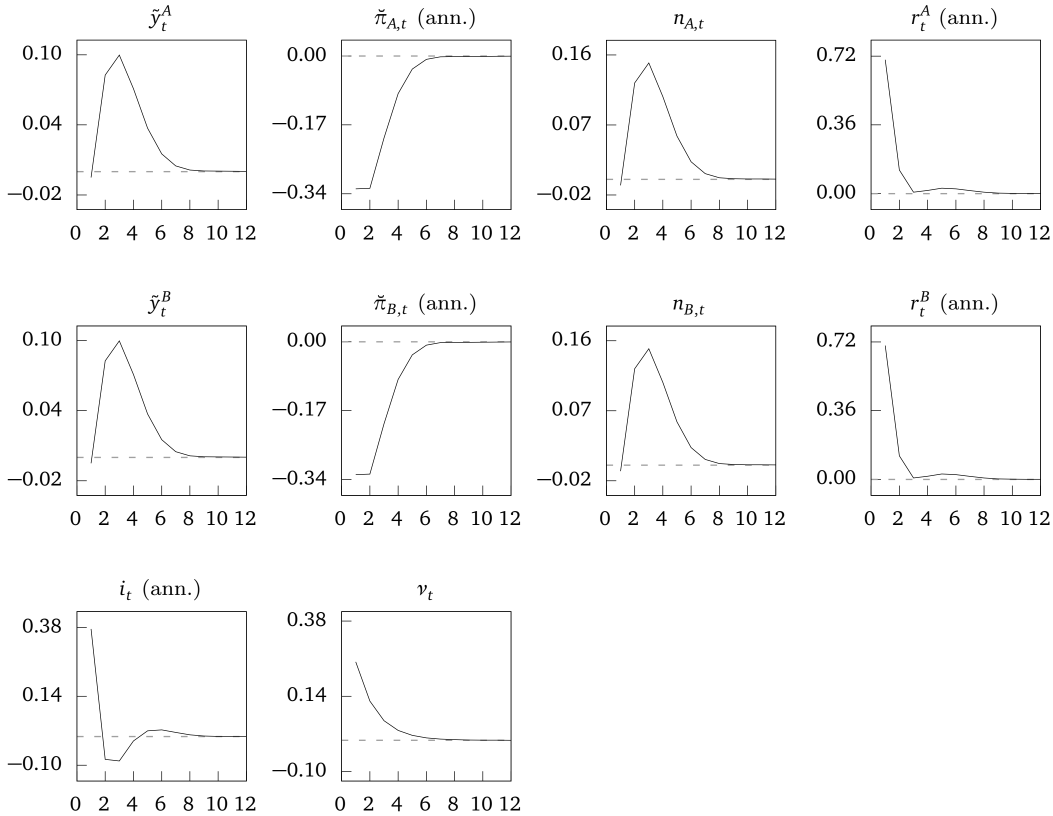

Figure 3.2.: IRFs of selected variables, following a contractionary monetary policy shock of 25 basis points, with persistence of $\rho_\nu = 0.5$.

Different Sizes Next consider a specification where one country has a larger weight than the other ($\omega = 0.6$). The price rigidities remain[28] at $\theta_A = 1/2$ and $\theta_B = 2/3$. The IRFs hardly differ from an MU of countries with equal weights[29], for this reason I skip their presentation. It seems that different weights is not a problematic asymmetry in the presence of a global monetary policy shock.

[28]For the weights to have an effect on the monetary policy decision of the CCB, there must be at least one asymmetry between the countries.

[29]I tested this also for for very extreme values (≥ 0.9) of ω, without much different results

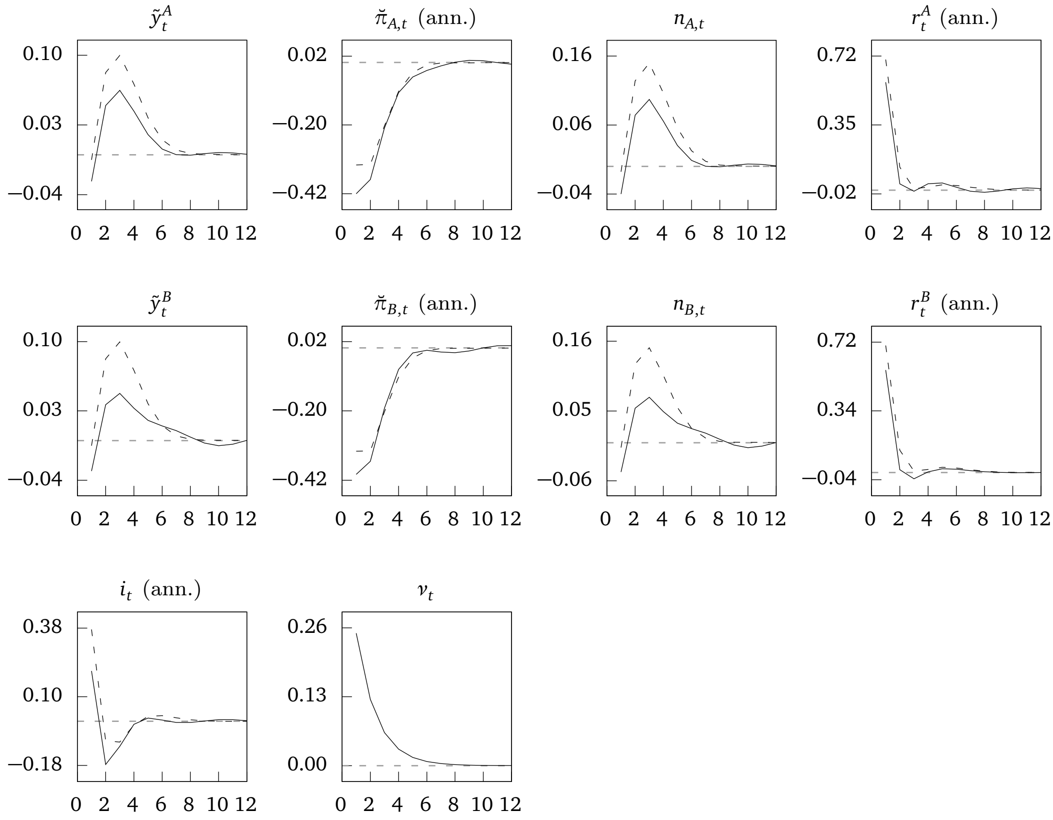

Figure 3.3.: IRFs of selected variables, following a contractionary monetary policy shock of 25 basis points. $\theta_A = 1/2, \theta_B = 2/3$. Dashed lines are the IRFs under the baseline specification.

3.3.3. Productivity Shock

Consider further the reactions to a shock to TFP, more precisely an idiosyncratic shock to the TFP of country A. Assume that the development of $a_{A,t}$ follows an AR(1) process:

$$a_{A,t} = \rho_{a,A} a_{A,t-1} + \varepsilon_t^{a,A}, \qquad \text{with: } \rho_{a,A} \in [0;1) \text{ and } \varepsilon_t^{a,A} \text{ is white noise} \tag{3.17}$$

For the present analysis, assume a very persistent shock of $\rho_{a,A} = 0.75$.

Baseline Calibration For a general idea of the effects of an idiosyncratic productivity shock consider again the model in its baseline calibration as given by table 3.1. Figure 3.4 shows the model's reaction under baseline calibration.

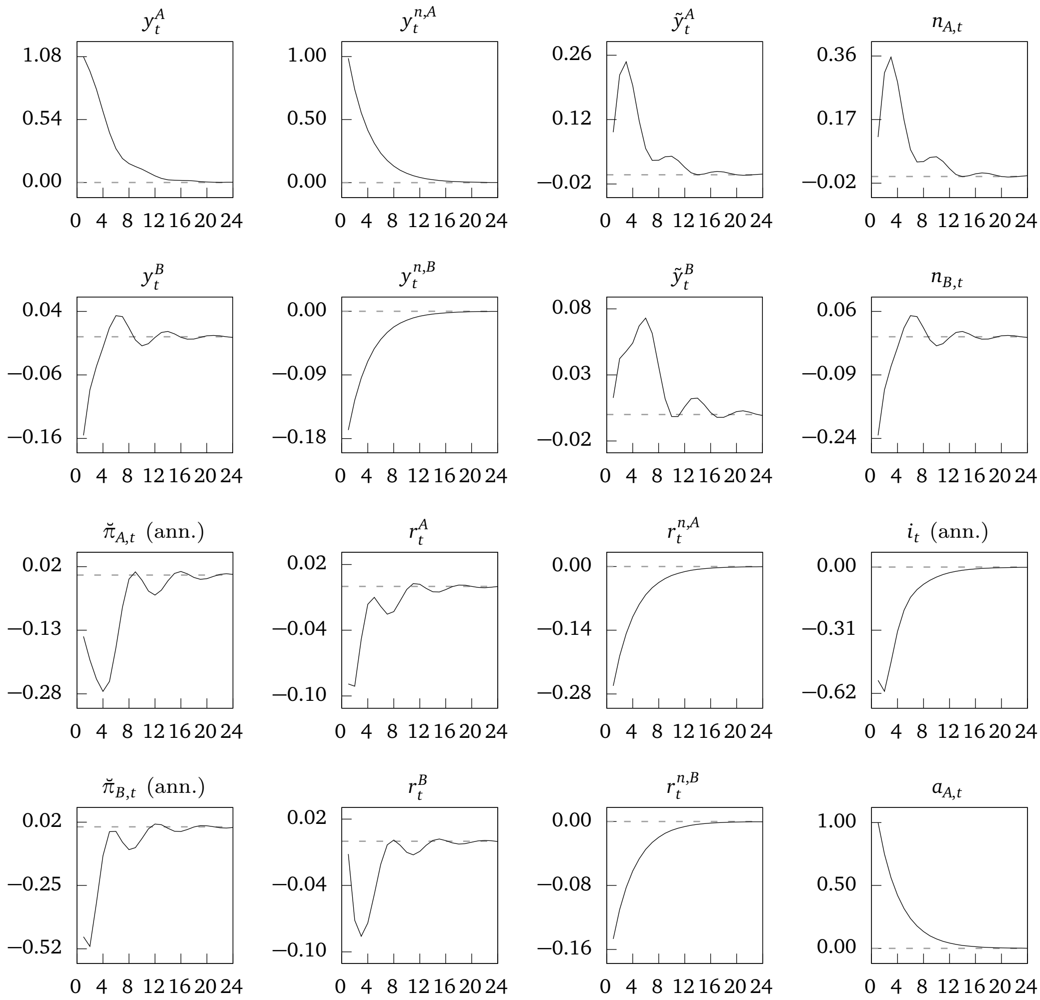

Figure 3.4.: IRFs of selected variables, following an idiosyncratic productivity shock to country *A*.

Although the shock is idiosyncratic, its effects are not. The effect of a productivity shock enters the system via its influence on the natural level of output. Natural output rises in country *A* and falls in *B*, still the increase in *A* is not enough to offset the dampening effect of falling natural output in *B* on the natural interest rates, hence both fall, but *A*'s natural interest rate falls more. This is due to the definition of the natural interest rates as the weighted sum of expected change in the natural level of output.

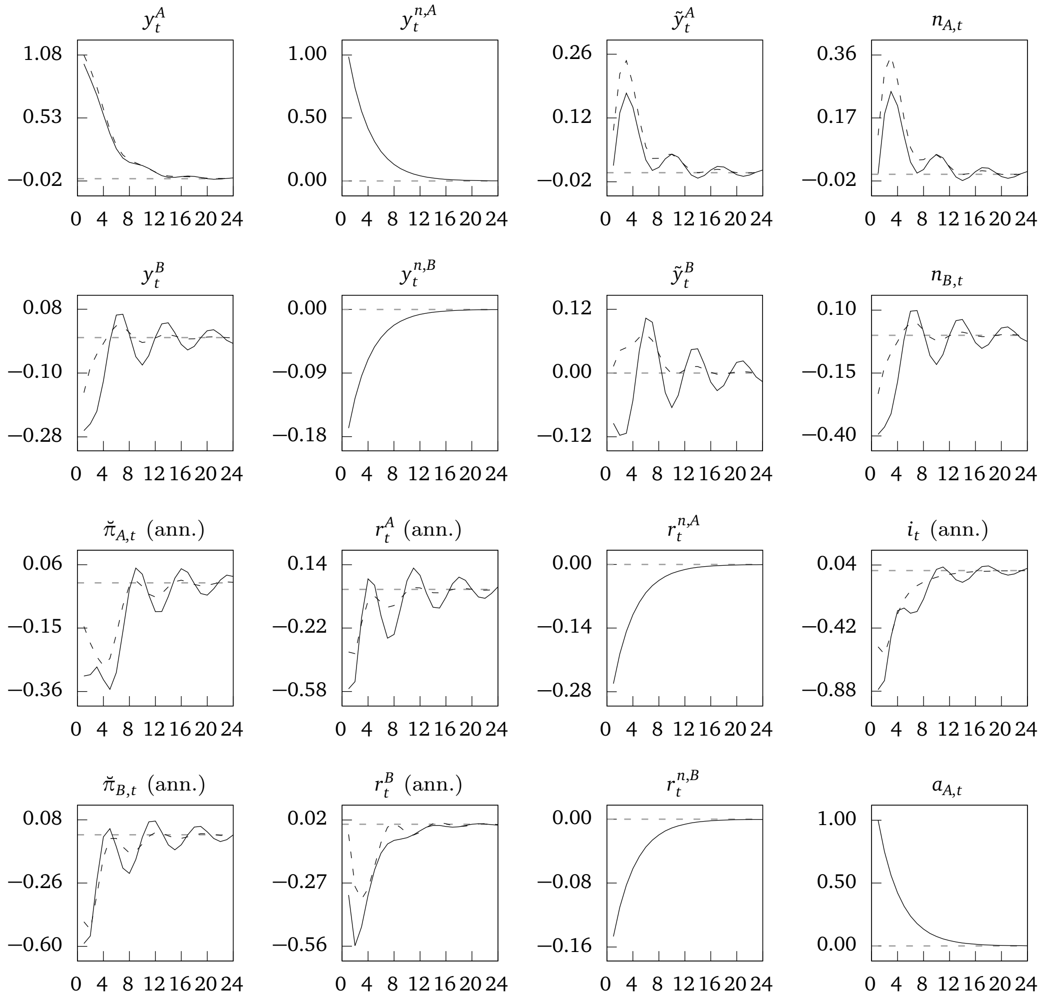

Figure 3.5.: IRFs of selected variables, following an idiosyncratic productivity shock to country A. Country A is less price rigid than B with $\theta_A = 1/2,\ \theta_B = 2/3$. Dashed lines are the IRFs under the baseline specification. The natural interest rate and natural output IRFs do not differ from the baseline calibration.

Since the consumers and firms know that the productivity increase in A is only temporary and fading, the initial rise (fall) a subsequent decline (recovery) to the steady state level of natural output in A (B), the rationally expected change in A is negative and in B positive. Given the sizes of the initial responses and knowing that the absolute magnitude of B's natural output reaction to the shock is only $\chi = 0.17021$ the magnitude of A's natural output reaction, it is clear that the absolute expected change in A's natural output is larger than the absolute expected change in B's natural output, hence the reaction of both natural interest rates must be negative[30].

The natural rates of output react with different signs to the productivity shock, while it rises strongly in A, it falls a little in B. By the same account, actual output rises in A and falls in B. An explanation would be that it is not only country A's more productive industry that just produces more due to better and increasing usage of the input factor labour, but also A's industry crowds out production in B. Still the output gap is positive in both countries, however in B this is only due to actual output falling less than natural output. Also, the output gap reaction in A is much larger than in B. Employment tracks the changes in actual output, albeit with a lag and not one-to-one in A, which is due to the more efficient production. Still, more employment is needed in A to make up for the production shortfall in B.

Inflation rates are negative partly because the upward pressure due to positive output gaps is mitigated and partly because they are expected to be negative tomorrow. Both effects are due to the persistence. It takes four quarters after the initial shock for A's inflation rate to begin to react to the positive output gaps, which is in A already closing again. In B, the delay is two quarters. Although both output gaps are positive, the declines in the inflation rate lets the CCB react with a lower nominal interest rate. This monetary stimulus also exerts upward pressure by widening the output gaps.

Different Price Rigidities Change now the calibration of the model to have again different price rigidities. Like above, set $\theta_A = 1/2$ and $\theta_B = 2/3$ to make country A less price rigid than country B. The effects of a positive productivity shock are shown in figure 3.5. Since A is more price flexible, the reactions of the output gap and employment are not as strong, follow however the same pattern as under the baseline calibration. On the other hand, of course, A's inflation rate fluctuates more due to the higher price flexibility. Country B instead experiences alternating movements in output gap and inflation rate, induced by persistence, because the impact of A's output gap is no longer strong enough to lift B's output gap into positive territory (note the large gap in the IRF of $\tilde{y}_t^B$).

[30]However, there are certainly calibrations where this relationship is not given, particularly when the model is calibrated for a very extreme preference for home goods.

Different Sizes Next, I keep price rigidities at $\theta_A = 1/2$ and $\theta_B = 2/3$, but set $\omega = 0.6$. The results hardly differ from the case of equally large countries, even for extreme cases ($\omega = 0.9$). Like above, different sizes do not seem to influence the paths back to equilibrium much, neither quantitatively and qualitatively, hence I skip the presentation.

Global Productivity Shock Assume now that the technology in both countries is equal $a_{A,t} = a_{B,t}$ and evolves according to (3.17). Still, oscillating behaviour is present and also the phase-shifts, but overall the divergence in reactions is then much less severe than with the idiosyncratic technology shock. The reactions resemble rather the ones of the common interest rate shock, and I skip their presentation. This reinforces the argument that the MU can deal much better with common shocks than with idiosyncratic ones.

3.3.4. Inflation Shock

Consider an idiosyncratic shock to inflation of country A. Examples would include a commodity price shock, where only A is affected or a global commodity price shock (the proverbial oil price hike) to which A is more vulnerable than B, or a sudden shift in inflation expectations that now include an exogenous, unsystematic part. The shock enters the system via an additional term u_t in the hybrid inflation rate dynamics (3.14) following an AR(1)-process:

$$u_t = \rho_{\pi,A} u_{t-1} + \varepsilon_t^{\pi,A}, \qquad \text{with: } \rho_{\pi,A} \in [0;1) \text{ and } \varepsilon_t^{\pi,A} \text{ is white noise} \tag{3.18}$$

Consider again the model in its baseline calibration and let the inflation shock be moderately persistent with $\rho_{\pi,A} = 0.5$. Then the effects of a positive inflation shock of 25 basis points in one quarter are shown in figure 3.6.

The shock to country A's inflation not only affects A itself but also B via the links of output and real interest rates. Different from the productivity shock, the natural levels of output and the real interest rate are not affected, since the shock has no influence on productivity. The higher inflation rate in A pushes its real interest rate down, widening (with a delay) the output gap in A. At the same time, the CCB reacts to A's higher inflation rate and output gap by raising the nominal rate, pushing the real rate up for both countries. This dampens the effects of the shock in A but creates a recession in B at the same time, further dampening the shock in A via the spillovers.

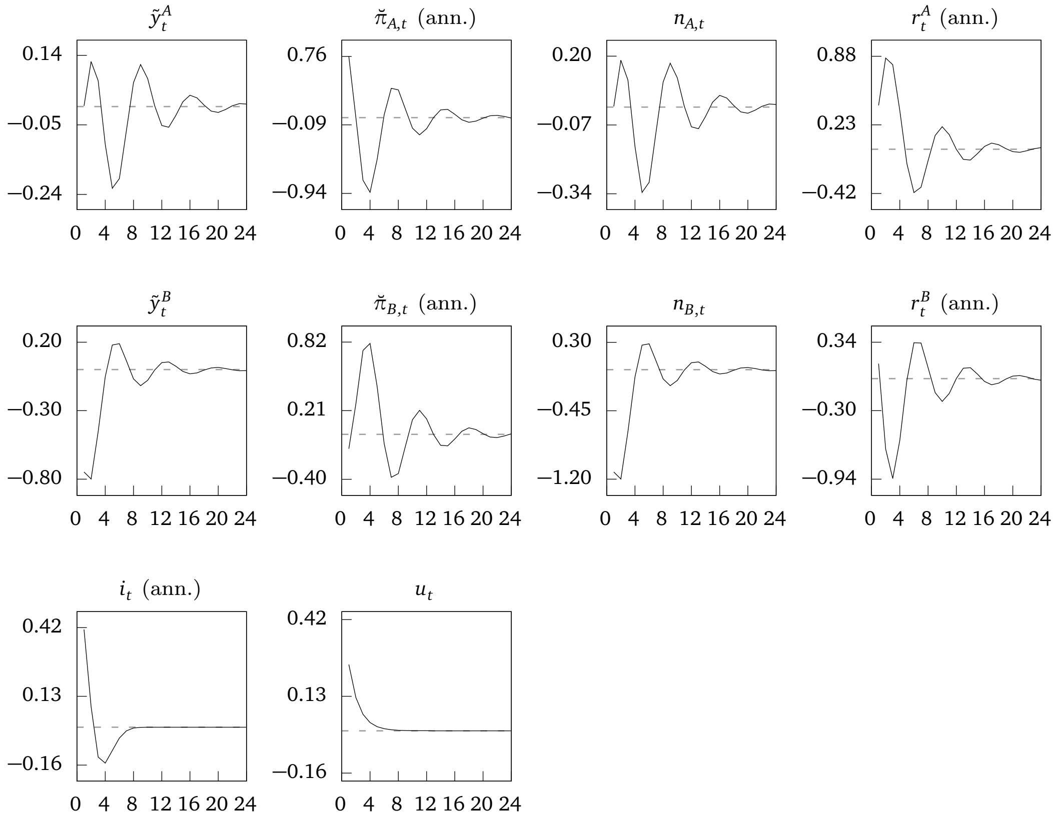

Figure 3.6.: IRFs of selected variables, following an idiosyncratic inflation shock to country *A*.

Persistence and anticipation of monetary policy even increases both the boom in *A* and the recession in *B*. Since the CCB immediately and strongly lowers the nominal interest rate below the steady state level, it sets in motion a sequence of ups and downs if both countries' inflation rates, output gaps and real interest rates, that only subside after about two years.

Different Price Rigidities Consider again differences in the price rigidities, and set $\theta_A = 1/2$ and $\theta_B = 2/3$ like above. The effects of an exogenous inflation shock to country *A* are shown in figure 3.7. Generally, the effects look much like the case of equal price rigidities, but due to the more flexible prices in *A*, the amplitudes of the effects are larger and the return to equilibrium is longer. The only notable difference is that the swings in *B*'s real interest rate are much less pronounced, which is a direct result of the nominal interest rate, which changes with B's inflation rate in way that a large part of the swings cancel each other out.

Different Sizes Keep the price rigidities at $\theta_A = 1/2$, $\theta_B = 2/3$ and assume additionally that the countries have different sizes, $\omega = 0.6$. The reactions are similar to the simulation with equal sizes. As expected, output and labour in A experiences smaller swings, since the CCB is putting more weight on stabilising the country A, with the higher voting power. However it seems that this does not happen at the expense of B, whose reactions are virtually identical to the simulation with equal sizes. For inflation, the opposite is true. While A's inflation rate is stabilised more, B experiences stronger swings.

