International Transmission of Monetary Policy Shocks: Can Asymmetric Price Setting Explain the Stylized Facts?

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Abstract

How does an unexpected domestic monetary expansion affect the foreign economy: Does it induce an increase or a decline in foreign production? And is it 'beggar-thy-neighbour', or does it raise foreign welfare? Empirical evidence from VARs indicates that monetary policy has positive international transmission effects on both foreign output and aggregate demand. A two-country dynamic general equilibrium model with sticky prices can account for this 'stylized fact' if we allow for asymmetric price setting insofar as domestic firms set export prices in their own currency (producer-currency pricing), whereas foreign firms price their exports in the importer's currency (local-currency pricing).

Keywords : Asymmetric price setting, Local-currency pricing, New Open Economy Macroeconomics, International transmission of monetary policy, VARs

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1 Introduction

Open economies are characterized by their international political and economic relations. Most economists agree that access to international financial and trade markets increases the overall welfare of the economy as it makes it possible for countries to uncouple domestic absorption from domestic production. However, the increasing international integration and intertwining of the economic process leads to more interdependence of the countries' economic state and makes the economy more vulnerable to economic shocks and policy decisions abroad.

The purpose of this paper is to investigate certain aspects of the international transmission of the business cycle. Precisely, it will be examined how a certain policy measure – a shock to domestic money supply – affects the domestic economy as well as the economic state of the rest of the world. Does a surprise increase in domestic money supply induce an increase or a decline in foreign production? And is a domestic monetary expansion a 'beggar-thy-neighbour'-policy, or does it raise foreign welfare?

In order to address these issues, the following section assesses some empirical evidence on the international transmission effects of monetary policy, focusing on the results obtained from vector autoregressions. In this context, not only evidence on the international transmission effects of monetary policy on output, but also on consumption and investment is presented.[1] It will be shown that for the flexible exchange rate period, starting 1974, U.S. monetary policy has had positive spill-over effects on foreign output for a number of countries as well as for a weighted average of the non-U.S. G-7 countries. This positive international transmission effect is also present for foreign aggregate consumption and investment.

The main part of the paper then consists of the theoretical analysis. A two-country dynamic general equilibrium model with nominal price rigidities in the tradition of the *Redux* model by Obstfeld and Rogoff (1995a) is derived to assess the international transmission effects of monetary policy.[2] For

[1] Although the state of the economy is best described by aggregate output, we also consider consumption and investment as they give different information about the country's economic situation, especially if we are interested in welfare effects.

[2] In this paper I restrict myself to the analysis of two equal sized economies. However, with a slight modification of the assumptions, it is also possible to extend the analysis to two economies of different size and hence to investigate the small open economy case at the limit.

a benchmark calibration, the effects of a permanent 1% increase in domestic money supply are analyzed for three different assumptions about the price-setting behavior of firms, i.e. the currency of export prices. For complete *producer-currency pricing* consumption and investment exhibit positive comovements in the domestic and the foreign country, whereas the response of foreign output to a domestic monetary expansion is small and might even be negative. For complete *local-currency pricing* the comovement in output is positive, but foreign consumption and investment decline due to the domestic monetary impulse.

So far, the assumption that producers in *both* countries behave symmetrically prevailed. Either producers in both countries set their export prices in their own currency or both domestic and foreign producers set their export prices in the currency of the export market. However, it will be shown that if we allow for an *asymmetric* price-setting behavior, positive spill-over effects on both aggregate production and aggregate demand can be obtained. Assuming that the domestic country is the U.S., it is plausible that domestic producers set their prices in the domestic currency, the U.S. dollar, independent of the market in which the product will be sold. Producers in the foreign country, which can also be viewed as the rest of the world, however, might set their prices differently for the foreign and the export market. Whereas prices in the foreign market will be set in the foreign currency (e.g. the Euro), prices in the export market will be set in U.S. dollars. We investigate the limiting assumption of complete producer-currency pricing in the domestic country and complete local-currency pricing in the foreign country, and find that with this price-setting assumption, a U.S. monetary expansion leads to an economic boom in both output and aggregate demand not only at home but also abroad. The effect is higher, the higher the import share and the lower the substitutability between domestic and foreign goods.

The structure of the paper is as follows. The next section summarizes the empirical evidence on the international transmission effects of monetary policy. In section 3, other relevant contributions in the NOEM are outlined and their ability to match the empirical results will be discussed. The model will then be derived in Section 4. The obtained results will be presented in section 5 before section 6 concludes.

2 Empirical evidence

The analysis of time series data shows that economic fluctuations and resulting business cycles are positively linked across countries.[3] In the international business cycle literature, this stylized fact is mostly summarized by positive cross-country correlations of economic aggregates like output, consumption and investment.[4] Although this finding indicates that economic performance is interdependent across countries, it is not sufficient to draw conclusions about the international transmission effects of a certain policy measure, as in our case a domestic expansionary monetary policy shock, since the correlation of national business cycles found in time series data is very likely to be caused by several factors and their interactions. Therefore, it is necessary for our purpose to assess the *conditional* correlation of certain aggregates due to a monetary policy shock, which can be found with the help of vector autoregressions.

2.1 The effects of monetary policy

With the introduction of vector autoregressions by Christopher Sims in 1980, it has become more feasible to explicitly determine the effects of a monetary policy shock on domestic and foreign aggregates.[5] Although still the majority of the VAR literature deals with the effects of monetary policy in 'closed' economies – with the U.S. as the example *par excellence* – ,[6] more and more studies incorporate the openness of the economy by including foreign variables in their analysis. When looking at international effects of monetary policy in these 'open-economy' VARs, substantial interest has been in the effects on nominal and real exchange rates.[7] Other researchers assess the

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[3]For evidence see e.g. Backus, Kehoe, Kydland (1995) and (1992).

[4]Backus, Kehoe and Kydland (1995) find correlations of 0.66 between European and U.S. ouput and about 0.5 between European and U.S. consumption and investment for quarterly data from 1970 to 1990. See page 351.

[5]For a recent comprehensive survey of VARs in the determination of monetary policy see Christiano, Eichenbaum and Evans (1999).

[6]E.g. Sims (1992) and Grilli and Roubini (1995) also conduct 'closed-economy' VAR analysis for other G-7 economies. However, it seems that monetary shocks are more difficult to identify for these countries.

[7]See e.g. Eichenbaum and Evans (1995) and Grilli and Roubini (1995/6), but also Clarida and Gali (1994). Eichenbaum and Evans assess evidence on overshooting of the nominal exchange rate and the validity of the uncovered interest parity. They estimate five seperate VARs (for the U.K, Canada, Germany, France and Japan). The variables included are U.S. industrial production (Y), the U.S. consumer price level (P), foreign output (Y^{For}), a foreign short term interest rate (R^{For}), the real exchange rate (s_R^{For}), and the U.S. monetary policy instruments, the ratio of non-borrowed reserves

effects of an unexpected monetary expansion on the current account.[8]

However, in the last years, several authors also have applied the VAR approach to determine how a domestic monetary policy shock affects the foreign economy in terms of economic aggregates.[9] The following sections will give a short survey of the obtained results.

2.2 The effects of monetary policy on foreign output

Betts and Devereux (2001) determine the international transmission effect of monetary policy on output. They estimate two different VARs for the U.S. where they include foreign output (Y^*), a foreign interest rate (I^*) and the real exchange rate (RER) besides domestic output (Y) and the domestic monetary policy instrument, which is either the federal funds rate (FF) or non-borrowed reserves (NBR).[10] The foreign country (or the 'rest of the world') is proxied by a GDP-weighted average of the non-U.S. G-7 countries. Using monthly data, Betts and Devereux find for both monetary shocks an increase in *both* domestic and foreign output.[11] Although the impact on domestic (U.S.) output is more pronounced, foreign output rises significantly and about two thirds the size of the domestic output increase.

to total reserves ($NBRX$), and the federal funds rate (FF). The foreign variables were included for one country at a time. The Wold ordering assumed for the federal funds rate shock is $\{Y, P, Y^{For}, R^{For}, FF, NBRX, s_R^{For}\}$ and for the $NBRX$ shock is $\{Y, P, Y^{For}, R^{For}, NBRX, R^{US}, s_R^{For}\}$. Using monthly data from 1974 to 1996, they find a delayed overshooting of the exchange rate as well as persistent deviations from uncovered interest parity for most countries. Although Eichenbaum and Evans include foreign output in their identification scheme, they do not plot the resulting responses for domestic and foreign output.

[8]See e.g. Philip Lane (2001b) for the U.S. and Cushman and Zha (1997) for Canada. Koray and McMillin (1999) also analyse the effects of monetary policy on the U.S. current account, and find a J-curve effect after eliminating the income-effects.

[9]In the 1980s several authors used variance decompositions in order to investigate whether flexible exchange rates were a successfull tool to insulate national economies from foreign shocks, see e.g. Genberg et. al. (1987) and Lastrapes and Koray (1990). Although these authors were interested in how much foreign shocks could account for the variability in domestic variables, and hence in the magnitude of the international transmission of shocks, they did not assess the direction of corresponding spill-over effects.

[10]The ordering of the variables included are $\{NBR, I - I^*, Y, Y^*, RER\}$ for the non-borrowed reserves shock and $\{FF, I^*, Y, Y^*, RER\}$ for the federal funds rate shock. In both recursive identification schemes the shock is ordered first. This implies that every variable can react to the monetary impulse immediately, whereas the central bank does not observe any of the currenct values before setting its instrument (for a more in depth explanation see Christiano, Eichenbaum and Evans (1999)).

[11]Betts and Devereux use industrial production as a proxy for output and they chose to HP-filter the data. The VAR is estimated in levels, where all variables except for the interest rates are in logs.

Faust and Rogers (2003) test the delayed overshooting finding of Eichenbaum and Evans (1995) for robustness, where they only consider Germany and the U.K. as foreign countries.[12] For the benchmark estimation they find a positive international transmission effect on output for both the U.K. and Germany. In an alternative identification which allows for more simultaneity, the positive effect on foreign output persists, although the delayed overshooting result is modified.

Kim (2001) undertakes an extensive investigation of the international transmission effects of U.S. monetary policy. As Betts and Devereux (2001), he constructs a weighted average of the remaining G-7 countries to proxy for the rest of the world.[13] In his study, he uses both the recursive identification scheme as well as a (more) structural identification of the monetary shock. In most cases, however, the results are very much alike.[14] His benchmark model consists of U.S. GDP (Y), the U.S. GDP deflator (P), a commodity price index (PC) and the federal funds rate (FFR) for the federal funds rate shock and of Y, P, PC, the ratio of non-borrowed reserves to total reserves ($NBRX$) and FFR for the $NBRX$ shock. Kim uses quarterly data from 1974 to1996. The variables of interest are then added in a 'marginal' way one by one to the basic model, which is re-estimated each time. Kim also finds a positive transmission effect on foreign output, albeit smaller than before.[15]

Holman and Neumann (2002) focus on the cross-country transmission of monetary shocks between the U.S. and Canada. As Kim, they use quarterly data from 1973:2 to 1996:4. They also find positive spill-over effects for an U.S. monetary policy shock on Canadian output. Contrary to the studies discussed above, monetary policy is identified by a wide monetary aggregate, M2.

Finally, Miniane and Rogers (2003) find positive transmission effects of

[12] The included variables are ordered as follows: $Y, P, Y^*, i^*, NBRX, i, S$. The monetary policy shock is identified as a surprise increase in the non-borrowed reserves to total reserves ratio ($NBRX$). Faust and Rogers use monthly data form 1974:1 to 1997:12 and the system is estimated in log-levels (except for the interest rates) with 6 lags and a constant. The benchmark model uses the Choleski decomposition, whereas the alternative identification allows for simulatenous influences on the exchange rate and the foreign interest rate.

[13] Kim excludes Canada on the grounds that Canadian monetary policy has been highly influenced by U.S. monetary policy.

[14] See Kim (2001), p. 361.

[15] In contrast to Betts and Devereux (2001), Faust and Rogers (2003) and Eichenbaum and Evans (1995), Kim's benchmark model does not include any foreign variable (not even the exchange rate), but includes a commodity price index PC. Although the introduction of an adequate commodity price index can eliminate the price puzzle, it is likely to produce an 'exchange rate puzzle', as for quarterly data the domestic currency appreciates in response to a domestic decline in the domestic interest rate.

U.S. monetary policy on output for a large set of countries and also for different sub-periods.

2.3 The effects of monetary policy on foreign aggregate demand

Although there is sufficient evidence on the transmission effects on foreign output, less evidence has been provided for the effects on consumption and investment. However, if we want to determine the effects on the foreign economy in terms of welfare, the way foreign consumption is affected might be crucial for the relevant model.

Holman and Neumann (2002) provide evidence for a positive transmission of a U.S. monetary policy shock on both Canadian consumption and investment.[16] In his comprehensive analysis, Kim (2001) also investigates how a U.S. monetary policy shock affects domestic and foreign aggregate demand. He finds an increase in foreign aggregate demand in response to an expansionary U.S. monetary policy shock. However, Kim does not distinguish between consumption and investment.

