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Arbeitspapiere/ Working Papers

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International Transmission Effects
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International Transmission Effects 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? In the traditional two-country Mundell-Fleming model, monetary policy has «beggar-thy-neighbor» effects. Yet, empirical evidence from VARs indicates that U.S. monetary policy has positive international transmission effects on both foreign (non-U.S. G-7) output and aggregate demand. In this paper, I will show that a two-country dynamic general equilibrium model with sticky prices can account for these «stylized facts» if we allow for international asymmetries in the price-setting behavior of firms. If U.S. firms set export prices in their own currency only (producer-currency pricing), whereas producers in the rest of the world price their exports to the U.S. in the local currency of the export market (local-currency pricing), a U.S. monetary expansion is found to increase output and aggregate demand abroad.

Keywords: Local-currency pricing, Producer-currency pricing, New Open Economy Macroeconomics, International transmission effects of monetary policy

JEL Classification: F41; E52

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1 Introduction

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.¹ In his analysis for flexible exchange rates, Mundell shows that a monetary expansion raises domestic production and income. Yet, the monetary induced boom at home is found to be at the expense of the foreign economy, which experiences a decline in its output. This result is due to the expenditure-switching effect induced by the depreciation of the home country's currency. Mundell therefore concludes that a domestic monetary expansion has 'beggar-thy-neighbor' effects. However, empirical evidence obtained from vector autoregressions assessing the effects of U.S. monetary policy highly contradicts this implication. Instead, U.S. monetary policy is found to have *positive* spill-over effects on foreign (non-U.S. G-7) output as well as on foreign aggregate demand. This shortcoming of the Mundell-Fleming model raises the question, whether other - possibly newer - models are better equipped to match the "stylized facts".

With the publication of the *Redux* model in 1995, Obstfeld and Rogoff launched what is now called the "New Open Economy Macroeconomics" (NOEM).² 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 induces demand-determined production in the short run, and thus leads to real effects of monetary shocks. Since 1995 a growing number of extensions to the *Redux* model have been developed, also concerning pricing decisions of firms. In their analyses, Betts and Devereux (2001, 2000, 1996) investigate how two alternative assumptions about price setting (local-currency pricing compared to producer-currency pricing) affect the international transmission of monetary policy shocks. They find that the price-setting behavior of firms crucially determines the direction of the international transmission effects in response to a monetary shock. Betts and Devereux (2001) show that the positive transmission effect on foreign output is reproduced for the assumption of local-currency pricing. Yet, this effect is not transmitted to foreign demand, which remains unaffected.

¹See e.g. Turnovsky (1986), and for more recent contributions Corsetti and Pesenti (2001), Tille (2001) and Betts and Devereux (2000).

²For an excellent survey of the research in this area see Lane (2001a), but also Sarno (2001) and Fendel (2002a).

In this paper, I show that for the assumption of asymmetries in the price-setting behavior of firms across countries, a generalized standard NOEM-model exhibits positive international transmission effects of monetary policy on both foreign output and aggregate demand. Empirical evidence, e.g. established in Clark and Faruquee (1997), suggests that the degree of exchange-rate pass-through to import prices is noticeably lower in the U.S. compared to other G-7 countries. This finding indicates that foreign producers are more inclined to set prices for exports to the U.S. separately, whereas exports sold to other (smaller) countries are more likely to be priced in the currency of the producer. This argument is also supported by recent work of Bacchetta and van Wincoop (2005), who show that the optimal choice of currency denomination of exports depends on the competition firms face in the foreign market. They find that a higher market share in the foreign market provides an incentive for firms to set prices in their own currency and vice versa. Hence, U.S. producers are more likely to set prices in their own currency, independent of the market in which their product will be sold, whereas producers in the rest of the world - which is assumed to consist of a number of smaller countries - will rather set two different prices, one for their domestic market and one for their exports to the U.S. For illustrational purpose, I investigate in this paper the limiting assumption of *complete producer-currency pricing* in the home country, which represents the U.S., and *complete local-currency pricing* in the foreign country representing the rest of the world which is assumed to consist of the non-U.S. G-7 countries. In this setting, I find that a monetary expansion in the U.S. raises production as well as aggregate demand in the foreign country. These results indicate that the suggested *asymmetric price-setting behavior* provides an explanation to the empirical evidence.

The structure of the paper is as follows. The next section briefly reviews empirical evidence on international transmission effects of monetary policy. In section 3, the model is derived. The results obtained for alternative assumptions on price-setting behavior including a short robustness check are presented in section 4 before section 5 concludes.

2 Empirical evidence

With the introduction of vector autoregressions (VARs) 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.³ Whereas research in this field is mostly concerned with effects of monetary policy shocks on domestic variables, a number of authors also investigate the transmission effects on foreign variables. For instance, Betts and Devereux (2001) determine the international transmission effects of U.S. monetary policy on foreign output. In their analysis, the foreign country (or the ‘rest of the world’) is proxied by a GDP-weighted average of the non-U.S. G-7 countries. They estimate two different VARs, where they include foreign output, the foreign interest rate and the real exchange rate besides domestic output and the monetary policy instrument, which is either the federal funds rate or non-borrowed reserves. Betts and Devereux find an increase in U.S. and foreign output for both expansionary monetary shocks considered.⁴ Although the impact on domestic (U.S.) output is more pronounced, foreign output rises significantly and about two thirds the size of the increase in domestic output. A positive international transmission effect of U.S. monetary policy on output for both the U.K. and Germany is also found by Faust and Rogers (2003). Miniane and Rogers (2003) provide evidence for a positive transmission effect of U.S. monetary policy on output even for a large set of countries and also for different sub-periods.

A more extensive investigation of the international transmission effects of U.S. monetary policy which also includes the effects on foreign demand is undertaken by Kim (2001). As Betts and Devereux (2001), he constructs a weighted average of the non-U.S. G-7 countries to proxy for the rest of the world. Besides an - albeit smaller - positive transmission effect on foreign output, Kim also 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. Holman and Neumann (2002) focus on the cross-country transmission effects of monetary shocks between the U.S. and Canada. They consider the effects on foreign (Canadian) consumption and investment separately and find positive spill-over effects for an U.S. monetary policy shock on Canadian consumption and investment

³For a recent comprehensive survey of VARs in the determination of monetary policy see Christiano, Eichenbaum and Evans (1999).

⁴Betts 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.

besides output. Contrary to the studies discussed above, monetary policy is identified by a wider monetary aggregate, M2. More evidence on the international transmission of U.S. monetary policy shocks, which also includes the effects on foreign consumption and investment in a two-country-setting, is provided in Schmidt (2004). In a two-country VAR similar to the approaches of Betts and Devereux (2001) and Kim (2001) the effects of a U.S. monetary policy shock on a weighted average of non-U.S. G-7 countries' output, consumption and investment are estimated for several alternative identifications of the shock. For the vast majority, a positive transmission effect for all three aggregates is found.

These empirical 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 the 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. A surprise increase in domestic money supply leads to a nominal depreciation of the exchange rate. As prices are assumed to be fixed in the currency of the producer, import prices exhibit a complete exchange-rate pass-through. Hence, relative prices change, and domestic products become more competitive abroad. This induces foreign agents to import more home goods, whereas home agents demand less foreign goods, and the trade balance improves. As long as output is demand determined, output and employment increase in the domestic economy, whereas they fall abroad. However, depending on the size of the domestic economy, an effect in the opposite direction might occur in response to a worldwide decline in the interest rates, as overall demand increases. Kollmann (2001a), who also studies international transmission effects of monetary policy shocks in a NOEM model, makes use of this second effect to compensate for the expenditure-switching. He obtains a positive transmission on both foreign output and aggregate demand. However, as will be shown in the sensitivity analysis in section 4, this result relies on the extremely low calibration values for interest and consumption elasticities of money demand in his model. For a lower degree of money demand elasticities, the home (but also foreign) interest rate will drop more in response to a surprise increase in home money supply, inducing a higher increase in world aggregate demand. If the latter effect is large enough it will compensate for the expenditure-switching effect and foreign output increases. However, recent estimates of money demand elasticities provided by Chari, Kehoe and McGrattan (2002) are much higher than the values used in Kollmann. For these values the positive spill-over effect on foreign output cannot be reproduced, which questions the robustness of Kollmann's results.

In this paper, I will present a dynamic general equilibrium model with sticky prices that can account for the positive international transmission effects of monetary policy on foreign output and aggregate demand, independent of the calibration values for money demand elasticities.

3 The Model

In the following, 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. To simplify the comparison to the results obtained by Kollmann (2001a) and Betts and Devereux (2001), no closed form solution is derived, but the model is simulated. Thus, 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 can then also be compared to impulse responses obtained from VARs.

As in Obstfeld and Rogoff (1995a), henceforth OR, there are two countries, home and foreign. The home country represents the U.S., while the foreign country represents the rest of the world which is assumed to consist of the non-U.S. G-7 countries. Both countries are inhabited by a continuum of agents, where each country's population is normalized to 1, which implies that both countries are assumed to be equal sized.⁵ Agents consume consumption goods, supply labor and own capital which they rent out to firms. A continuum of individual monopolistic firms resides in the home and the foreign country, which are respectively indexed by $z^h \in [0, 1]$ and $z^f \in [0, 1]$. 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.⁶ In the following, I will first examine the representative home agent's optimization problem before addressing the optimization of the firms.⁷

⁵Considering that the foreign country consists of several smaller countries which represent the rest of the world, this assumption is not too restrictive.