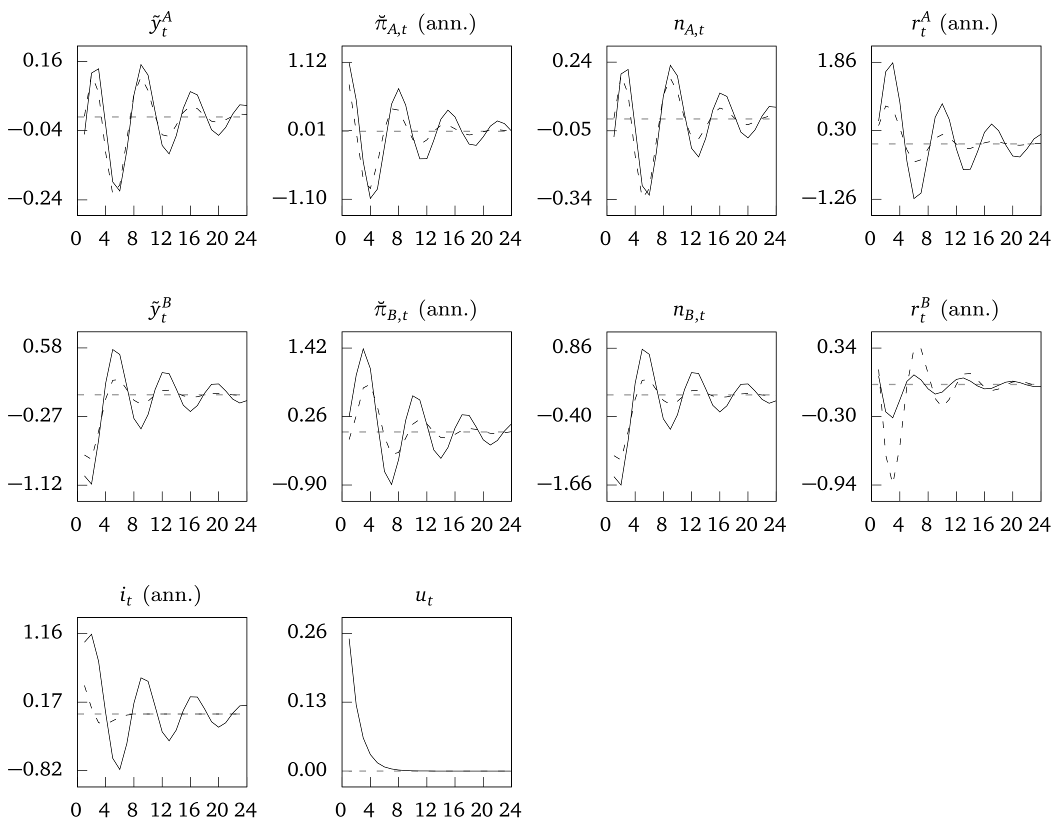

Figure 3.7.: IRFs of selected variables, following an idiosyncratic inflation shock to country A. Different price rigidities, $\theta_A = 1/2$, $\theta_B = 2/3$. Dashed lines are the reactions from the baseline calibration.

3.3.5. Robustness Checks

Since the swings in the reactions to monetary policy are quite substantial, I now consider an amendment to the interest rate rule, to limit the interest rate reaction, as I suspect the "overreaction" of the CCB as the main source of the heavy oscillations, as it does not perfectly incorporate the spillovers.

$$i_t = (1 - \phi_i) i_{t-1} + \phi_i i_{\mathrm{T}} + \nu_t \tag{3.19}$$

An interest rate rule like this is called a *partial adjustment model*, a special case of a generalised Taylor rule, see e.g. Clarida, Galí, and Gertler (1999), English, Nelson, and Sack (2002), Orphanides (2007), and Sauer and Sturm (2007).

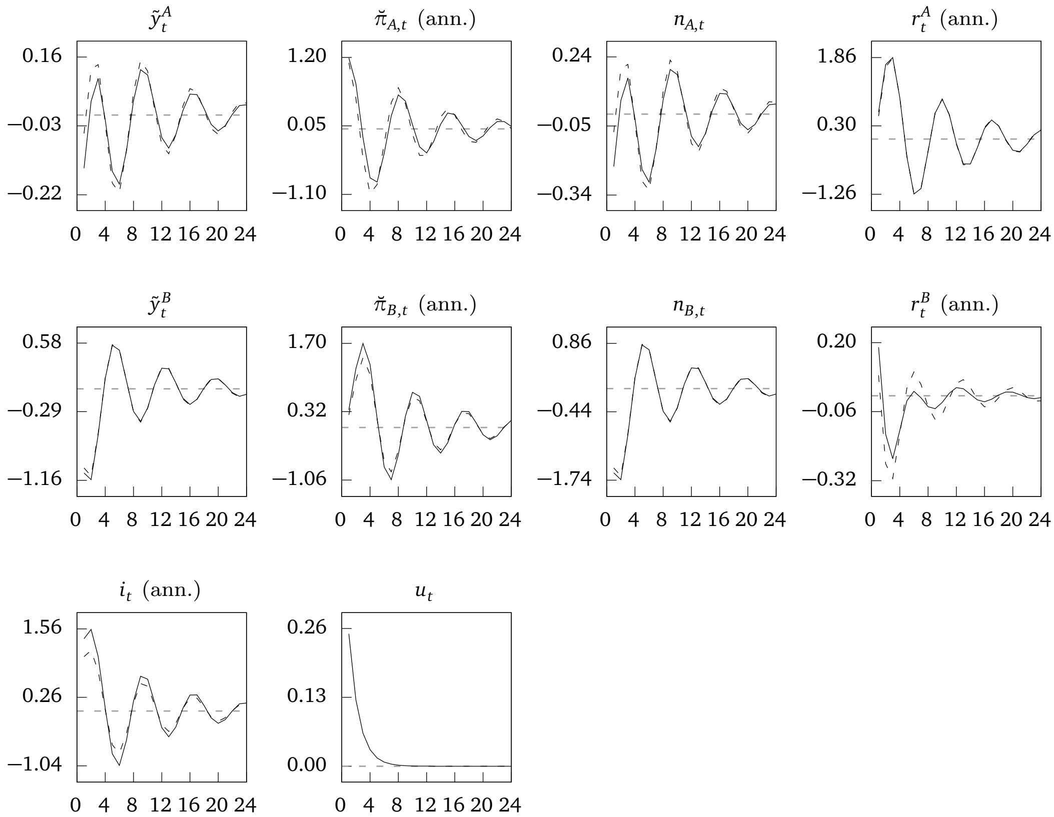

Figure 3.8.: IRFs of selected variables, following an idiosyncratic inflation shock to country *A*. Different price rigidities, $\theta_A = 1/2$, $\theta_B = 2/3$, different sizes $\omega = 0.6$. Dashed lines are the reactions from the calibration with equal voting powers.

Then, ϕ_i denotes the policy preference for the Taylor rate, i.e. a reaction to contemporaneous inflation rates and output gaps and i_{T} denotes the systematic part of the Taylor-type rule (3.13), i.e. without the distortion term ν_t. Further, I consider monetary policies that do not take into account the output gaps ($\phi_y = 0$), both with and without partial adjustment. Qualitatively, the results remain robust against these alternative specifications, hence I skip their presentation[31].

3.4. Conclusion

This chapter derives a sticky-price, forward-looking model of an asymmetric two-country MU. Following e.g. Galí (2008), Benigno (2004), Beetsma and Jensen (2005), the structure of the economy has a representative household in each country, continua of differentiated goods and firms, imperfect substitutability among varieties and among domestic and foreign goods, monopolistic competition and staggered price setting as suggested by Calvo (1983). These assumptions give rise to a non-linear DSGE model. I show that this model has a linear approximation around a global zero-inflation steady state that can be represented by five laws-of-motion: a supply curve and a demand curve for each of the countries and an interest rate rule for the CCB.

Different from models in the literature, these laws-of-motion feature direct and explicit dependencies on the magnitudes of the opposite country, rather than union-wide aggregates. This approach allows to study the impact the countries have on each other, without average developments shrouding movements in opposite directions. Having direct spillover channels also allows further empirical research, in how exactly members of an MU influence each other.

In line with the consensus in the literature that inflation and output dynamics are not purely forward-looking, I introduce lags to allow backward-looking behaviour in the laws-of motion. Again, the two economies may have asymmetries in the strength of the backward-looking behaviour, for the present analysis they are assumed to be identical. The four economic laws-of-motion are accompanied by one of two interest rate rules that capture the behaviour of the CCB.

To analyse the equilibrium dynamics, the model is then exposed to one of three different exogenous, unanticipated shocks. First, there is a monetary policy shock, where the CCB increases the nominal interest rate more than its rule would prescribe, showing how the MU will react to less-than-perfect monetary policy decisions, here exemplary an unanticipated tightening. This shock is more of a global shock, since

[31] The simulations can be run using the provided Dynare codes.

it hits a variable that is identical for both countries. Second, one of the countries experiences a persistent but fading increase in total factor productivity, describing e.g. an unanticipated technological advancement. The third shock is to inflation of one of the countries, showing the reaction to an unanticipated price hike. The latter two shocks of an idiosyncratic nature, hitting only one country. Of course, these idiosyncratic shocks have repercussions in the other country as well, and the CCB will react to both, the direct and indirect effects. Idiosyncratic shocks in an MU have been studied before, however the spillover of the shock to the country's fellow members was either through union-wide aggregates or through monetary policy. While the spillover via monetary policy is of course still there, the present model offers a novel way to study cross-country spillovers.

Simulations with Dynare show that the equilibrium dynamics induced by a global shock and by idiosyncratic shocks differ quite profoundly. I find that a global monetary policy shock is absorbed in a symmetric way. Introducing price rigidity asymmetries results in expected behaviour. When faced with global shock the MU acts mostly like a single economy, albeit with differently strong responses in the two regions, not uncommon to regular "nation"-economies, where different regions are hit harder by a shock than others, but not in opposite ways. This picture, however, changes drastically by introducing idiosyncratic shocks, here productivity and inflation shocks. Such shocks result in rather large amplitudes and long oscillating behaviour, due to the direct spillover channels with different signs of contemporaneous and expected effects, which makes it impossible for the CCB to stabilise, given its interest rate rule and the availability of but one monetary policy instrument. This suggests that the CCB should conduct monetary policy differently. Since the oscillations are the result of the CCB reacting to steady state deviations of the target variables, a sensible alternative would be to change its mandate to smooth out shocks, but not react to the natural development of prices and output. In practice, unfortunately, it should prove difficult to decide how much of, say, inflation is truly exogenous and how much is the result of economic dynamics.

Further follow-up work would be to amend the theoretical derivation in a way to establish lags without the need to introduce them ad-hoc. Also the introduction of sticky wages or fiscal policy-makers could be worth exploring. Another important point for extension is welfare analysis, i.e. imposing a loss function on the CCB and on the member countries and see how global and idiosyncratic shocks affect welfare of the MU as a whole and the single countries and where the trade-offs are. Also, a proper welfare analysis enables us to assess quantitatively the importance of the spillovers as compared to conventional models of an MU. Finally, an extension to a three-country setting would make it possible to also study secondary spillovers.

From an empirical point of view, the model should be estimated using data from the Eurozone – e.g. with Germany and France as the two countries – to recover the actual parameters of the laws-of-motion. Estimating the model allows, firstly, to make adequate statements about the core of the world's largest MU and its developments and secondly, to test how well the theoretically established parameters reproduce real world magnitudes. The next chapter will present estimation results using European and American data for the non-linear variant of the model.

4. Estimated Inflation Dynamics in Monetary Unions

In recent years, a debate among economists and policy makers began around the question, whether inflation is driven rather by domestic or international factors (Auer, Levchenko, and Sauré, 2017), not least because of the curiously low levels of inflation in industrialised countries, despite very loose monetary policies.

Understanding inflation spillovers is especially relevant for the conduct of monetary policy in a monetary union (MU). Since the member countries of an MU retain only fiscal policies (which may be constrained due to legal agreements), but share a common monetary policy (CMP), their instruments in tackling (low) inflation are more limited than those of countries with their own currency. Thus, (inflation) spillovers from other members of the MU are not as easily countered by policy, which puts more pressure on the common central bank (CCB) to deal with the problem.

Moreover, the interplay of prices and costs are at the centre of how modern central banks define and (try to) steer welfare. While also the central banks of countries with their own currency do indeed look into the spillover effects of their monetary policy onto inflation and thus welfare in their own country, they are not responsible for the welfare of the other countries. In a monetary union (MU), however, the common central bank (CCB) – like the ECB in the European Econonomic and Monetary Union (EEMU) – is responsible for the welfare of all the member countries, albeit indirectly through their part in the overall aggregate of the MU. Hence, the size and sign of the spillovers has direct effects on the conduct of the CMP.

Any monetary policy, but more so a CMP must take into account not only the effects of the policy as such, but also the feedback effects through the spillover channels, making the conduct of monetary policy in an MU all the more challenging – especially if spillovers cause inflation to be above target in some countries of the MU and below target in the others.

To understand the inflation dynamics of an MU it is necessary to look at the way members influence each other directly. It is not sufficient to analyse the effect of shocks on MU aggregates and then, in turn, the effect of the aggregates on the members, because regional effects may cancel each other in the aggregate, thus shrouding policy relevant movement. While an MU can be seen for some purposes as a whole (e.g. foreign trade, customs, etc.), for other purposes it is more instructive to look at its constituent regions. For example, the EEMU does not clear internal, cross-border trade or consumption at the union level but instead leaves this to its member countries. Thus, it is the consumers, workers and firms of the countries that interact *directly* with each other given their respective utility and profit maximisation problems and the imposed constraints and rigidities.

Moreover, the prevailing notion of the source for inflation (or more generally price deviations from the optimum) is that it is micro-founded, and driven by both nominal pricing rigidities and the profit-/utility-maximising interplay of supply and demand[1]. In turn, inflation spillovers may also be micro-founded in the preferences for imports and the degree of substitutability of domestically produced goods. This warrants the use of a micro-founded model with direct spillovers, which incorporates a consumption decision, an import decision, a production decision and some rigidities in place. In fact, the pricing rigidities and preferences should be allowed to differ across countries, to capture transmission asymmetries. The previous chapter establishes such a model, albeit in a stylised two-country setting and used it to theoretically study MUs. Estimating this model, this chapter analyses the direct spillover channels in an empirical way, not only for the maturing but still fairly new EEMU but also for a more established one, namely the US.

As the most advanced "proper" monetary union, the EEMU is an obvious candidate for taking the model to the data. The EEMU comes closest to the theoretical model – asymmetric countries with different traditions in wage and price setting, a true common monetary policy, and a rather low cross-border labour movement, (cf. Andor, 2014; Barslund and Busse, 2016).

The US on the other hand has a strong federal tradition with a lot of autonomy of the states. But since the degree of economic integration at the federal level has increased

[1]There is also inflation as a result of excessive monetary growth. The theoretical central bank considered in this thesis does not pursue inflationary policies. Formally, the policy rule considered in chapter 4 aims at keeping both, inflation and output gap, as close to zero as possible, given the different weights on the two policy objectives. That is, any "excess" (i.e. different from zero) in- or deflation in the model is a result of either stabilising output, or a non-systematic shock beyond the control of the CCB.

dramatically as compared to the original US two hundred years ago[2], it is a *within-nation* MU, as compared to the current EEMU, which does not feature the degree of economic integration the US does, and is of the *among-nations* type of MU (see Hamada and Porteous, 1993). Comparing the results of estimating the model to European data with the results obtained from the estimation with US data is a worthwhile exercise to assess both the model's capabilities and to highlight differences of the European and American notions of monetary union.

This chapter is organised as follows. The next section gives a brief overview of the relevant literature. Section 4.2 introduces the non-linear model and its reduced form and relates it to the data, which is presented in section 4.3, for both EEMU countries and US census regions. Section 4.4 presents the results of the estimations and a discussion. The last section concludes.

4.1. Literature Review

This chapter adds to several strands of the literature. First, there is the empirical study of international inflation spillovers, which has for the last decade or so been viewed in the context of globalisation, mostly in the context of either the Europe/US spillovers or in the setting of advanced countries (G7 or OECD). Studies of this strand include e.g. Altansukh et al. (2017), Bianchi and Civelli (2015), Borio and Filardo (2007), Hakkio (2009), IMF (2014), Kondo and Kitaura (2012), Monacelli and Sala (2009), and Yang, Guo, and Wang (2006) But there is also a body of literature on the spillovers of inflation from large economies to their smaller neighbours, e.g. Hałka and Szafranek (2015), Iossifov and Podpiera (2014), Jeong and Lee (2001), Jordan (2015), and Osorio and Unsal (2013).

Others examine different channels through which pricing dynamics spill over to other countries, Auer, Levchenko, and Sauré (2017) study the supply side, Ciccarelli and García (2015) investigate the role of inflation expectations, Buitron and Vesperoni (2015) consider spillovers between the Euro area and the US via differences in monetary conditions, and Auer and Sauré (2013) look at the influence of trade integration.

Second is the strand of literature concerned with regional asymmetries in the macroeconomic dynamics of MUs and the associated spillovers within the MU. There is literature about regionalities in the EEMU, e.g. Beck, Hubrich, and Marcellino (2006) and Magkonis and Sharma (2018), in the US, e.g. Kumar and Orrenius (2016) and about these

[2]See e.g. Rolnick, Smith, and Weber (1993), Carlino and DeFina (1998), Rockoff (2000), Rolnick, Smith, and Weber (2001), HM Treasury (2003), Grubb (2003), and Beck, Hubrich, and Marcellino (2006).

heterogeneities in both and possibly comparisons, e.g. Berk and Swank (2007; 2011). Nagayasu (2012) provides a study about regional inflation spillovers in Japan.

Quite a few of these studies utilise a data set that is rather limited in the number of countries, or without any consideration of the rest-of-the-world as sources or sinks of spillover effects. It seems that meaningful policy advice can be deduced despite this alleged limitedness.

The third strand of literature connected to this chapter is about the estimation of the (hybrid) New-Keynesian Phillips Curve (NKPC), which was pioneered by Fuhrer (1997), Galí and Gertler (1999), and Galí, Gertler, and López-Salido (2001; 2005). In particular Sbordone (2002; 2005) makes the case for the marginal costs based NKPC as opposed to the output-gap based version, which is empirically not very well established[3]. Recent studies of the Hybrid New-Keynesian Phillips Curve (HNKPC) in the Euro Area and the US are Blanchard (2016), Kim (2018), Mazumder (2018), and Oinonen and Paloviita (2014), and of course the analysis in chapter 2. See also Abbas, Bhattacharya, and Sgro (2016) for an overview. For technical details see also Nason and Smith (2008) for derivation and identification of the HNKPC, also Mavroeidis (2004) for specification, identification and instrumentation.

Finally, this chapter departs from the literature on estimating the HNKPC in a theoretical way by considering direct, micro-founded spillover channels and in an empirical way by using the moment conditions from two equations, while the literature on GMM-estimated DSGE models as far as I know only estimates one[4] equation at a time.

4.2. Theory

Consider the MU-NKM, established in chapter 3. The model is a sticky-price, forward-looking model of the inflation rate in a two-country MU setting. This model brings certain advantages and disadvantages to the analysis. Certainly, a two-country model cannot hope to capture all of the inflation spillovers and the full extent of the countries' economic connections that go beyond the connection to each other in their MU. Still, it is quite common in the literature on inflation spillovers to consider datasets with only a very limited number of countries, as this keeps the analysis tractable and reduces the loss of degrees of freedom, thus preserving the explanatory power of the estimates. Furthermore, the model used here is completely micro-founded and every estimated

[3] See also the remarks in section 2.1.

[4] Except for the models that are estimated using *System GMM*, which is to my knowledge only available for linear models, see Hayashi (2000).

parameter has a direct meaning in the underlying optimisation problems of firms and households, mitigating the somewhat narrow focus on only two countries.

In particular consider equation (3.6), here repeated for convenience:

$$\pi_t^k = \beta \mathrm{E}_t \left\{\pi_{t+1}^k\right\} + \lambda_k \tilde{mc}_t^k. \tag{3.6}$$

This is the marginal cost based, forward-looking Phillips curve of country k, where $k \in \{A, B\}$ denote one of the two countries, and $-k$ the respective opposite country, like in chapter 3. Here π^k denotes the inflation rate of prices of domestically produced goods.

Further, let $\tilde{mc}$ denote the deviation of marginal costs from their steady state. By assuming a very simple production function with only labour as an input and a Cobb-Douglas structure, marginal costs can be expressed as the real labour income share (see appendix D.1 for details). Since the production function has only domestic labour as its input, this relationship is formally the same as in the baseline, closed-economy New-Keynesian model.

Following e.g. Galí, Gertler, and López-Salido (2001) and as previously shown in chapter 2 with rule-of-thumb pricing, lags of the inflation rate can be introduced:

$$\pi_t^k = \beta\theta_k\phi_k^{-1}\mathrm{E}_t \left\{\pi_{t+1}^k\right\} + \omega_k\phi_k^{-1}\pi_{t-1}^k + \lambda_k\phi_k^{-1}\tilde{mc}_t^k. \tag{4.1}$$

Here ω_k denotes the "pricing backwardness", that is the share of firms who set prices to the inflation-adjusted average of last period instead of optimising. Then (4.1) is formally equivalent to the marginal-cost based HNKPC investigated in the literature.

Further define the following notational shortcuts

$$\phi_k \equiv \theta_k + \omega_k(1-\theta_k(1-\beta)) \qquad \lambda_k \equiv \Theta(1-\omega_k)(1-\beta\theta_k)(1-\theta_k) \qquad \Theta \equiv \frac{1-\alpha}{1-\alpha+\alpha\varepsilon}$$

and the reduced coefficients of the HNKPC

$$\xi_k^f \equiv \beta\theta_k\phi_k^{-1} \qquad \xi_k^b \equiv \omega_k\phi_k^{-1} \qquad \delta_k \equiv \lambda_k\phi_k^{-1}. \tag{4.2}$$

Since up until this point we are looking at purely domestic developments, the coefficients have the same interpretation as in chapter 2, see especially sections 2.2 and 2.3 for details.

To account for the spillovers, define the (core[5]) consumer price inflation rate as the weighted average of the inflation rates of both domestically and foreign produced goods. This relationship is described in equation (3.10), here repeated for convenience:

$$\breve{\pi}_{k,t} = \gamma_k \pi_t^k + (1-\gamma_k)\pi_t^{-k}, \tag{3.10}$$

where the weight γ_k is the consumption elasticity for domestically produced goods, see 3.2.1, especially equation (3.2).

Combining (4.1) and (3.10) gives the estimation equation. Assuming rational expectations, the equation for country k is given by:

$$\begin{aligned}\breve{\pi}_{k,t} = {} & \gamma_k \xi_k^f \pi_{t+1}^k + (1-\gamma_k)\xi_{-k}^f \pi_{t+1}^{-k} + \gamma_k \xi_k^b \pi_{t-1}^k + (1-\gamma_k)\xi_{-k}^b \pi_{t-1}^{-k} \\ & + \gamma_k \delta_k \tilde{mc}_t^k + (1-\gamma_k)\delta_{-k}\tilde{mc}_t^{-k},\end{aligned} \tag{4.3}$$

where $\breve{\pi}$ denotes the (core) inflation rate. As the ξ's and δ's are shorthands for expressions of fundamental parameters, the model is non-linear and can be estimated via Generalised Method of Moments (GMM).