To provide more in depth evidence for the effects on foreign consumption and investment in a two-country-setting, I estimate a two-country VAR similar to the approaches of Betts and Devereux (2001) and Kim (2001) to determine the effects of a U.S. monetary policy shock on a weighted average of non-U.S. G-7 countries' economic aggregates. As Kim (2001) and Holman and Neumann (2002), I use *quarterly* data from 1974:1 to 2001:4.[17] The monetary policy shock in the benchmark model is identified similar to Eichenbaum and Evans (1995). The variables included in the benchmark are hence U.S. GDP (Y), U.S. consumer prices (P), G-6 GDP (Y^*), the federal funds rate (FFR), the ratio of non-borrowed reserves to total reserves ($NBRX$), a foreign short term interest rate (IR_{G6}) and the real exchange rate ($REER$) for the federal funds rate shock and Y, P, Y^*, $NBRX$, FFR-IR_{G6}, $REER$ for the $NBRX$ shock.[18] The real exchange rate is defined as

[16] Holman and Neumann (2002) use a recursive identification scheme. Interestingly, the positive spill-over also arises for a Canadian monetary policy shock on U.S. aggregates. Note, however, that Holman and Neumann use a broad monetary aggregate (M2) to identify the shock (p. 1840).

[17] Except for the interest rates and the exchange rates, all data are seasonally adjusted.

[18] Note that contrary to Eichenbaum and Evans (1995), I order the foreign interest rate after the U.S. monetary shock. Since I use quarterly data (as data on aggregate consumption and investment is only available quarterly), I find it more plausible to allow the foreign interest rate to immediately react to a U.S. monetary policy shock than to assume that the Federal Reserve bank takes the current foreign interest rate into account.

the U.S. dollar price per unit of foreign currency multiplied with the relative price level $\frac{CPI_{G6}}{CPI_{U.S.}}$. Hence, an increase in $REER$ corresponds to a depreciation of the U.S. dollar. Like Kim, I add the variables of interest one by one as the last element and then re-estimate the VAR for each variable. The system is estimated in levels, where all variables except the interest rates enter the system in logs, and four lags are included.[19] For the identification I use the Choleski decomposition.[20]

2.3.1 Findings

For the benchmark model, I find significant spill-over effects not only for output, but also for consumption and investment. As Eichenbaum and Evans, I use two identification methods for the monetary policy shock: a surprise innovation in the U.S. federal funds rate and a surprise innovation in the non-borrowed reserves to total reserves ratio.[21,22]

Figure 1 depicts the impulse responses of the benchmark system to a negative one standard deviation innovation of the U.S. federal funds rate.[23] The dotted and dashed lines represent one and two standard errors respectively.[24] In response to a surprise decrease in the U.S. federal funds rate, both the domestic and the foreign economy experience an increase in output, where the rise in foreign output is more delayed. Also, the real exchange rate depreciates significantly.[25]

Although this might seem arbitrary, most evidence suggests that U.S. monetary policy leads foreign monetary policy (see e.g. Grilli and Roubini (1995)). Koray and McMillin (1999) use the same ordering with the same reasoning.

[19] The estimation in levels instead of first differences is based on the reasoning outlined in Enders (1995) and Holman and Neumann (2002).

[20] Although there might be plausible reasons to use a more structural identification of the shock, I use a Choleski identification where (except for the determination of the lag length and the ordering of the variables) no further assumptions and restrictions are imprinted on the system, in the hope that the identification is less 'biased'.

[21] The ratio of non-borrowed reserves to total reserves for the monetary aggregate as a measure for monetary policy has been put forward by Strongin (1995).

[22] The results obtained for a positive shock to the U.S. non-borrowed to total reserves ratio look similar and the corresponding graphs are displayed in the appendix.

[23] To facilitate the comparisons both with the shock to $NBRX$ and the monetary shock in the model, I focus on an expansionary monetary shock.

[24] The standard errors are obtained from 1000 Monte Carlo draws following Doan (1992) and Uhlig (2001).

[25] Note that the maximum effect does not occur immediately, but only after about 10 quarters, which confirms Eichenbaum and Evans' result of a delayed overshooting for quarterly data.

Figure 1: Impulse responses of the benchmark model to a negative one standard deviation of the U.S. federal funds rate

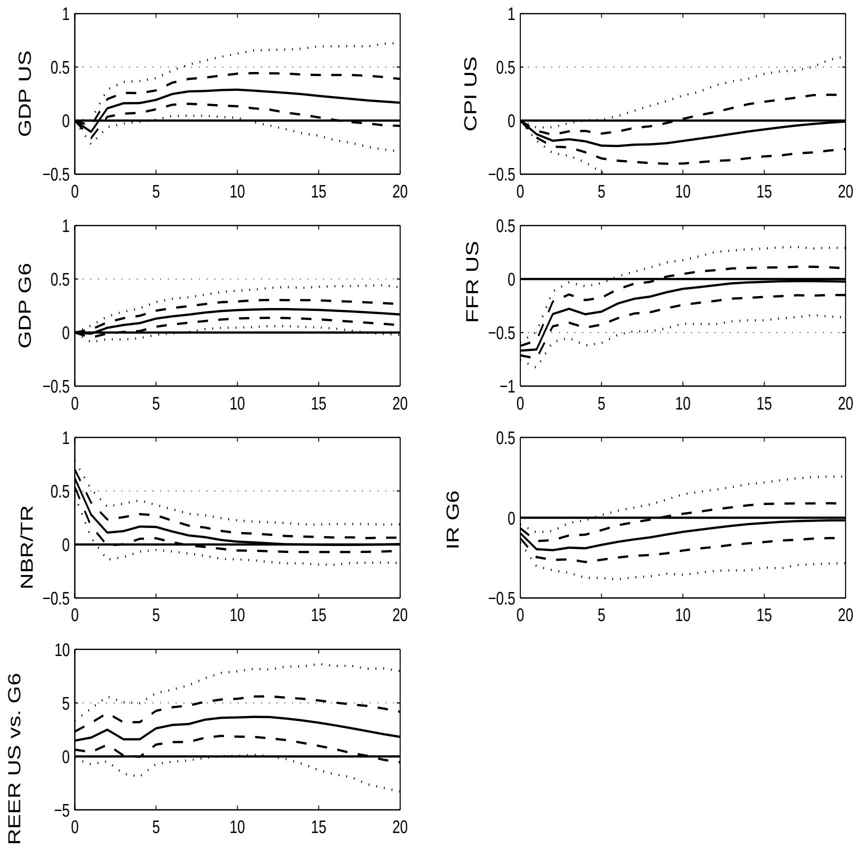
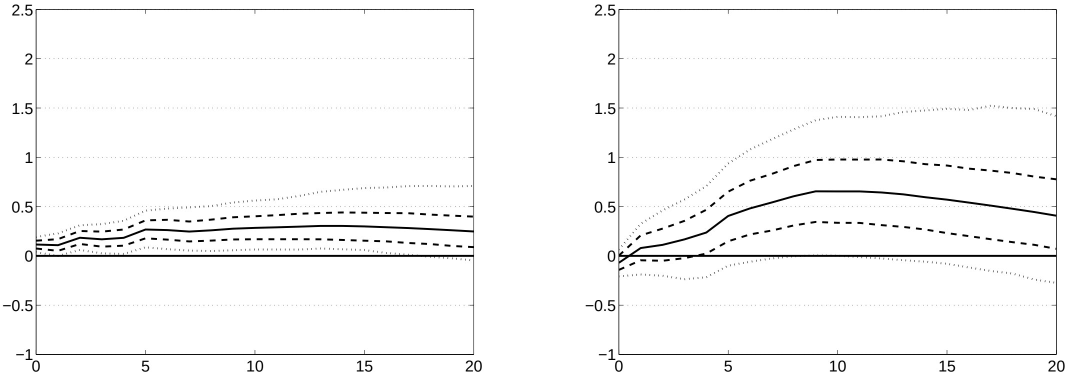


Figure 2 then depicts the effects on foreign consumption and investment. The results show that both foreign consumption and investment increase significantly in response to an expansionary domestic policy shock.[26] Hence, even with flexible exchange rates, an expansionary U.S. monetary impulse induces a boom in the other G-7 countries, leading to an increase in aggregate demand and output.

Several robustness checks were conducted to obtain some generalization for the results. Among other things, different weights for the construction of the G-6 variables were tested. The benchmark weights are obtained using relative GDP shares from the Penn World Tables. However, as the international

[26] U.S. consumption and investment increase as well. The corresponding impulse response functions are depicted in the appendix.

Figure 2: Impulse Responses of G-6 Consumption and Investment in response to a negative 1 standard deviation Innovation in the U.S. federal funds rate



G-6 Consumption G-6 Investment

linkages might be more important for closer trading or financial partners, the implications of using the relative trade-shares as weights (see also Koray and McMillin (1999)) and relative foreign direct investment positions as a proxy for the weights were tested. However, the results were very similar. The corresponding weights are listed in the appendix.[27]

The presented results seem to question some of the implications of traditional monetary open-economy models. They especially cast doubt on the importance of the 'expenditure-switching' effect, which is a central mechanism in most monetary open-economy models like the Mundell-Fleming and the Dornbusch model, but is also inherent in the *Redux* model by Obstfeld and Rogoff.

The question of how monetary policy affects the economic performance abroad is not new. It was amongst others addressed by Mundell in 1964 has been a matter of interest since.[28] In his analysis, Mundell concludes that for flexible exchange rates a domestic monetary expansion has 'beggar-thy-neighbour' effects. The monetary induced boom in the home economy is

[27]Other robustness checks were the inclusion of a commodity price index to reduce the prize-puzzle effect and a change in the order of the shock. With the commodity price index, the effect on foreign investment was more pronounced, whereas the effect on foreign consumption was less important. Ordering the shock first and hence allowing all variables to respond to the shock immediately has almost no effect on the impulse response functions.

[28]See e.g. Turnovsky (1986), and for more recent contributions Corsetti and Pesenti (2001), Tille (2001) and Betts and Devereux (2000).

found to be at the expense of the foreign economy, which experiences a decline in its output. This is due to the expenditure-switching effect. The surprise increase in domestic money supply leads to a nominal depreciation of the exchange rate. As prices are assumed to be fixed, real relative prices change, and domestic products become more competitive abroad. This induces the foreigners to import more domestic goods, whereas domestic agents demand less foreign goods, and the trade balance improves. As output is solely demand determined, output and employment increase in the domestic economy, whereas they fall abroad, and monetary policy has 'beggar-thy-neighbour' effects.[29]

However, the empirical evidence discussed above seems to indicate that the increase in worldwide aggregate demand is directed to *both* domestic and foreign goods. Although the degree of exchange rate flexibility between the U.S. and the other G-7 countries is presumably far from perfect,[30] the degree of monetary interdependence does not seem to be sufficient to explain the amount of international transmission effects.

In the remaining part of the paper, a theoretical model that can account for the comovements found in the data is presented. First, I will discuss the most relevant theoretical contributions in this field and explain how they relate to the two-country general equilibrium model which is then derived below. It will be shown that for a certain plausible assumption - complete *producer-currency pricing* for domestic producers and complete *local-currency pricing* for foreign producers - the model exhibits positive international transmission effects of monetary policy on both foreign output and aggregate demand for internationally perfectly uncorrelated money supply. The suggested asymmetric price setting assumption therefore contributes an explanation to the empirical results.

3 New Open Economy Macroeconomics

The model that will be derived below is in the tradition of the New Open Economy Macroeconomics literature and is based on the *Redux* model by Obstfeld and Rogoff (1995a). As we are interested in the dynamic responses

[29] Depending on the size of the domestic economy, the increase in demand due to the depreciation is complemented by an interest rate induced increase in demand (however only if the domestic economy is big enough to influence the world interest rate).

[30] From the impulse response functions for the U.S. and G-6 nominal interest rates in Figure 1 it can be seen that monetary policy in the non-U.S. G-7 countries is not completely independent of the U.S. monetary policy.

due to a monetary shock, no closed form solution is derived. Instead, certain features that allow for more persistence - e.g. capital as a factor of production, capital adjustment costs and price rigidities à la Calvo - are included in the model. After all equilibrium conditions are derived, the model is calibrated to obtain impulse responses for the variables of interest, which are then compared with the impulse responses obtained from the VAR analysis.

With the publication of the *Redux* model in 1995, Maurice Obstfeld and Kenneth Rogoff launched what is now called the "New Open Economy Macroeconomics".[31] The main features of these two-country dynamic general-equilibrium models are an explicit microfoundation of the household's decisions, the inclusion of the money-in-the-utility-function formulation, monopolistic competition and nominal rigidities. The combination of the latter two induce demand-determined production in the short run, and thus lead to real effects of monetary shocks. Since 1995 a growing number of extensions to the *Redux* model have been developed, concerning e.g. pricing decisions and the nature of nominal rigidities, but also welfare implications have been discussed. Although the major part of research studies models that incorporate closed form solutions and hence focus on qualitative results, several authors combine the NOEM structure with insights obtained from the real business cycle literature and simulate the models to obtain more quantitative results. To facilitate the comparison with the empirical results obtained above, I follow the latter approach. The most relevant contributions in this context are Betts and Devereux (2001), Kollmann (2001a) and Chari, Kehoe and McGrattan (2002). Whereas Chari, Kehoe and McGrattan concentrate on finding a model which can replicate the empirical evidence on volatile and persistent real exchange rates, Kollmann as well as Betts and Devereux are also interested in the international transmission effects of monetary policy on economic aggregates.