⁶This assumption is similar to Betts and Devereux (2001) but differs from Kollmann (2001a), who assumes differentiated labor to introduce wage rigidities. Wage rigidities are certainly an important feature of a monetary model, but they do not qualitatively alter the results obtained.

⁷The analysis of the representative foreign agent is analogous.

3.1 The home agent

The representative agent residing in the home country chooses her level of consumption, her holding of real money balances as well as her supply of labor and capital so as to maximize her expected discounted lifetime utility U subject to her intertemporal budget constraint. Direct utility is derived from consumption of a basket of differentiated goods C_t , from real money balances $\frac{M_t}{P_t}$, and from leisure. The amount of leisure is by definition the total amount of time available to the agent, which is normalized to 1, less the time dedicated to work H_t . The ‘money-in-the-utility’ formulation, common in the NOEM literature, is introduced to generate a demand for money. In the benchmark model, the agent’s utility is additively separable and has the following explicit form:⁸

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

The parameter β ($0 < \beta < 1$) denotes the representative home agent’s subjective discount factor which determines how future consumption is valued in terms of today’s utility.⁹ The intertemporal elasticity of substitution is given by $\frac{1}{\sigma}$. For a high σ , which implies a low intertemporal elasticity of substitution, agents are less willing to alter their consumption path in response to a change in the intertemporal price – the real interest rate – and prefer to smooth consumption over time. The parameters χ and η govern the relative importance of real money balances and leisure compared to consumption in the utility function, while the parameter ϵ is crucial for money demand elasticities.

When choosing optimal consumption, leisure and real money balances, the agent faces an *intertemporal budget constraint*. Nominal expenditures on consumption $P_t C_t$, investment $P_t V_t$, money balances M_t , internationally traded bonds B_{t+1}^h and $e_t B_{t+1}^f$ and the payment of nominal lump-sum taxes

⁸The assumption of separability of the utility function is common in the NOEM literature, see e.g. OR (1995a) and Lane (2001a). The specific utility function employed here is also used in Betts and Devereux (2001). For the robustness analysis, however, I also consider a non-separable utility function to isolate the determination of the intertemporal elasticity of substitution from the determination of money demand elasticities, as e.g. in Chari, Kehoe and McGrattan (2002) and in Kollmann (2001a).

⁹Since each home agent is assumed to have completely identical preferences and to face the same constraints, all agents will reach the same demand and supply decisions in this model economy. Therefore, the introduction of indices to denote different home agents is waived for notational simplicity. To distinguish foreign from home agents, the foreign variables will be identified with an asterisk.

amounting to $P_t \tau_t$ may not exceed the sum of nominal returns from last period's bonds in terms of the home currency, i.e. $(1 + i_t) B_t^h$ and $(1 + i_t^*) e_t B_t^f$, nominal profits Π_t from the shares of home firms, nominal wage income $W_t H_t$, nominal rental payments received on the capital stock K_t which are determined by the real rental rate on capital r_t^K , plus last period's money balances M_{t-1} . P_t is the consumer price index and applies to both consumption and investment as the commodity baskets for both are assumed to be identical. The intertemporal budget constraint of each home agent is explicitly written as

$$P_t C_t + P_t V_t + M_t + B_{t+1}^h + e_t B_{t+1}^f + P_t \tau_t = (1 + i_t) B_t^h + (1 + i_t^*) e_t B_t^f + \Pi_t + W_t H_t + r_t^K P_t K_t + M_{t-1} \quad (1)$$

Agents can trade only two internationally traded bonds B_t^h and B_t^f , where the former is denominated in the home and the latter in the foreign currency.¹⁰ The subscript $t + 1$ denotes the amount of bonds the agent acquires at time t , which indicates that bonds are predetermined variables. The bonds yield the nominal riskless interest rate i_t and i_t^* between period $t - 1$ and t , respectively, and are assumed to be perfect substitutes. This implies perfect capital mobility in the sense of Mundell. The nominal exchange rate e_t is defined as the home currency price of one unit of the foreign currency. As a consequence, an increase in e_t denotes a depreciation of the home currency.

For the distribution of profits, I assume that all agents within one country hold equal shares of all firms residing in this country. The profit revenue of home agents Π_t can be written as a weighted average of all profits earned by firms producing in the home country.¹¹

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

¹⁰The present analysis abstracts from complete asset markets, introduced in Betts and Devereux (2001) and Chari et. al. (2002). The assumption of complete asset markets for symmetric countries and separable preferences implies complete risk sharing insofar as a trade balance surplus or deficit caused by a country-specific shock is compensated by the corresponding insurance payments, and no redistribution of wealth arises. By the same token, complete asset markets raise international co-movements in consumption, which would be perfectly correlated in the present setup. Yet, empirical evidence of international time series data suggests that consumption is internationally correlated only to a lower degree. Therefore, I assume in the following that agents only trade in two riskless bonds, and abstract from contingent markets.

¹¹Foreign agents hold shares of all foreign firms correspondingly.

Thus, there is no portfolio choice and within each country every agent receives the same amount of distributed profits.¹²

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

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

The parameter ϕ governs the importance of capital adjustment costs. Adjustment costs are higher, the greater the change in the capital stock and the smaller the initial capital stock.¹³

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

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

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

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

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

¹²The assumption that shares of domestic firms are only held by domestic agents implies that an increase in domestic firms' profits will benefit domestic agents only. As I also abstract from complete asset markets, this assumption follows as a logical consequence.

¹³The specific form of capital adjustment costs is the same as in Kollmann (2001a).

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

The first optimality condition, equation (3) is the Euler equation which determines the optimal intertemporal consumption path. The higher the expected home real interest rate r_{t+1} , the higher the opportunity cost of consumption today, and the more the agent will be inclined to postpone consumption to the next period. Consumption is optimally allocated between today and tomorrow if the marginal utility derived from an additional unit of consumption today is equal to the expected discounted marginal utility of consumption derived from consuming the real-interest-augmented unit tomorrow.

Money demand is shown in equation (4). The demand for real money balances 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). For the agent to be indifferent between additional investment in capital stock and more consumption, the cost borne in terms of foregone utility of consumption in order to increase today's capital stock by one unit has to be equal to the marginal utility derived from this investment. While the adherent cost of an additional unit of capital is augmented by the marginal capital adjustment costs, $\phi \frac{K_{t+1} - K_t}{K_t}$, the revenue associated with this investment is measured in terms of the increase in expected consumption possibilities and the resulting expected increase in utility tomorrow. The rise in consumption possibilities consists of the increase in the capital stock itself, the expected real interest payment of the firm minus depreciation, $r_{t+1}^K - \delta$, plus the expected decrease in capital adjustment costs tomorrow, $\frac{\phi}{2} \frac{K_{t+2}^2 - K_{t+1}^2}{K_{t+1}^2}$.¹⁴ The latter outcome is due to the fact that capital adjustment costs are declining in the actual size of the capital stock.

The last optimality condition, equation (7), corresponds to the uncovered interest parity. It determines the optimal allocation of assets between home and foreign bonds. Optimality then requires that expected utility in terms

¹⁴Note, however, that the expected real return on the capital stock $E_t [r_{t+1}^K]$ still depends on other determinants like expected demand, expected marginal costs and the expected overall capital stock. But for now I will take the expected rental rate as given.

of consumption derived from an investment in home bonds, which consists of the home-nominal-interest-augmented unit deflated by tomorrows expected price level, needs to balance the corresponding expected utility derived from an investment in foreign bonds, which also depends on the change in the exchange rate.¹⁵

As Ricardian equivalence holds in this type of models, assuming a balanced budget has no consequence on the results of the following analysis. In order to focus on the effects of monetary policy, I further simplify by abstracting from government spending. Hence, it is assumed that all seigniorage revenue accruing to the central bank is redistributed to agents in form of a lump-sum transfer

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

3.2 Consumption preferences, the price level and demand

3.2.1 Consumption

The agent's intertemporal allocation of consumption as well as the optimal allocation between consumption, leisure and real balances was determined 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 can be viewed as a two-stage process.¹⁶ First, the agent needs to opt for the share of import goods in their consumption basket. Second, he needs to decide on how to allocate his expenditures on home (foreign) goods further on each differentiated home (foreign) good.¹⁷

As in Kollmann (2001a), I assume that the household's consumption basket is an aggregate of the consumption of home and foreign differentiated goods, which takes the explicit form of a CES-function. This form also allows for the introduction of a home bias in consumption as in Warnock

¹⁵For the assumption of certainty equivalence used for the linear approximation of the model below, equation (7) reduces to $1 + i_{t+1} = (1 + i_{t+1}^*) E_t \left[\frac{e_{t+1}}{e_t} \right]$.

¹⁶Note, however, that the decisions are reached simultaneously.