Define further the preference-weighted, reduced coefficients as

$$\zeta_k^f \equiv \gamma_k \xi_k^f \qquad \zeta_k^b \equiv \gamma_k \xi_k^b \qquad \chi_k^f \equiv (1-\gamma_k)\xi_{-k}^f \qquad \chi_k^b \equiv (1-\gamma_k)\xi_{-k}^b$$

$$\kappa_k \equiv \gamma_k \delta_k = \gamma_k \lambda_k \phi_k^{-1} \qquad \eta_k \equiv (1-\gamma_k)\delta_{-k} = (1-\gamma_k)\lambda_{-k}\phi_{-k}^{-1}. \tag{4.4}$$

Observe, that just like for the HNKPC, restricting[6] the discount factor $\beta = 1$ results[7] in $\xi^f + \xi^b = 1$, giving the two parameters a convenient interpretation of the strength of the forward- and backward-looking component in the inflation dynamics. Thus follows that $\zeta^f + \zeta^b = \gamma$ and $\chi^f + \chi^b = 1-\gamma$, and finally $\zeta^f + \zeta^b + \chi^f + \chi^b = 1$. Finally, observe that since the model of chapter 3 mathematically requires the substitution elasticity ε

[5]It is sensible to call this the *core* consumer price inflation rate, because it excludes distortions from imports of outside the MU, especially price-volatile imports like oil, and prices from goods that are susceptible to out-MU price changes, like energy or seasonal foods.

[6]In fact, since theory requires the discount factor β to be equal across countries/regions, it is convenient to restrict it. See the definition of the representative household, section 3.2.1.

[7]There is another consequence of restricting β, namely that the (delta-method) standard errors of ξ^f and ξ^b are equal. Recall that from $\beta = 1$ follows $\xi^f = \frac{\theta}{\theta+\omega}$ and $\xi^b = \frac{\omega}{\theta+\omega}$. Simple algebra shows that $\frac{\partial \xi^f}{\partial \theta} = -\frac{\partial \xi^b}{\partial \theta}$ and $\frac{\partial \xi^f}{\partial \omega} = -\frac{\partial \xi^b}{\partial \omega}$. In particular, this means that the squares of the partial derivatives are equal, and so are their (co)variance-weighted sum in the Taylor-expansion of the variance of the reduced form coefficients ξ^f and ξ^b. This should come as no surprise given that the restriction of β results in $\xi^f + \xi^b = 1$, thus any variation in one reduced coefficient must be met by an equally sized, opposite variation in the other to maintain the sum of unity.

and production elasticity of labour $1-\alpha$ to be identical across the two countries, it is convenient to also restrict[8] the notational shortcut Θ (see above) to unity[9], for this first analysis.

Note that the model considers two types of inflation, the development of prices of k-produced goods π^k (see eq. 3.6), and the development of elasticity weighed prices of k- and $-k$-produced goods $\breve{\pi}_k$, the consumer price inflation (eq. 3.10). By using equation (4.3) the estimation runs basically from the lags and leads of domestically and foreign produced goods price inflation and cost developments in both countries to the consumer price inflation rate. This method allows to identify the spillover parameter γ_k.

4.3. Data

The dataset in use is basically the same as the one for chapter 2, i.e. macroeconomic time series (inflation, marginal costs, interest rates, etc., see appendix A) for Germany and France[10]. For this chapter, this dataset is augmented with the equivalent of these series for the US census regions, or similar; again see appendix A. In general, data are available on a monthly frequency, either because of the natural frequency of the data or via linear interpolation. Lags and leads are calculated on a one-quarter frequency (i.e. a three-month lag) to keep the interpretation compatible to the literature.

The inflation rate[11] of domestic products π^k is measured by the monthly annualised rate of change of the GDP Deflator, and consumer price inflation $\breve{\pi}_k$ is measured by the monthly annualised rate of change of the Core HICP for countries of the Euro area and the Core consumer price index (CPI) for the US regions, respectively. Table A.1 shows the sources of the raw series and the calculations performed before including them in the dataset.

[8]This restriction could be lifted, either to require ε and α to be equal in both countries without requiring Θ to be unity, or to even lift the identity requirement altogether, albeit at the cost deviating from the theoretical model.

[9]Equivalently, $\alpha = 0$, thus assuming a very simple production function of linear labour input with constant capital.

[10]The series for Italy, Spain, The Netherlands and Austria are also in the dataset but not used

[11]Most of the literature uses the GDP Deflator as the inflation measure because it is a superior measure for inflation in the sense of the New-Keynesian Model (NKM), precisely price changes due to marginal costs movements, instead of (Core) Harmonised Index of Consumer Prices (HICP) inflation which includes imported products whose prices are not as strongly affected by domestic marginal cost changes, if at all. In particular the HICP contains energy prices, which are a major contribution to inflation (see figure B.29 in the appendix), thus usually the GDP Deflator – i.e. *without* imported inflation – gives a better fit than the HICP inflation. This is however not available here, because we need the GDP Deflator to measure the domestically produced goods price inflation, and must therefore resort to another measure to capture headline inflation.

The deviation of marginal costs from its steady state $\tilde{mc}$ is expressed as the HP-filtered cyclical movement of the (log) labour income share of real GDP, in per cent, see appendix D.1.

European Economic and Monetary Union The data for the EEMU is available from 1998-1 through 2016-6, see appendix A. The measures for the HICP core inflation rate are represented by the HICP without energy and seasonal food prices. All time series are available for six large and medium-sized EEMU member countries, Germany, France, Italy, Spain, Austria and The Netherlands, except for the core inflation series, which is available only for Germany and France in the concerned time period. The core inflation rate for the remaining countries starts at different times and is completely available for all six countries in the sample only from 2002-01 onward[12]. The main variables, i.e. GDP Deflator, Core HICP and the marginal costs deviations for Germany and France are shown in the appendix, in figures B.2, B.4 and B.12, B.14. The appendix also contains charts for the data in Italy, Spain, The Netherlands and Austria.

United States of America Data on the US are available from 2007-1 through 2017-9, see appendix A. Availability is limited by the publication of quarterly, state-level GDP data by the BEA, starting only in 2005[13], see also Kumar and Orrenius (2016). All data, except for the interest rates and the survey-based inflation expectations, are available for the four census regions (North-East, Midwest, South, and West), in addition GDP and labour share data are available on the state level, too[14]. State level data are aggregated to census region level, which is straightforward for all data in question, as the state level data are available in nominal levels.

The main variables, i.e. GDP Deflator, Core CPI and the marginal costs deviations for the census regions North-East and South are shown in the appendix, in figures B.7, B.9 and B.17, B.19. The appendix also contains charts for the data in the census regions Midwest and West.

[12]The series for Italy, Austria and the Netherlands begin in 2001-01, while the series for Spain begins only in 2002-01.

[13]The figures for 2005 are needed for the calculation of growth rates, in particular GDP Deflator rates of change. Requiring four quarters of lags uses up another year.

[14]In fact, GDP and labour share data for the census regions are weighted averages of state level data. The restriction to census regions comes from the availability of the CPI which, in a geographically disaggregate way, is consistently only available on the regional level or metropolitan area level, however *not* on the state level. Notably, individual states publish a CPI, e.g. California, but this seems to be rather the exception than the rule.

Data Sources and Remarks The dataset is compiled from various sources. Table A.1 in the appendix gives an overview. European survey-based inflation expectations are available on a disaggregate level, per country in quarterly frequency and are kindly provided by CESifo (see Garnitz et al., 2016). US survey-based inflation expectations are only available at the federal level, however there are two such series available. The first comes from the Fed Cleveland, based on a model using Treasury yields, inflation data, inflation swaps, and survey-based measures of inflation expectations[15]. The second one is the survey of professional forecasters and is provided by the Fed Philadelphia[16].

Additionally the dataset contains the series of oil prices (both Brent and WTI) and an associate oil price inflation rate (annualised growth rate of the oil price). Since oil is priced in US Dollars, the oil prices and inflations are deflated by the USD/EUR nominal exchange rate when used for the estimation of the model for European countries.

4.4. Estimations

The inflation dynamics in the two countries of the MU can be fully described by eq. (4.3), in both its reduced (linear) and structural (non-linear) form. Notice that the full inflation dynamics consists of two equations, one for each country.

As usual in the estimation of such models, imposing rational expectations rids the equations of the expectation operators, see e.g. Sbordone (2002: 3.3). We obtain thus a set of moment functions g_A, g_B that, together with GMM and a set of instrumental variables, can be used to estimate the structural parameters

$$\vartheta = \{\theta_A, \omega_A, \gamma_A, \theta_B, \omega_B, \gamma_B\} \tag{4.5}$$

The central parameters of interest are γ_A and γ_B, which I call the *spillover parameters*. In the context of the model, γ_k denotes the consumption elasticity of domestically produced goods, thus $(1-\gamma_k)$ is the consumption elasticity of foreign produced goods. Hence $1-\gamma_k$ ca be interpreted as the strength of the spillovers[17] from country $-k$ to k.

The remaining structural parameters θ_k, ω_k retain their usual interpretation as price stickiness and pricing backwardness. While the pricing optimisation problem of the firms takes into account the demand of both countries, the underlying rigidities are

[15] https://www.clevelandfed.org/en/our-research/indicators-and-data/inflation-expectations.aspx

[16] https://www.philadelphiafed.org/research-and-data/real-time-center/survey-of-professional-forecasters/historical-data/inflation-forecasts

[17] Other interpretations of γ_k include the degree of economic interconnectedness, or the home bias.

country-specific and reflect differences in pricing traditions, e.g. many small adjustments or few big adjustments.

To estimate the endogenous equations consistently, GMM requires instrumental[18] variables. There are two (not necessarily identical) instrument sets z_A and z_B the two equations $g_A(\vartheta, x_A)$ and $g_B(\vartheta, x_B)$, where ϑ contains all parameters of *both* equations. The according moment conditions are then

$$E\left\{\begin{bmatrix} \mathbf{z_A} \times g_A(\vartheta, x_A) \\ \mathbf{z_B} \times g_B(\vartheta, x_B) \end{bmatrix}\right\} = \mathbf{0}, \tag{4.6}$$

where g_A, g_B are the (normalised[19]) moment functions of the two equations (4.3), and x_A, x_B are the observations of the endogenous variables. See Chaussé (2010) for details.

In general, the direct estimation of (4.3) has proven to be unreliable, probably due to the high degree of non-linearity. Therefore, the estimation is broken up into two steps.

First Step Consider the moment conditions based on (4.1)

$$\mathrm{E}_t\left\{\mathbf{w}_k \times (\pi_t^k - \beta\theta_k\phi_k^{-1}\pi_{t+1}^k - \omega_k\phi_k^{-1}\pi_{t-1}^k - \lambda_k\phi_k^{-1}\tilde{mc}_t^k)\right\} = \mathbf{0}, \tag{4.7}$$

where $\mathbf{w}_k$ is the first step instrument set for country k. This instrument set contains the second lag of the GDP Deflator, the first lag of the marginal costs deviation, the contemporaneous and first lag survey-based inflation expectations[20], the contemporaneous wage inflation rate and the Brent oil price[21] inflation rate

The two first step estimations[22] yield $\hat{\theta}_A$, $\hat{\theta}_B$, $\hat{\omega}_A$ and $\hat{\omega}_B$, the price stickiness parameters and the pricing backwardness parameters of the two countries (or regions) A and B. These parameters govern the autonomous mechanics of the model, i.e. the mechanics that do not affect the respective other country. Use these estimates for price stickiness and pricing backwardness to calibrate (4.3) before estimating.

[18]For the appropriateness of an instrument set, see the remarks in chapter 2, especially on page 30.

[19]Equalised to zero.

[20]For the estimations using US data, survey based inflation expectations are only available at the national level but not at the regional level, see figure B.28. For the estimations using European data, country-level survey-based inflation expectations are available, see figure B.27.

[21]For the estimations using European data, oil prices are converted to Euro using the spot nominal exchange rate, see figures B.21 and B.22.

[22]The results seem more plausible when imposing the restriction $\beta = 1$. However, estimating the model with an unrestricted discount factor is easily facilitated in the provided source code. Strictly speaking, different values for β in the first step estimation would indicate a violation of the theory, as β is required to be symmetric across the countries in the model to derive the dynamics, see the definition of the households in section 3.2.1.

Second Step Unlike the first step, consider the moment conditions for both countries/regions jointly, as given by eq. (4.6). Thus, the estimation equation is given by the following moment conditions[23]:

$$E\left\{\begin{bmatrix} \mathbf{z}_A \times \Big(\breve{\pi}_{A,t} - \gamma_A \xi_A^{f,*} \pi_{t+1}^A - (1-\gamma_A)\xi_B^{f,*}\pi_{t+1}^B \\ -\gamma_A \xi_A^{b,*} \pi_{t-1}^A - (1-\gamma_A)\xi_B^{b,*}\pi_{t-1}^B \\ -\gamma_A \delta_A^* \tilde{mc}_t^A - (1-\gamma_A)\delta_B^* \tilde{mc}_t^B\Big) \\ \mathbf{z_B} \times \Big(\breve{\pi}_{B,t} - \gamma_B \xi_B^{f,*} \pi_{t+1}^B - (1-\gamma_B)\xi_A^{f,*}\pi_{t+1}^A \\ -\gamma_B \xi_B^{b,*} \pi_{t-1}^B - (1-\gamma_B)\xi_A^{b,*}\pi_{t-1}^A \\ -\gamma_B \delta_B^* \tilde{mc}_t^B - (1-\gamma_B)\delta_A^* \tilde{mc}_t^A\Big) \end{bmatrix}\right\} = \mathbf{0}, \tag{4.8}$$

where $\breve{\pi}$ denotes the core inflation rate as measured by the Core HICP in the EEMU and the Core CPI in the US, respectively, Further, starred variables are calibrated to the results of the first step estimates. The calibration reduces the number of coefficients to be estimated to two, as only γ_A and γ_B are left unknown. Thus, the second step estimation using the moment conditions (4.8) jointly estimates the spillover parameters $\hat{\gamma}_A$ and $\hat{\gamma}_B$.

The instrument sets $\mathbf{z}_A$ and $\mathbf{z}_B$ contain the second lag of the GDP Deflator, the contemporaneous and first lag of the survey-based inflation expectations, the first lag of the wage inflation rate, four lags of the marginal cost deviations, the contemporaneous and first and second lag of the output gap, the long and short term interest rate, and the oil price inflation rates.

Reduced Form Parameters and Error Propagation Since not only the structural, but also the reduced parameters carry economic meaning, I present all parameter estimates in the results below. For both steps, the reduced parameters are calculated as they are defined in (4.2) and (4.4), and their respective standard errors are calculated via error propagation, precisely the delta method, see appendix C. Given that there are two steps of estimation, covariances between first-step and second step estimates are unavailable, because the parameters estimates in the first step are calibrated and thus fixed in the second step, therefore there is no covariance. As a result, however, the error propagation misses possibly a non-zero covariance term. Thus, the standard errors of the *reduced* parameters in the second step contain only the first-order propagated error.

Next are the estimations of the model for the EEMU and the US, respectively.

[23]Recall that $\beta = 1$ from the first step.

4.4.1. Euro Area: Germany and France

For the EEMU, the model is estimated for Germany and France, the two largest member countries by both GDP and population[24]. Germany and France are both highly developed and diversified industrial economies, and similar[25] in economic size and population.

First Step Table 4.1 shows the first-step GMM estimations of the deep (structural) parameters, price stickiness θ and pricing backwardness ω, of Germany and France. Presented alongside are the resulting reduced coefficients and the average price duration.

German prices are estimated to be less sticky than French prices. The price stickiness $\hat{\theta}$ is estimated at 0.54 and 0.82, respectively. That is, in Germany an average share of 0.54 of firms are not able to re-optimise prices in any given period, the corresping share estimate in France is 0.82.

Further, prices in Germany are more backward-looking than in France. Pricing backwardness $\hat{\omega}$ is estimated at 0.45 and 0.21, respectively. French firms, once they are able to re-optimise, tend to choose prices according to rational expectations, the share of re-optimising French firms doing so is estimated at about 0.21. In contrast, the corresponding estimated share of German firms is only 0.45. In the remaining instances, firms use the average price of the last period, corrected for contemporaneous inflation, which is the backward-looking rule-of-thumb, without forming (rational) expectations about the future development of costs, prices, demand and supply.

The reduced form estimated coefficients reflect of course the structural coefficient estimates. France's goods prices have a stronger forward-looking component $\hat{\xi}^f$ than Germany's, due to the differences in price stickiness and backwardness. In Germany, inflation expectations $\hat{\xi}^f$ account for an estimated share of domestic goods inflation of about 0.54, and inflation inertia $\hat{\xi}^b$ accounts for the remaining 0.46. In France, an estimated share of 0.79 of the contemporaneous domestic goods inflation rate can be explained with the expectations thereof, while inflation inertia $\hat{\xi}^b$ estimatedly accounts for about 0.21 of these price movements.

Still, the estimated effect of the marginal costs on the inflation rate $\hat{\lambda}$ is considerably larger in Germany than it is in France, 0.12 and 0.03, respectively. This higher pass-

[24]I have chosen Germany and France also for the pragmatic reason that the time series for core inflation begins the earliest in these two countries. For other EEMU-countries the core inflation series are available only starting from a later date. See previous section.

[25]Real GDPs in PPP-Dollars are 4.7 trillion and 2.8 trillion respectively, which translates to a share of roughly 41 % and 25 % of the Euro area total of 11.5 trillion in 2017 (Eurostat). Germany's population is 80.6 million (24.6 %) and France's is 67.2 million (20.6 %), of the 340.7 million of the Euro area total.

Dep. var.	GDP Deflator (monthly, annualised rate of change)	
	Germany	France
Price Stickiness θ	0.5366***	0.8154***
	(0.0003)	(0.0004)
Pricing backwardnes ω	0.4541***	0.2127***
	(0.0003)	(0.0004)
Inflation expectation ξ^f	0.5416***	0.7931***
	(0.0003)	(0.0004)
Inflation inertia ξ^b	0.4584***	0.2069***
	(0.0003)	(0.0004)
MC deviation λ	0.1172***	0.0268***
	(0.0001)	(0.0001)
Avg. Price Duration D	2.1578***	5.4174***
	(0.0014)	(0.0106)

Coefficient restriction $\beta = 1, \Theta = 1$ for all models. Upper panel shows the GMM estimates of the structural (deep) parameters, HAC-robust SEs in parentheses. Lower panel shows the reduced form coefficients based on the structural parameter estimates. SEs of the reduced form estimates are calculated via error propagation. Significance: $p < 0.01$ ***, $p < 0.05$ **, $p < 0.1$ *.

Table 4.1.: First Step Estimation. Euro countries Germany and France, Non-linear hybrid NKPC, GDP Deflator (monthly, annualised rate of change), Log labour income share, HP-filtered.

through is because German prices are less sticky than French prices, i.e. cost changes are more strongly reflected in price changes. The price stickiness is of course reflected in the average price duration. Average domestic goods prices last 2.2 quarters in Germany, and almost 5.4 quarters (i.e. over a year) in France. All structural and reduced coefficient estimates are statistically highly significant.

Second Step The results of the second step estimation of the consumption elasticity parameters γ – the spillover degree – for both France and Germany are shown in table 4.2. German consumers have a lower preference for domestic goods, than French consumers. The estimated consumption elasticity of domestic goods $\hat{\gamma}$ is 0.65 in Germany and 0.8 in France. That in turn means that generally the influence of prices and marginal costs in France on prices in Germany are higher than vice versa, i.e. the price and cost developments of France spill over to Germany to a larger degree, than German price and cost developments spill over to France. An exception is the foreign price inertia, where the spillover is larger from Germany to France than vice versa, due to the low degree of pricing backwardness in France.

Now consider the estimates of the reduced form coefficients As expected from the first step estimates of the price stickiness, the influence of domestic price developments on the consumer price inflation rate dominate. The estimated share of domestic core consumer price inflation accounted for by domestic inflation expectations $\hat{\zeta}^f$ in Germany and France are 0.35 and 0.64, respectively. Similarly as expected, the share of domestic core consumer inflation accounted for by domestic inflation inertia $\hat{\zeta}^b$ in Germany and France are estimated at 0.3 and 0.17, respectively. However, reflecting the lower degree of spillovers from Germany, France's domestic inflation expectations and inertia account for more of the French core consumer price inflation rate, than in Germany. Still, while domestic price movements dominate, there is still considerable influence of foreign price movements.

Expectations of foreign price movements $\hat{\chi}^f$ have a markedly stronger influence in Germany than in France, estimated at 0.28 and 0.11, respectively, i.e. the effect is about two-and-a-half times as large in Germany as it is in France. Foreign inflation inertia $\hat{\chi}^b$ then account for the remaining estimated share of consumer price inflation of about 0.07 and 0.09 in Germany and France, respectively.

In Germany, the estimated impact of domestic marginal costs deviations $\hat{\kappa}$ with 0.08 clearly dominate foreign marginal costs deviations $\hat{\eta}$ with 0.01 , i.e. the effect is about eight times as strong, again following from the low price stickiness in Germany and the subsequent high cost pass-through. However, in France estimated domestic and foreign marginal costs deviations influence the French inflation rate about equally strong, 0.22 and 0.23, respectively. Still, in aggregate marginal cost developments have a markedly stronger pass-through on the inflation rate in Germany, than in France, following from Germany's low price stickiness.

All structural and reduced coefficient estimates are statistically highly significant.

Discussion The first step estimations of the HNKPCs for Germany and France are very well in line with earlier results, e.g. Galí, Gertler, and López-Salido (2001; 2005), and confirm again the validity of the marginal-costs based variant of the NKM.

Also, the second step estimation produces plausible results, showing that – given the model – France's core consumer price inflation rate is considerably more autonomous than Germany's.

Looking then at the estimates of the marginal costs influences, Germany's core consumer price inflation rate is very much driven by German cost movements, unlike France where not only domestic costs but also foreign (German) costs play almost equal roles.

Dep. var.	Core HICP (monthly, annualised rate of change)	
	Germany	France
Domestic goods preference γ	0.6459***	0.8026***
	(0.0452)	(0.0651)
Domestic Infl. Exp. ζ^f	0.3498***	0.6366***
	(0.0245)	(0.0517)
Domestic Infl. Inertia ζ^b	0.2961***	0.166 ***
	(0.0207)	(0.0135)
Foreign Infl. Exp. χ^f	0.2808***	0.1069***
	(0.0358)	(0.0353)
Foreign Infl. Inertia χ^b	0.0732***	0.0905***
	(0.0093)	(0.0299)
Domestic MC deviation κ	0.0757***	0.0215***
	(0.0053)	(0.0017)
Foreign MC deviation η	0.0095***	0.0231***
	(0.0012)	(0.0076)

Coefficient restriction $\beta = 1, \Theta = 1$ for all models, and θ, ω are calibrated and restricted to their first step estimates. Upper panel shows simultaneous GMM estimates of the consumption elasticity of substitution of home goods in both countries, HAC-robust SEs in parentheses. Lower panel shows the reduced form coefficients based on the structural parameter estimates. SEs of the reduced form estimates are calculated via error propagation. Significance: $p < 0.01$ ***, $p < 0.05$ **, $p < 0.1$ *.

Table 4.2.: Second Step Estimation. Euro countries Germany and France, Non-linear MU hybrid NKPC, Core HICP (monthly, annualised rate of change), Log labour income share, HP-filtered.

This may be due to the much lower price stickiness in Germany, i.e. that German cost developments more easily spill over to France, than vice versa.

4.4.2. US: North-East and South

For the US[26], the model is estimated for the census regions[27] *North-East* and *South*, including New York and Texas, respectively, the third and second largest US states by real GDP.

[26]The provided data contains also time series for the other two regions, West and Midwest, see also `https://www2.census.gov/geo/docs/maps-data/maps/reg_div.txt`.

[27]Real GDP in USD are 5.77 trillion (34.4 %) and 3.37 trillion (20.1 %), respectively of the total US real GDP of 16.8 trillion USD in 2017 (BEA). The population in the South region is 123.6 million (38 %) and in the North-East region 56.5 million (17.3 %) of the US total population of 325.7 million in 2017. Thus, the South is larger in both real GDP and population, the North-East has a higher real GDP per capita.