Betts and Devereux (2001) investigate in particular the impact of local-currency pricing versus producer-currency pricing on the international transmission effects of monetary policy on output. As was documented above, empirical evidence indicates that the transmission effect of monetary policy on foreign output is positive, even for flexible exchange rates. Betts and Devereux (1996) and Engel (2000) show that this result can be obtained in a theoretical model, if the expenditure-switching effect which results from the combination of sticky prices and producer-currency pricing is repressed. As long as prices are set in the producer currency, respective import prices

[31]For an excellent survey of the research in this area see Lane (2001a), but also Sarno (2001) and Fendel (2002a).

will change with an exchange rate change, and domestic products become more competitive as the domestic currency depreciates. This is also referred to as 'complete exchange rate pass-through'. However, when prices are set in the respective local currency of the market, the exchange rate depreciation will have no effect on relative prices, and hence the increase in consumption is directed to *both* domestic and foreign goods proportionately.[32] Betts and Devereux (2001) therefore set up a two-country dynamic general equilibrium model, which they simulate for both producer-currency and local-currency pricing. They are able to reproduce the empirical outcome of a positive transmission effect on output with the assumption of complete local-currency pricing. Betts and Devereux conclude that the price-setting behavior of producers might therefore be more accurately described by local-currency pricing. With their quantitative analysis, Betts and Devereux give valuable insights into the importance of the pricing decision of firms on the international transmission effects of monetary policy. However, there are two drawbacks of this model, which I would like to address.

First, and most important, the local-currency pricing assumption not only produces positive comovements in output, but it also detaches domestic from foreign consumption and investment responses to a monetary shock, whereas for producer-currency pricing domestic and foreign consumption responses are very similar. The reason is that with producer-currency pricing, real interest rates react similar in both countries, hence stimulating domestic and foreign consumption and investment in the same way, whereas local-currency pricing drives a wedge between domestic and foreign real interest rates. In Betts and Devereux, a domestic monetary policy shock has basically no effect on foreign consumption and investment under the assumption of local-currency pricing. This implies that while the model generates a positive transmission effect of a domestic monetary expansion on output, this effect is not transmitted to aggregate demand in the model.[33] This has important implications for foreign welfare effects. Since agents derive utility from the consumption of leisure, they are likely to experience a decline in welfare due to a domestic monetary expansion for local-currency pricing, as they work more, but consume less over most of the adjustment path. Hence, to assess whether monetary policy has 'beggar-thy-neighbour' effects, we need to build a model that can also replicate the corresponding responses for consumption

[32] For the assumption of no home bias in consumption the increase in demand will ceteris paribus be equal in both countries.

[33] Note that although foreign production increases, foreign income does not. As the domestic currency depreciates, the markup for domestic exports increases while the markup for foreign exports declines. The foreign country now experiences a deterioration of their terms of trade (in contrast to PCP, where their terms of trade improve).

and not only output.

Second, the extremely high degree of the positive international transmission effect of a domestic monetary policy shock on foreign output obtained by Betts and Devereux vitally depends on the non-existence of a home bias in consumption. Implicitly, the model assumes that – for countries of identical size – the consumption basket of domestic agents contains 50% import goods. This explains why an increase in domestic demand is *equally* directed towards domestic and foreign goods. However, if a home bias in consumption is allowed, and, say, imports represent only 15% of the goods consumed, the increase in demand for foreign goods will be clearly smaller.[34] This result together with the negative responses on consumption and investment seem to indicate that full local currency pricing for all producers is not sufficient to solve the puzzle of the positive international transmission effects of monetary policy.

Kollmann (2001a) primarily studies the influence of monetary policy and nominal rigidities on international comovements of output and asset returns, but also assesses the international transmission effects on both foreign output and aggregate demand. In his model, both price and wage rigidities are inherent. He includes a home bias, and assumes throughout the paper that producers set their prices in their own currency.[35] For his benchmark calibration he obtains a positive transmission on both foreign output and aggregate demand. However, this result seems to rely on the extremely low degrees of interest and consumption elasticities of money demand. In response to a surprise increase in domestic money supply, the domestic (but also foreign) interest rate will decrease by more, inducing a higher increase in world aggregate consumption. The effect on foreign output then depends on which effect dominates, the expenditure-switching effect or the general increase in aggregate demand – for both domestic and foreign goods. In presence of a home bias, the effect of an exchange rate change on consumption behavior also attenuates, so that for the calibration values used, Kollmann obtains international comovements in output and aggregate demand. However, this result seems to depend strongly on the calibration values for money demand elasticities and might thus not be viewed as robust.

In the following, I will present a dynamic general equilibrium model with sticky prices that can account for the comovements found both in output and

[34] In this case, the decline in foreign consumption and output is less pronounced, as the deterioration of the terms of trade is not as important for absolute consumption.

[35] Kollmann states that assuming local-currency pricing has no significant effect on his results.

aggregate demand, independent of the calibration values for money demand elasticities.

4 The Model

As in Obstfeld and Rogoff (1995a), henceforth OR, there are two countries, home and foreign. Each country is inhabited by a continuum of agents, where each country's population is normalized to 1.[36] Agents consume consumption goods, supply labor and own capital which they rent to firms. In both the domestic and the foreign country resides a continuum of firms indexed by $z^h \in [0,1]$ and $z^f \in [0,1]$ respectively. Each firm produces a single differentiated good, whereas labor and capital are assumed to be homogenous and can be substituted across firms without any cost.[37] In the following, we first contemplate the home representative agent's optimization problem, before we turn to the optimization of the firms.[38]

4.1 The agent

The representative home agent chooses her consumption of goods, holdings of real balances as well as her supply of labor and capital in order to maximize her expected discounted lifetime utility, subject to her intertemporal budget constraint. Direct utility is derived from consumption of a consumption basket C_t, of real balances $\frac{M_t}{P_t}$, and leisure which is measured as 1 (the total amount of time available for the agent) minus H_t (the time dedicated to work). In the benchmark model, the agent's utility is additive separable and has the following explicit form

$$U = E_t \sum_{s=t}^{\infty} \beta^{s-t} \left[\frac{C_s^{1-\sigma}}{1-\sigma} + \frac{\chi}{1-\epsilon} \left(\frac{M_s}{P_s} \right)^{1-\epsilon} + \eta \ln (1 - H_s) \right].^{39}$$

[36] For simplicity, both countries are assumed to be equal sized.

[37] This assumption is similar to Betts and Devereux (2001) but differs from Kollmann (2001a), who assumes differenciated labor to introduce wage rigidities. Wage rigidities are certainly an important feature of a monetary model. However, including them here would go beyond the present scope of the analysis.

[38] The analysis of the representative foreign agent is analogous.

[39] The seperability of the utility function is common in the NOEM-literature (see e.g. OR (1995a) and Lane (2001)). The specific utility function is also used in Betts and Devereux (2001). For the robustness analysis, however, I will consider a non-seperable utility function to isolate the intertemporal elasticity of subsitution from the determination of the intratemporal elasticity of substitution between consumption and real balances. This kind of non-separable utility function is commonly used in the real business cycle literature (see e.g. Chari, Kehoe and McGrattan (2002)).

The parameter β (< 1) denotes the subjective discount factor which determines how much future consumption is valued in terms of today's utility, and σ determines the intertemporal elasticity of substitution for consumption. A high σ implies a low intertemporal elasticity of substitution. The parameters χ and η govern the relative importance of real balances and leisure compared to consumption in terms of utility, while ϵ pins down money demand elasticities.

The agent faces the following intertemporal budget constraint

$$\begin{aligned} P_tC_t + P_tV_t + M_t + B_{t+1}^h + e_tB_{t+1}^f &= (1+i_t)\,B_t^h + (1+i_t^*)\,e_tB_t^f + \Pi_t \\ &\quad + W_tH_t + r_t^K P_tK_t + M_{t-1} + P_t\tau_t \end{aligned} \quad (1)$$

Nominal expenditures on consumption P_tC_t, investment P_tV_t, balances M_t and internationally traded bonds B_t^h and B_t^f may not exceed nominal income from last period's bonds in home currency, nominal profits Π_t from the share of each firm, labor income and the rental payments received on the capital stock K_t plus last period's money holdings and a nominal government lump sum transfer amounting to $P_t\tau_t$.

Agents can only trade in two internationally traded riskless bonds B_t^h and B_t^f, where the former is denominated in the home and the latter in the foreign currency. The bonds yield the nominal interest rate i_t and i_t^* between period $t-1$ and t respectively, and are assumed to be perfect substitutes. Hence, the model comprises perfect capital mobility in the sense of Mundell.[40] Nominal interest rates have to be identical, except for expected exchange rate changes. The exchange rate e is defined in terms of the foreign currency, hence an increase in e_t denotes a depreciation of the home currency.

For the distribution of profits, we assume that all agents within one country hold equal shares of all firms residing in this country. Thus, there is no portfolio-choice and within each country every agent receives the same amount of distributed profits.[41,42]

[40] The physical capital stock however is internationally immobile.

[41] The profit revenue of domestic agents Π_t can be written as a weighted average of all domestic firms' profits

$$\Pi_t = \int_0^1 \Pi_t\left(z^h\right) dz^h.$$

This holds for foreign agents accordingly.

[42] The assumption that domestic firm's shares are only held by domestic agents implies that an increase in domestic firm's markup and hence profits will only benefit domestic

The capital stock K_t used for production is owned and accumulated by home agents. Each period, agents rent their existing capital stock to the firms and receive a nominal interest payment of $r_t^K P_t$ per unit.[43] Capital depreciates at the constant rate δ and increases with investment but at a decreasing rate because of capital adjustment costs. The explicit form of the law of motion for capital is

$$K_{t+1} = (1-\delta) K_t + V_t - \frac{\phi}{2} \frac{\{K_{t+1} - K_t\}^2}{K_t}. \tag{2}$$

The parameter ϕ governs the importance of capital adjustment costs. Absolute adjustment costs are higher, the higher the absolute change of the capital stock, and the smaller the initial capital stock.

The agent maximizes her expected lifetime utility with respect to C_t, M_t, H_t, K_{t+1}, $B_{t+1}^h$and B_{t+1}^f subject to her intertemporal budget constraint and to the law of motion for the capital stock. The resulting first order conditions of the domestic representative agent are

$$C_t^{-\sigma} = \beta E_t \left[(1 + i_{t+1}) \left(\frac{P_t}{P_{t+1}} \right) C_{t+1}^{-\sigma} \right] \tag{3}$$

$$\frac{M_t}{P_t} = \left[\chi C_t^{\sigma} E_t \left[\frac{1}{1 - \frac{1}{1+i_{t+1}}} \right] \right]^{\frac{1}{\epsilon}} \tag{4}$$

$$\eta \frac{1}{(1 - H_t)} = C_t^{-\sigma} \frac{W_t}{P_t} \tag{5}$$

$$\left(1 + \phi \frac{K_{t+1} - K_t}{K_t} \right) C_t^{-\sigma} = \beta E_t \left[\left(1 + r_{t+1}^K - \delta + \frac{\phi}{2} \frac{K_{t+2}^2 - K_{t+1}^2}{K_{t+1}^2} \right) C_{t+1}^{-\sigma} \right] \tag{6}$$

$$(1 + i_{t+1}) E_t \left[\frac{C_{t+1}^{-\sigma}}{P_{t+1}} \right] = \left(1 + i_{t+1}^* \right) E_t \left[\frac{C_{t+1}^{-\sigma}}{P_{t+1}} \left(\frac{e_{t+1}}{e_t} \right) \right] \tag{7}$$

The first optimality condition, equation (3) is the Euler equation which determines the optimal intertemporal consumption path. The intertemporal elasticity of substitution between consumption today and tomorrow is $\frac{1}{\sigma}$.

agents. As we also abstract from complete asset markets, this assumption follows as a logical consequence. However, it might be worthwile to examine how a relaxation of this assumption would affect the results.

[43] The real rate of return on capital is then r_t^K.

The higher the domestic real interest rate, the higher the opportunity costs of consumption today, and the more the agent will be inclined to postpone consumption to some future day.

Money demand is shown in equation (4). The demand for real moneybalances is increasing in real consumption expenditures (instead of real income) and declines with an increase in the nominal interest rate as the opportunity cost of holding the non-interest bearing asset rises.

The third optimality condition, equation (5), is referred to as the labor-leisure trade-off. It determines the agent's optimal supply of labor H_t, which is increasing in the real wage $\frac{W_t}{P_t}$ and decreasing in consumption.