¹⁷A notational remark: To distinguish home from foreign variables, the superscript h denotes the goods and prices of home producers, whereas f denotes goods and prices of foreign producers. As goods are traded, we also differentiate between prices and goods that are valid for respective markets: Variables marked with an *asterisk* identify goods that are sold in the *foreign* market and prices that are charged in the *foreign* currency.

(2003). A home bias makes it possible to restrict steady-state import shares – which would otherwise be 50% for equal sized countries – to correspond to the ones observed in the data.¹⁸

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

C_t^h and C_t^f are home agent's 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.¹⁹ 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.²⁰

Expenditure minimization results in the following consumption demand of the representative home agent for the home and the foreign consumption baskets, respectively

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

¹⁸For simplicity, I assume that investment features the same composition as consumption, and hence is written as

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

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

¹⁹The preferences and degree of home bias are assumed to be symmetric for foreign agents. Hence, the consumption index of foreign agents C_t^* is

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

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.

²⁰Both a high home bias in consumption and a low elasticity of substitution between domestic and foreign goods reduce the expenditure-switching effect.

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 consist of a weighted average of home and foreign differentiated goods each of which is produced by an individual monopolistic firm.²¹ The composition of the commodity basket of home goods consumed by agents in the home country is then defined as

$$C_t^h = \left(\int_0^1 c_t^h(z^h)^{\frac{\theta-1}{\theta}} dz^h \right)^{\frac{\theta}{\theta-1}}.^{22}$$

The parameter θ denotes the elasticity of substitution between different goods produced in one country, but also governs the magnitude of the markup and hence is an indicator of the extent of monopolistic distortion in the market. The higher is 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 , $c_t^h(z^h)$, as

$$c_t^h(z^h) = \left(\frac{p_t^h(z^h)}{P_t^h} \right)^{-\theta} C_t^h.^{23}$$

The home agent's consumption demand for home good z^h thus depends on its price $p_t^h(z^h)$ 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 . This implies that if a firm sets the price of its good higher

²¹Recall 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.

²²Consumption on foreign goods is allocated analogously.

²³The domestic demand for the representative foreign good looks similar.

than the average price of domestic goods, the firm will sell less than average ($c_t^h(z^h) < C_t^h$).

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

$$c_t^h(z^h) = \lambda \left(\frac{p_t^h(z^h)}{P_t^h} \right)^{-\theta} \left(\frac{P_t^h}{P_t} \right)^{-\mu} C_t. \quad .^{24}$$

3.2.2 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

$$P_t^h = \left[\int_0^1 p_t^h(z^h)^{1-\theta} dz^h \right]^{\frac{1}{1-\theta}}. \quad .^{25}$$

The home price index for imported goods P_t^f is

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

where $p_t^f(z^f)$ 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

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

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.

²⁴The same holds for domestic demand for foreign differentiated goods.

²⁵Note 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.

3.2.3 Demand

For completion of the analysis, I will determine the total demand the representative home firm faces for its goods.²⁶ From the individual demand schedules derived above, the total demand for the *representative* home good h is

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

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.

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.

3.3 Firms

3.3.1 Optimal prices

As outlined above, a continuum of firms resides in both countries. As firms produce differentiated goods, each firm faces an individual demand schedule similar to the one derived above. Taking their demand into account, firms will set prices so as to maximize profits. Yet, profits crucially depend on the assumptions made about price setting and price adjustment. Hence, before examining the prices firms will set to maximize profits, these assumptions need to be clarified.

Price Adjustment For monetary policy to have real effects in the short run, nominal rigidities need to be included. Only if firms cannot adjust all prices immediately in response to a shock, changes in the money supply will affect quantities. I incorporate nominal rigidities in form of sticky

²⁶Demand for the representative foreign firm is derived analogously.

goods prices, where I assume that only a part of firms can adjust prices immediately. Following Calvo (1983), firms adjust their prices infrequently at random intervals,²⁷ where the opportunity to adjust follows a Bernoulli distribution. In every period, all firms face the same constant probability $(1 - \gamma)$ to change prices next period and γ to keep prices constant, independent of their history of price changes. By the law of large numbers, a constant fraction $(1 - \gamma)$ of firms will actually change their prices each period, while the remaining fraction γ cannot adjust their prices. Since price adjustment is restricted, firms differ in the prices they charge as well as in the level of output produced and factor inputs employed, and thus in the profits they receive. 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 an important factor and is therefore taken into account by the firm when the optimal price is chosen.

Price Setting Following Betts and Devereux (2001, 2000, 1996) and Engel (2000), I distinguish between two different types of firms. One type, which is represented by a fraction $(1 - s)$ of firms, sets one price for its good, independent of the market where the good is sold. Since the price is set in the currency of the producer, import prices of these goods exhibit a complete exchange-rate pass-through in the presence of short-run price rigidities. This pricing behavior is referred to as *producer-currency pricing* (henceforth PCP). The second type of firm, which is represented by the remaining fraction s of firms in each country, is assumed to set two different prices, one for the home market and one for the foreign market. As both prices are denominated in the respective local currency of the market, this price-setting behavior is referred to as *local-currency pricing* (henceforth LCP).²⁸ Contrary to the case of PCP goods, import prices of LCP goods are not affected by an exchange rate change in the presence of sticky prices. Therefore, export revenues of the two types of firms are affected differently by a depreciation of the domestic currency if the firm cannot adjust its price immediately in response to an exogenous shock. Whereas the PCP firm experiences an increase in its export demand due to the reduction of the relative price of its goods sold in

²⁷This assumption about price adjustment is quite common in the quantitative models of the NOEM literature, see for instance Betts and Devereux (2001) and Kollmann (2001a). 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 given time intervals, whereas in the present setting, the arrival date of adjustment is random.

²⁸Firms are assumed to possess sufficient market power, so that international price differences for the same good cannot be arbitrated away by agents.

the foreign market, the LCP firm's markup for its exports increases. This will *ceteris paribus* raise LCP firms' profits earned in the export market. In order to analyze profit maximization, it is therefore necessary to distinguish between PCP and LCP firms.

A different question is how the degree of LCP firms in each country should be determined. Two recent contributions by Devereux, Engel and Storgaard (2004) and Bacchetta and van Wincoop (2005) study which of the two presented pricing behaviors is optimal for firms. For a static framework, Bacchetta and van Wincoop find that the optimal pricing choice crucially depends on the market share in the foreign market. Devereux, Engel and Storgaard show that the optimal choice of the currency of denomination in a general equilibrium setting is mainly determined by the relative variance of money growth. In the present paper, the choice of currency invoicing is not treated as endogenous. Instead, I analyze the effects of different alternative assumptions of price-setting behavior of firms on the international transmission effects of monetary policy shocks. A somewhat similar investigation has already been undertaken by Betts and Devereux (2001), who compare the resulting transmission effects for LCP and PCP. However, Betts and Devereux presume throughout their analyses an *identical* fraction of LCP firms in both countries, as do Kollmann (2001) and Chari et al. (2002).²⁹ Devereux, Engel and Tille (2003) emphasize, though, that empirical evidence provided by the European Union indicates a lower extent of local currency-pricing in the U.S. compared to Europe. Analogous evidence on international differences in LCP between the U.S. and other G-7 countries is also found by Clark and Faruquee (1997) and by Gagnon and Knetter (1995) among others. Therefore, I will allow for *asymmetries* in the price-setting behavior of firms across countries by distinguishing between a share of LCP firms for the home country, s^h , and a corresponding share for the foreign country, s^f . In the dynamic analysis presented below, I will investigate how this asymmetry affects the international transmission of monetary policy shocks.³⁰ In particular, I will show that for the limiting assumption of complete PCP in the U.S. and complete LCP in the rest of the world, the stylized facts of a positive transmission effect on both foreign output and demand can be reproduced.

²⁹While Kollmann assumes complete PCP in both countries, Chari et al. adopt complete LCP in both countries.

³⁰Devereux (2000) also allows the degree of LCP in the home country to differ from the foreign country. Yet, he focuses on the effects of a devaluation on the current account, not on how the asymmetry in price setting affects the international transmission of monetary policy on output and consumption.

3.3.2 Profit maximization of the representative home PCP firm

In the presence of price rigidities à la Calvo, firms set the price so 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.³¹ The optimal new price chosen by the PCP firm, which is denoted $\tilde{P}_t^{h,PCP}(h)$, is charged in both the home and the foreign market.³² Hence the home currency price the representative home PCP firm receives for goods exported to the foreign market is not different from the one for goods sold in the domestic market. Expected real futures profits correspond to the sum of expected future real marginal profits times the expected quantity of goods sold. Expected future real marginal profits are defined as the difference of optimal price and the expected nominal marginal costs MC_{t+i} in terms of the relevant expected future home country price level. Expected profits are then

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

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 firm at time $t+i$ provided that the price set at time t is still effective. This can be explicitly written as

$$\begin{aligned} y_{t,t+i}^{h,PCP}(h) &= \lambda \left(\frac{\tilde{P}_t^{h,PCP}(h)}{P_{t+i}^h} \right)^{-\theta} \left(\frac{P_{t+i}^h}{P_{t+i}} \right)^{-\mu} [C_{t+i} + V_{t+i}] \\ &\quad + (1 - \lambda) \left(\frac{\tilde{P}_t^{h,PCP}(h)}{E_{t+i} P_{t+i}^{h*}} \right)^{-\theta} \left(\frac{P_{t+i}^{h*}}{P_{t+i}^*} \right)^{-\mu} [C_{t+i}^* + V_{t+i}^*]. \end{aligned} \quad (10)$$

Given that the representative home PCP firm cannot adjust its price between time t and time $t+i$, the expected future demand of the representative home PCP good at time $t+i$ depends on aggregate consumption and investment demand, both in the home and in the foreign country, as well as on

³¹The derivation follows Gertler (2003).