First Step The first step estimation for the US census regions North-East and South show considerable differences. Table 4.3 shows the GMM estimations of the deep (structural) parameters, alongside the resulting reduced form coefficients and the average price duration.

The North-East has a much higher estimated price stickiness $\hat{\theta}$ than the South, the shares of prices that cannot be re-optimised in any given period are 0.75 and 0.49, respectively. Further, estimated pricing backwardness $\hat{\omega}$ in the North-East is about half as large as the South. Once firms are able to re-optimise the shares of the new prices that follow the inflation-corrected average price of the last period are 0.28 and 0.54, respectively. The pattern from Europe is again visible, that the less price-sticky region relies more on the rule-of-thumb, while the more price-rigid region optimises using rational expectations, once they are finally able to re-optimise.

In terms of reduced coefficients, the estimated forward-looking component $\hat{\xi}^f$ of inflation expectations in the North-East is higher than in the South. The shares of domestic goods price inflation accounted for by inflation expectations are 0.73 and 0.48, respectively. Accordingly, the estimated shares accounted for by inflation inertia $\hat{\xi}^b$ are lower in the North-East than in the South, 0.27 and 0.52, respectively. In fact, in the South backward-looking pricing dominates forward-looking.

Also, since price stickiness is higher in the North-East, changes in the real marginal costs can be passed on to prices less well than in the more price-flexible South. Hence the estimated coefficient $\hat{\lambda}$ is lower in the North-East, than in the South, at 0.05 and 0.12, respectively. The higher price stickiness in the North-East is of course reflected in the estimated average domestic goods price duration $\hat{D}$ of 3.9 quarters as compared to 2 quarters in the South. All estimates, structural and reduced are highly statistically significant.

Second Step The results of the second step estimation of the consumption elasticity parameters $\hat{\gamma}$ for both census-regions, North-East and South are shown in table 4.4. Like in the first step, we see again considerable differences between the regions. Domestically produced goods seem to play a major role in the North-East, but only a very minor role in the South, the estimated consumption elasticities of domestic goods in the consumption basket are 0.88 and 0.14, respectively. This stark contrast drives also the patterns of the reduced parameter estimates. In general, the North-East core consumer price inflation rate is unaffected by price and cost developments in the South. Further, the North-East has a stronger effect on Southern core consumer price inflation rate than Southern price and cost developments themselves.

Dep. var.	GDP Deflator (monthly, annualised rate of change)	
	North-East	South
Price Stickiness θ	0.7461***	0.4935***
	(0.0003)	(0.0004)
Pricing backwardnes ω	0.2715***	0.5444***
	(0.0004)	(0.0004)
Inflation expectation ξ^f	0.7332***	0.4755***
	(0.0004)	(0.0004)
Inflation inertia ξ^b	0.2668***	0.5245***
	(0.0004)	(0.0004)
MC deviation λ	0.0469***	0.1169***
	(0.0001)	(0.0001)
Avg. Price Duration D	3.9393***	1.9743***
	(0.0053)	(0.0017)

Coefficient restriction $\beta = 1, \Theta = 1$ for all models. Upper panel shows the GMM estimates of the structural (deep) parameters, HAC-robust SEs in parentheses. Lower panel shows the reduced form coefficients based on the structural parameter estimates. SEs of the reduced form estimates are calculated via error propagation. Significance: $p < 0.01$ ***, $p < 0.05$ **, $p < 0.1$ *.

Table 4.3.: First Step Estimation. US census regions North-East and South, Non-linear hybrid NKPC, GDP Deflator (monthly, annualised rate of change), Log labour income share, HP-filtered.

The estimated shares of core consumer price inflation accounted for by domestic goods proce inflation expectations $\hat{\zeta}^f$ are 0.88 and 0.14, in the North-East and South, respectively, and the estimated shares accounted for by domestic goods price inflation inertia $\hat{\zeta}^b$ are 0.23 and 0.08, respectively.

For the North-East, the parameters $\hat{\chi}^f$ and $\hat{\chi}^b$ showing the estimated influence of Southern price development on core consumer price inflation in the North-East are not significantly different from zero, i.e. the price developments in the South have no statistically significant influence on core consumer price inflation in the North-East. However, in the South the estimated shares of the core consumer price inflation rate that is accounted for by expected inflation $\hat{\chi}^f$ and by inflation inertia $\hat{\chi}^b$ in the North-East are estimated at 0.63 and 0.23, respectively. That is, a total share of 0.86 of the Southern core consumer price inflation rate can be explained by out-region price and cost developments.

Similarly, in the North-East, only the influence of domestic real marginal costs developments $\hat{\kappa}$ have a statistically significant impact on the core consumer price inflation rate, estimated at 0.04, while the estimated influence of Southern real marginal costs developments are insignificant, i.e. marginal costs developments do not spill over from the South to the North-East. Conversely, in the South the estimated influences of domestic and North-Eastern real marginal cost deviations, $\hat{\kappa}$ and $\hat{\eta}$, are estimated at 0.02 and 0.04, again the influences from the North-East are stronger than the domestic developments.

All estimates are highly statistically significant, except for $\hat{\chi}^f_{\text{NE}}$, $\hat{\chi}^b_{\text{NE}}$ and $\hat{\eta}_{\text{NE}}$ which are not statistically significant at all. Still, these parameters estimates – insignificant as they are – are of a similar order of magnitude as the significant ones, but their standard errors are much larger. This rather points to a lot of noise in the data but not necessarily to economic insignificance.

Dep. var.	Core CPI (monthly, annualised rate of change)	
	North-East	South
Spillover γ	0.8799***	0.1449***
	(0.1036)	(0.0355)
Domestic Infl. Exp. ζ^f	0.6452***	0.0689***
	(0.076)	(0.0169)
Domestic Infl. Inertia ζ^b	0.2348***	0.076 ***
	(0.0276)	(0.0186)
Foreign Infl. Exp. χ^f	0.0571	0.6269***
	(0.0493)	(0.026)
Foreign Infl. Inertia χ^b	0.063	0.2281***
	(0.0543)	(0.0095)
Domestic MC deviation κ	0.0413***	0.0169***
	(0.0049)	(0.0041)
Foreign MC deviation η	0.014	0.0401***
	(0.0121)	(0.0017)

Coefficient restriction $\beta = 1, \Theta = 1$ for all models, and θ, ω are calibrated and restricted to their first step estimates. Upper panel shows simultaneous GMM estimates of the consumption elasticity of substitution of home goods in both countries, HAC-robust SEs in parentheses. Lower panel shows the reduced form coefficients based on the structural parameter estimates. SEs of the reduced form estimates are calculated via error propagation. Significance: $p < 0.01$ ***, $p < 0.05$ **, $p < 0.1$ *.

Table 4.4.: Second Step Estimation. US census regions North-East and South, Non-linear MU hybrid NKPC, Core CPI (monthly, annualised rate of change), Log labour income share, HP-filtered.

Discussion In particular the second-step estimations for the US census regions North-East and South are peculiar[28]. The very low value of $\hat{\gamma}$ in the South could be indicating

[28] Including US House prices as an instrument did not alter the results qualitatively.

that consumers vastly prefer consumption goods from other census regions such as the North-East. Put differently, the South's industry seems to produce considerably more goods whose prices are not reflected in the Core CPI goods basket. This is further supported by the fact that the Core CPI in the South tracks the GDP Deflator of the North-East much closer than that of the South itself, see figure 4.1.

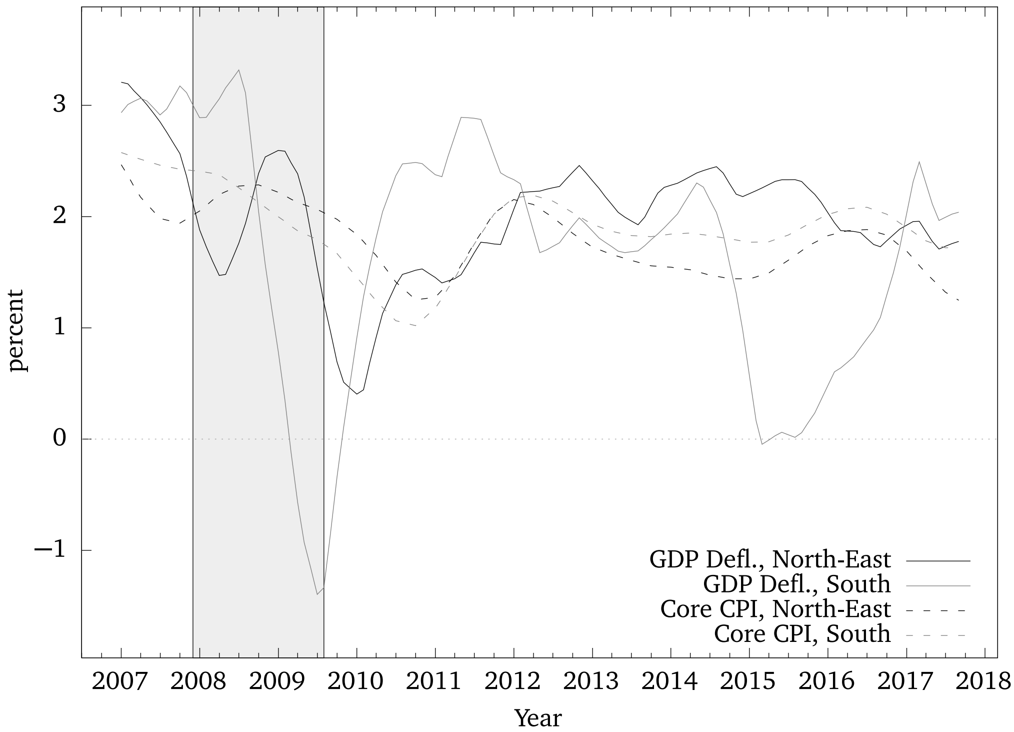

Figure 4.1.: GDP Deflator (solid) and Core CPI (dashed) monthly annualised inflation rate, census regions North-East (black) and South (grey).
Source: BEA and own calculations.

In fact, the South's GDP Deflator exhibits much stronger swings, especially during the sub-prime crisis and then again in 2015/16, maybe due to a severe oil price drop, affecting especially Texas' economy. Indeed, looking at the inflation measures (figure B.9 we see that both the CPI and the GDP Deflator declined in 2015/16, but not the Core CPI. The latter does not contain energy prices, but the two former do, and the decline coincided with a decline in oil prices (see figure B.21). This lends plausibility to the idea that a decrease in oil prices is behind the swings in the GDP Deflator in the South. Thus, it may be that the unusually low estimate of the South's home good preference is due to the underlying economic structures of a largely oil export based economy.

4.4.3. Remarks

While the MU-NKMseems to work fairly well in quantifying the strengths of cross-country inflation spillovers within the EEMU and US, a word of caution is in order. The MU-NKMis a highly stylised, two-country monetary union with no other countries/regions or rest-of-the-world, which is obviously too simple a view. First, the MUs in question have more than just two members, and second the countries/regions import from many other sources than just the other country/region. Accounting for all this would, however, inflate the equations without adding insight into the theoretical macroeconomic dynamics of MUs, albeit very desirable from an empirical point of view.

Further, a central relationship in the MU-NKMis the production function. In calibrating $\Theta = 1$, the assumed production function reduces to $Y = AN$, i.e. real production is linear to labour input, which is one of the most basic production functions. It may very well be that this is too simplistic to account for all variations between marginal costs and the inflation rate. Still, on theoretical grounds, as argued above, restricting Θ to be identical across the countries/regions is justified.

Another possible source for error is data. Especially that HP-filtering the marginal costs does not give deviations from the steady state, i.e. the employed measure is wrong. Note that eq. (3.7) describes approximate movements around the steady state. Following a related argument, it may also be that the economies are rather far away from the steady state such that the relationship predicted by the model cannot be observed in the data – if a steady state exists in the first place. Visual inspection of the data as shown in the charts above does indeed not refute suspicions about being far away from the steady state or, for that matter, that the steady state may have changed with the crisis or secular stagnation.

Moreover, instrumentation and appropriateness of the instrument set is a common problem in the literature on estimating NKMs. As mentioned in section 2.4.1, the Sargan/Hansen J-Test with the null hypothesis of a correctly specified model has only little power when sample length T is large. Like in chapter 2, I rely on a very conservative first-stage (not first-step!) F-test. I report neither the J-statistics nor the first stage F-statistics – the latter always fulfil my requirement of $F > 30$.

4.5. Conclusion

This chapter aims to add a new perspective on inflation spillovers within MUs, by using a fully micro-founded model. Central to the analysis is a variant of the HNKPC extended for MUs with direct spillovers of inflation expectations, inflation lags and marginal cost developments from one country to the other. This MU-HNKPC provides a straightforward estimation equation, which is taken to the data on Germany and France in the EEMU and the US census regions North-East and South. The estimation encompasses two steps: The first-steps gives estimated price stickiness and pricing backwardness parameters of the non-linear HNKPC, as well as the derived reduced form coefficients. Further, the second step estimations provide evidence on the preferences γ for home-made and "imported" goods – i.e. goods made in the respective other region. This is the central parameter in the MU-HNKPC, governing the strengths of the direct spillover channels.

For Germany and France, the estimations are in very good agreement with the theoretical prediction of $\gamma \approx 0.6$ for the model to show saddle-path stable dynamics (see 3.3), while the estimations for the US census regions are less satisfactory in that regard

The difference suggests that the EEMU and the US are two different kinds of MU, see also section 1.2. To explain this difference, consider again the underlying model and its channel of price spillovers. The model in chapter 3 considers economies where every good is produced (see eq. 3.5) in both regions and consumers have non-zero preferences for both regional varieties of the same good. In other words, the model requires economies that produce the full range of consumer goods and happen to share a currency. The price spillovers in the model works via the imports of goods varieties from the other region. Naturally, only produced goods can be exported to the other region and lead to price spillovers. When only a subset of the goods continuum is produced in the first place, price spillovers are partially blocked, at least in one direction – from the specialised region to the other, but not necessarily vice versa. From this theoretical reasoning, fitting the model to regions with industrial specialisation should not work too well.

Both the EEMU and the US are highly developed and well-diversified economies with a strong federal aspect. However, given the age of the US economy, its degree and of political and fiscal integration, there is much more scope for regional economic specialisation, for example products that are largely meant for export such as oil in the South, but more domestically consumed goods and (financial) services in the North-East. This economic specialisation may be behind the differences in the second step estimations of the US census regions as compared to Germany and France. We can thus use the model as a possible operationalisation to distinguish among-nations MUs from within-nations MUs (Hamada and Porteous, 1993). Judging from the empirical evidence from the analyses in this chapter, the EEMU is one of the former, while the US is one of the latter.

Both Germany and France are "full-range" economies that produce, consume, import and export all types of goods and services, because of their centuries-old history as nation-states. Quite differently, the US regions (and states) have virtually always been a part of a larger economic area, and thus had not had the need to develop the full range of goods and services, unlike the European nation-states. This highlights a central difference between the "sui generis" EEMU (Eichengreen, 2008) and the US as a fully integrated economy with a strong federal nature.

Future research could take the estimates presented here to calibrate the model. Like in section 3.3, this calibrated model is then simulated to see the effects of shocks. Rephrasing the question from chapter 2, the model could also be estimated, calibrated and then simulated for the three periods to see how the effects of shocks changed over time.

Another worthwhile expansion of the analysis in this chapter would be to estimate the full five-equation model of 3, adding the aggregate demand (AD) schedule and an interest rate rule. Using the simultaneous moment condition approach of the second-step estimates, we can estimate the non-linear[29], closed-form variants of the model.

Finally, to reinforce or challenge the argument of industrial specialisation being behind the unexpected estimation results of the US census regions, we can use two metropolitan areas of the US as regions of an MU instead of the rather large census regions, see also section 5.2.

[29] Earlier attempts at estimating the linear model have unfortunately been less successful.

5. Conclusion

THIS thesis looks into the "inner workings" of monetary unions, from the perspective of asymmetry, direct spillovers and microeconomic foundations. More precisely, I investigate how the macroeconomic dynamics of prices, costs and production of one country influence these magnitudes in other countries, under the premise of sharing a currency and thus monetary policy. The immediate consequences of being in a monetary union (MU) are that the nominal interest rate is identical for all countries and that there are no nominal exchange rates that could fluctuate to offset changes – acknowledging this feature sets the analyses of the thesis apart from studies of international economic that use similar models.

5.1. Summary

The first chapter gives an overview of the problem of economic interconnectedness in monetary union, i.e. when nominal interest rates are the same for all members and nominal exchange rates are unavailable to smooth out idiosyncratic shocks. Further, I sketch the operationalisation of this problem using the (New Keynesian) Phillips Curve and highlight the three aspects of micro-foundations, asymmetries and direct spillover channels. The introduction also includes an encompassing literature review and how this thesis connects to previous contributions.

Chapter 2 looks empirically into how the common monetary policy (CMP) of the European Central Bank (ECB) influenced the inflation dynamics in six European countries. The analysis considers three distinct time periods, first from the establishment of the European Econonomic and Monetary Union (EEMU) until the crisis, second during the financial crisis of 2008/09, the sovereign-debt crisis in Europe in 2010/11, and third after the reaction of the ECB to the crisis, in particular the announcement of ECB president Draghi to do "whatever it takes" to preserve the EEMU. This announcement signals a fundamental shift in the monetary policy stance of the ECB, committing it fully to unconventional monetary policy[1] in order to fight the crisis and its divergent forces on Europe's economies. Splitting the sample in three periods, pre-crisis, crisis and "Whatever-It-Takes", and estimating an Hybrid New-Keynesian Phillips Curve (HNKPC) for each period and each country in the sample, we can pin down the effects of both the crisis and the ECB's monetary policy response on the macroeconomic developments in Europe. The results from these estimations varied strongly across the countries in the sample, reinforcing the skepticism of treating an MU as a big monolithic bloc instead of a set of countries with different economies. Thus, the need arises to describe such an MU theoretically as something between countries merely engaged in trade and an aggregate setting.

Such a model is developed in chapter 3, in many ways a two-country, monetary union analogue to the standard New-Keynesian Model (NKM), hence I call it the MU-NKM. In a two-country setting, introducing goods from another country into the consumption basket of a household gives rise to an inflation schedule as the weighted average of the domestically and foreign-produced goods prices, and – together with staggered price setting and monopolistic competition – on both countries' marginal costs developments, augmenting the familiar New-Keynesian Phillips Curve (NKPC) with an additional term, the spillover from the other country. Further, with goods market clearing, the model describes the development of the marginal costs as a function of both countries' output gaps. The output gaps in turn are a function of productivity or technology of both countries, and can be solved to an augmented variant of the familiar Dynamic IS Curve (DISC), containing again spillovers from the other country. These spillover terms show the strong interconnectedness of the countries. A simulation study then investigates how the price and production dynamics of the countries in such a union react to various common and idiosyncratic shocks. Confirming the notion of the existing literature, idiosyncratic shocks are harder to remedy than common ones, due to the absence of national monetary policies. However, a proper welfare analysis is needed to see whether idiosyncratic shocks in a spillover setting are easier to mitigate than in a non-spillover setting. While for an MU idiosyncratic shocks are more difficult to deal with than common shocks, they may be not as difficult as previously thought, because the spillovers introduce a certain degree of pro-cyclicality thus reducing the transmission asymmetry (see section 1.3.1).

In chapter 4 the MU-NKMis then estimated. Using data for Germany and France, and the US census regions North-East and South, the model is estimated for these pairs.

[1]Due to its expectation changing effects, the *Whatever-It-Takes* announcement can be seen as a *pars pro toto* for all the unconventional monetary policies employed by the ECB.

The main finding is that, at least for Europe, the usual magnitudes of the parameters can be reproduced alongside a very plausible estimate for the measures of economic interconnectedness or the degree of spillovers. However, the model works less well for the US. This points towards the notion that the US are indeed no MU "among" countries like the EEMU but rather a "within-nation" MU (Hamada and Porteous, 1993) or a highly integrated national economy analysed by one-country macro-models.

5.2. Shortcomings and Future Research

This thesis explores several established concepts of the analysis of interacting economies, combining direct spillovers in a micro-founded New-Keynesian setting with various sources of asymmetry, to the best of my knowledge a novel approach. There are however, some shortcomings of the analyses in this thesis, most of them can be addressed in future research.

The analysis in chapter 2 could benefit from introducing also a measure of the aggregate demand side of the economies, in this context usually a DISC. This would require, however, the adoption of a structure on the utility function. Previous experience with the estimation of a DISC, especially using the output gap as the driving variable, shows rather poor results. A possible remedy may be the use of the non-linear variants, relying on global moment conditions like in the first step of the two-step estimation approach in chapter 4. Still, estimating two equations per country and possibly an interest rate rule may turn out to be too taxing on the dataset, as I have experienced in an earlier attempt[2] at the analysis of chapter 2.

The model of chapter 3 could be extended to a three-country or an n-country setting, to analyse cross-spillovers and secondary spillovers. Moreover, an n-country extension would also provide a micro-founded spillover-model that can be estimated for all of the EEMU-members. In principle, such an extension should be possible, Galí and Monacelli (2008) for example analyse a micro-founded MU of infinitely many, infinitely small members, naturally without bilateral, direct spillovers. Still, their work could be a starting point for an extension to more than two countries. Early attempts indicate however that extending the model gives rise to very large, unwieldy equations, especially in the derivation of natural output. Additionally, to answer the question about optimal monetary policy under direct spillovers, the model would benefit from a proper welfare

[2] My earlier attempts at estimating equation systems suffered from large standard errors and in turn from insignificant results, although the estimates themselves seemed plausible. I concluded that I did not have had enough data to cover for all the parameters and for using auto-correlation robust standard errors.

analysis, as shown by Galí (2008) and Woodford (2003) who derive a welfare function as an approximation to the utility function. Such an approximation may however require additional assumptions in the context of the model of chapter 3. Quite possibly, however using the established ad-hoc linear-quadratic welfare-loss functions prevalent in the literature on optimal (monetary) policy may provide a reasonable first attempt. As Monteforte and Siviero (2010) point out, there is the possibility of economically relevant "welfare underperformance" when only looking at area-wide developments. A starting point from the literature could be the analysis of Wolski (2015), but also Gros and Hefeker (2002). These two extensions combined, more than two countries and a welfare-measure, open the door to analysing policy interactions in the spirit of i.a. Canzoneri (1982), Canzoneri and Gray (1982), and Canzoneri and Henderson (1991), or institutional design in the spirit of Hefeker (2003). Another extension could be the introduction of public sectors, taxes and (possibly uncoordinated) fiscal policies, both country-wise to better capture the current set-up and policy discussion of the EEMU, and centralised to analyse the effects of a "fiscal union".

For the EEMU, it would be worthwhile to expand the analysis in chapter 4 by splitting the sample like in chapter 2 to isolate the spillover-effects before, during and after the crisis. Further, the model could be estimated using more than two countries to improve the policy recommendations. However, without a properly micro-founded n-country version, such an estimation would necessarily be ad-hoc, as would be the corresponding policy recommendations. Desirable from a policy point of view would be the introduction of interest rate spreads in the model and also a proper welfare analysis. Given the poor results using data from the US census regions, as a robustness check, it may be worthwhile to estimate the model again using US data on metropolitan regions, given that the census regions are very large and disparate. Finally, the model may also be estimated using data from regions of other MUs or federally organised countries, say Swiss cantons or Australian regions.