The agent's investment decision is determined by equation (6). The cost borne in terms of foregone utility of consumption in order to increase today's capital stock by one unit (which is one unit plus the marginal capital adjustment costs) has to be equal to the marginal revenue derived from this investment. This revenue is measured in terms of the increase in consumption possibilities and the resulting increase in utility tomorrow, and consists of the increase in the capital stock itself, the expected real interest payment of the firm minus depreciation and plus the expected decrease in capital adjustment costs tomorrow.[44]

The last optimality condition, equation (7), corresponds to the uncovered interest parity. It determines the optimal allocation of assets between home and foreign bonds.[45]

In the following analysis, we abstract from government spending. Although I realize that this is restrictive, it keeps the model more parsimonious and we can focus on the effects of monetary policy. It is assumed that seigniorage is redistributed to the agents as a lump-sum transfer, hence

$$M_t - M_{t-1} = P_t \tau_t.$$

[44]Note, however, that the expected real return on the capital stock $E_t\left[r_{t+1}^K\right]$ still depends on other determinants like expected demand and the expected overall capital stock. But for now we will take the expected rental rate as given.

[45]Note that for the assumption of certainty equivalence used for the linear approximation of the model below, equation (7) reduces to $(1+i_{t1}) = \left(1+i_{t+1}^*\right) E_t\left[\frac{e_{t+1}}{e_t}\right]$.

4.2 Consumption preferences, the price level and demand

4.2.1 Consumption

The agent's intertemporal allocation of consumption as well as the optimal allocation between consumption, leisure and real balances has been pinned down in the optimization presented above. However, consumers also face the decision how to optimally allocate their total expenditure on consumption goods C_t between differentiated home and foreign goods. This allocation decision is a two-stage process. First, agents need to opt for the share of import goods in their consumption basket. Second, they need to decide how to distribute the expenditures for home goods further on each differentiated domestic good.[46]

As Kollmann (2001a), we assume that the household's consumption is an aggregate of home and foreign differentiated goods, which takes the explicit form of a CES-function. This is done in order to allow for a home bias in consumption.[47]

$$C_t = \left(\lambda^{\frac{1}{\mu}} \left(C_t^h \right)^{\frac{\mu-1}{\mu}} + (1-\lambda)^{\frac{1}{\mu}} \left(C_t^f \right)^{\frac{\mu-1}{\mu}} \right)^{\frac{\mu}{\mu-1}}$$

C_t^h and C_t^f are home agents' consumption baskets that consist of domestically produced goods and imported foreign goods respectively. The coefficient λ determines the degree of home bias in consumption. If λ is greater than 0.5, agents exhibit a home bias. In this case, home agents will consume more domestic than foreign goods when facing equal domestic and foreign prices.[48]

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[46] Of course, this holds for foreign products as well.

[47] For simplicity, we assume that investment features the same composition as consumption, and hence looks like

$$V_t = \left(\lambda^{\frac{1}{\mu}} \left(V_t^h \right)^{\frac{\mu-1}{\mu}} + (1-\lambda)^{\frac{1}{\mu}} \left(V_t^f \right)^{\frac{\mu-1}{\mu}} \right)^{\frac{\mu}{\mu-1}}.$$

Although the following analysis only referrs to consumption, it applies to investment decision in an analogous way.

[48] The preferences and degree of home bias are assumed to be symmetric for foreign agents. Hence, the consumption index of foreign agents $C_t^*$is

$$C_t^* = \left(\lambda^{\frac{1}{\mu}} \left(C_t^{f*} \right)^{\frac{\mu-1}{\mu}} + (1-\lambda)^{\frac{1}{\mu}} \left(C_t^{h*} \right)^{\frac{\mu-1}{\mu}} \right)^{\frac{\mu}{\mu-1}}$$

where C_t^{f*} represents the consumption of foreign goods consumed by foreign agents and C_t^{h*} represents the consumption of imported domestic goods consumed by foreign agents.

The parameter μ denotes the elasticity of substitution between domestically produced goods C_t^h and imported foreign goods C_t^f. The lower μ, the less agents are willing to substitute between home and foreign goods in response to international relative price changes.[49]

Expenditure minimization of the agents results in the following consumption demand for the home and the foreign consumption basket respectively

$$\begin{aligned} C_t^h &= \lambda \left(\frac{P_t^h}{P_t} \right)^{-\mu} C_t \\ C_t^f &= (1-\lambda) \left(\frac{P_t^f}{P_t} \right)^{-\mu} C_t. \end{aligned}$$

P_t^h denotes the price level for the basket of domestically produced goods, whereas P_t^f is the domestic currency price level of goods imported from abroad. P_t then denotes the absolute consumer price level in the home country. How expenditures for consumption goods are allocated between home and foreign goods – and hence the import share of the country – thus depends on the preference parameter λ, the relative price of home goods compared to the overall price level and the elasticity of substitution μ. The lower λ, the higher the relative price of home goods and the higher μ, the higher is the import share. Whereas prices are determined endogenously, however, the values for λ and μ are constant and the respective values are assigned via calibration.

Both C_t^h and C_t^f (and analogous V_t^h and V_t^f) further consists of a weighted average of home and foreign differentiated goods each produced by a different firm.[50] The weighted average of the home consumption basket is composed of home goods as follows

$$C_t^h = \left(\int_0^1 c_t^h \left(z^h \right)^{\frac{\theta-1}{\theta}} dz^h \right)^{\frac{\theta}{\theta-1}}.$$ [51]

The parameter θ denotes the elasticity of substitution between different goods produced in one country, but it also governs the magnitude of the

[49] Both a high home bias in consumption and a low elasticity of substitution between domestic and foreign goods reduce the expenditure-switching effect.

[50] Recall that there is a continuum of firms in each economy indexed by $z^h \in [0,1]$ and $z^f \in [0,1]$ respectively, each producing a differentiated good, and that both countries are assumed to have equal size for tractability of the analysis.

[51] Consumption on foreign goods is allocated analogously.

markup and hence is an indicator of the extent of monopolistic distortion in the market. The higher θ, the more agents are willing to substitute away from one differentiated good in response to an increase in its price, and the less market-power each single firm has.

Via expenditure minimization we obtain the domestic consumption demand of the home agent for home good z^h, $c_t^h\left(z^h\right)$, as

$$c_t^h\left(z^h\right) = \left(\frac{p_t^h\left(z^h\right)}{P_t^h}\right)^{-\theta} C_t^h.$$ [52]

The demand for each individual good thus depends on its price $p_t^h\left(z^h\right)$ relative to the overall price level of the other domestically produced goods P_t^h, and on the overall expenditure on domestic consumption goods, C_t^h. If a firm sets the price of its good higher than the average price of domestic goods, the firm will sell less than average ($c_t^h\left(z^h\right) < C_t^h$).

Combining the two results obtained above, home consumption demand for each differentiated good produced in the home country can be written as a function of total home real expenditure on consumption goods C_t

$$c_t^h\left(z^h\right) = \lambda\left(\frac{p_t^h\left(z^h\right)}{P_t^h}\right)^{-\theta}\left(\frac{P_t^h}{P_t}\right)^{-\mu} C_t.$$ [53]

4.2.2 Price level

The composition of the home and the foreign good price index is also derived via expenditure minimization. The home price index for domestically produced goods P_t^h is

$$P_t^h = \left[\int_0^1 p_t^h\left(z^h\right)^{1-\theta} dz^h\right]^{\frac{1}{1-\theta}}.$$ [54]

The home price index for imported goods P_t^f is

$$P_t^f = \left[\int_0^1 \left(p_t^f\left(z^f\right)\right)^{1-\theta} dz^f\right]^{\frac{1}{1-\theta}}$$

[52] The domestic demand for the representative foreign good looks similar.

[53] The same holds for domestic demand for foreign differentiated goods.

[54] Note that P_t^h denotes both a price level and a price index, as the whole population of firms (and hence products) is normalized to 1.

where $p_t^f\left(z^f\right)$ denotes the *home* currency price of the foreign good variety z^f. The explicit form of the intermediate price indices depends on the price-setting assumption and will be derived below. The domestic price level of all goods purchased by home agents is

$$P_t = \left[\lambda\left(P_t^h\right)^{1-\mu} + (1-\lambda)\left(P_t^f\right)^{1-\mu}\right]^{\frac{1}{1-\mu}}. \tag{8}$$

As the intermediate price indices P_t^h and P_t^f are *both* denominated in the home currency the exchange rate does not appear in the aggregation of prices for home and foreign goods.

4.2.3 Demand

For completion of the analysis, I will determine the total demand the representative home and foreign firm faces for its goods. From the individual demand schedules derived above,the total demand for the *representative* home good h is

$$\begin{aligned} y_t^h(h) &= \lambda\left(\frac{p_t^h(h)}{P_t^h}\right)^{-\theta}\left(\frac{P_t^h}{P_t}\right)^{-\mu}\left[C_t + V_t\right] \\ &\quad + (1-\lambda)\left(\frac{p_t^{h*}(h)}{P_t^{h*}}\right)^{-\theta}\left(\frac{P_t^{h*}}{P_t^*}\right)^{-\mu}\left[C_t^* + V_t^*\right]. \end{aligned} \tag{9}$$

Total demand consists of home and foreign demand for consumption and investment, and depends on the aggregate level of expenditure and relative prices. Note that foreign agents decide upon their demand for the home good h on the basis of the *foreign currency* price p_t^{h*} relative to P_t^{h*} and P_t^* which denote the foreign currency price level of domestic goods and all consumption goods respectively.[55]

Since all firms produce a differentiated good, each firm faces an individual demand schedule, which it takes as given when choosing its prices such as to maximize profits. The profit maximization process of the firm, which is derived below, also depends on the form of price rigidities. Before we analyze the optimal price setting, we turn to the determination of optimal production first.

[55] How the foreign currency price p_t^{h*} is determined will be explicitely derived below.

4.3 The firm

4.3.1 Optimal production

All firms at home and abroad produce under constant-returns-to-scale, employing the following Cobb-Douglas production function, displayed for the exmple of the representative home firm h

$$y_t(h) = A_t K_t(h)^{\alpha} H_t(h)^{1-\alpha}.$$

The variable A_t represents the common level of technology available to all firms in the home country. $K_t(h)$ and $H_t(h)$ denote the individual capital and labor inputs of the representative home firm h. The parameter α determines the relative income share of capital and labor. Cost minimization implies that firms will demand factor inputs to satisfy

$$W_t = MC_t(1-\alpha)\frac{y_t^h(h)}{H_t(h)} = MC_t(1-\alpha)\frac{y_t^h}{H_t} \tag{10}$$

and

$$P_t r_t^K = MC_t \alpha \frac{y_t^h(h)}{K_t(h)} = MC_t \alpha \frac{y_t^h}{K_t} \tag{11}$$

where MC_t are the nominal marginal costs of production. Since all home firms face the same wage for labor and rental rate for capital, cost minimization implies the same capital-labor-ratio, and thus the same output-capital and output-labor ratio for each firm. Hence, marginal costs will be equal for all firms.

4.3.2 Optimal prices

It is important to note that profits vitally depend on the assumptions made about price setting and price adjustment. Hence, before examining what prices firms will set to maximize profits, we need to clarify the assumptions about price setting and price adjustment.

Price setting Price setting is severely affected by the amount of market power of the firm. Following Betts and Devereux (1996) and Engel (2000) we distinguish between two different types of firms. One type, which is assumed to represent a fraction s of firms in each country, is able to price discriminate between countries. These firms are assumed to be powerful enough, so that resulting international price differences for the same good cannot be arbitraged away from agents. The other type of firms which represents the remaining fraction $1-s$ of firms in each country has no power to prevent arbitrage and hence sets one price for its good, independently of the market where it is sold. The former price setting is referred to as *local-currency pricing* (henceforth LCP), and the latter as *producer-currency pricing* (henceforth PCP). Note that when the firm cannot adjust its price immediately in response to an exogenous shock, the two types of firms are affected quite differently by a devaluation of the domestic currency. Whereas the PCP firm experiences an increase in its export demand due to the reduction in its relative price in the foreign market, the LCP firm experiences an increase in its markup and thus profits. In order to analyze the profit maximization, we therefore need to distinguish between the problem of a PCP and a LCP firm.

Whereas Betts and Devereux (2001), Kollmann (2001) and Chari et. al. (2002) presume throughout their analysis the same share of LCP firms in *both* countries, I will also allow for an *asymmetric* price-setting behavior across countries. Following Devereux, Engel and Tille (2003) it is plausible to assume that the degree of local currency- pricing is lower in the U.S. than in Europe. Hence, I will distinguish between a share s^h for the domestic country and a share s^f for the foreign country respectively.

Price adjustment Following Calvo (1983), firms adjust their prices infrequently at a random interval, where the opportunity to adjust follows a Bernoulli distribution.[56] Each period, all firms face the same constant probability $1 - \gamma$ to change prices next period and γ to keep prices constant, independently of their history of price changes. By the law of large numbers, each period a constant fraction $1 - \gamma$ of firms will actually change their prices, while the remaining fraction γ will keep their prices constant. Since price adjustment is restricted, firms differ in the prices they charge as well as in their amount of production output and factor inputs, but also in their profits. As the probability of a price change for each firm is independent of past price changes, the expected time between price changes and thus the expected time that a chosen price will be effective is $\frac{1}{1-\gamma}$ for each firm. The probability of price-adjustment is thus an important factor for optimal price setting and therefore also needs to be included in the optimization problem.