³²A 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.

relative prices. Note that while the price for the representative home PCP good is – by assumption – fixed at its time t level, aggregate prices in the home and the foreign economy can change, as a constant proportion of firms is assumed to adjust prices each period. The exchange rate affects demand of foreign agents for the home PCP good, as for producer-currency pricing, the foreign currency price fluctuates with exchange rate changes.

Via maximization of expected future profits the optimal price at time t , $\tilde{P}_t^{h,PCP}(h)$, is then derived as a markup over expected future nominal marginal costs, weighted with expected future real sales revenues $D_{t,t+i}^{h,PCP}$

$$\tilde{P}_t^{h,PCP}(h) = \frac{\theta}{\theta - 1} \frac{E_t \left[\sum_{i=0}^{\infty} (\gamma\beta)^i \Lambda_{t,t+i} D_{t,t+i}^{h,PCP} MC_{t+i} \right]}{E_t \left[\sum_{i=0}^{\infty} (\gamma\beta)^i \Lambda_{t,t+i} D_{t,t+i}^{h,PCP} \right]} \quad (11)$$

with

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

The optimal price of the representative home PCP firm at time t is determined by the sequence of expected future nominal marginal costs since firms are assumed to adjust prices only randomly. Thus, when given the opportunity to adjust prices, firms will consider the likelihood that the price adjusted at time t will be effective in the future. Note that price rigidities à la Calvo further imply that in response to an exogenous shock, a fraction γ of firms cannot adjust prices immediately, but has to meet demand for the preset price. As a result, the production level of these firms is entirely demand determined. For $\gamma = 0$, i.e. when the probability of a price change is equal to one, the optimal price is $\tilde{P}_t^{h,PCP}(h) = \frac{\theta}{\theta-1} MC_t$. This is exactly the solution resulting with flexible prices, where for the assumption of a constant elasticity of substitution, prices are set as a constant markup over nominal marginal costs.

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

$$P_t^{h,PCP} = \left[\gamma \left(P_{t-1}^{h,PCP} \right)^{1-\theta} + (1-\gamma) \left(\tilde{P}_t^{h,PCP}(h) \right)^{1-\theta} \right]^{\frac{1}{1-\theta}}. \quad (12)$$

3.3.3 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

$$E_t \left[\sum_{i=0}^{\infty} (\gamma\beta)^i \Lambda_{t,t+i} \left(\frac{\tilde{P}_t^{h,LCP}(h)}{P_{t+i}} - \frac{MC_{t+i}}{P_{t+i}} \right) y_{t,t+i}^{h,LCP}(h) \right. \\ \left. + (\gamma\beta)^i \Lambda_{t,t+i} \left(\frac{e_{t+i} \tilde{P}_t^{h,LCP,*}(h)}{P_{t+i}} - \frac{MC_{t+i}}{P_{t+i}} \right) y_{t,t+i}^{h,LCP,*}(h) \right]$$

where $\Lambda_{t,t+i}$ is defined as above. Note that $\tilde{P}_t^{h,LCP,*}(h)$ denotes the optimal export price of the representative *home* LCP firm set in the *foreign* currency. As the home LCP firm maximizes home currency profits, the export price of the LCP firm needs to be converted to the home currency via the exchange rate e_{t+i} . As before, expected future profits are weighted with the subjective discount factor $\beta^i E_t [\Lambda_{t,t+i}]$ and with the probability that the price set today will still be effective in the future. Expected future profits of the representative home LCP firm depend on the quantities $y_{t,t+i}^{h,LCP}$ and $y_{t,t+i}^{h,LCP,*}$, which denote home and foreign agents' demand for the representative home LCP good at $t+i$ given the prices $\tilde{P}_t^{h,LCP}(h)$ and $\tilde{P}_t^{h,LCP,*}(h)$ set at time t . The respective demand functions of the home and the foreign market are

$$y_{t,t+i}^{h,LCP,dom}(h) = \lambda \left(\frac{\tilde{P}_t^{h,LCP}(h)}{P_{t+i}^h} \right)^{-\theta} \left(\frac{P_{t+i}^h}{P_{t+i}} \right)^{-\mu} [C_{t+i} + V_{t+i}] \\ y_{t,t+i}^{h,LCP,for}(h) = (1 - \lambda) \left(\frac{\tilde{P}_t^{h,LCP,*}(h)}{P_{t+i}^{h*}} \right)^{-\theta} \left(\frac{P_{t+i}^{h*}}{P_{t+i}^*} \right)^{-\mu} [C_{t+i}^* + V_{t+i}^*] \quad (13)$$

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

Home 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 As pointed out before, the LCP firm is characterized by the assumption that it sets two different prices for its good, one for the domestic market and one for the export market. While the price chosen for the domestic market is basically identical to the price of the PCP firm, prices for the foreign market will differ for the two types of firm. Maximizing future expected profits in the foreign market given the opportunity to adjust its price at time t , the representative home LCP firm will choose the optimal export price $\tilde{P}_t^{h,LCP,*}(h)$ as

$$\tilde{P}_t^{h,LCP,*}(h) = \frac{\theta}{\theta - 1} \frac{E_t \left[\sum_{i=0}^{\infty} (\gamma\beta)^i \Lambda_{t,t+i} D_{t,t+i}^{h*,LCP} \frac{MC_{t+i}}{e_{t+i}} \right]}{E_t \left[\sum_{i=0}^{\infty} (\gamma\beta)^i \Lambda_{t,t+i} D_{t,t+i}^{h*,LCP} \right]} \quad (14)$$

with

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

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

$$P_t^{h,LCP,*} = \left[\gamma \left(P_{t-1}^{h,LCP,*} \right)^{1-\theta} + (1 - \gamma) \left(\tilde{P}_t^{h,LCP,*}(h) \right)^{1-\theta} \right]^{\frac{1}{1-\theta}}. \quad (15)$$

3.3.4 Optimal Production

After the optimal price is set, firms are assumed to produce the quantity demanded at this price. All firms at home and abroad produce under constant-returns-to-scale, employing the following Cobb-Douglas production function, displayed for the example 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

$$W_t = MC_t (1 - \alpha) \frac{y_t^h(h)}{H_t(h)} = MC_t (1 - \alpha) \frac{y_t^h}{H_t} \quad (16)$$

and

$$P_t r_t^K = MC_t \alpha \frac{y_t^h(h)}{K_t(h)} = MC_t \alpha \frac{y_t^h}{K_t} \quad (17)$$

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.

3.3.5 Price indices

With the derivation of the optimal price setting and the optimal production decision for each type of firm, it is possible to simplify the intermediate price indices for home and foreign goods. From equation (12) 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,³³ 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

$$P_t^h = P_t^{h,PCP}. \quad (18)$$

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 $(1 - s^f)$ sets their prices in the currency of the producer, hence in the foreign currency. Therefore, the home price index of imported goods is

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

³³The 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.

³⁴The analogous reasoning holds for the foreign price index of domestically produced

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

3.4 Profits and the consolidated budget constraint

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

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

Aggregated profits of the home economy are then

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

Above it was 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

goods, which can now be written as

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

and the foreign price index for foreign goods is simply

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

for both goods. The reduced form of the home economy's budget constraint can then be written as

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

with

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

3.5 Market clearing conditions

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

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

Making use of the average prices for home PCP and LCP goods derived in equations (12) and (15), 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 $y_t^{h,PCP}$

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

For goods market equilibrium, total demand needs to equal total supply. Since all firms face the same wage rate and rental rate for capital, they will

all produce with the same capital-labor ratio, and total supply can be written as

$$Y_t^h = \int_0^1 A_t K_t^\alpha (z^h) H_t^{1-\alpha} (z^h) dz^h = A_t K_t^\alpha H_t^{1-\alpha}.^{3536} \quad (22)$$

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

$$\begin{aligned} H_t &= \int_0^1 H_t(z^h) dz^h \\ K_t &= \int_0^1 K_t(z^h) dz^h. \end{aligned}$$

Finally, asset markets need to clear. As each country's currency is held only by the country's residents, the home and the foreign money market are in equilibrium if $M_t = M_t^S$, and $M_t^* = M_t^{S*}$. M_t^S and M_t^{S*} are the respective exogenous supplies of home and foreign currency provided by the corresponding national central bank. Bond markets clear in equilibrium if aggregate *world* assets, i.e. the joint net assets of home and foreign agents, are equal to zero in all periods. Hence, total net assets owned by home agents thus always coincide with net debt accumulated by foreign agents.