5.3. Key Message

The key message from the analyses of MUs presented in this thesis is the importance of the single member countries of said union and their economic interconnectedness with their fellow members. Especially in advanced economies, like in Europe where there is a high degree of trade and the free flow of goods, services, capital and people – the Four Freedoms – across the union, economic developments in the countries affect their peers quickly. These spillovers are quantifiable as parameters in a micro-founded model of an MU and are of course subject to asymmetries, reflecting a member country's degree of exposure to economic developments from its peers. The literature on MUs in general and on EEMU in particular focusses mainly on unsystematic spillovers, i.e. the propagation of random shocks, both idiosyncratic and common ones, see section 1.5, and especially sections 1.5.2 and 1.5.3. As long as the EEMU remains a set of – highly interconnected – economies, instead of a fully integrated economy, with different avenues for equalisation of shocks, it is not only worthwhile but necessary to look at the disaggregate level of the member countries – and especially at how they directly interact. Thus, the somewhat novel approach of this thesis, at least in the specific context of MUs and using the EEMU as an example, is to consider direct systematic spillovers from one country to another, not only via the movements in aggregate magnitudes. While the aggregates themselves are of course what we observe, spillovers play an integral role in their future development. The aggregate magnitudes of an MU as a whole – in its notion as a net magnitude – are not sufficient to analyse the macroeconomic dynamics, because they lack cross-country spillovers and their effects. Understanding these dynamics, however, is important for the proper conduct of economic policy and has implications for economic theory as well.

Policy makers, especially in the EEMU, need to be aware of these (asymmetric) systematic spillovers across countries, to see how price and cost movements propagate through an MU and to more accurately forecast the future developments. Taking these systematic spillovers into account will change the expectations of (welfare) outcomes of policies across the countries. Whenever expected welfare changes, so does the result of the reaction function – even if the reaction function itself does not change. Yet including direct, systematic spillovers also changes the reaction function, because the system of interactions becomes more complex. This in turn changes the calculus of feasible and desirable policy outcomes. Necessarily, the spillovers and the reactions need to be quantified in order to formulate actual policy. A such estimated model would allow both monetary and fiscal policy makers to evaluate the effects and dynamics of policies in greater detail, leading perhaps to more appropriate policies and welfare improvements.

For theory, the notion that the systematic spillovers of macroeconomic magnitudes like prices, costs and production across countries can be modelled in a micro-founded, disaggregate way, may give rise to improved macroeconomic models of open economies. Consequently, this also holds for the open economies of MUs themselves, i.e. how an MU's trade with third countries influences the member countries both directly and via the spillover channels. Such MU-trade models could be used to formulate a better trade policy of the whole MU vis-à-vis third countries, and to understand more of the distributional effect of trade among the members of an MU. Finally, the way direct spillovers among the members of an MU are incorporated into an otherwise conventional model may be adapted to medium and large-scale models, improving again our theoretical understanding of the macroeconomic dynamics of MUs and hence give policy makers a better tool to base their decisions on.

5.4. Outlook

The EEMU's nature of being more than just a free-trade area with a common currency but less than a fully integrated economy, requires the use of specialised models, that take into account the peculiarities of the only "proper" MU of highly developed, industrialised economies. Indeed, the last three years since the United Kingdom (UK)'s 2016 referendum on leaving the European Union (EU) has revealed to the general public the enormous interconnectedness[3] between the member countries themselves, and the repercussions if they are severed without an agreement. The UK's planned leaving and the negotiations among the members of the EU after the European Elections about the leading positions in its institutions are a strong reminder that it is the members of the EU themselves that are central economic players, not the union. Recognising this fact by using adequate models is necessary for both the conduct of economic policy and for a healthy, evidence-based debate about the future of European integration. This debate must be pursued not only among economists or politicians, but mainly among citizens and voters, who must be able to base their decisions on the most accurate description of the European economies as possible – whether they do it in the end does not matter for the duty of economic researchers to provide the best available analysis. It is my hope that this thesis contributes towards this goal.

[3] Even though the UK has its own currency.

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A. Data Sources

Data series	Source	Calculations
EEMU		
(Core) HICP inflation rate	Eurostat	-
GDP Deflator	Eurostat	linear interpolated
MC deviations	Eurostat	labour income share, de-seasonalised, linear interpolated, HP-filtered
Survey based inflation expectations	CESifo GmbH, München	-
Wage inflation	OECD	Compensation of employees, linear interpolated, growth rates
Output gap	Eurostat	Real GDP, linear interpolated, HP-filtered
Long-term interest rates (10-year sovereign bond yields)	Eurostat	-
Short-term interest rate (EONIA)	Eurostat	-
US		
(Core) CPI inflation rate	BLS	de-seasonalised
GDP Deflator	BEA	state-level real and nominal GDP, summed to regional level, linear interpolated
MC deviations	BEA	labour income share, linear interpolated, HP-filtered
Survey based inflation expectations 1	Fed Philadelphia	linear interpolated
Survey based inflation expectations 2	Fed Cleveland	-
Output gap	BEA	Real GDP, linear interpolated, HP-filtered
Wage inflation	BEA	employee compensation, linear interpolated, growth rates
Long-term interest rates (10-year sovereign bond yields)	Fed St. Louis	-
Short-term interest rate (EFFR)	Fed St. Louis	-
General		
Oil prices (Brent and WTI)	US Energy Information Administration	growth rates, as appropriate deflated with USD/EUR nominal exchange rate
USD/EUR nominal exchange rate	ECB (1998-2017) Fed St. Louis (1979-1998, synthetic)	-

Table A.1.: Data sources

B. Data Charts

This appendix shows the charts of the time series used in the estimation of the models in chapters 2 and 4. The main series, inflation measures and marginal costs deviations, are presented in larger charts, whereas the instruments and controls are shown in smaller charts. See also appendix A for a more detailed description of the sources and the calculations done to raw data in order to arrive at the series presented here.

B.1. Inflation Measures

Following are charts of several inflation measures, for the European Econonomic and Monetary Union (EEMU) countries and the US census regions in the sample. European data are available from Eurostat and US data from the Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics (BLS), see also appendix A. The data have been de-seasonalised where necessary, and interpolated to monthly frequency in the case of the GDP Deflator figures. Finally, the so edited data are used to calculate year-on-year (annualised) rates of change, which are presented below. Shaded regions denote the "crisis" period in Europe as used in chapter 2 and the NBER "Great Recession"[1] in the US, respectively.

[1] See `https://www.nber.org/cycles/`.

B.1.1. EEMU

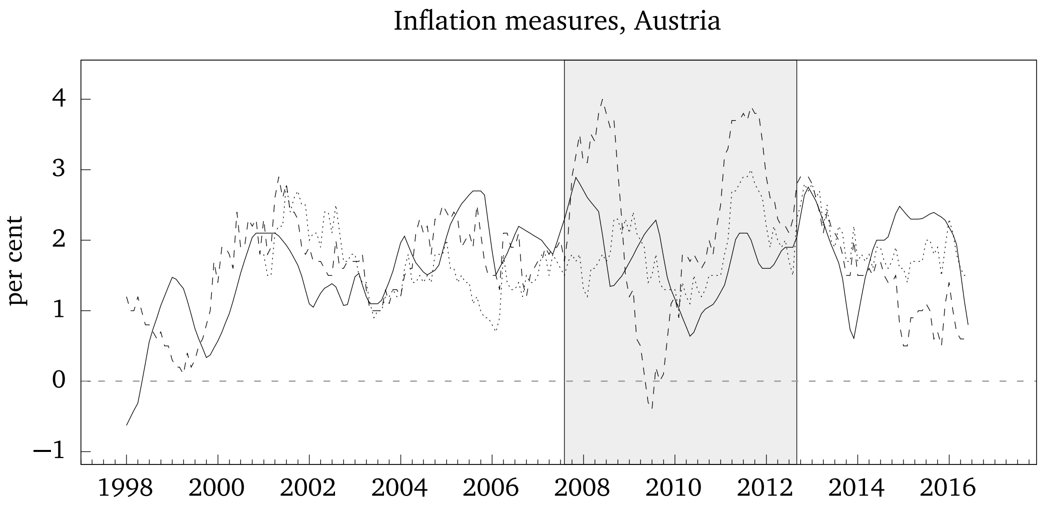


Figure B.1.: Austria, monthly, annualised rates of change of the GDP Deflator (interpolated, solid), HICP (dashed) and Core HICP (dotted). Shaded region is the crisis period. *Source: Eurostat, own calculations and illustration*.

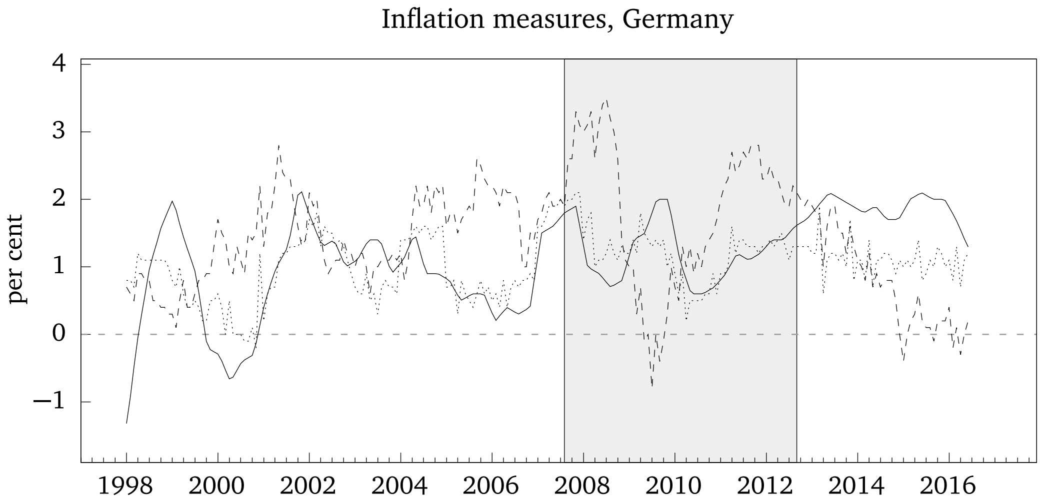


Figure B.2.: Germany, monthly, annualised rates of change of the GDP Deflator (interpolated, solid), HICP (dashed) and Core HICP (dotted). Shaded region is the crisis period. This is the same as figure 2.1, here repeated for convenience and completeness. *Source: Eurostat, own calculations and illustration*.

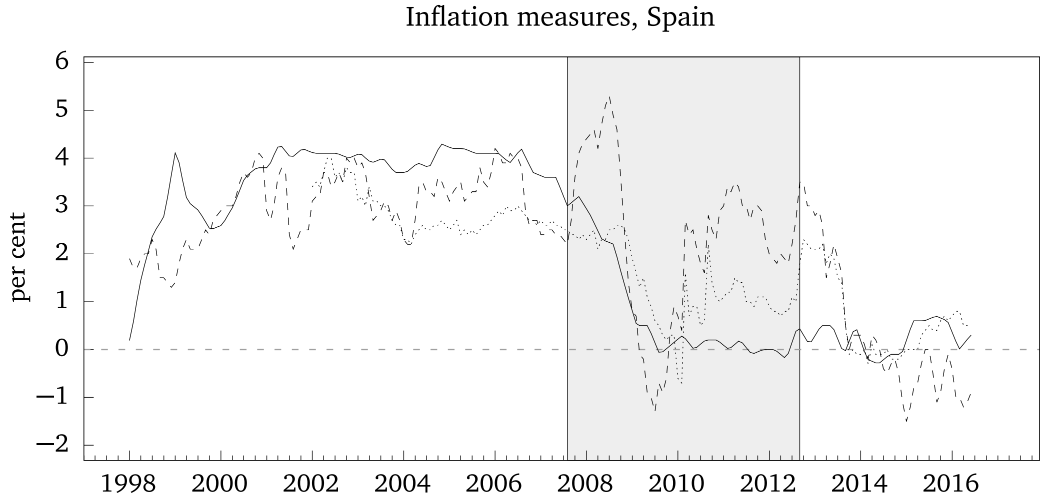


Figure B.3.: Spain, monthly, annualised rates of change of the GDP Deflator (interpolated, solid), HICP (dashed) and Core HICP (dotted). Shaded region is the crisis period. *Source: Eurostat, own calculations and illustration*.

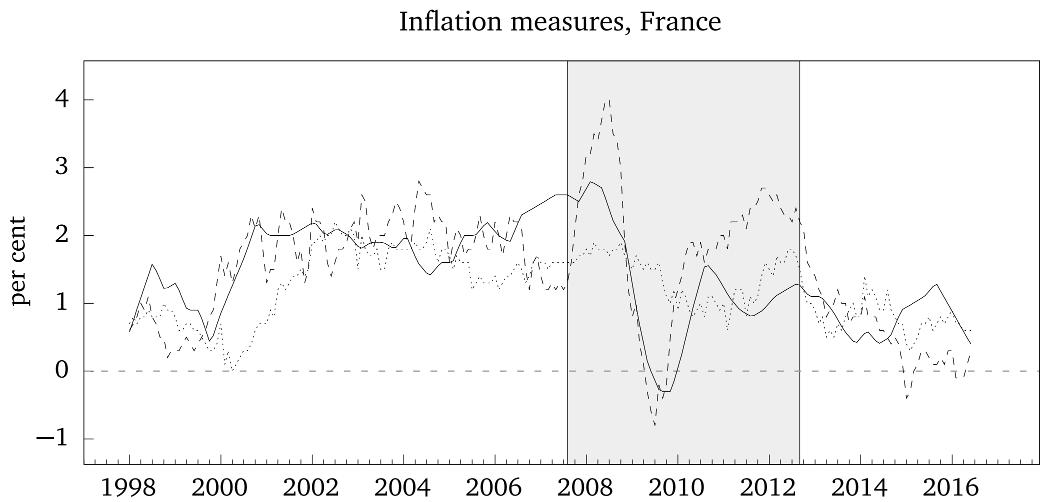


Figure B.4.: France, monthly, annualised rates of change of the GDP Deflator (interpolated, solid), HICP (dashed) and Core HICP (dotted). Shaded region is the crisis period. *Source: Eurostat, own calculations and illustration*.

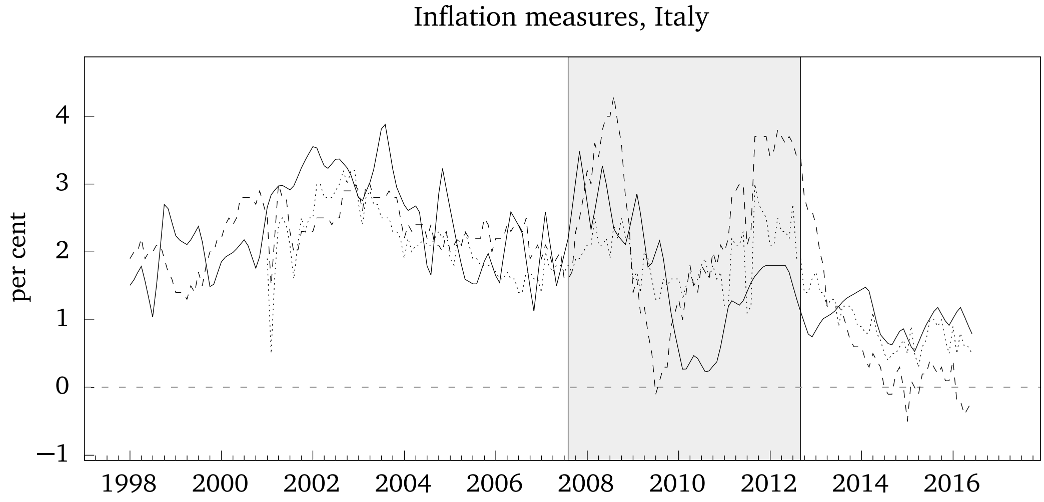


Figure B.5.: Italy, monthly, annualised rates of change of the GDP Deflator (interpolated, solid), HICP (dashed) and Core HICP (dotted). Shaded region is the crisis period. *Source: Eurostat, own calculations and illustration*.

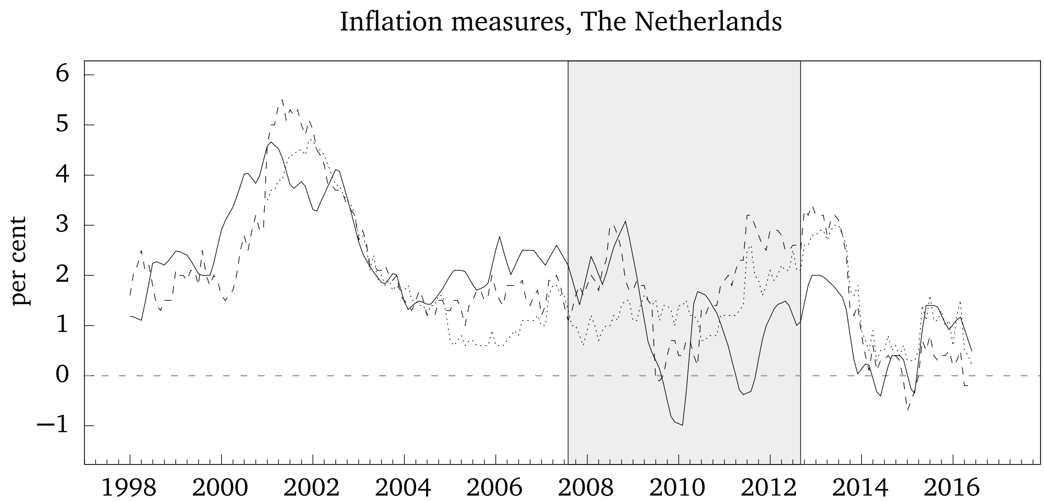


Figure B.6.: The Netherlands, monthly, annualised rates of change of the GDP Deflator (interpolated, solid), HICP (dashed) and Core HICP (dotted). Shaded region is the crisis period. *Source: Eurostat, own calculations and illustration*.

B.1.2. US Census Regions

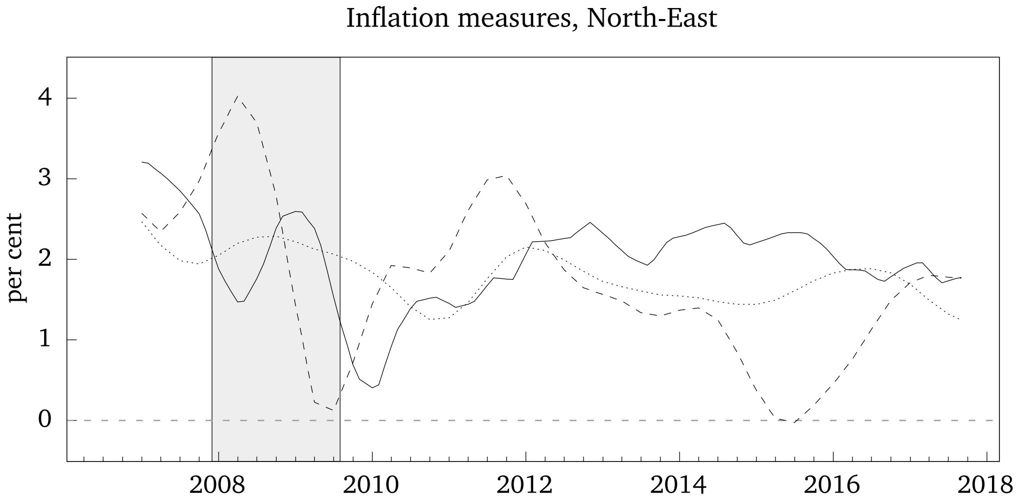


Figure B.7.: US census region North-East. Monthly, annualised rates of change of the GDP Deflator (interpolated, solid), CPI (dashed) and Core CPI (dotted). Shaded region is the "Great Recession". *Source: BEA, BLS, own calculations and illustration*.

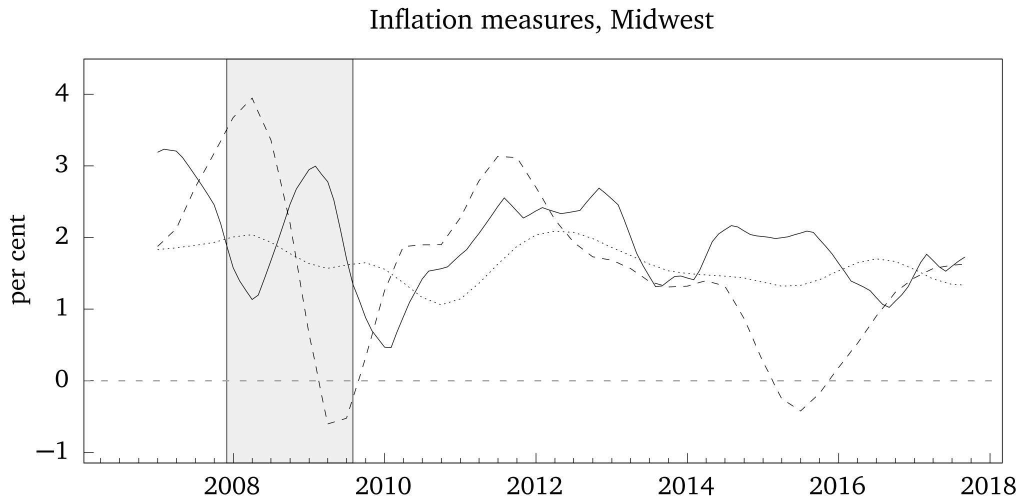


Figure B.8.: US census region Midwest. Monthly, annualised rates of change of the GDP Deflator (interpolated, solid), CPI (dashed) and Core CPI (dotted). Shaded region is the "Great Recession". *Source: BEA, BLS, own calculations and illustration*.

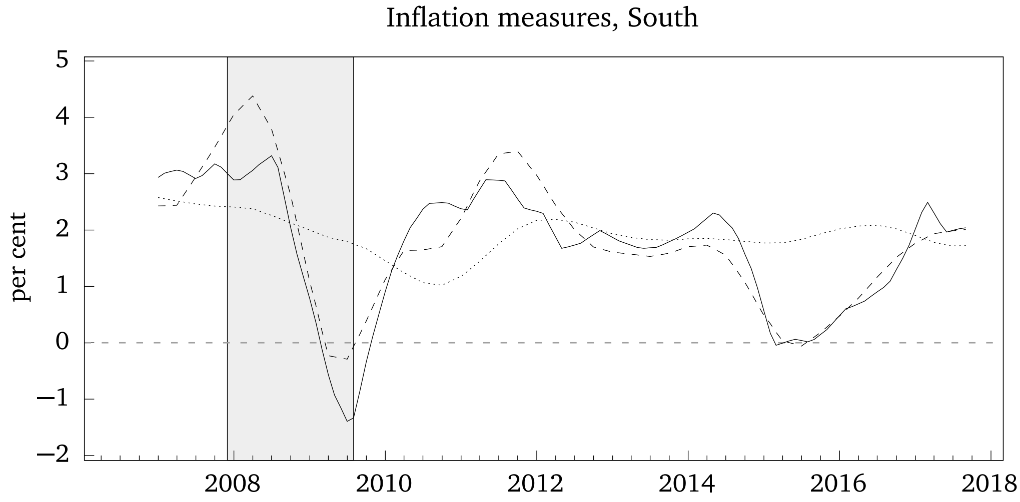


Figure B.9.: US census region South. Monthly, annualised rates of change of the GDP Deflator (interpolated, solid), CPI (dashed) and Core CPI (dotted). Shaded region is the "Great Recession". *Source: BEA, BLS, own calculations and illustration*.