[56] This assumption about price adjustment is quite common in the quantitative models of the NOEM-literature (see for instance Betts and Devereux (2001) and Kollmann (2001)). Chari, Kehoe and McGrattan (2002) differ in their assumption about price adjustment, as they presume different cohorts of firms, that can adjust their prices at a given time interval, where in our setting, the arrival date of adjustment is random.

4.3.3 Profit maximization of the representative PCP firm

In the presence of price rigidities à la Calvo, firms set the price such as to maximize their expected discounted future profits, weighted with the probability, that the price they set today will still be effective in the future.[57] The optimal new price chosen by the PCP firm, which is denoted $\widetilde{P}_t^{h,PCP}(h)$, is charged in both the domestic and the foreign market.[58] Hence the price the representative home PCP firm obtains from goods exported to the foreign market is not different from the one for the domestic market. Expected profits are then

$$E_t \sum_{i=0}^{\infty} (\gamma\beta)^i \Lambda_{t,t+i} \left(\frac{\widetilde{P}_t^{h,PCP}(h)}{P_{t+i}} - \frac{MC_{t+i}}{P_{t+i}} \right) y_{t,t+i}^{h,PCP}(h)$$

with

$$\Lambda_{t,t+i} = \left(\frac{C_{t+i}}{C_t} \right)^{-\sigma}.$$

The coefficient $\Lambda_{t,t+i}$ refers to the individual discount rate of expected future earnings. $y_{t,t+i}^{h,PCP}(h)$ denotes the expected total demand of the representative home PCP firme at time $t+i$ provided that the price set at time t is still effective. This can be explicitly written as

$$\begin{aligned} y_{t,t+i}^{h,PCP}(h) &= \lambda \left(\frac{\widetilde{P}_t^{h,PCP}(h)}{P_{t+i}^h} \right)^{-\theta} \left(\frac{P_{t+i}^h}{P_{t+i}} \right)^{-\mu} [C_{t+i} + V_{t+i}] \qquad (12) \\ &+ (1-\lambda) \left(\frac{\widetilde{P}_t^{h,PCP}(h)}{E_{t+i} P_{t+i}^{h*}} \right)^{-\theta} \left(\frac{P_{t+i}^{h*}}{P_{t+i}^*} \right)^{-\mu} \left[C_{t+i}^* + V_{t+i}^* \right]. \end{aligned}$$

The optimal newly set price can then be written as a markup over expected future nominal marginal costs, weighted with expected future real sales revenues

$$\widetilde{P}_t^{h,PCP}(h) = \frac{\theta}{\theta - 1} \frac{E_t \sum_{i=0}^{\infty} (\gamma\beta)^i \Lambda_{t,t+i} D_{t,t+i}^{h,PCP} MC_{t+i}}{E_t \sum_{i=0}^{\infty} (\gamma\beta)^i \Lambda_{t,t+i} D_{t,t+i}^{h,PCP}} \qquad (13)$$

[57] The derivation follows Gertler (2003).

[58] A notational remark: The superscript PCP identifies goods produced and prices charged by PCP firms, the superscript LCP marks the respective variables for LCP firms. The superscript h denotes the goods and prices of the representative home producers, and f respectively denotes goods and prices of the representative foreign producer. Finally, variables marked with an asterisk identify goods that are sold in the *foreign* market and prices that are charged in the *foreign* currency.

with

$$D_{t,t+i}^{h,PCP}=\frac{\widetilde{P}_t^{h,PCP}(h)}{P_{t+i}}y_{t,t+i}^{h,PCP}(h).$$

Note that for $\gamma=0$, i.e. the probability of a price change is equal to one, the optimal price is $\widetilde{P}_t^{h,PCP}(h)=\frac{\theta}{\theta-1}MC_t$, which is the exactly the flexible price solution.

Since all domestic PCP firms face the same labor and capital costs, possess the same technology and face the same demand, each firm which can adjust its price in period t will choose the same price $\widetilde{P}_t^{h,PCP}(h)$. The domestic price index for domestic PCP goods $P^{h,PCP}$ is then a weighted average of last period's price index and the optimal price at time t

$$P_t^{h,PCP}=\left[\gamma\left(P_{t-1}^{h,PCP}\right)^{1-\theta}+(1-\gamma)\left(\widetilde{P}_t^{h,PCP}(h)\right)^{1-\theta}\right]^{\frac{1}{1-\theta}}. \tag{14}$$

4.3.4 Profit maximization of the representative LCP firm

The representative LCP firm faces essentially the same optimization problem as the PCP firm, but it maximizes profits arising from the home and the foreign market, choosing *two different* prices, one for each market respectively. Expected profits then are

$$E_t\sum_{i=0}^{\infty}(\gamma\beta)^i\Lambda_{t,t+i}\left(\frac{\widetilde{P}_t^{h,LCP}(h)}{P_{t+i}}-\frac{MC_{t+i}}{P_{t+i}}\right)y_{t,t+i}^{h,LCP,dom}(h)$$
$$+\left(\frac{e_{t+i}\widetilde{Q}_t^{h,LCP}(h)}{P_{t+i}}-\frac{MC_{t+i}}{P_{t+i}}\right)y_{t,t+i}^{h,LCP,for}(h)$$

with

$$\Lambda_{t,t+i}=\left(\frac{C_{t+i}}{C_t}\right)^{-\sigma}$$

subject to total demand for home LCP goods at $t+i$ given the prices $\widetilde{P}_t^{h,LCP}(h)$ and $\widetilde{Q}_t^{h,LCP}(h)$. The respective demand functions of the home and the foreign market are

$$y_{t,t+i}^{h,LCP,dom}(h) = \lambda \left(\frac{\widetilde{P}_t^{h,LCP}(h)}{P_{t+i}^h} \right)^{-\theta} \left(\frac{P_{t+i}^h}{P_{t+i}} \right)^{-\mu} [C_{t+i} + V_{t+i}]$$

$$y_{t,t+i}^{h,LCP,for}(h) = (1-\lambda) \left(\frac{\widetilde{Q}_t^{h,LCP}(h)}{P_{t+i}^{h*}} \right)^{-\theta} \left(\frac{P_{t+i}^{h*}}{P_{t+i}^{*}} \right)^{-\mu} \left[C_{t+i}^* + V_{t+i}^*\right] \quad (15)$$

Note that $\widetilde{Q}_t^{h,LCP}(h)$ denotes the optimal export price of the representative *home* LCP firm set in the *foreign* currency.

Domestic market The solution to the optimization problem for the home market is similar to the one of the PCP firm. The optimal home price of the LCP firm is again a markup over a weighted average of expected nominal marginal costs, where the weights now depend solely on expected real sales revenue in the *home* market.

Foreign market The optimality condition for the price set by the domestic LCP firm for the foreign market is slightly different from the optimality condition derived above. The optimal new export price for the LCP firm is then

$$\widetilde{Q}_t^{h,LCP}(h) = \frac{\theta}{\theta-1} \frac{E_t \sum_{i=0}^{\infty} (\gamma\beta)^i \Lambda_{t,t+i} D_{t,t+i}^{h*,LCP} \frac{MC_{t+i}}{e_{t+i}}}{E_t \sum_{i=0}^{\infty} (\gamma\beta)^i \Lambda_{t,t+i} D_{t,t+i}^{h*,LCP}} \quad (16)$$

with

$$D_{t,t+i}^{h*,LCP} = \frac{\widetilde{Q}_t^{h,LCP}(h)}{P_{t+i}} \left[(1-\lambda) \left(\frac{\widetilde{Q}_t^{h,LCP}(h)}{P_{t+i}^{h*}} \right)^{-\theta} \left(\frac{P_{t+i}^{h*}}{P_{t+i}^{*}} \right)^{-\mu} \left[C_{t+i}^* + V_{t+i}^*\right] \right]$$

As the LCP price for the foreign market is set in the *foreign* currency, the optimal newly set price not only depends on expected future nominal marginal costs and expected real returns, but also on the expected future path of the nominal exchange rate. This result is not very surprising, as the LCP firm also needs to consider the increase in markup due to a devaluation. Hence, if a devaluation is expected, the optimal newly set price will be lower.

The price index for domestic goods produced by LCP firms evolves analogously

$$Q_t^{h,LCP} = \left[\gamma \left(Q_{t-1}^{h,LCP} \right)^{1-\theta} + (1-\gamma) \left(\widetilde{Q}_t^{h,LCP}(h) \right)^{1-\theta} \right]^{\frac{1}{1-\theta}}. \quad (17)$$

4.3.5 Price indices

With the derivation of the optimal price setting for each firm type, it is possible to simplify the intermediate price indices for home and foreign goods. From equation (14) we know that the average domestic price for home PCP goods is $P_t^{h,PCP}$. Since all firms face the same factor costs, the same home demand and the same probability to change the price, and all have access to a constant returns to scale production technology,[59] the optimal price setting in the domestic market of home firms will be identical, independent of the market power of the firm. Hence, the home market price of the LCP firm is identical to the PCP firm price and the home intermediate price index can be written as

$$P_t^h = P_t^{h,PCP}. \tag{18}$$

The home price index of foreign consumer goods (or import goods) however is composed of two different prices. As was addressed above, a share s^f of foreign firms sets their prices in the local currency of the buyer, hence in the home currency, whereas the share $\left(1 - s^f\right)$ sets their prices in the currency of the producer, hence in the foreign currency. Therefore, the home price index of imported goods is

$$P_t^f = \left[s^f \left(Q_t^{f,LCP} \right)^{1-\theta} + \left(1 - s^f\right) \left(e_t P_t^{f,PCP} \right)^{1-\theta} \right]^{\frac{1}{1-\theta}}. \tag{19}$$ [60]

Note that we again make use of the fact that $Q_t^{f,LCP}$ and $P_t^{f,PCP}$ are the average price of respective foreign LCP and PCP goods intended for the home market.

[59] The latter assumption is crucial, as it implies for the LCP firm, that the production cost in one market is independent of the amount produced in the other market.

[60] The analogous reasoning holds for the foreign price index of domestically produced goods, which can now be written as

$$P_t^{h*} = \left[s^h \left(Q_t^{h,LCP} \right)^{1-\theta} + \left(1 - s^h\right) \left(\frac{P_t^{h,PCP}}{e_t} \right)^{1-\theta} \right]^{\frac{1}{1-\theta}}$$

and the foreign price index for foreign goods is simply

$$P_t^{f*} = P_t^{f,PCP}.$$

4.4 Profits and the consolidated budget constraint

As was indicated above, profits vitally depend on the assumptions made about price-setting and price-adjustment. To determine each firm's profit, it is first necessary to distinguish between LCP and PCP firms. However, profits will be different for each firm, even if they are of the same type, because of price-adjustment à la Calvo. Although firms face the same capital and labor costs, it is assumed that only a fraction of firms can adjust their prices in a given period. Hence firms differ in the prices they set and thus also in their amount of output they produce and factor inputs they demand. The profits of the representative home country firm h can be written as follows

$$\Pi_t\left(h\right) = p_t^h\left(h\right) y_t^h\left(h\right) - W_t H_t\left(h\right) - P_t r_t^K K_t\left(h\right).$$

Aggregated profits of the home economy are then

$$\begin{aligned}\Pi_t &= \int_0^1 \Pi_t\left(z^h\right) dz^h = \int_0^1 p_t^h\left(z^h\right) y_t^h\left(z^h\right) dz^h - \int_0^1 W_t H_t\left(z^h\right) dz^h - \int_0^1 P_t r_t^K K_t\left(z^h\right) dz^h \\ &= \int_0^{s^h} p_t^{h,LCP}\left(z^h\right) y_t^{h,LCP}\left(z^h\right) dz^h + \int_{s^h}^1 p_t^{h,PCP}\left(z^h\right) y_t^{h,PCP}\left(z^h\right) dz^h \\ &\quad - W_t H_t - P_t r_t^K K_t.\end{aligned}$$

Above we have shown that although firms' prices differ, it is possible to compute an average price in each market for PCP and LCP goods respectively. Inserting this average price in the respective demand function for domestic LCP and PCP goods it is possible to obtain an average quantity for both goods. The reduced form of the home economy's budget constraint can then be written as

$$P_t C_t + P_t V_t + B_{t+1}^h + B_{t+1}^f e_t = \left(1 + i_t\right) B_t^h + \left(1 + i_t^*\right) B_t^f e_t + \Pi_t + W_t H_t + P_t r_t^K K_t \tag{20}$$

with

$$
\begin{aligned}
\Pi_t &= s^h \left[P_t^{h,LCP} \lambda \left(\frac{P_t^{h,LCP}}{P_t^h} \right)^{-\theta} \left(\frac{P_t^h}{P_t} \right)^{-\mu} [C_t + V_t] \right] \\
&+ s^h \left[Q_t^{h,LCP} (1-\lambda) \left(\frac{Q_t^{h,LCP}}{P_t^{h*}} \right)^{-\theta} \left(\frac{P_t^{h*}}{P_t^*} \right)^{-\mu} [C_t^* + V_t^*] \right] \\
&+ \left(1 - s^h\right) P_t^{h,PCP} \left(\lambda \left(\frac{P_t^{h,PCP}}{P_t^h} \right)^{-\theta} \left(\frac{P_t^h}{P_t} \right)^{-\mu} [C_t + V_t] \right) \\
&+ \left(1 - s^h\right) P_t^{h,PCP} (1-\lambda) \left(\frac{P_t^{h,PCP}}{e_t P_t^{h*}} \right)^{-\theta} \left(\frac{P_t^{h*}}{P_t^*} \right)^{-\mu} [C_t^* + V_t^*] \\
&- W_t H_t - P_t r_t^K K_t.
\end{aligned}
$$