3.6 Equilibrium

Equilibrium is characterized by equations (2), (3), (4), (5), (6), (8), (16), (17), (11), (12), (14), (15), (13), (10), (21), (22), (18), (19) and their foreign

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$$\frac{Y_t^h}{\underbrace{\int_0^1 H_t(z^h) dz^h}_{=H_t}} = \int_0^1 A_t \left(\frac{K_t(z^h)}{H_t(z^h)} \right)^\alpha dz^h = A_t \left(\frac{K_t}{H_t} \right)^\alpha$$

Hence,

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

³⁶Goods market equilibrium also holds on the foreign market:

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

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

$$X_t = \{C_t, C_t^*, H_t, H_t^*, V_t, V_t^*, K_t, K_t^*, W_t, W_t^*, r_t^k, r_t^{k*}, i_t, i_t^*, MC_t, MC_t^*, e_t, B_t^h, B_t^f, P_t, P_t^*, P_t^h, P_t^f, P_t^{h*}, P_t^{f*}, \tilde{P}_t^{h,PCP}, \tilde{P}_t^{h,LCP,*}, \tilde{P}_t^{f,PCP}, \tilde{P}_t^{f,LCP}, P_t^{h,PCP}, P_t^{h,LCP}, P_t^{f,PCP}, P_t^{f,LCP}, Y_t^h, Y_t^f, Y_t^{h,PCP}, Y_t^{h,LCP}, Y_t^{f,PCP}, Y_t^{f,LCP}\}$$

3.7 Steady State

The analysis starts from the symmetric steady state, where neither country owns net foreign assets, and where I abstract from real growth due to technological progress and from growth in the monetary base. Hence, in equilibrium all nominal and real variables are constant. Since I assume identical preferences (including the parameter values) and technologies across countries, home agents can differ from foreign agents only in their amount of external wealth.³⁷ If external wealth is equal for home and foreign agents, i.e. neither country owns net foreign assets, consumption, leisure (and thus also labor) as well as investment decisions will be identical. Accordingly, there are no differences in the real sectors of the economies.³⁸ If I also assume that the initial amount of money in both countries is identical, prices will be the same, and the nominal exchange rate will be equal to 1. In this case, only the steady state for the home economy needs to be determined, since the foreign economy steady state will simply be a mirror image.

3.8 Calibration

Before I can turn to the dynamic analysis and run simulations to evaluate the effects of an unexpected monetary shock, it is necessary to numerically specify the parameters and determine the steady state. For the benchmark calibration, I choose the following parametrization.

Consistent with the vast majority of the literature, which quantitatively assesses business cycle features by means of dynamic general equilibrium models, the quarterly real interest rate is set to 1% in the steady state.³⁹ This implies a value of $\frac{1}{1.01}$ for β .

³⁷The assumption of an international 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.

³⁸See OR (1995a, p. 631).

³⁹This corresponds approximately to a 4% real interest rate per year commonly assumed both in the NOEM literature and in the RBC literature. See e.g. Chari et al. (2002),

The consumption elasticity of money demand in the benchmark model is $\frac{\sigma}{\epsilon}$, whereas the interest elasticity of money demand is $-\frac{\beta}{\epsilon}$. The estimates for these elasticities found in empirical studies comprise a wide range. For the interest elasticity of money demand, the estimates vary from -0.39 in Chari et al. (2002) to -0.051 in Mankiw and Summers (1986).⁴⁰ For the benchmark value, I choose -0.39 , the estimate provided by Chari et al. (2002), but in the sensitivity analysis, the effects for the interest elasticity estimated by Mankiw and Summers are also examined. Kollmann (2001a) uses an interest rate elasticity of money demand of -0.01 , whereas Betts and Devereux (2001) employ a value of -0.12 . The value of ϵ implied by the benchmark interest rate elasticity is 2.5 . The consumption elasticity of money demand is commonly estimated to be about unity, see, e.g., Mankiw and Summer (1986), which is the value I adopt. Chari et al. (2002) implicitly assume a unity consumption elasticity of money demand in their regression. For comparison, 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. As outlined in section 2, smaller elasticities of money demand imply higher consumption and investment demand responses, which in turn raises the responses of – demand-determined – output.

The benchmark values for money demand elasticities imply that σ is about 2.5 . This value lies in the range of estimates provided by Hall (1988), which range from about 2 to 10 . Yet, I also considered a value of 10 for σ in the sensitivity analysis, in order to examine how the results of the dynamic analysis are affected by a lower elasticity of intertemporal substitution. It is shown that the effect on consumption is reduced as agents respond less to a given change in the real interest rate.

The parameter θ determines the markup over marginal costs. Consistent with the findings of Basu and Kimball (1997), which suggest a markup of prices over marginal costs of about 10% in the U.S., I assume $\theta = 10$.⁴¹ The capital share α is set to $\frac{1}{3}$. This value is in line with empirical evidence on the labor share provided by Bentolila and Saint-Paul (2003), which is found to range from 62% to 68% for the G-7 countries in the 1990s. The rate of depreciation, δ , is set to 0.021 , which implies an annual depreciation rate of about

Betts and Devereux (2001), Kollmann (2001a), but also Backus et al. (1992) and Baxter (1995).

⁴⁰Note that both Chari et al. and Mankiw and Summers use consumption as the relevant quantity variable for the estimation of money demand elasticities, which corresponds to the setup in the model.

⁴¹ $\theta = 10$ implies a markup of about 11% , which is also similar to the values used in Chari, Kehoe and McGrattan (2002) and Betts and Devereux (2001).

10%, corresponding to the typical estimates for U.S. data.⁴² 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. These values correspond to the average U.S. consumption and investment shares to GDP, excluding government expenditures, in the post Bretton Woods era.⁴³ Average consumption shares of the remaining G-7 countries for the same time period are somewhat lower than in the U.S. and range from 64% for Japan to 78% for the U.K.⁴⁴

Based on the fact, that employees work in general for 8 to 9 hours per day, I assume that in the steady state, agents dedicate 30% of their available time to work, hence $\bar{H}_0 = 0.3$.⁴⁵ For simplicity, the relative preference parameter for real balances, χ , is assumed to be 1. These two assumptions further determine η , the preference parameter for leisure, to be 2.8.

The price adjustment parameter is set such that the average time between price adjustment for a firm is one year. This implies $\gamma = 0.75$ and corresponds to the value chosen in Betts and Devereux (2001) and Kollmann (2001a). The import share in the steady state is assumed to be 15% for both countries. While the U.S. average import share in the post Bretton Woods era amounts to about 11%, import shares in the remaining G-7 countries during this time period range from 10% in Japan at the lower end to almost 30% in Canada.⁴⁶ Kollmann (2001a) assumes a steady-state import share of 10% and Chari et al. (2002), who only consider U.S. imports which stem from Europe, set steady-state imports to 1.6% of GDP. On the other hand, Betts and Devereux (2001) implicitly assume a steady-state import share of 50% as they do not take a home bias into account. In the sensitivity analysis, I therefore also examined variations in the degree of home bias, which determines the steady-state import share.

⁴²These values are also used in Chari et al. (2002), while Betts and Devereux (2001) set α to 0.36 and δ to 0.025. Kollmann (2001a) employs $\alpha = 0.34$ and $\delta = 0.025$.

⁴³As the government sector is not included in the model, since Ricardian equivalence holds and I focus on monetary policy shocks, it seems useful to abstract from government spending in deriving the relevant consumption and investment shares.

⁴⁴The averages are computed from quarterly data on consumption, capital formation including changes in inventories, GDP, and government spending from the IMF IFS CD-ROM, from 1974:1 to 2001:1. The respective values and corresponding standard deviations are reported in table 1. Consumption and investment shares are computed relative to GDP less government spending.

⁴⁵This value is also used in Betts and Devereux (2002), while Chari et al. (2002) use a slightly lower value of 0.25 for the steady-state share of labor.

⁴⁶The corresponding averages are shown in table 1.

Table 1: Average consumption, investment and import shares in the G-7 countries in the post Bretton Woods era

Averages 1974 - 2000	U.S.	Canada	France	Germany	Italy	Japan	U.K.
Consumption share	0.812 (0.019)	0.717 (0.026)	0.733 (0.019)	0.705 (0.017)	0.720 (0.012)	0.638 (0.019)	0.779 (0.022)
Investment share	0.205 (0.019)	0.263 (0.031)	0.259 (0.027)	0.267 (0.018)	0.276 (0.032)	0.346 (0.024)	0.233 (0.026)
Import share	0.107 (0.017)	0.284 (0.057)	0.216 (0.016)	0.257 (0.019)	0.213 (0.021)	0.101 (0.025)	0.273 (0.032)

The value for capital adjustment costs ϕ is set to 8, since this induces an investment response to an unanticipated increase in home money supply for the benchmark calibration which is about 3 to 4 times the size of the corresponding output response in the home country, and thus corresponds to the findings of the VAR analysis in Schmidt (2004). Yet, in the sensitivity analysis, I consider both a smaller and a larger value for ϕ in order to assess how this variation affects the results.