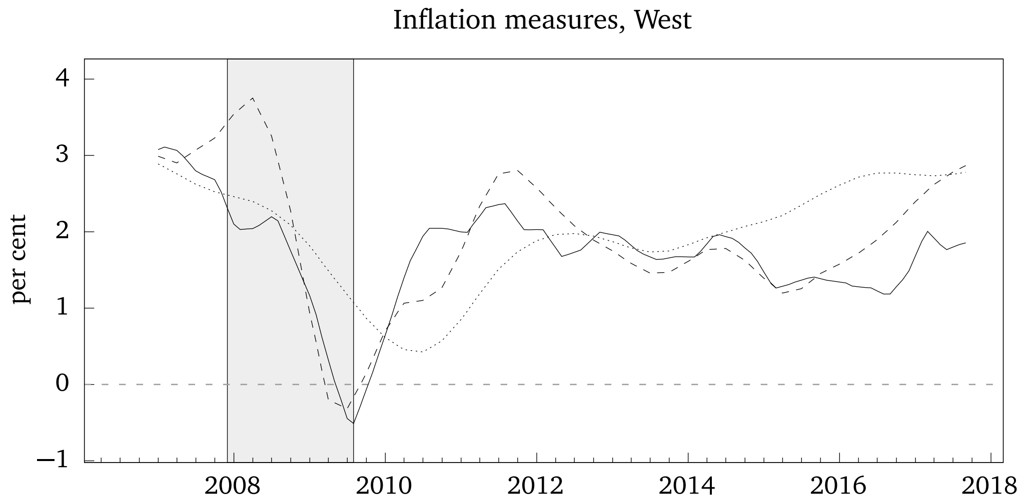


Figure B.10.: US census region West. Monthly, annualised rates of change of the GDP Deflator (interpolated, solid), CPI (dashed) and Core CPI (dotted). Shaded region is the "Great Recession". *Source: BEA, BLS, own calculations and illustration*.

B.2. Marginal Costs Deviations

The main driving variable of the estimated New-Keynesian Models (NKMs) in chapter 2 and 4 are the log deviations of real marginal costs from their steady state. Imposing a standard Cobb-Douglas production function allows expressing real marginal costs as the labour income share, see appendix D.1.

For the European countries, the data are compensation of employees as percentage of GDP, available from Eurostat, de-seasonalised and linearly interpolated from quarterly to monthly data.

Their deviations from the steady state are then, akin to the concept of the output gap, calculated as the cyclical component of the HP-filtered log series of labour income share, denoted by $\tilde{mc}_t$.

Shaded regions denote the "crisis" period in Europe as used in chapter 2 and the NBER "Great Recession"[2] in the US, respectively.

B.2.1. EEMU

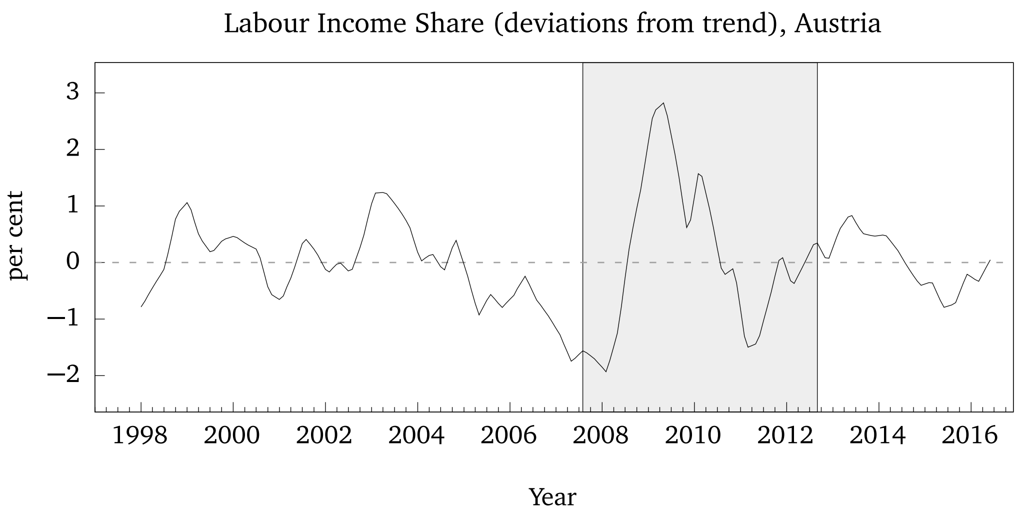


Figure B.11.: Austria, monthly marginal costs deviation from steady state, expressed as cyclical component of HP-filtered labour income share (monthly). Shaded region is the crisis period.
Source: Eurostat and own calculations.

[2]See `https://www.nber.org/cycles/`.

Labour Income Share (deviations from trend), Germany

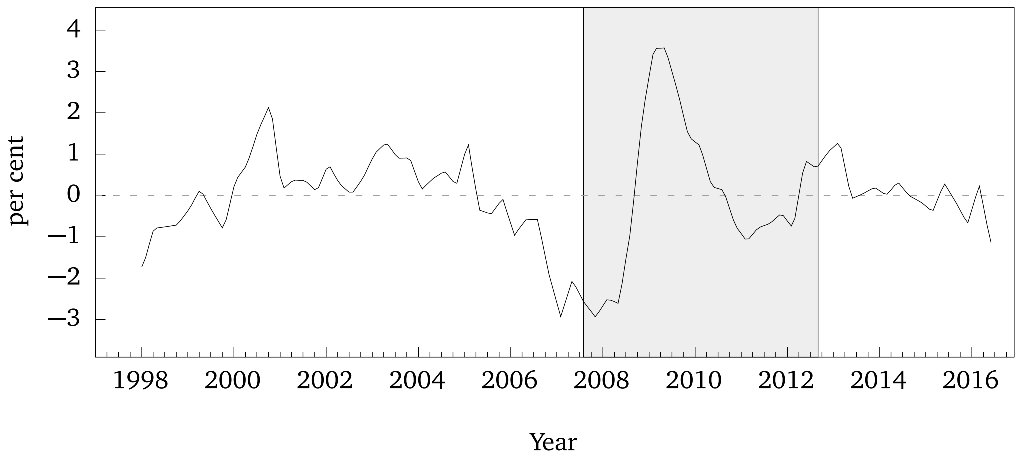


Figure B.12.: Germany, monthly marginal costs deviation from steady state, expressed as cyclical component of HP-filtered labour income share (monthly). Shaded region is the crisis period.
Source: Eurostat and own calculations.

Labour Income Share (deviations from trend), Spain

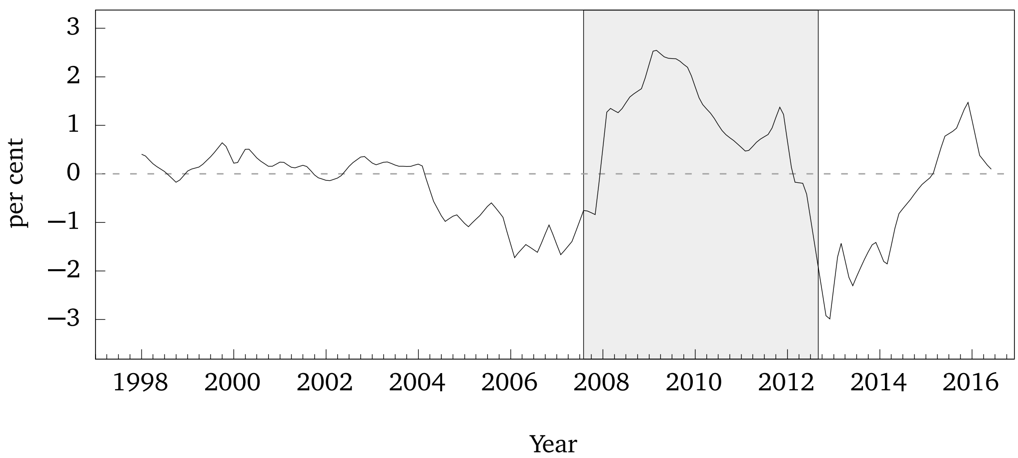


Figure B.13.: Spain, monthly marginal costs deviation from steady state, expressed as cyclical component of HP-filtered labour income share (monthly). Shaded region is the crisis period.
Source: Eurostat and own calculations.

Labour Income Share (deviations from trend), France

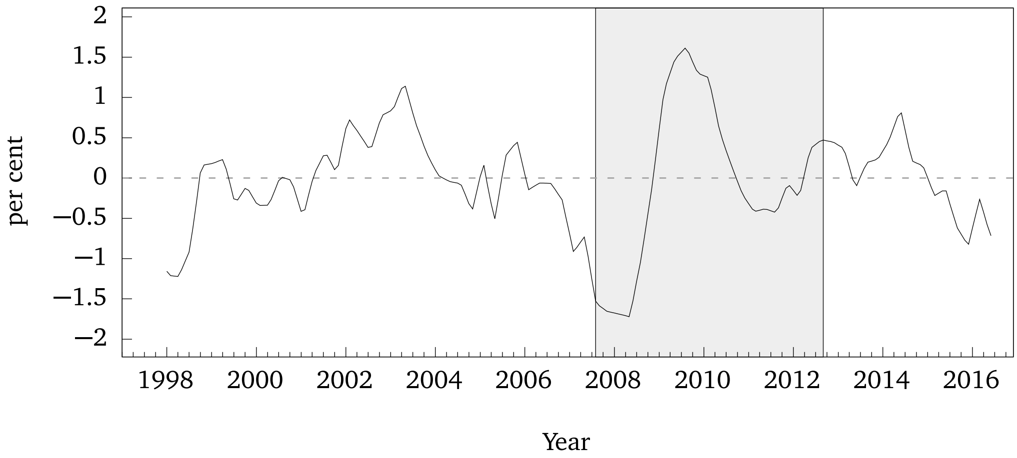


Figure B.14.: France, monthly marginal costs deviation from steady state, expressed as cyclical component of HP-filtered labour income share (monthly). Shaded region is the crisis period.
Source: Eurostat and own calculations.

Labour Income Share (deviations from trend), Italy

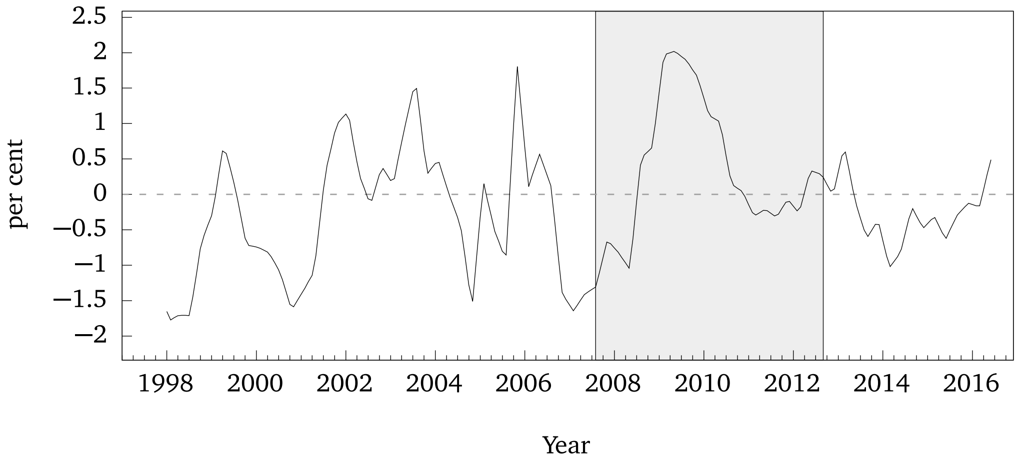


Figure B.15.: Italy, monthly marginal costs deviation from steady state, expressed as cyclical component of HP-filtered labour income share (monthly). Shaded region is the crisis period.
Source: Eurostat and own calculations.

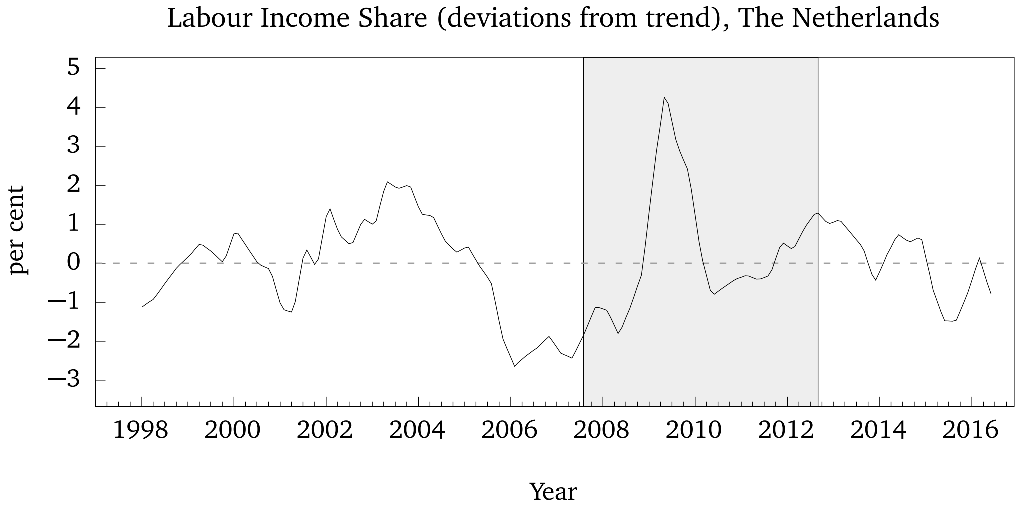


Figure B.16.: The Netherlands, monthly marginal costs deviation from steady state, expressed as cyclical component of HP-filtered labour income share (monthly). Shaded region is the crisis period.
Source: Eurostat and own calculations.

B.2.2. US Census Regions

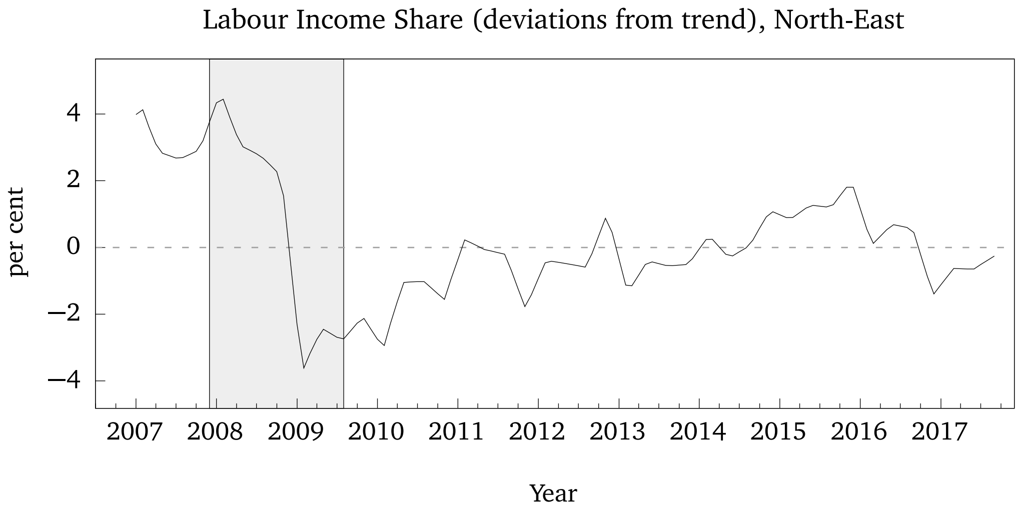


Figure B.17.: US census region North-East, monthly marginal costs deviation from steady state, expressed as cyclical component of HP-filtered labour income share. Shaded region is the "Great Recession" period.
Source: BEA and own calculations.

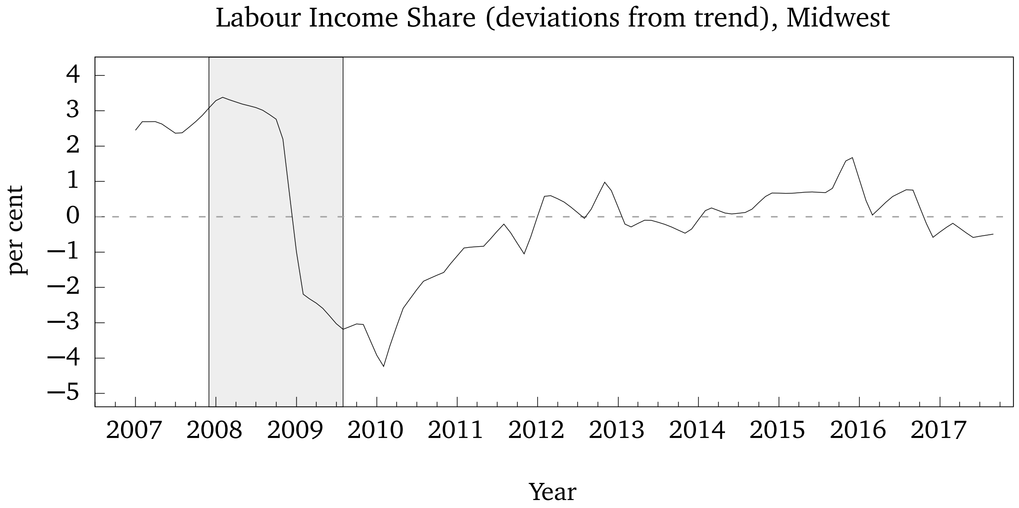


Figure B.18.: US census region Midwest, monthly marginal costs deviation from steady state, expressed as cyclical component of HP-filtered labour income share. Shaded region is the "Great Recession" period.
Source: BEA and own calculations.

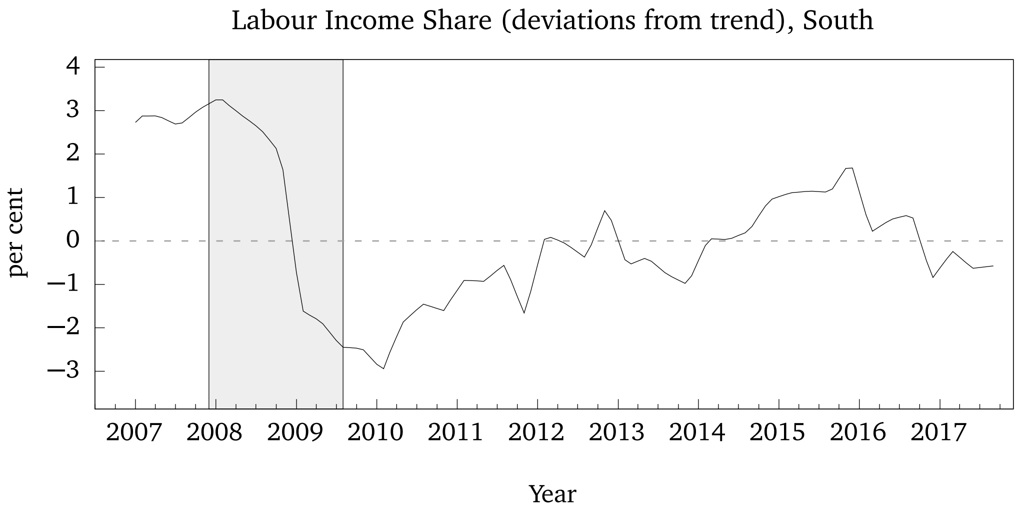


Figure B.19.: US census region South, monthly marginal costs deviation from steady state, expressed as cyclical component of HP-filtered labour income share. Shaded region is the "Great Recession" period.
Source: BEA and own calculations.

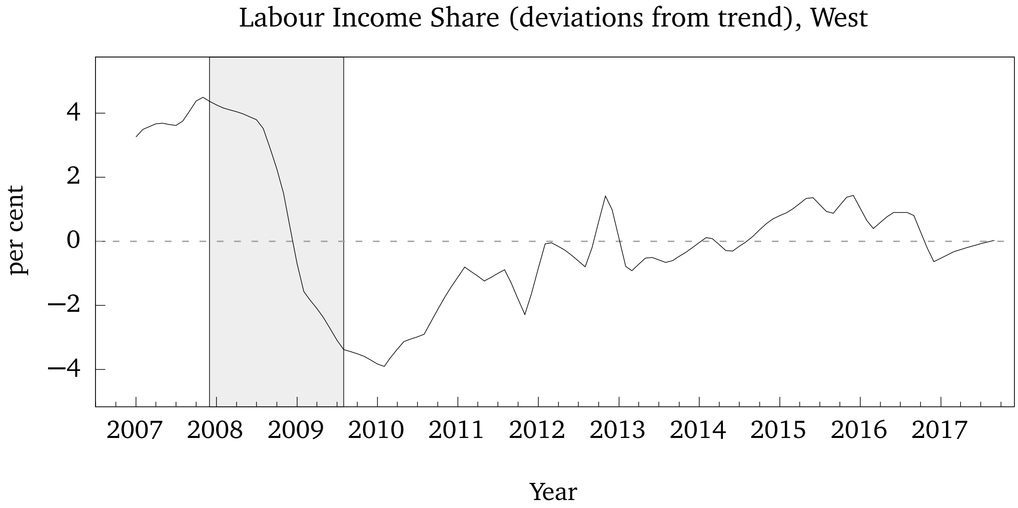


Figure B.20.: US census region West, monthly marginal costs deviation from steady state, expressed as cyclical component of HP-filtered labour income share. Shaded region is the "Great Recession" period.
Source: BEA and own calculations.

B.3. Oil Prices

The following chart shows crude oil prices (spot) of the dominating brands Brent and WTI in USD (dashed) and in EUR (solid; divided by the nominal exchange rate in quantity notation, see below.)

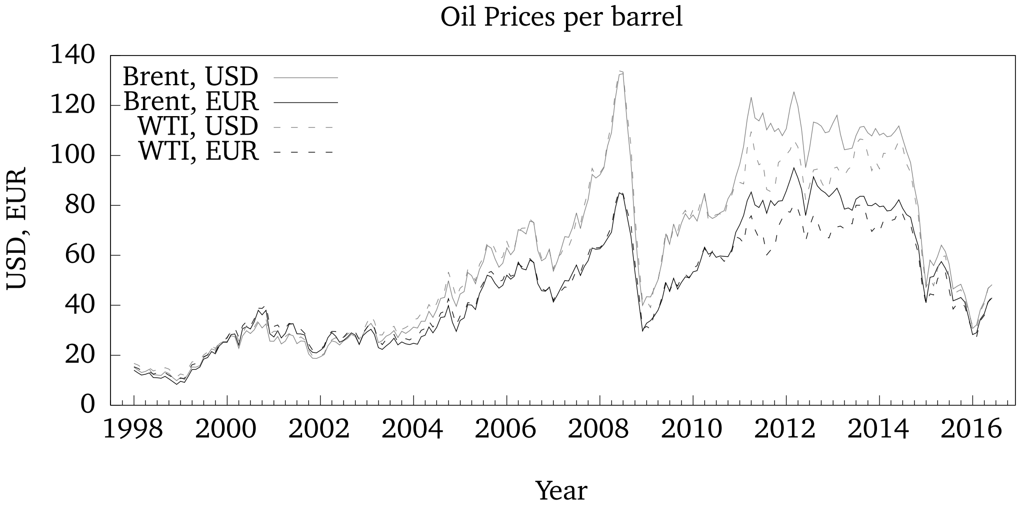


Figure B.21.: Crude Oil, Brent and WTI spot prices, monthly averages.
Source: US Energy Information Agency.

B.4. USD/EUR Nominal Exchange Rate

The following chart shows the USD/EUR nominal exchange rate, quantity notation, i.e. the number of USD one EUR buys.