4.5 Market clearing conditions

In equilibrium, all goods and factor markets need to clear. In the home goods market, aggregated demand is

$$
Y_t^h = \int_0^1 y_t^h \left(z^h\right) dz^h = \int_0^{s^h} y_t^{h,LCP} \left(z^h\right) dz^h + \int_{s^h}^1 y_t^{h,PCP} \left(z^h\right) dz^h.
$$

Making use of the average prices for home PCP and LCP goods derived in equations (14) and (17), the average demand for both home PCP and LCP goods can be deduced from the general demand function for home goods, equation (9). Total demand for home goods is then a weighted average of both, the average demand for domestic LCP goods $y_t^{h,LCP}$ and the average price of home PCP goods $y_t^{h,PCP}$

$$
Y_t^h = s^h y_t^{h,LCP} + \left(1 - s^h\right) y_t^{h,PCP} \tag{21}
$$

For goods market equilibrium, total demand needs to equal total supply. Since all firms face the same wage rate and rental rate for capital, all firms will produce with the same capital-labor ratio, and total supply can be written as

$$Y_t^h = \int_0^1 A_t K_t^\alpha \left(z^h\right) L_t^{1-\alpha} \left(z^h\right) dz^h = A_t K_t^\alpha L_t^{1-\alpha}.^{6162} \tag{22}$$

The factor markets need to clear both in the home and the foreign economy

$$\begin{aligned} L_t &= \int_0^1 L_t \left(z^h\right) dz^h \\ K_t &= \int_0^1 K_t \left(z^h\right) dz^h \end{aligned}$$

and the bonds markets needs to clear which implies that aggregate worlds bond holding is equal to zero.

4.6 Equilibrium

Equilibrium is characterized by equations (2), (3), (4), (5), (6), (8), (10), (11), (13), (14), (16), (17), (15), (12), (21), (22), (18), (19) and their foreign counterparts as well as equations (7), (20) and the bonds market equilibrium, which gives 39 equations. This is a dynamic system in the following thirty-nine variables, given by X_t

$$\begin{aligned} X_t = \; & \{C_t, C_t^*, H_t, H_t^*, V_t, V_t^*, K_t, K_t^*, W_t, W_t^*, r_t^k, r_t^{k*}, i_t, i_t^*, MC_t, MC_t^*, e_t, B_t^h, B_t^f \\ & P_t, P_t^*, P_t^h, P_t^f, P_t^{h*}, P_t^{f*}, \widetilde{P}_t^{h,PCP}, \widetilde{Q}_t^{h,LCP}, \widetilde{P}_t^{f,PCP}, \widetilde{Q}_t^{f,LCP}, P_t^{h,PCP}, \\ & P_t^{h,LCP}, P_t^{f,PCP}, P_t^{f,LCP}, Y_t^h, Y_t^f, Y_t^{h,PCP}, Y_t^{h,LCP}, Y_t^{f,PCP}, Y_t^{f,LCP}\} \end{aligned}$$

---

[61]

$$\underbrace{\frac{Y_t^h}{\int_0^1 L_t(h)\, dh}}_{=L_t} = \int_0^1 A_t \left(\frac{K_t(h)}{L_t(h)}\right)^\alpha dh = A_t \left(\frac{K_t}{L_t}\right)^\alpha$$

Hence,

$$Y_t^h = A_t K_t^\alpha L_t^{1-\alpha}$$

[62] Goods market equilibrium also holds on the foreign market:

$$Y_t^f = s^f y_t^{f,LCP} + \left(1 - s^f\right) y_t^{f,PCP} = A_t \left(K_t^*\right)^\alpha \left(L_t^*\right)^{1-\alpha}$$

4.7 Steady State

In order to preserve some tractability for the computational methods, the analysis starts from the symmetric steady state, where neither country owns net foreign assets. We also abstract from both real and monetary growth in the steady state, hence, in equilibrium all nominal and real variables are constant. Since we assumed identical preferences (including the parameter values) and technologies across countries, home agents can only differ from foreign agents in their amount of external wealth.[63] Hence, if external wealth is equal for home and foreign agents, consumption, leisure (and thus labor) and investment decisions will be identical, and there is no difference in the real sectors of the economies. If we also assume the identical initial amount of money in both countries, prices will be equal, and the nominal exchange rate will be equal to 1. In this case, we only need to determine the steady state for the home economy, since the foreign economy will simply be a mirror image.

4.8 Calibration

In order to run simulations to evaluate the effects of an unexpected monetary shock, we first need to find adequate values for the parameters and numerically determine the steady state.[64]

Consistent with most of the RBC-literature, the quarterly real interest rate is set to 1% in the steady state, which implies a value of $\frac{1}{1.01}$ for β.[65] The consumption elasticity of money demand is easily derived as $\frac{\sigma}{\epsilon}$, whereas the interest elasticity of money demand is $-\frac{\beta}{\epsilon}$. Estimations for these elasticities apparently vary quite a lot, but I will refer to the results of Mankiw and Summers (1986) for the benchmark levels, as they use consumption as the quantity variable. Their interest elasticity estimate for demand for M1 is -0.051.[66] This implies a value of approximately 19.5 for ϵ. Since Mankiw and Summers' estimate of the consumption elasticity of money demand is

[63] The assumption of an asymmetric degree of local-currency pricing has no consequences for the determination of the steady state, since optimal steady-state prices will be equal to the flexible price solution, which is the same for both LCP and PCP firms.

[64] For the calibration, I mostly follow Betts and Devereux (2001), but also Chari, Kehoe and McGrattan (2002) as well as Kollmann (2001a).

[65] It is common to assume a 4% real interest rate per year both in the NOEM-literature and in the RBC-literature. See e.g. Chari, Kehoe and McGrattan (2002).

[66] Kollmann (2001a) uses an interest rate elasticity of money demand of -0.01, whereas Betts and Devereux (2001) employ -0.12.

exactly 1,[67] this implies a very low intertemporal elasticity of substitution as $\sigma = \epsilon = 19.5$.[68]

The parameter θ determines the markup over marginal costs. Consistent with the literature, I assume that the markup is about 10% which implies a value of 11 for θ.[69] I follow Chari, Kehoe and McGrattan (2002) for the capital share, who set α to $\frac{1}{3}$, as well as for the rate of depreciation, which is set to 0.021. This combination (together with the value for θ), implies an investment share of roughly 20% and hence a consumption share of 80% in the steady state. This is consistent with the long-run average of the consumption and investment shares to GDP excluding government expenditures.[70]

As Betts and Devereux, we assume that in the steady state, agents dedicate 30% of their available time to work, hence $\overline{H} = 0.3$. For simplicity, the relative preference parameter for real balances, χ, is assumed to be 1. These two assumptions make it possible to pin down η.[71]

The elasticity of substitution between domestic and foreign goods μ is set equal to 1.5, which corresponds Chari, Kehoe and McGrattan (2002), and is equal to the number used in Backus, Kehoe and Kydland (1994). The price adjustment parameter is set as $\gamma = 0.75$ as in Betts and Devereux (2001). This implies that the average time between price adjustment for a firm is one year. The import share in the steady state is assumed to be 15% for the U.S. as in Backus, Kehoe and Kydland (1994). Finally, the value for capital adjustment costs ϕ is set to 8 as in Kollmann, but some robustness checks are conducted.[72] Different degrees of pricing to market s in both the domestic and the foreign economy are then analyzed to determine the

[67] Kollmann (2001a) uses a value of 0.2 and Betts and Devereux (2001) use a value of 0.85 for the consumption elasticity of money demand. The lower elasticities of money demand imply higher consumption responses.

[68] In order to determine the intertemporal elasticity of substitution independently of the the money demand elasticities, a second - non-separable - utility function will be assessed below.

[69] See e.g. Chari, Kehoe and McGrattan (2002), p. 17, and Betts and Devereux (2001).

[70] As the government sector is not included in the model, it seems useful to abstract from government spending in deriving the relevant consumption and investment shares.

[71] η turns out to be very high for the benchmark calibration, i.e. $\eta = 398$. This is due to the extremely high intertemporal elasticity of substitution, resulting from the calibrated money demand elasticities. In a second set-up, we will assess a non-seperable utility function, where the degree of intertemporal risk sharing will be independent of the calibration values for money demand.

η is reduced to 23 when we assume the money demand elasticities employed by Betts and Devereux (these values imply a lower σ of about 9). However, the impulse responses of output, consumption and investment to a permanent increase in dometic money supply are hardly affected.

[72] The list of the benchmark parameter values is provided in the appendix.

effects of different price-setting behavior on the international transmission mechanism of monetary policy.

5 Results

5.1 The benchmark model

For the benchmark model and the benchmark calibration, I obtain the following set of impulse responses.[73] The shock considered is a permanent 1% increase in domestic (nominal) money supply. The plotted impulse responses are then resulting percentage deviations from respective steady-state values. The exchange rate is assumed to be perfectly flexible and foreign nominal money supply remains constant.

Figure (3) depicts the impulse responses for the case that all producers set their prices in their own currency, i.e. *complete producer-currency pricing in both countries.*[74] Solid lines show the responses of home variables, dashed lines the corresponding responses of foreign variables.

Due to the home monetary surprise impulse, home production as well as aggregate demand increase. Although both foreign consumption and investment experience a temporary – albeit smaller – increase as well, foreign output is basically unaffected. The reason is that the expenditure-switching effect redirects the whole augmentation in world aggregate demand induced by the decline in the real interest rate towards domestic products. With complete producer-currency pricing, import prices exhibit a complete exchange rate pass-through, which leads to a proportionate decline in foreign import prices, whereas domestic import prices rise. At the same time, the home country experiences a deterioration of its terms of trade, such that the rise in income is smaller than the rise in production, and foreign income increases.[75]

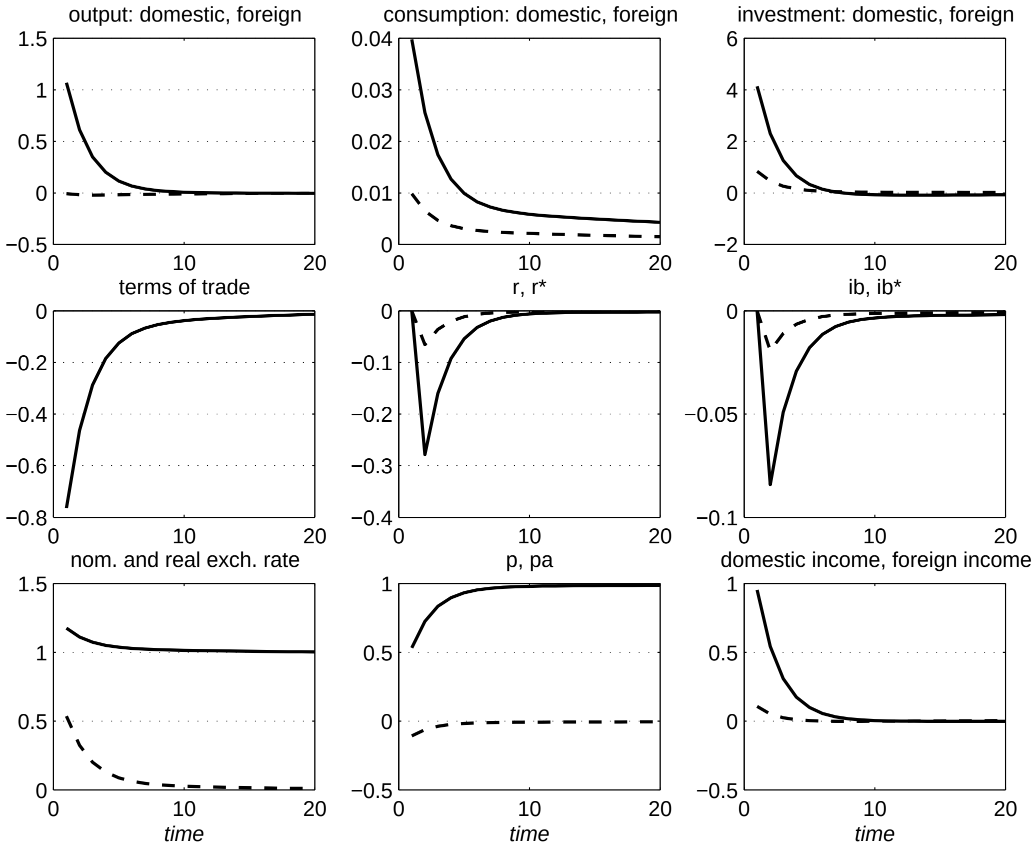
The results obtained correspond to the findings of Betts and Devereux (2001). The impact on the foreign economy is smaller, however, since the import share we presumed is only 15% here versus 50% in Betts and Devereux. The home bias also allows for a slight overshooting of the nominal exchange rate.