For the benchmark calibration, the elasticity of substitution between home and foreign goods μ is set equal to 1.5. Earlier empirical studies surveyed in Hooper and Marquez (1995, Table 4.1) indicate a value about this size for the U.S., and this value is also adopted in Chari et al. (2002) and Betts and Devereux (2001). However, according to Kollmann (2001a), estimates for the cross-country substitutability vary for different countries insofar as the estimates for the U.S. exceed unity, while estimates for the remaining G7-countries are in part clearly below unity, see, e.g., Hooper and Marquez (1995), but also Marquez (1990). Although it is possible to allow for different degrees of substitutabilities between home and foreign goods for the two economies, Kollmann (2001a) states that the effect on the impulse responses only depends on the *mean* of the cross-country substitutabilities, and not on the composition (see Kollmann (2001a), p. 1562). Own investigations in this regard confirm Kollmann's statement. Yet, as the empirical evidence suggests a cross-country substitutability of about unity for the average of the G-7 countries, I considered how a change in this way affects the results.

Finally, different degrees of pricing to market s^h and s^f in both the home and the foreign economy are analyzed to determine the effects of different price-setting behavior on the international transmission mechanism of monetary policy shocks. This kind of analysis follows Betts and Devereux (2001). However, besides considering the same degree of either complete PCP or complete LCP in *both* countries, I will also account for international differences

in the way firms set their prices. Put differently, I will examine a stylized scenario where both home and foreign firms set prices in the home currency, i.e. in U.S. dollars, which corresponds to complete PCP in the home country and complete LCP in the foreign country. International differences in local-currency pricing between the U.S. and other G-7 countries are documented in a number of empirical studies, as, e.g., in Clark and Faruquee (1997) and in Gagnon and Knetter (1995). Table 2 summarizes the benchmark calibration values – including the variations considered – and compares them to the values employed in alternative studies.

Table 2: Parameter values

Parameter values	Values employed below			Values employed by others		
	benchmark model	max (abs. value)	min (abs. value)	BD (2001)	Kollmann (2001a)	CKM (2002)
β	$\frac{1}{1.01}$	-	-	0.99	$\frac{1}{1.01}$	$\frac{1}{1.01}$
interest rate elasticity	-0.39	-0.39	-0.051 (resp. -0.01)	-0.12	-0.01	-0.39
consumption elasticity	1	1	0.2	0.85	0.2	1
θ	10	-	-	11	6	10
μ	1.5	1.5	1	1.5	1	1.5
α	$\frac{1}{3}$	-	-	0.36	0.34	$\frac{1}{3}$
δ	0.021	-	-	0.025	0.025	0.021
σ	2.5	10	2	7	2	5
λ	0.85	0.98	0.5	0.5	0.9	0.984
γ	0.75	-	-	0.75	0.75	n.a.
ϕ	8	20	2	n.a.	8	n.a.
\overline{H}_0	0.3	-	-	0.3	n.a.	0.25
χ	1	-	-	1	n.a.	n.a.
η	2.8	n.a.	n.a.	3	n.a.	n.a.
s^h	0	1	0	0;1	0	1
s^f	0	1	0	0;1	0	1

4 Results

In this section, the set of impulse responses obtained for the benchmark calibration is presented for three alternative price-setting assumptions.⁴⁷ The shock considered is a permanent 1% increase in home nominal money supply. The exchange rate is assumed to be perfectly flexible and foreign nominal money supply remains constant. The plotted impulse responses are percentage deviations from respective steady-state values, except for the interest rates, the current account and net foreign assets.

4.1 Complete Producer-Currency Pricing (PCP)

First, I will derive the impulse responses for *complete producer-currency pricing in both countries*, which is the primal assumption made by OR (1995a), as well as in the Mundell-Fleming and in the Dornbusch model. Both s^h and s^f are set to zero. Figures 1 and 2 depict the impulse responses resulting from the benchmark calibration. Impulse responses are plotted for 20 quarters. Solid lines show the responses of home variables, dashed lines the corresponding responses of foreign variables. The respective horizontal axes depict the time. The shock to home money supply occurs in period 1, and all non-predetermined variables react immediately. The predetermined variables, like the home and foreign capital stock, K_t and K_t^* , the stock of net foreign assets (NFA) as well as real and nominal interest rates in both countries, will only react with a lag.

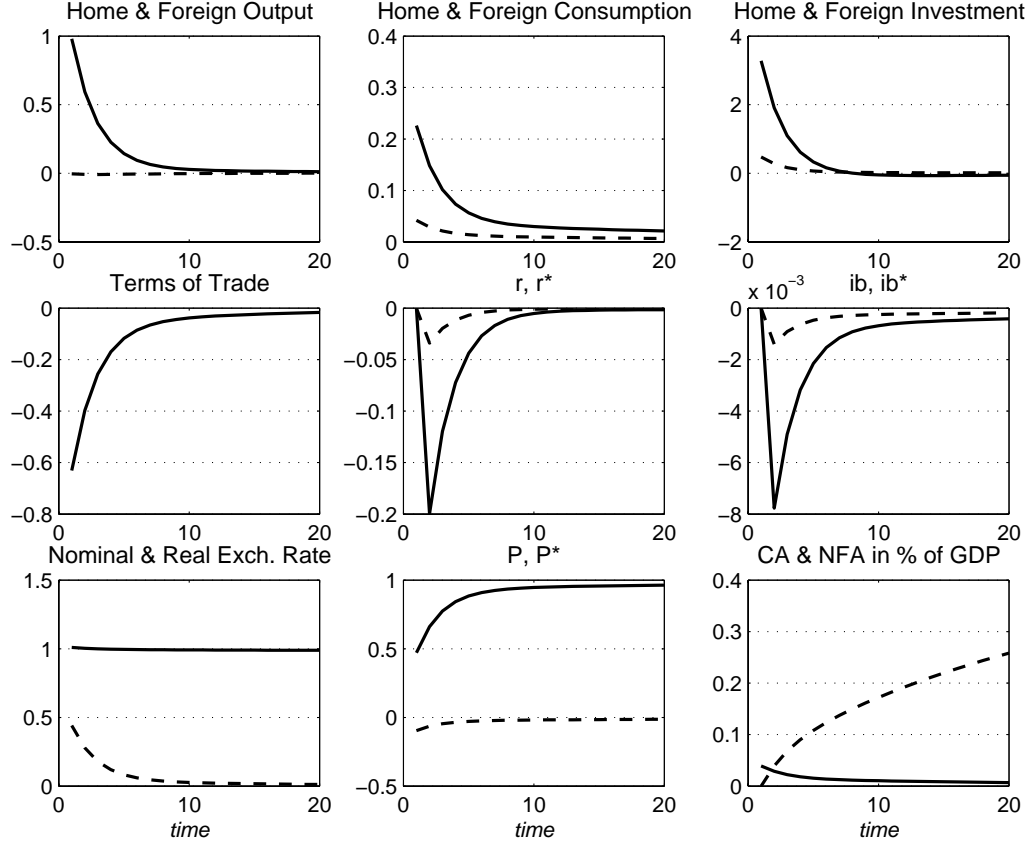
In response to the surprise increase in home money supply, home production as well as home aggregate demand increase. As shown in Figure 1, output in the home country rises almost proportionately to the increase in domestic money supply, whereas home consumption initially rises by about 0.23%, and the initial deviation in home investment from its steady-state value exceeds 3%. Although both foreign consumption and investment experience a temporary – albeit smaller – increase as well, foreign output is basically unaffected.⁴⁸

The transmission mechanism can be described as follows. The initial, unanticipated increase in home money supply raises home country real money balances. The resulting excess supply in the domestic money market causes

⁴⁷For the solution of the model, the MATLAB code provided by Schmitt-Grohé and Uribe (2004) is employed.

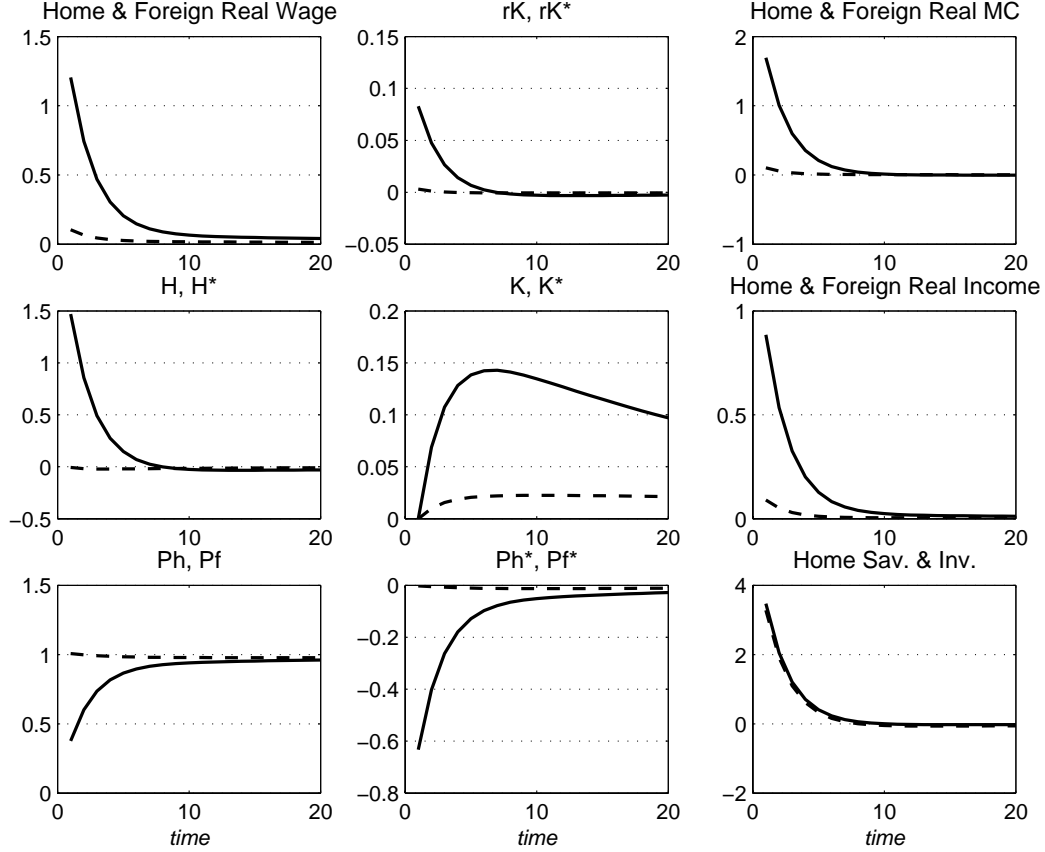
⁴⁸The increase in foreign consumption and investment is about one fifth of the increase in the respective home variables.