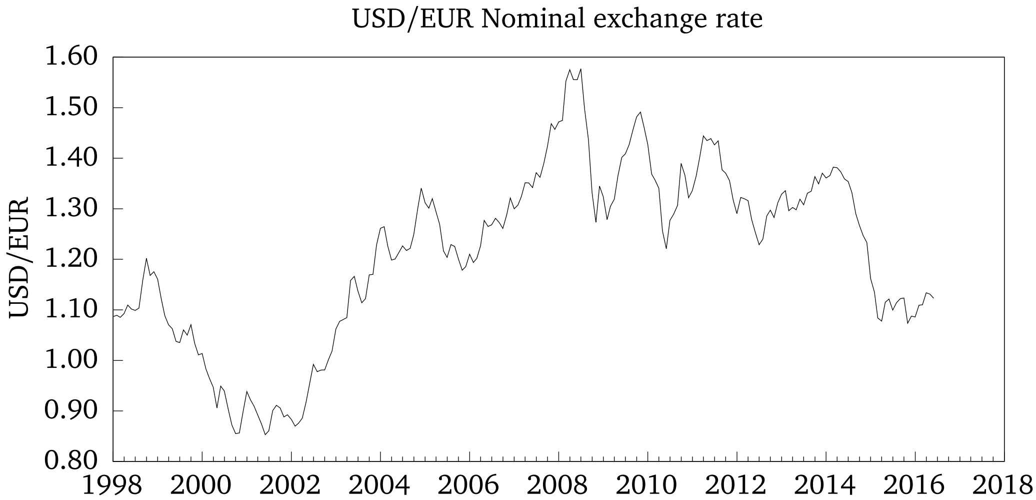


Figure B.22.: USD/EUR nominal exchange rate, quantity notation. *Source: ECB (from 1999) and Federal Reserve of St. Louis (1998, synthetic).*

B.5. Interest Rate Spreads

10-year sovereign bond yields less EONIA, monthly averages, vertical axes are in percentage points.

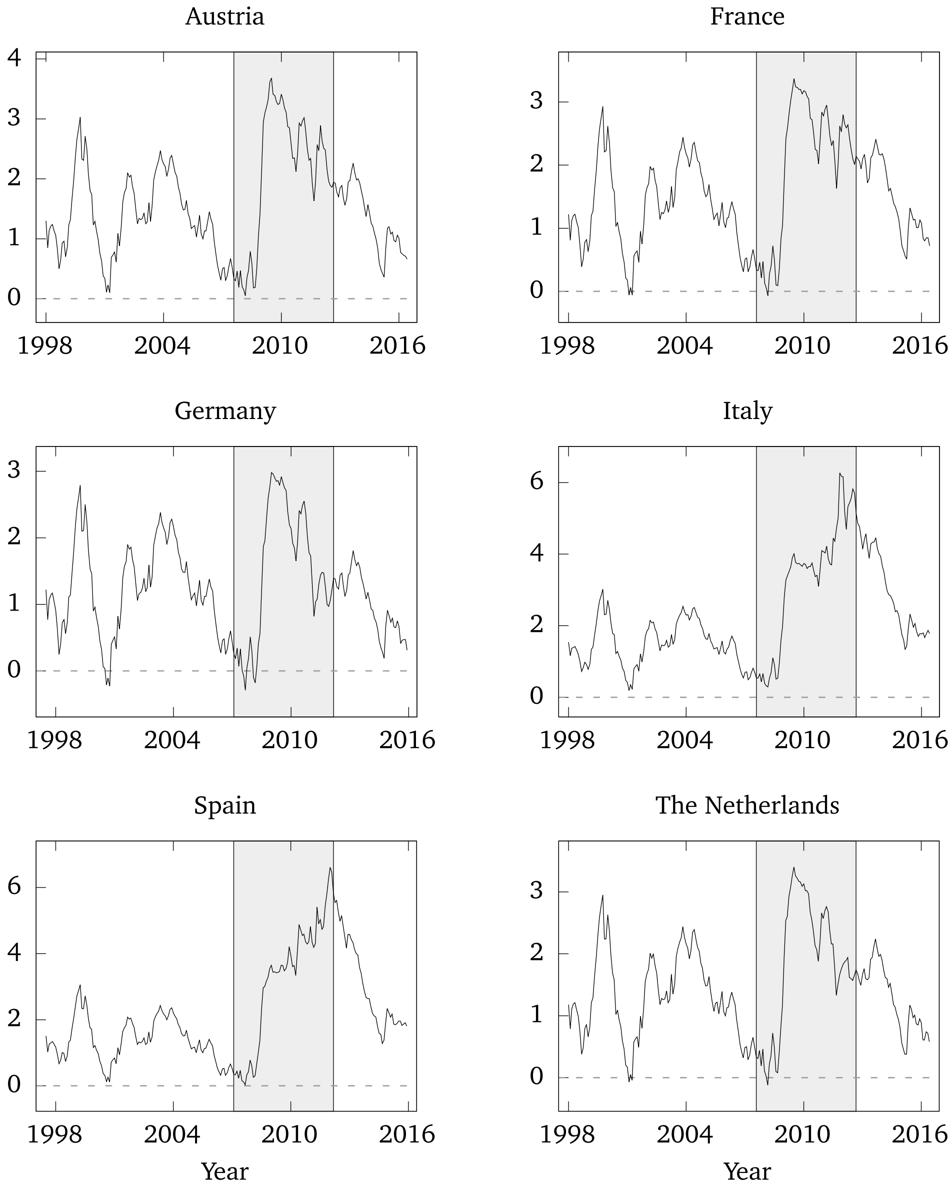


Figure B.23.: Long-term/short-term interest rate spread in selected EEMU countries. 10-year sovereign bond yields less EONIA in percentage points, monthly averages. Shaded regions are the crisis period from chapter 2. *Source: Eurostat.*

B.6. EONIA

EONIA, monthly averages.

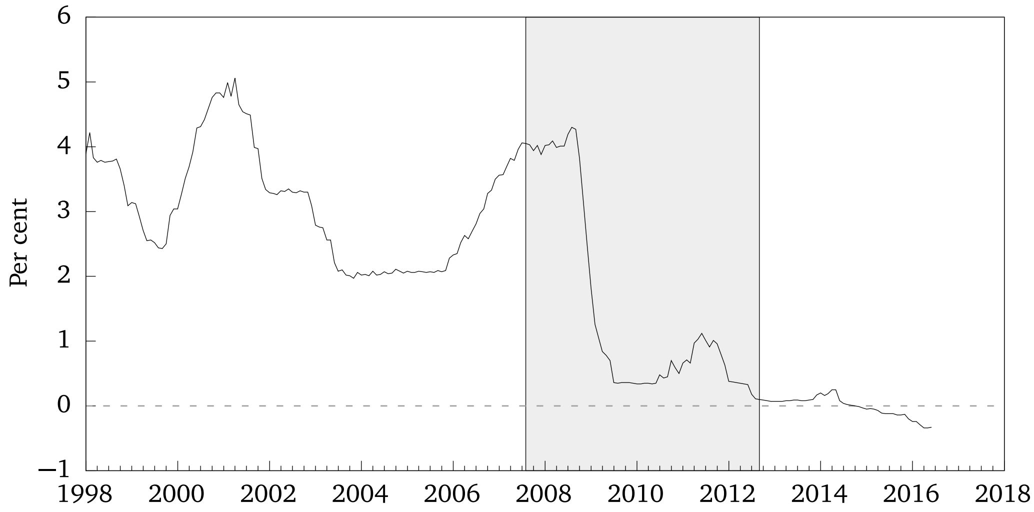


Figure B.24.: EONIA, monthly averages. Shaded regions are the crisis period from chapter 2. *Source: Eurostat.*

B.7. Output Gaps

Deviation of observed output from natural output, vertical axes are in percentage points.

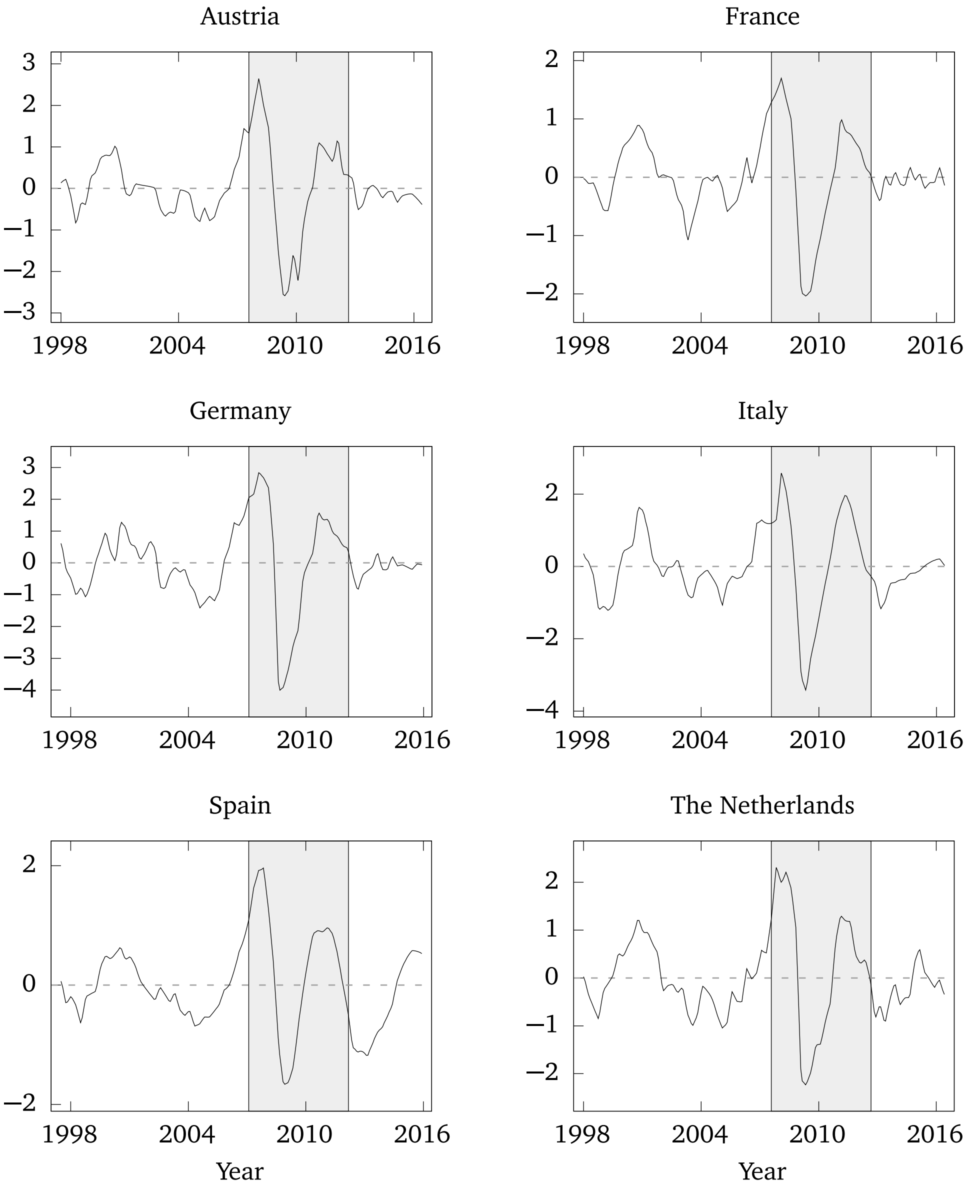


Figure B.25.: Output gap in selected EEMU countries. Cyclical component of HP-filtered real GDP in percentage points, interpolated monthly. Shaded regions are the crisis period from chapter 2. *Source: Eurostat.*

B.8. Wage Inflation

Growth rate of employee compensation, monthly annualised rate in per cent.

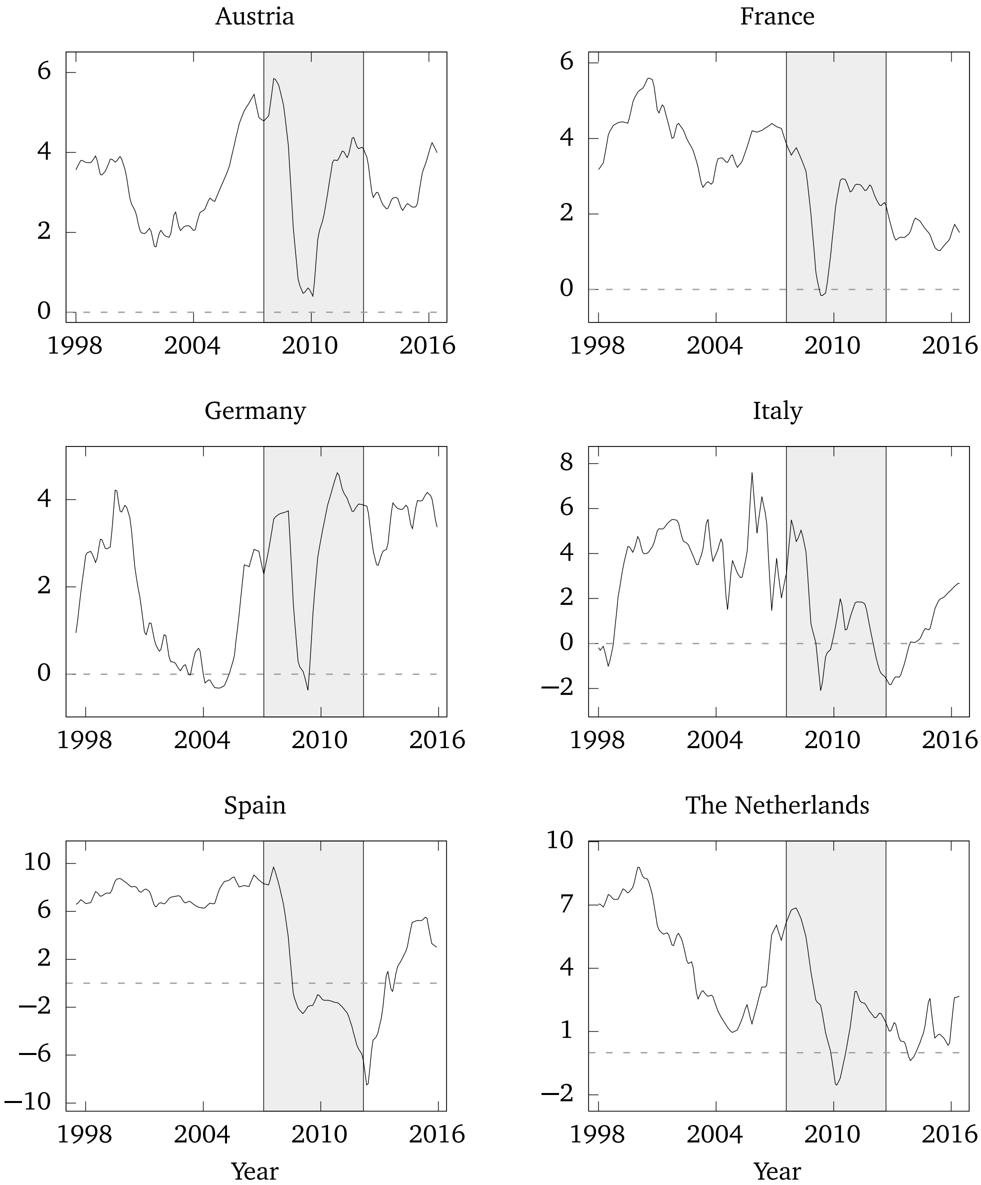


Figure B.26.: Wage inflation in selected EEMU countries. Shaded regions are the crisis period from chapter 2. *Source: OECD.*

B.9. Inflation Expectations

Survey-based, one-year-ahead inflation expectations.

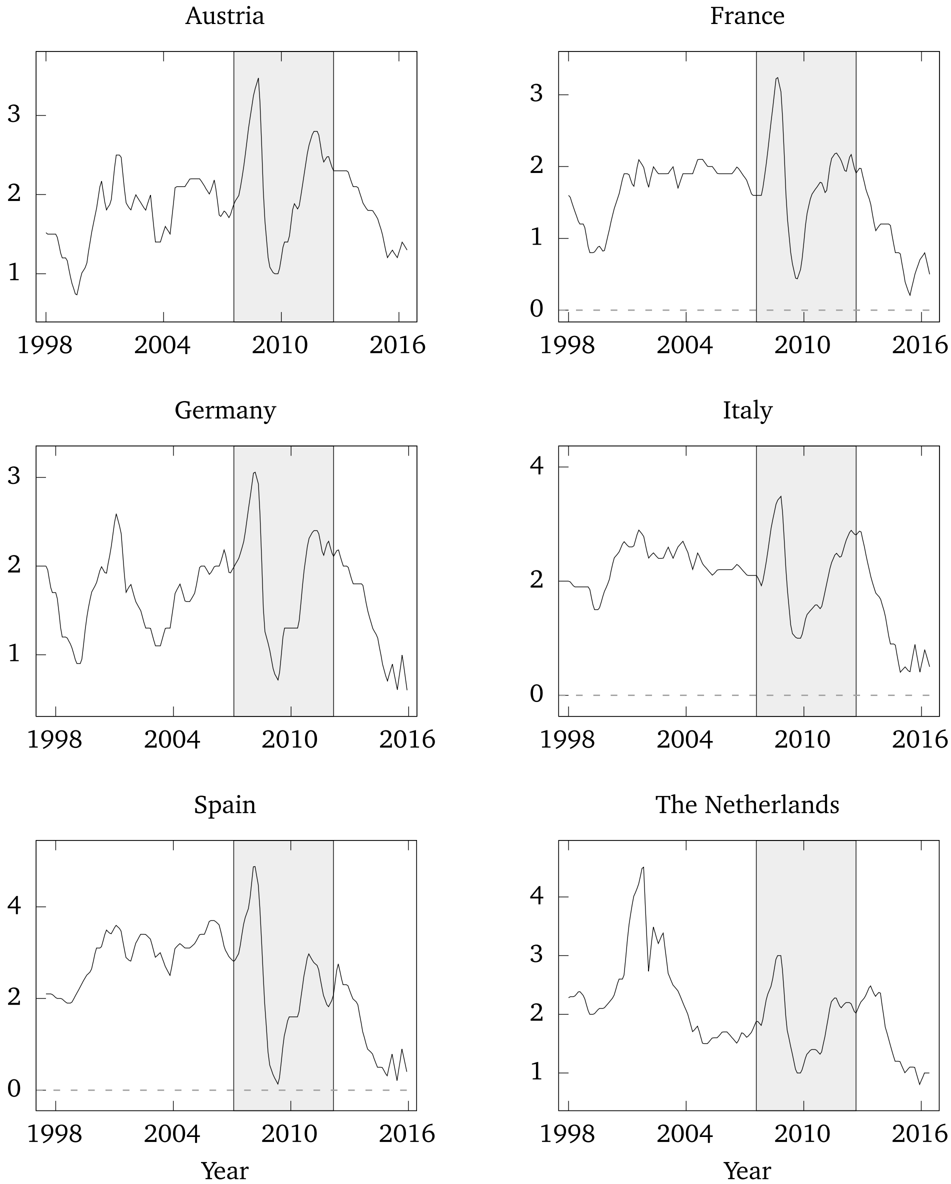


Figure B.27.: Survey-based, one-year-ahead inflation expectations in selected EEMU countries, monthly interpolated. Shaded regions are the crisis period from chapter 2. *Source: Garnitz et al. (2016)*.

B.10. Inflation Expectations (US)

One-year-ahead inflation expectations for the US at the federal level. The first is provided by the Fed Cleveland[3] (monthly) and is based on a model using Treasury yields, inflation data, inflation swaps, and survey-based measures of inflation expectations. The second one is the survey of professional forecasters and is provided by the Fed Philadelphia[4] (quarterly).

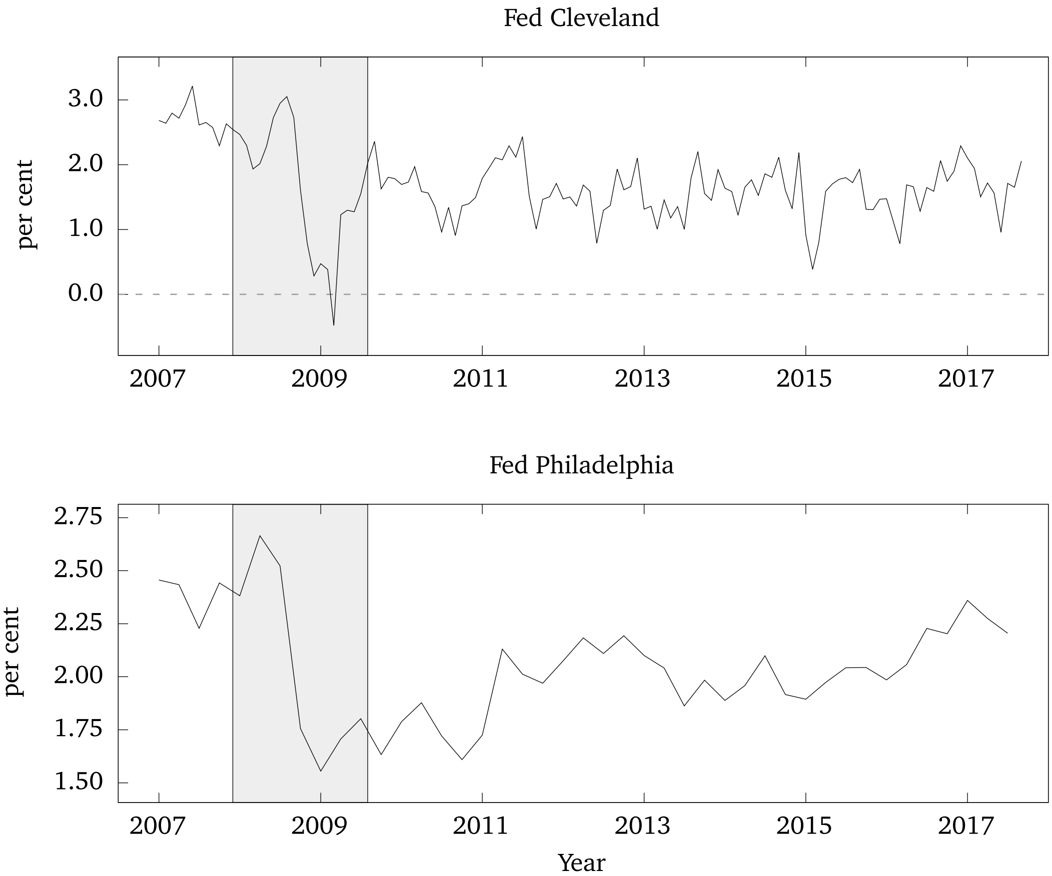
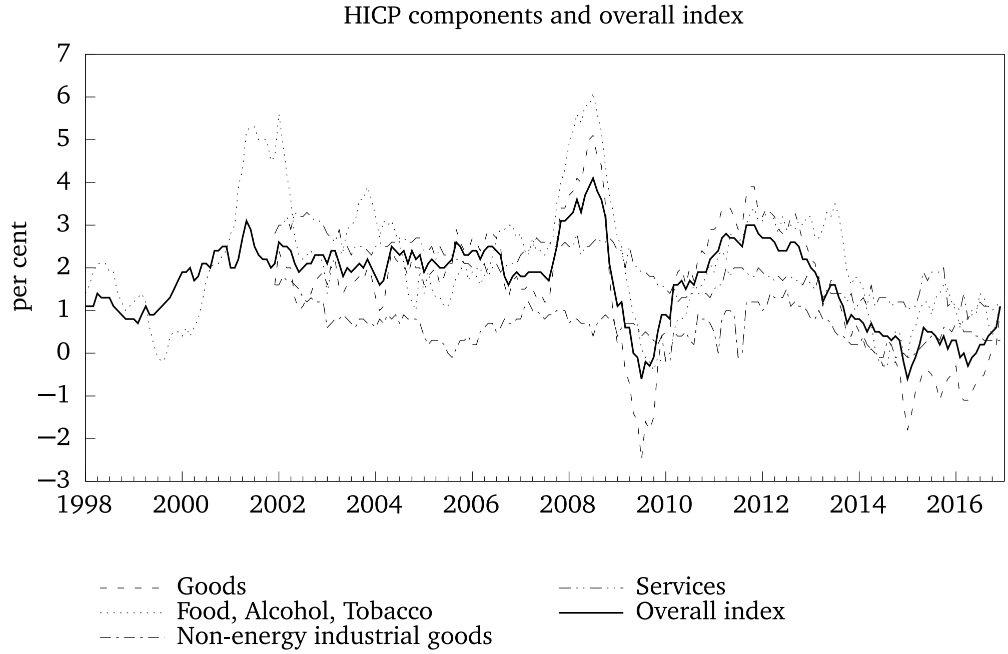


Figure B.28.: One-year-ahead inflation expectations in the US. *Source: Federal Reserve Banks of Cleveland (upper panel) and Philadelphia (lower panel).*

[3]See https://www.clevelandfed.org/en/our-research/indicators-and-data/inflation-expectations.aspx, last visited on 26 Nov 2018.