[73] For the solution of the model, the MATLAB code provided by Schmitt-Grohé and Uribe (2004) is employed. However, I only derive a first-order approximation, as a second order approximation exceeds the computational facilities.

[74] Hence, both s^h and s^f are equal to zero.

[75] The decline in the foreign country's import prices raises foreign purchasing power. I define foreign income as nominal returns from domestic firms' sales plus interest earned on bonds in terms of the foreign consumer price index P^*.

Figure 3: Impulse responses to a permanent increase in home money supply for complete PCP

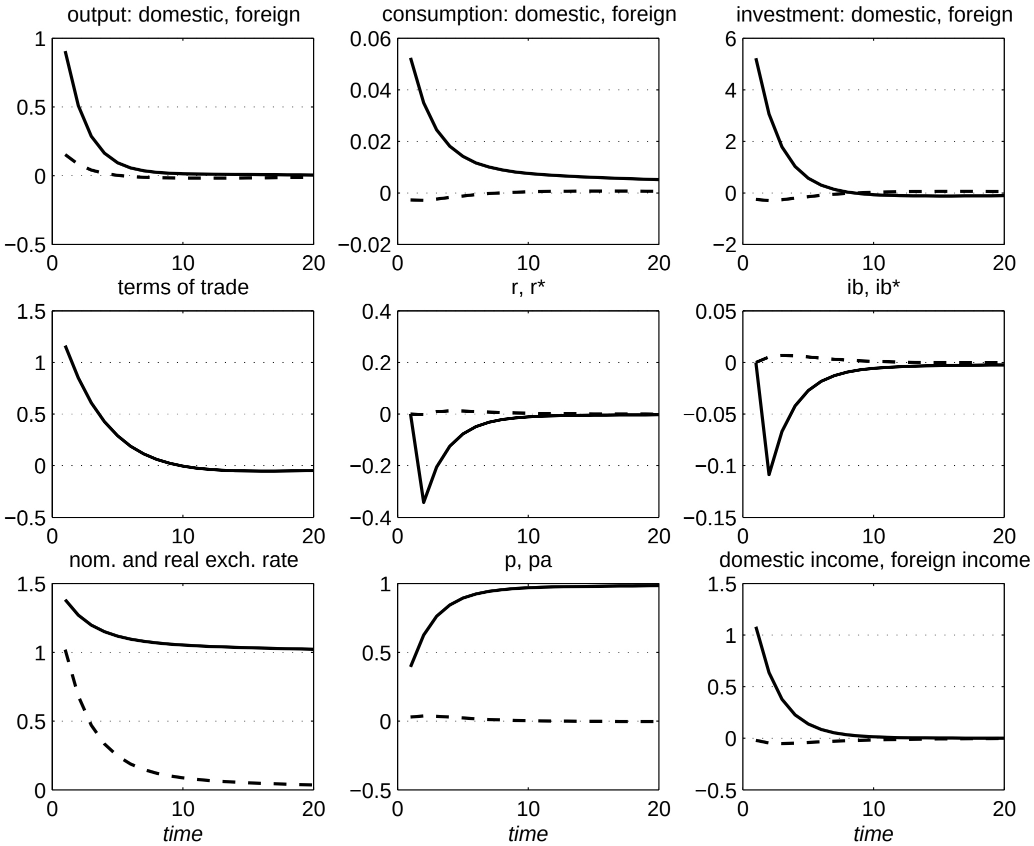


The corresponding impulse responses for *complete local-currency pricing in both countries* are shown in Figure (4).[76]

When all producers set their export prices in the export currency, a surprise increase in the home money supply increases not only domestic but also foreign production. The reason is that for complete LCP, the expenditure-switching effect is repressed. There is no exchange rate pass-through to import prices whatsoever. Hence, the increase in home demand is directed to *both* home and foreign goods proportionately to their consumption shares of home agents. However, foreign agents' income falls. The devaluation of the home currency augments the markup of domestic producers in their export

[76] This corresponds to the case where s^h and s^f are both equal to 1.

Figure 4: Impulse responses to a permanent increase in home money supply for complete LCP



market, whereas the markup of foreign producers declines. Since the decline in markup more than compensates the increase in production, foreign income falls.

What happens to the interest rates? In the PCP setting, the increase in domestic money supply is spread across both countries.[77] As the home currency depreciates, domestic imports become more expensive, whereas foreign import prices decline. This affects the home and the foreign (consumer) price level in the opposite way. The home price level increases, reducing the initial increase in real balances, whereas the foreign price level declines. This induces an increase in real balances abroad, which in turn allows for

[77]The following argumentation relates to the initial impact period and presumes for simplicity that no price adjustment has been undertaken so far.

a decline in the foreign nominal interest rate. With anticipated home and foreign inflation, the decline in the real interest rate in both countries will be even bigger, which induces an increase in consumption (and investment) demand, both at home and abroad.

In the LCP setting, import prices are not affected, neither at home, nor abroad. Hence, foreign real balances remain initially constant. There is no possibility for a decline in the foreign real interest rate, and foreign consumption and investment remain almost unaffected.[78]

Finally, we consider the case where all home producers set their prices in their own currency (the U.S. dollar), whereas foreign producers set their export prices in the currency of the export market.[79] This scenario is denoted the *complete asymmetric price setting*, with $s^h = 0$ and $s^f = 1$. The corresponding impulse response functions are depicted in Figure (5).

Under the assumption of this asymmetric price-setting behavior, the home monetary impulse leads to *both*, an increase in foreign output *and* an increase in foreign demand, and thus replicates the empirical results found.

Since foreign imports are denominated in the domestic currency (the U.S. dollar), a devaluation still reduces foreign import prices and thus leads to a decline in the foreign overall price level. This again increases foreign real balances and allows for a decline in the nominal interest rate. With expected foreign inflation (due to the decrease in P^*), also the foreign *real* interest rate declines which inherently leads to an increase in foreign consumption and investment demand. The effect on foreign consumption will be higher, the higher the import share, since with more import, the decline in import prices is more important to the overall price level.

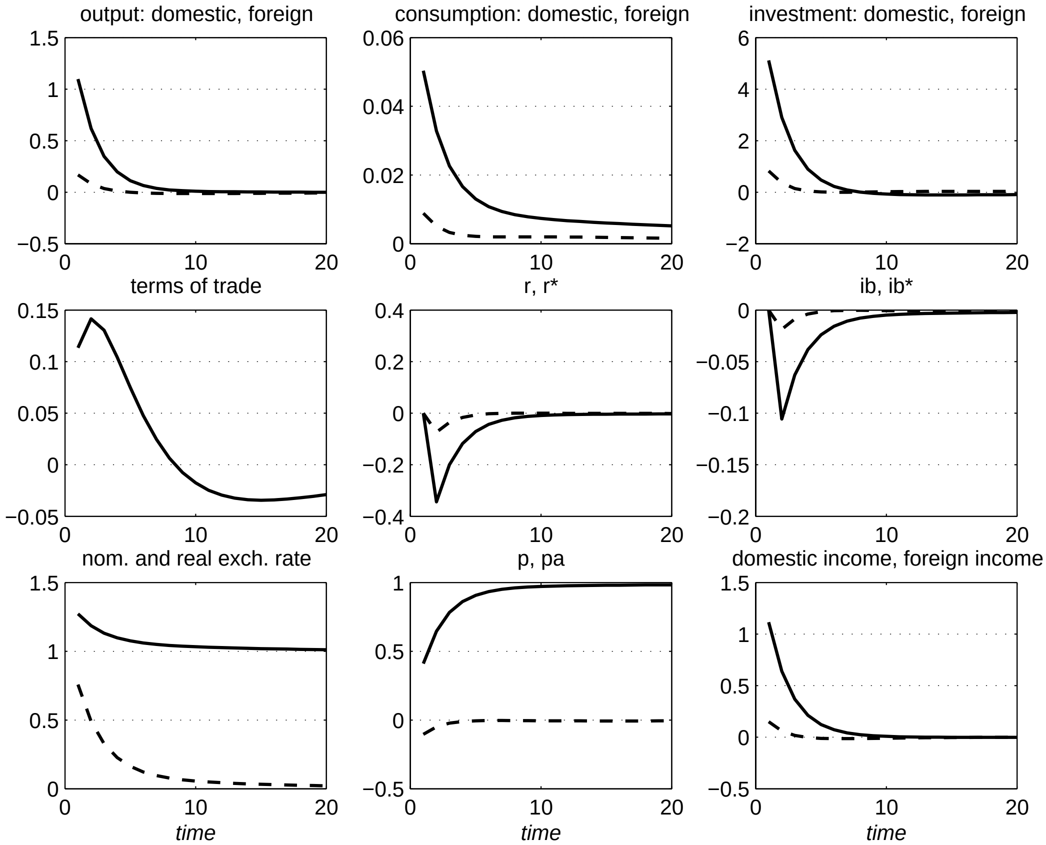
On the other hand, the expenditure-switching effect is clearly extenuated, since for home agents, relative prices of home and foreign goods do not change on impact with the devaluation. Thus, the increase in home demand is directed to both home and foreign goods proportionately, and foreign production, which is demand determined in the short run, increases.

In this setting, the terms of trade of the home country still initially improve, albeit by much less. The reason is that both home country's import prices and export prices (in home currency) are initially basically fixed, and hence there is not much room for a change in the terms of trade.

[78] Also note that since the foreign price level did not decline in the first place, there is no inflation expectation for the foreign price level.

[79] Devereux, Engel and Tille (2003) provide evidence that the degree of local currency pricing in the U.S. has been clearly lower than in Europe. They assume that this will change, however, with the introduction of the Euro.

Figure 5: Impulse responses to a permanent increase in home money supply for complete PCP in the domestic country and complete LCP in the foreign country



The obtained result seems to indicate that the asymmetric price-setting behavior might be crucial to explain international transmission effects of monetary policy.

However, a certain feature of the impulse responses is striking. Comparing the magnitude of the output and consumption responses, consumption responses are vanishing small. This is due to the extremely low intertemporal elasticity of substitution of 0.05, which is implied by the calibrated values for money demand elasticities. The consumption effect does not considerably increase when we employ the same money demand elasticities as Betts and Devereux, which reduces the value of σ from almost 20 to roughly 9, which is still extremely high. Therefore, we will examine the effects for a utility function, that is non-separable in real balances and consumption, which makes it possible to determine the parameter of risk aversion independent of money demand elasticities.

5.2 Robustness check: non-separable utility

To separate the determination of the intertemporal elasticity of substitution from the money demand elasticities, we assess a second type of utility function, where consumption and real balances are non-separable. The explicit form considered is

$$U = E_t \sum_{s=t}^{\infty} \beta^{s-t} \left[\begin{array}{c} \frac{1}{1-\sigma} \left(\left(\omega C_s^{\frac{\nu-1}{\nu}} + (1-\omega) \left(\frac{M_s}{P_s} \right)^{\frac{\nu-1}{\nu}} \right)^{\frac{\nu}{\nu-1}} \right)^{1-\sigma} \\ + \frac{\eta}{1-\psi} (1 - H_s)^{1-\psi} \end{array} \right],$$

which is also used by Chari, Kehoe and McGrattan (2002). The resulting money demand equation is then

$$\frac{M_t}{P_t} = \left(\frac{\omega}{1-\omega} \right)^{-\nu} C_t \left(\frac{i_{t+1}}{1+i_{t+1}} \right)^{-\nu}.$$

In this specification of the preferences, the consumption elasticity of money demand is equal to one. Interest elasticity is derived as $-\frac{\nu}{\beta}$. For comparability, we again calibrate interest elasticity to -0.051.[80] The parameter σ is now set to 2.