Figure 1: Impulse responses to a permanent increase in home money supply for the benchmark calibration and complete PCP I



on the one hand a decline in the home nominal interest rate ib as depicted in Figure 1. As prices adjust slowly, expected inflation increases and the real interest rate declines even more than the nominal interest rate. The fall in the real interest rate induces home agents to consume and invest more, since ‘implicit returns’ on consumption and investment are higher than the associated costs in terms of the real interest rate. On the one hand, the real return on bonds r is lower than the real rental rate on capital, r^K , shown in Figure 2. This discrepancy in real returns induces home agents to invest in the domestic capital stock. On the other hand, the increase in utility due to current consumption outweighs the associated costs in terms of a reduction in consumption tomorrow, and home consumption rises as well. Hence, the home country experiences a boom in demand. At the same time its currency depreciates. For complete PCP, import prices exhibit

Figure 2: Impulse responses to a permanent increase in home money supply for the benchmark calibration and complete PCP II



a complete exchange rate pass-through. Thus, the depreciation leads to a decline in the average foreign import price P^{h*} , whereas the average price of home agents' imports, P^f , rises.⁴⁹ This change in relative prices is associated with a decline in competitiveness of foreign goods similar to the one in the Mundell-Fleming and in the Dornbusch model. However, contrary to the models just mentioned, in the present setup home and foreign real money balances are deflated by the consumer price index which comprises respective import prices. Thus, the home currency depreciation affects the overall price level in both countries and with this the supply of real money balances.

⁴⁹This can be seen in Figure 2. Note, however, that import prices are not only affected by the home currency depreciation since one fourth of firms in each country can already adjust their prices in the shock period.

The resulting effect is captured in the responses of the home and foreign consumer price levels, P and P^* , in Figure 1. Hence, the monetary impulse initiated in the home country is spread to the foreign economy as the decline in the deflator of foreign money, P^* , in combination with a constant foreign nominal money supply allows for a fall in the foreign nominal interest rate. Since agents know that the decline in the foreign price level is only temporary, expected inflation also rises in the foreign country. The foreign real interest rate falls as well, albeit less than the home real interest rate. This in turn induces an increase in consumption and investment in the foreign country. Foreign output, however, remains unchanged since the expenditure-switching due to the change in relative prices redirects the whole augmentation in world aggregate demand induced by the decline in the real interest rates r and r^* towards goods produced at home. The nominal exchange rate hardly overshoots, as for the benchmark value of interest rate elasticity of money demand, nominal interest rates in both countries barely fall and the resulting spread in nominal interest rates is marginal. Nevertheless, the real exchange rate depreciates in the short run as the home bias causes real interest rates to temporarily diverge in both countries which leads to deviations from PPP.⁵⁰ Because of the increase in the home country's import prices P^f , the home country experiences a deterioration in its terms of trade, depicted in Figure 1. This reduces the purchasing power of home agents such that the rise in 'real income' is lower than the rise in production, whereas foreign 'real income' increases.⁵¹

As can be seen from Figure (1), the home country runs a current account surplus and accumulates net foreign assets throughout the whole adjustment process. Thus, the increase in home investment is financed exclusively by an increase in home savings which can also be seen from Figure 2. Whereas the real return on bonds declines both at home and abroad, rental rates on capital rise in both countries, albeit by a larger amount in the home country. The same holds for real wages, which primarily increase at home. The reason is that in order to meet the rise in demand for home goods, given pre-set prices, firms have to pay higher wages and rental rates to induce home agents to supply both more labor and capital. Whereas the capital stock rises only slowly, due to capital adjustment costs, home labor supply increases immediately. Note that the capital stock, after increasing for several

⁵⁰In the presence of a home bias, deviations from PPP can occur, even if all producers set their prices in their own currency.

⁵¹Real income is defined as nominal returns from home firms' sales in the home and the foreign market plus interest earned on bonds, both in terms of the home country consumer price index P .

quarters, is finally restored towards its former steady-state level, whereas net foreign assets increase permanently. As soon as the expected return on capital falls below the expected real return on bonds, agents switch from one asset – the home capital stock – to the other asset – foreign bonds.

Thus, for complete PCP and the benchmark calibration, the monetary surprise impulse in the home country exhibits positive international transmission effects on foreign demand, but not on output. This result corresponds to the findings of Betts and Devereux (2001). The impact on the foreign economy is smaller in the present setting, however, since the import share I presumed is only 15% here versus an assumed 50% in Betts and Devereux.

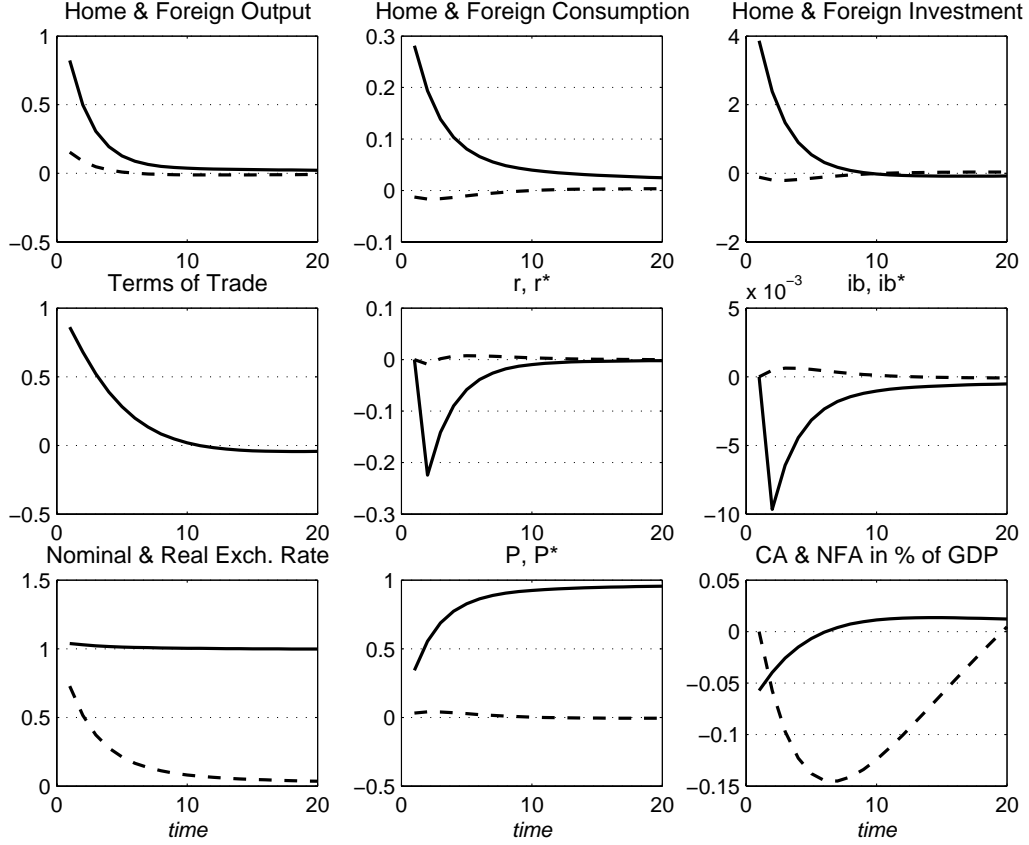
4.2 Complete Local-Currency Pricing (LCP)

For complete local currency pricing, all firms set their export prices in the currency of the export market, which corresponds to the case where s^h and s^f are both set to 1. The corresponding impulse responses are shown in Figures 3 and 4. Again, an unanticipated increase in home money supply raises home production as well as home consumption and investment in the short run. However, when all producers set their export prices in the export currency, a surprise increase in the domestic money supply also raises foreign production, whereas foreign aggregate demand falls, if anything, as is shown in Figure 3. The reason for the decline in foreign demand is that for complete LCP, there is no exchange rate pass-through to import prices. On the one hand, this inhibits the foreign consumer price level to fall and thus prevents a decline in foreign nominal and real interest rates. Therefore, foreign consumption and investment will not rise. By the same token, the international differences in nominal interest rates are higher, which induces a slight overshooting of the nominal exchange rate and larger deviations of the real exchange rate from its steady-state value, as depicted in Figure 3.⁵² On the other hand, with no exchange rate pass-through to import prices, the expenditure-switching effect is repressed. Hence, the increase in home agents' demand is directed to *both* home and foreign goods according to the respective expenditure shares of home agents on imports and domestic goods.⁵³ Note, however, that although foreign production rises, foreign agents' real income falls which is shown in Figure 4. The devaluation of the home currency deteriorates the foreign country's terms of trade. For the foreign country, the terms of trade are

⁵²LCP causes deviations from the law of one price and thus induces deviations from PPP.