[4]See https://www.philadelphiafed.org/research-and-data/real-time-center/survey-of-professional-forecasters/historical-data/inflation-forecasts, last visited on 26 Nov 2018.

B.11. Main Components of European Consumer Price Inflation



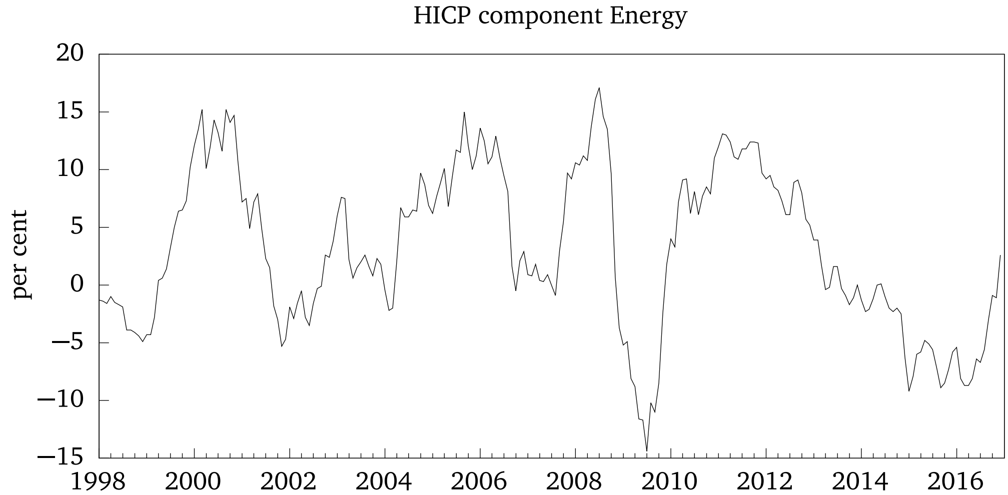


Figure B.29.: HICP inflation rate and main components, EEMU. Due to the larger range, the energy price inflation rate is shown in the lower panel.
Source: Eurostat. The selected aggregates follow Eurostat practice for monthly inflation rate press releases.

C. Error Propagation

This appendix is based on the excellent exposition of error propagation in Shalizi (2017), appendix G. See there for greater detail.

In chapters 2 and 4, the estimation results are presented in the structural parameters of the non-linear estimation equations, and also in the reduced form coefficients of the linear variants of the equations. Since the reduced form coefficient estimates are functions of the structural parameters, they are random and have a variance.

Calculating an estimate of a reduced form parameter (a *derived* quantity) requires us to calculate a standard error as well, which in turn is also a derived quantity. A common technique to calculate such derived standard errors is the *delta method*, which relies on a Taylor-expansion of the reduced coefficient.

Consider a derived parameter estimate

$$\hat{\varrho} = f(\hat{\psi}_1, ..., \hat{\psi}_p) \tag{C.1}$$

as a function of p structural parameter estimates $\hat{\psi}_1, ..., \hat{\psi}_p$, then its true value $\varrho^* = \text{const}$ can be expressed by a first-order Taylor-expansion, and a little algebra shows that

$$\hat{\varrho} \approx \varrho^* + \sum_{i=1}^{p} (\hat{\psi}_i - \psi_i^*) \times \left. \frac{\partial \varrho}{\partial \psi_i} \right|_{\psi_i = \hat{\psi}_i} . \tag{C.2}$$

Let $\varrho'(\hat{\psi}_i) \equiv \frac{\partial \varrho}{\partial \psi_i}|_{\psi_i = \hat{\psi}_i}$ denote the first partial derivative of the derived parameter estimate with respect to the i-th structural parameter ψ_i , evaluated at its estimate $\hat{\psi}_i$. Using the rules for variances, especially that the variance of a constant is zero and that the variance of the sum of random quantities involves the covariances of these, we can express the standard error of the derived quantity $\hat{\varrho}$ as:

$$\begin{aligned} \text{SE}(\hat{\varrho}) &= \sqrt{\text{Var}(\hat{\varrho})} \\ &\approx \left(\sum_{i=1}^{p} (\varrho'(\hat{\psi}_i))^2 \times \text{Var}\left(\hat{\psi}_i\right) + 2 \sum_{i=1}^{p-1} \sum_{j=i+1}^{p} \varrho'(\hat{\psi}_i) \varrho'(\hat{\psi}_j) \times \text{Cov}\left(\hat{\psi}_i, \hat{\psi}_j\right) \right)^{\frac{1}{2}} \end{aligned} \tag{C.3}$$

D. Derivation of Equations

D.1. Equivalence of Real Marginal Costs and the Labour Income Share

Recall the production function in place is a simple Cobb-Douglas function. That is, real GDP is given by:

$$Y_t = A_t K_t^{\alpha} N_t^{1-\alpha}, \tag{D.1}$$

where A_t denotes total factor productivity, K_t is the capital stock, N_t is employed labour, and α is the production elasticity with respect to capital. Thus the marginal product of labour is

$$\begin{aligned}\frac{\partial Y_t}{\partial N_t} &= (1-\alpha) A_t K_t^{\alpha} N_t^{-\alpha} \qquad \text{(expand by } N_t/N_t = 1\text{)} \\ &= (1-\alpha) Y_t N_t^{-1}\end{aligned}$$

Recall further that (real) marginal costs are just (real) wages over the marginal product of labour:

$$\begin{aligned} MC_t &= \frac{W_t/P_t}{\partial Y_t/\partial N_t} \\ &= \frac{W_t/P_t}{(1-\alpha) Y_t N_t^{-1}} \\ &= \frac{1}{1-\alpha} \frac{W_t/P_t}{Y_t/N_t} \end{aligned}$$

Rearranging:

$$= \frac{1}{1-\alpha} \frac{W_t N_t}{Y_t P_t},$$

where the numerator is total nominal wage income and the denominator is nominal GDP. Note further that by detrending the log-series of the labour income share, the coefficient $\frac{1}{1-\alpha}$ drops out.

D.2. Average Duration of Prices Under Calvo-Pricing (2.2)

Under Calvo pricing, every firm in the economy may re-optimise its price only with a probability of $1-\theta$. Since the probability of being able to re-optimise is independent across time, the probability of having the same price for n periods before being able to change it is given by the product of probabilities to keep the price for $n-1$ periods and the probability to be able to re-optimise in the n-th period (cf. the geometric distribution)

$$P(n) = \theta^{n-1}(1-\theta).$$

In other words, the firm charges the same price for $n-1$ periods with the probability θ for each period, and is only able to re-optimise in period n with probability $(1-\theta)$. Note that every price lasts by assumption for at least one period, i.e. $n \geq 1$.

The average duration of prices D is then simply the sum of probability-weighted number of periods a price lasts:

$$D = \sum_{n=1}^{\infty} P(n) \times n$$

Plugging in the probability:

$$D = \sum_{n=1}^{\infty} \theta^{n-1}(1-\theta) \times n = (1-\theta) \sum_{n=1}^{\infty} \theta^{n-1} \times n$$

Recognise the sum as the first derivative of the geometric series, which converges to $\frac{1}{(1-\theta)^2}$ for $|\theta| < 1$, which is satisfied by assumption of $0 < \theta < 1$. Thus

$$D = (1-\theta) \times \frac{1}{(1-\theta)^2} = \frac{1}{(1-\theta)} \qquad \square$$

D.3. Consumption Euler Equation (3.4)

Recall from above the consumption function (3.2) and the consumption indices (3.3). Imposing the standard expenditure constraints gives the usual demand schedules for single varieties i of both countries:

$$C_{k,t}^{k}(i) = C_{k,t}^{k}\left(\frac{P_t^k(i)}{P_t^k}\right)^{-\varepsilon} \qquad C_{k,t}^{-k}(i) = C_{k,t}^{-k}\left(\frac{P_t^{-k}(i)}{P_t^{-k}}\right)^{-\varepsilon}, \tag{D.2}$$

and the usual aggregation of consumption expenditures

$$\int_0^1 P_t^k(i)C_{k,t}^k(i)\,di = P_t^k C_{k,t}^k \qquad \int_0^1 P_t^{-k}(i)C_{k,t}^{-k}(i)\,di = P_t^{-k}C_{k,t}^{-k},$$

where P_t^k, P_t^{-k} denote the price indices[1]:

$$P_t^k = \left(\int_0^1 P_t^k(j)^{1-\varepsilon}\,dj\right)^{\frac{1}{1-\varepsilon}} \qquad P_t^{-k} = \left(\int_0^1 P_t^{-k}(j)^{1-\varepsilon}\,dj\right)^{\frac{1}{1-\varepsilon}} \tag{D.3}$$

The households are subject to a sequence of budget constraints. Expenditures for consumption and one-period bonds must be less or equal to bond income from last period, wage income and (lump-sum) taxes or transfers.

$$P_t^k C_{k,t}^k + P_t^{-k}C_{k,t}^{-k} + B_{k,t}Q_t = B_{k,t-1} + W_{k,t}N_{k,t} + T_{k,t} \tag{D.4}$$

Maximising the utility stream (3.1) subject to the budget constraint (D.4) gives rise to the following optimality conditions. First, relative consumption of domestic and foreign goods must be inverse to the price ratio:

$$\frac{C_{k,t}^k}{C_{k,t}^{-k}} = \frac{\gamma_k}{1-\gamma_k}\frac{P_t^{-k}}{P_t^k} \tag{D.5}$$

Further, the optimal consumption-leisure decision requires that the relative marginal (dis-) utility of labour and consumption is proportional to the real wage.

$$\frac{\partial U}{\partial N_{k,t}}\Bigg/\frac{\partial U}{\partial C_{k,t}} = -\left(\gamma_k{}^{\gamma_k}(1-\gamma_k)^{1-\gamma_k}\right)\frac{W_{k,t}}{P_t^{k\,\gamma_k}P_t^{-k\,1-\gamma_k}} \tag{D.6}$$

[1] P_t^k is the price index of k-made goods. This is conceptually different from the consumer price index (CPI) in country k, given by $P_{k,t} = P_t^{k\,\gamma_k}P_t^{-k\,1-\gamma_k}$. The analogue applies of course for country $-k$.

Finally, using the optimality conditions for consumption and saving yields the consumption Euler-equation:

$$Q_t = \beta \mathrm{E}_t \left\{ \frac{\partial U / \partial C_{k,t+1}}{\partial U / \partial C_{k,t}} \left(\frac{P_t^k}{P_{t+1}^k} \right)^{\gamma_k} \left(\frac{P_t^{-k}}{P_{t+1}^{-k}} \right)^{1-\gamma_k} \right\} \tag{D.7}$$

Assume now the usual CES utility functions, with $\sigma_k, \varphi_k > 0$ as the respective elasticities:

$$U_k(C_{k,t}, N_{k,t}) = \frac{C_{k,t}^{1-\sigma_k}}{1-\sigma_k} - \frac{N_{k,t}^{1+\varphi_k}}{1+\varphi_k} \tag{D.8}$$

Observe that marginal utility of consumption is given by:

$$\frac{\partial U_k}{\partial C_{k,t}} = C_{k,t}^{-\sigma_k} = C_{k,t}^{k}{}^{-\sigma_k \gamma_k} C_{k,t}^{-k -\sigma_k(1-\gamma_k)}$$

Plug this into (D.7):

$$Q_t = \beta \mathrm{E}_t \left\{ \frac{C_{k,t+1}^{k}{}^{-\sigma_k \gamma_k} C_{k,t+1}^{-k}{}^{-\sigma_k(1-\gamma_k)}}{C_{k,t}^{k}{}^{-\sigma_k \gamma_k} C_{k,t}^{-k -\sigma_k(1-\gamma_k)}} \left(\frac{P_t^k}{P_{t+1}^k} \right)^{\gamma_k} \left(\frac{P_t^{-k}}{P_{t+1}^{-k}} \right)^{1-\gamma_k} \right\} \tag{D.9}$$

Let $\Pi_t^k \equiv {}^{P_t^k}/_{P_{t-1}^k}$ denote the ratio of today's and yesterday's prices of k-goods. Further let $\pi_t^k \equiv \ln(\Pi_t^k) = \ln(P_t^k) - \ln(P_{t-1}^k) \equiv p_t^k - p_{t-1}^k$ denote the inflation rate of k-good prices. Moreover let $c_{k,t}^k \equiv \ln(C_{k,t}^k)$ denote the log consumption of k-goods. Now log-linearise:

$$\begin{aligned} \ln(Q_t) = \ln(\beta) + \mathrm{E}_t \Big\{ & -\sigma_k \gamma_k c_{k,t+1}^k - \sigma_k(1-\gamma_k) c_{k,t+1}^{-k} + \sigma_k \gamma_k c_{k,t}^k + \sigma_k(1-\gamma_k) c_{k,t}^{-k} \\ & + \gamma_k p_t^k - \gamma_k p_{t+1}^k + (1-\gamma_k) p^k{-}k_t - (1-\gamma_k) p_{t+1}^{-k} \Big\} \end{aligned}$$

Rearrange to arrive at (3.4):

$$\begin{aligned} \gamma_k c_{k,t}^k + (1-\gamma_k) c_{k,t}^{-k} = {} & \mathrm{E}_t \left\{ \gamma_k c_{k,t+1}^k + (1-\gamma_k) c_{k,t+1}^{-k} \right\} \\ & - \frac{1}{\sigma_k} \left(i_t - \gamma_k \mathrm{E}_t \left\{ \pi_{t+1}^k \right\} - (1-\gamma_k) \mathrm{E}_t \left\{ \pi_{t+1}^{-k} \right\} - \rho \right) \end{aligned} \tag{3.4}$$

where $i_t \equiv -\ln(Q_t)$ denotes the nominal interest rate and, $\rho \equiv -\ln(\beta)$ denotes the time preference.

D.4. Consumer Price Inflation and the Consumer Price Inflation Rate (3.10)

Recall from above that the real wage in (D.6) as the price level in the denominator a term combining the price levels for k- and $-k$-goods with the same elasticities as the consumption basket (3.2), namely γ_k and $1-\gamma_k$. Define this term now as the consumer price level for country k:

$$P_{k,t} \equiv P_t^{k\,\gamma_k} P_t^{-k\,1-\gamma_k} \tag{D.10}$$

With $\Pi_t^k \equiv P_t^k / P_{t-1}^k$ from above the following equalities hold:

$$\breve{\Pi}_{k,t} \quad \equiv \quad \frac{P_{k,t}}{P_{k,t-1}} = \left(\frac{P_t^k}{P_{t-1}^k}\right)^{\gamma_k} \left(\frac{P_t^{-k}}{P_{t-1}^{-k}}\right)^{1-\gamma_k} \quad = \quad \left(\Pi_t^k\right)^{\gamma_k} \left(\Pi_t^{-k}\right)^{1-\gamma_k} \tag{D.11}$$

This is consumer price inflation, reflecting the change of prices with weights according to the consumption basket. Taking logarithms and observing from above that $\breve{\pi}_t^k = \ln(\breve{\Pi}_t^k)$ gives the consumer price inflation *rate*:

$$\breve{\pi}_{k,t} = \gamma_k \pi_t^k + (1-\gamma_k)\pi_t^{-k} \tag{3.10}$$

Analogous equations exist for country $-k$.

D.5. Goods Markets Clearing

For goods markets to be cleared, production must equal consumption for all goods i:

$$Y_t^k(i) = C_{k,t}^k(i) + C_{-k,t}^k(i)$$

Assume that all firms in a country have a common, time-invariant
export share $0 < s_k < 1$:

$$C_{k,t}^k(i) = (1-s_k)Y_t^k(i) \qquad C_{-k,t}^k(i) = s_k Y_t^k(i)$$

Aggregating production in a Dixit/Stiglitz-way, $Y_t^k = \left(\int_0^1 Y_t^k(i)^{\frac{\varepsilon-1}{\varepsilon}}\, di\right)^{\frac{\varepsilon}{\varepsilon-1}}$ and plugging in the above export schedules gives:

$$C_{k,t}^k = (1-s_k)Y_t^k \qquad C_{-k,t}^k = s_k Y_t^k$$

From this follows directly that:

$$Y_t^k = C_{k,t}^k + C_{-k,t}^k \tag{D.12}$$

Together with the demand schedules (D.2), these market clearing conditions give the firms' demand constraints:

$$Y_t^k(i) = C_{k,t}^k(i) + C_{-k,t}^k(i) = C_{k,t}^k\left(\frac{P_t^k(i)}{P_t^k}\right)^{-\varepsilon} + C_{-k,t}^k\left(\frac{P_t^k(i)}{P_t^k}\right)^{-\varepsilon} = Y_t^k\left(\frac{P_t^k(i)}{P_t^k}\right)^{-\varepsilon} \tag{D.13}$$

Further, by taking logs:

$$c_{k,t}^k = \ln(1-s_k) + y_t^k \qquad c_{-k,t}^k = \ln(s_k) + y_t^k$$

And hence:

$$\begin{aligned} c_{k,t} &= \gamma_k c_{k,t}^k + (1-\gamma_k)c_{k,t}^{-k} \\ &= \gamma_k y_t^k + (1-\gamma_k)y_t^{-k} + \gamma_k \ln(1-s_k) + (1-\gamma_k)\ln(s_{-k}) \end{aligned} \tag{D.14}$$

D.6. Deviation of Real Marginal Costs From Their Steady State Value (3.7)

To derive (3.7) proceed twofold. First observe that real marginal costs are equal to real wages less marginal product of labour:

$$mc_t^k = w_{k,t} - p_{k,t} - mpn_{k,t}$$

With the (log) optimal consumption-labour condition (D.6), the utility function (D.8) and by using the approximate aggregate production function[2] to see that $mpn_{k,t} \approx a_{k,t} - \alpha n_{k,t} + \ln(1-\alpha)$, real marginal costs are then:

$$\begin{aligned} mc_t^k &= \varphi_k n_{k,t} + \sigma_k c_{k,t} - \gamma_k \ln \gamma_k - (1-\gamma_k)\ln(1-\gamma_k) - \big(a_{k,t} - \alpha n_{k,t} + \ln(1-\alpha)\big) \\ &= \varphi_k n_{k,t} + \sigma_k c_{k,t} - \gamma_k \ln \gamma_k - (1-\gamma_k)\ln(1-\gamma_k) - \big(y_t^k - n_{k,t}\big) - \ln(1-\alpha) \end{aligned}$$

Recall the consumption structure and the goods market clearing conditions, hence observe that $c_{k,t} = \gamma_k c_{k,t}^k + (1-\gamma_k)c_{k,t}^{-k} = \gamma_k y_t^k + (1-\gamma_k)y_t^{-k} + \gamma_k \ln(1-s_k) + (1-\gamma_k)\ln(s_{-k})$. Then real marginal costs become:

$$\begin{aligned} mc_t^k &= \varphi_k n_{k,t} + \sigma_k \gamma_k y_t^k + \sigma_k(1-\gamma_k)y_t^{-k} - y_t^k + n_{k,t} + K_k \\ &= \left(\sigma_k \gamma_k + \frac{\varphi_k + \alpha}{1-\alpha}\right) y_t^k + \sigma_k(1-\gamma_k)y_t^{-k} + \frac{1+\varphi_k}{1-\alpha} a_{k,t} + K_k \end{aligned} \tag{D.15}$$

with $K_k \equiv \sigma_k \gamma_k \ln(1-s_k) + \sigma_k(1-\gamma_k)\ln(s_{-k}) - \gamma_k \ln \gamma_k - (1-\gamma_k)\ln(1-\gamma_k) - \ln(1-\alpha)$.

To arrive at the steady state value of real marginal costs, observe first that in the steady state $mc^k = -\mu$ and further that the economies produce at their natural level of output. Thus, the following equality holds:

$$-\mu = \left(\sigma_k \gamma_k + \frac{\varphi_k + \alpha}{1-\alpha}\right) y_t^{n,k} + \sigma_k(1-\gamma_k)y_t^{n,-k} + \frac{1+\varphi_k}{1-\alpha} a_{k,t} + K_k \tag{D.16}$$

which is just the zero-inflation steady state (i.e. flexible price) variant of (D.15). Then (3.7) is the difference of (D.15) and (D.16):

$$\tilde{mc}_t^k = \left(\sigma_k \gamma_k + \frac{\varphi_k + \alpha}{1-\alpha}\right) \tilde{y}_t^k + \sigma_k(1-\gamma_k)\tilde{y}_t^{-k} \tag{3.7}$$

[2]It is $y_t^k \approx a_{k,t} + (1-\alpha)n_{k,t}$. See Galí (2008: 46; 62-63) for a derivation.

D.7. Natural Output (3.8)

Solve (D.16) for $y_t^{n,k}$:

$$y_t^{n,k} = \psi_k a_{k,t} - \chi_k y_t^{n,-k} + \vartheta_k \tag{D.17}$$

Combine (D.17) with its country $-k$ analogue, to obtain (3.8):

$$y_t^{n,k} = \frac{\psi_k}{1-\chi_k \chi_{-k}} a_{k,t} - \frac{\psi_{-k}\chi_k}{1-\chi_k \chi_{-k}} a_{-k,t} - \frac{\chi_k \vartheta_{-k} - \vartheta_k}{1-\chi_k \chi_{-k}} \tag{3.8}$$

where

$$\psi_k \equiv \frac{1+\varphi_k}{(1-\alpha)\sigma_k \gamma_k + \varphi_k + \alpha}, \qquad \chi_k \equiv \frac{\sigma_k(1+\gamma_k)(1-\alpha)}{(1-\alpha)\sigma_k \gamma_k + \varphi_k + \alpha}$$

$$\vartheta_k \equiv -\frac{(1-\alpha)(\mu + K_k)}{(1-\alpha)\sigma_k \gamma_k + \varphi_k + \alpha}$$

and

$$\mu \equiv \ln \frac{\varepsilon}{\varepsilon - 1} > 0$$

is the logarithm of the desired gross mark-up that firms may charge due to their market power. See Galí (2008: 45) for an interpretation. Analogous equations exist for country $-k$.

E. Abbreviations

AD	aggregate demand
AS	aggregate supply
BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
CCB	common central bank
CPI	consumer price index
CMP	common monetary policy
DISC	Dynamic IS Curve
DSGE	Dynamic Stochastic General Equilibrium
ECB	European Central Bank
EEMU	European Econonomic and Monetary Union
EONIA	Euro Overnight Index Average
EU	European Union
GMM	Generalised Method of Moments
HICP	Harmonised Index of Consumer Prices
HNKPC	Hybrid New-Keynesian Phillips Curve
IRF	Impulse-Response-Function
MU	monetary union
NKM	New-Keynesian Model
NKPC	New-Keynesian Phillips Curve
OECD	Organisation for Economic Co-operation and Development
OCA	Optimal Currency Area
TFP	Total Factor Productivity
UK	United Kingdom
WIT	Whatever-It-Takes remark by Mario Draghi

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