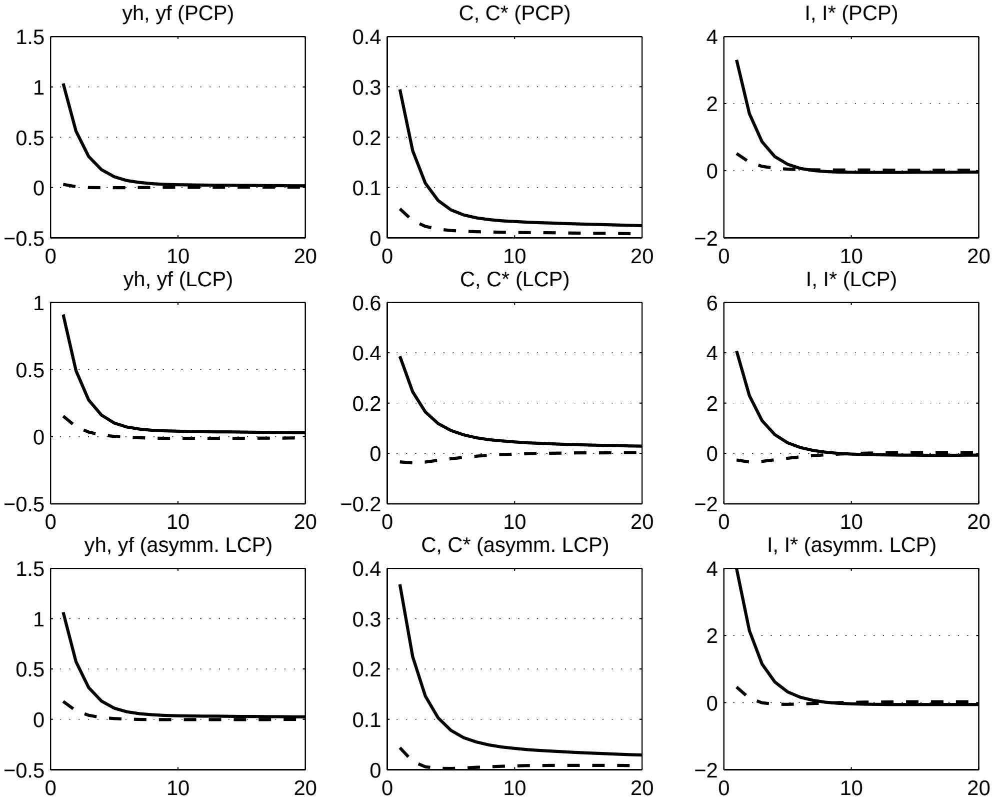
For comparison, the corresponding impulse responses for both home and foreign consumption, investment and output are plotted for all three different price-setting assumptions in figure (6). Whereas now the quantitative consumption responses – both at home and abroad – are much more in line with the empirical evidence, the general conclusions derived above still hold, and thus are not sensitive to the precise specification of the utility function.

Hence, asymmetric price-setting behavior of domestic and foreign firms can help us understand how a monetary policy shock is transmitted internationally.

[80] Chari, Kehoe and McGratten (2002) estimate their money demand equation and obtain a value of -0.39 for interest elasticity. My general conclusions are not affected by such a variation in the interest rate elasticity.

Note however, that when we use the same utility function as in Kollmann (2001a), we obtain comovements in output responses for PCP price setting for the interest and consumption elasticities employed by Kollmann. The positive effect on foreign output disappears as soon as the absolute value of the interest elasticity is raised from -0.01 to -0.051 and consumption elasticity is raised from 0.2 to 1, i.e. for our benchmark calibration, we obtain no effect of a domestic monetary policy shock on foreign output effect for PCP pricing.

Figure 6: Impulse responses to a permanent increase in home money supply for non-separable preferences: a comparison of PCP, LCP and asymmetric price setting behvior



5.3 Welfare

Although I will not depict any welfare results explicitely, it is evident from the utility function, that the manner of price setting vitally effects welfare results. Betts and Devereux (2000) explicitley derive the effects of local-currency pricing on international welfare effects of a monetary shock for a model with closed form solutions. They show that for a high degree of local-currency pricing, expansionary monetary policy has 'beggar-thy-neighbour' effects. This result is quite obvious. As we know from the impulse responses, for complete LCP foreign production rises, whereas consumption and investment (and income) even decline. Hence, the deterioration of the foreign terms of trade induce foreigners to work more, and consume less at the same time, which evidently makes them worse off.

Tille (2001) as well as Corsetti and Pesenti (2001) on the other hand show that for producer-currency pricing, monetary policy can even be 'beggar-thyself' for the country raising the nominal money supply. Tille shows, that the result (for a closed form solution model) depends on the relative size of the elasticity of substitution between goods produced in the same country compared to the elasticity of substitution between home and foreign good. For the plausible assumption, that the *international* elasticity of substitution is lower than the *intranational* elasticity of substitution, monetary policy is found to have 'prosper-thy-neighbour' and 'beggar-thyself' effects.

For the asymmetric price-setting assumption assessed above, welfare effects are in between the two extreme results of 'prosper-thy-neighbour' for PCP and 'beggar-thy-neighbour' for LCP. The induced increase in foreign consumption raises per se foreign utility, whereas the rise in labor supply reduces foreign welfare. The net effect then depends on the specific calibration of the parameters.[81]

6 Conclusion

In this paper, I provide some empirical evidence for positive international transmission effects of monetary policy from the U.S. to the other G-6 countries. A surprise U.S. monetary expansion induces both an increase in the G-6 production as well as in G-6 aggregate demand. In the two-country dynamic general equilibrium model with sticky prices derived above, these 'stylized facts' can be reproduced if we allow for an asymmetric price-setting behavior for producers in the U.S. and in the other G-6 countries. Since between 1974 and 2001 the U.S. dollar has been the key currency, it is plausible that most U.S. firms set their prices in their own currency even for goods designated for export and hence pursue a producer-currency pricing strategy. At the same time, it seems obvious that the predominance of the U.S. currency and the U.S. market led foreign producers from Europe and Japan to set the prices for their exports to the U.S. in U.S. dollars and hence pursue a local-currency pricing strategy. This asymmetric price-setting behavior allows for positive spill-over effects of a U.S. monetary shock on the G-6 countries, as it reduces

[81] For the benchmark model, we obtain that foreign welfare first declines for a couple of periods, but the overall welfare effect is positive, if we assume that the agent continues to live for at least 18 and the most 156 more periods. For the non-separable utility function, the computed welfare effects on foreign agents are positive, if we assume that they will continue to live for more than 25 periods. These effects were computed with a first-order approximation, and therefore I acknowledge that these results can only be viewed as a first proxy and have to be handled with care.

and almost eliminates the expenditure-switching effect in the U.S., but still makes a decline in import prices (and hence the overall price level) in the foreign country possible, which induces foreign consumption and investment to rise.

Other authors – especially Betts and Devereux (2000,1996) and Engel (2000) – have shown that the currency of pricing for export goods plays a decisive role for the international transmission of monetary shocks. In this paper, I point out that it is equally important to allow for international differences in the degree of local-currency if we want to understand the international transmission of business cycles induced by a monetary policy shock.

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A Description of the data:

all data are seasonally adjusted (except for the interest rates)

A.1 Benchmark model:

A.1.1 U.S. Data:

- GDP U.S.: real GDP, source: Bureau of Economic Analysis (BEA), National Income and Products Accounts (NIPA) Table 1.2, Line 1
- CPI U.S.: Federal Reserve Economic Data (FRED), series CPIAUCSL
- FFR: FRED, series FEDFUNDS
- NBR: Non-borrowed reserves, source: FRED, series BOGNONBR
- TR: Total reserves, source: FRED, series TR

A.1.2 G6 Data:

- GDP G6: weighted real GDP, source of the individual series: IMF IFS, GDP volume, series 99BVRZF..., geometric weighted average
- IR G6: weighted nominal interest rate, source of individual series: IMF IFS, money market rates for Japan, Germany and Italy, series 60B..ZF..., and treasury bill rates for UK, Canada and France, series 60C..ZF...
- CPI G6: weigthed CPI, source of the individual series: IMF IFS, Consumer Prices, series 64...ZF..., geometric weighted average
- NEER G6: weighted nominal exchange rate, source of the individual series: IMF IFS, Market Rate (Index Number), series ..AHXZF..., geometric weighted average. An increase in the nominal exchange rate is a devaluation of the U.S. dollar.
- REER G6: weighted real exchange rate of individual countrie's j real exchange rate, computed as $REER_j = NEER_j * CPI_j/CPI_{US}$ where $NEER_j$ is the individual countries nominal exchange rate index, series ..AHXZF.

A.2 Variables of interest

A.2.1 U.S. data

- Investment: Real fixed private domestic investment: source FRED, series FPIC1 (real data)
- Consumption: Real personal consumption expenditure, source BEA, NIPA, table 1.2 line 2 (real data)

A.2.2 G6 data

- Consumption G6: weighted average of real household consumption: source of individual series IMF IFS, nominal consumption, series 96F.CZF..., each deflated by the consumer price index and normalized to 100 at 1995
- Investment G6: weighted average of real gross fixed investment: source of individual series IMF IFS, nominal gross fixed capital formation, series 93E.CZF..., each deflated by the consumer price index (for comparability to the model) and normalized to 100 at 1995

A.3 The weights

	GDP weights	Trade weights	FDI position weights
Canada	8.47	37.31	20.2
France	15.35	6.08	9.2
Germany	17.58	11.27	12.9
Italy	13.77	4.51	2.7
Japan	30.40	28.90	20.2
U.K.	14.44	11.94	34.7

B Calibration values

For the benchmark model

Parameter	Value	Parameter	Value	Parameter	Value
σ	19.5	χ	1	θ	11
ϵ	19.5	δ	0.021	μ	1.5
ϕ	8	β	$\frac{1}{1.01}$	λ	0.85
η	0.55	α	$\frac{1}{3}$	γ	0.75

For the non-separable utility model

Parameter	Value	Parameter	Value	Parameter	Value
σ	2	ω	0.94	θ	11
ψ	2	δ	0.021	μ	1.5
ϕ	8	β	$\frac{1}{1.01}$	λ	0.85
ν	0.05	α	$\frac{1}{3}$	γ	0.75

C VAR results

Figure 7: Impulse responses of the benchmark system to a NBR/TR shock

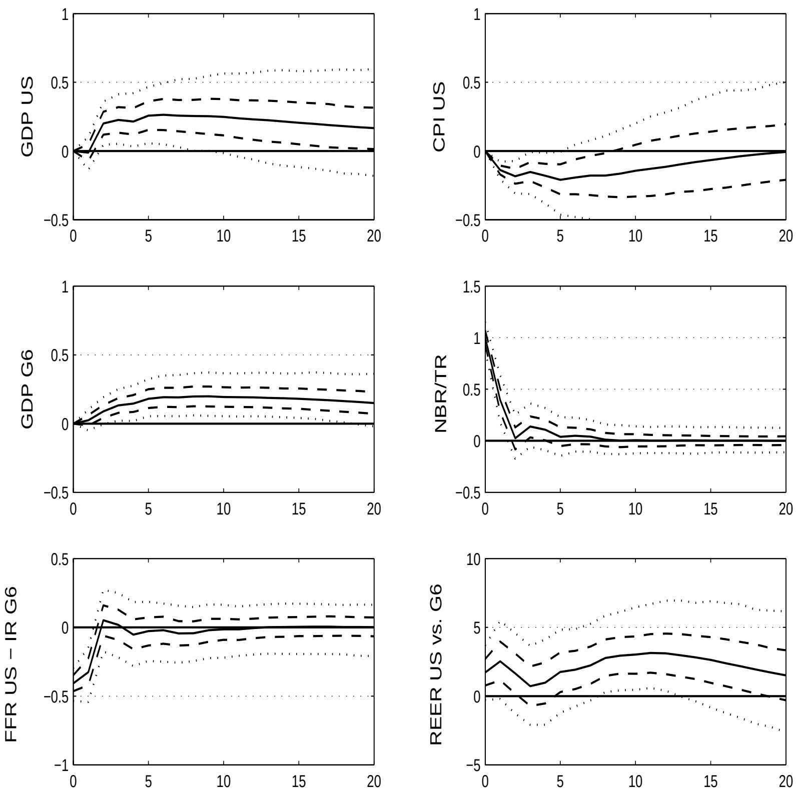

Figure 8: Impulse Responses of U.S. Consumption and Investment in response to a negative 1 standard deviation Innovation in the U.S. federal funds rate

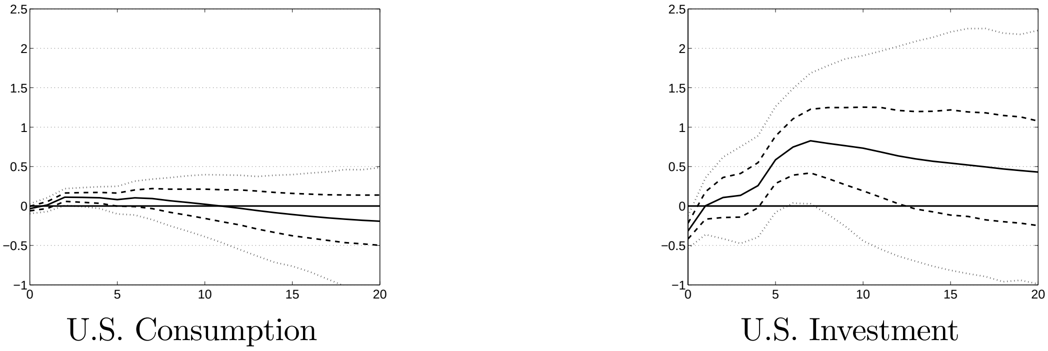

Figure 9: Impulse Responses of G-6 and U.S. Consumption and Investment in response to a positive 1 standard deviation Innovation in the U.S. NBR/TR ratio