⁵³As the steady-state import share is set to 15%, the initial increase in foreign production is accordingly about $\frac{15}{85}\%$ of the increase in home production.

Figure 3: Impulse response to a permanent increase in home money supply for the benchmark calibration and complete LCP I

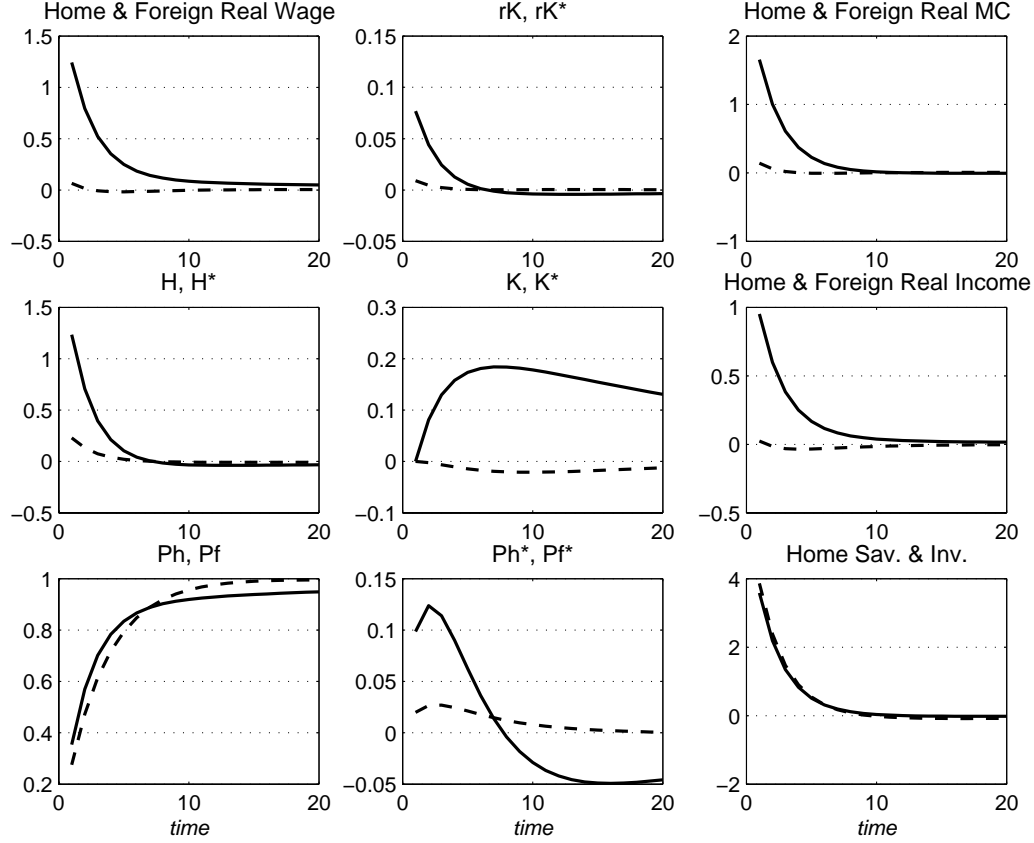


$\frac{P^f}{eP^{h*}}$, or in log-linearized form, $p^f - \hat{e} - p^{h*}$. Whereas foreign import prices P^{h*} rise, even though not by much as can be inferred from Figure 4, foreign export prices denoted in the foreign currency fall. Since the deterioration in the terms of trade more than compensates the increase in foreign production, foreign ‘real income’ falls.

Although the intertemporal elasticity of substitution is less than one, the unanticipated increase in home money supply further induces a home country current account deficit.⁵⁴ Devereux (2000) shows for the absence of capital accumulation, that an intertemporal substitutability of less than unity is a necessary and sufficient condition for the home country to realize a current

⁵⁴However, the current account balance is again small. Thus, most of the increase in home investment is financed by home agents’ savings, which is documented in Figure 4.

Figure 4: Impulse responses to a permanent increase in home money supply for the benchmark calibration and complete LCP II



account surplus in response to a depreciation of the home currency under complete LCP. However, in the presence of capital accumulation, the increase in home investment demand induces a current account deficit.⁵⁵ Note, though, that even if home agents run a current account deficit in the short run, in the long run, their net external wealth position will be positive for the values of the benchmark calibration. Although home agents accumulate foreign debt in the short run, they simultaneously build up another asset, the home capital stock. As the increase in the capital stock is only transitory, agents will shift from the capital asset to the foreign asset as soon as the

⁵⁵It can be shown that the magnitude of the reaction of investment to a real interest differential between the real return on bonds and on the capital stock is affected only by capital adjustment costs and the rate of capital depreciation and not by the intertemporal elasticity of substitution.

return on the latter exceeds the return on the former. Hence, in the long run, home agents will be net foreign creditors.⁵⁶

From the comparison of Figures 1 and 3, it can be seen that the increase in home demand is larger for complete LCP than for the assumption of complete PCP. As import prices are not affected by the exchange rate change under complete LCP, the home price level initially rises less, and the resulting increase in home country real money balances is higher. This requires a sharper fall in both the nominal and real home interest rates, which enhances home consumption and investment responses. At the same time, home production rises by less than for the assumption of complete PCP, since foreign demand is unaffected, and part of the increase in home demand is satisfied via consumption of foreign goods.

Before turning to the assumption of complete asymmetric price-setting behavior, let me briefly comment on the welfare implications. From the derived impulse response functions in Figures 1 and 3, it is straightforward that for the assumption of complete LCP, the likelihood of a ‘beggar-thy-neighbour’ effect of monetary policy is enhanced compared to complete PCP, as foreign agents consume less and work more in the short run, without an according accumulation of net foreign assets. For complete PCP in turn, foreign agents participate from the increase in short-run consumption, without a noticeable increase in their work effort.

4.3 Complete Asymmetric Price-Setting Behavior

So far, I have assumed that the same degree of LCP prevails in both countries. Yet, empirical evidence provided by a number of authors indicate differences in the degree of LCP between the U.S. and other G-7 countries. Clark and Faruquee (1997) compare the relative volatility of import prices, i.e. the variance of import prices relative to the variance of the nominal exchange rate, for the G-7 countries. They find that while the relative volatility is basically zero for the U.S., which suggests that U.S. import prices do not react to exchange rate changes, the relative volatility is noticeably higher for the remaining G-7 countries.⁵⁷ Similar results are provided by Knetter (1989) for a comparison of the U.S. and Germany, but also to some degree by Knetter (1993) for a

⁵⁶Note that this result can be reversed if the cross-country substitutability becomes very small.

⁵⁷The estimates of relative volatility range from 0.25 for the U.K. to 0.94 for Italy. Accordingly, these values suggest that changes in the exchange rate are almost completely passed on to import prices in Italy.

comparison of the variability of import prices in the U.S., the U.K., Germany and Japan. Likewise, the results of Gagnon and Knetter (1995), who assess bilateral automobile export prices from exporters in the U.S., Germany and Japan, suggest that exports to the U.S. and Canada are invoiced in the importer's currency, while exports to the other countries (Japan, U.K., France, Germany, Australia, Switzerland and Sweden) seem to be invoiced in the exporter's currency.⁵⁸ For illustrational purposes, I will consider a stylized scenario where all trade in goods is invoiced in the home currency, i.e. in U.S. dollars. This implies complete PCP in the home country and complete LCP in the foreign country. The corresponding impulse response functions for complete asymmetric price-setting behavior are depicted in Figure 5.⁵⁹

The unanticipated increase in home (U.S.) money supply induces a decline in nominal and real interest rates in both countries, as for the assumption of complete PCP shown in Figure 1. On this account, foreign consumption and investment rise. At the same time, we can infer from Figure 5 that foreign output increases. Thus, for the specific assumption of complete asymmetric price-setting behavior, the home monetary impulse leads to *both*, an increase in foreign output *and* an increase in foreign demand. As these responses mirror the main features of the empirical results, they suggest that asymmetric price setting in the export markets can contribute to the explanation of the stylized facts. In the following, I will give an intuitive explanation of how this result arises.

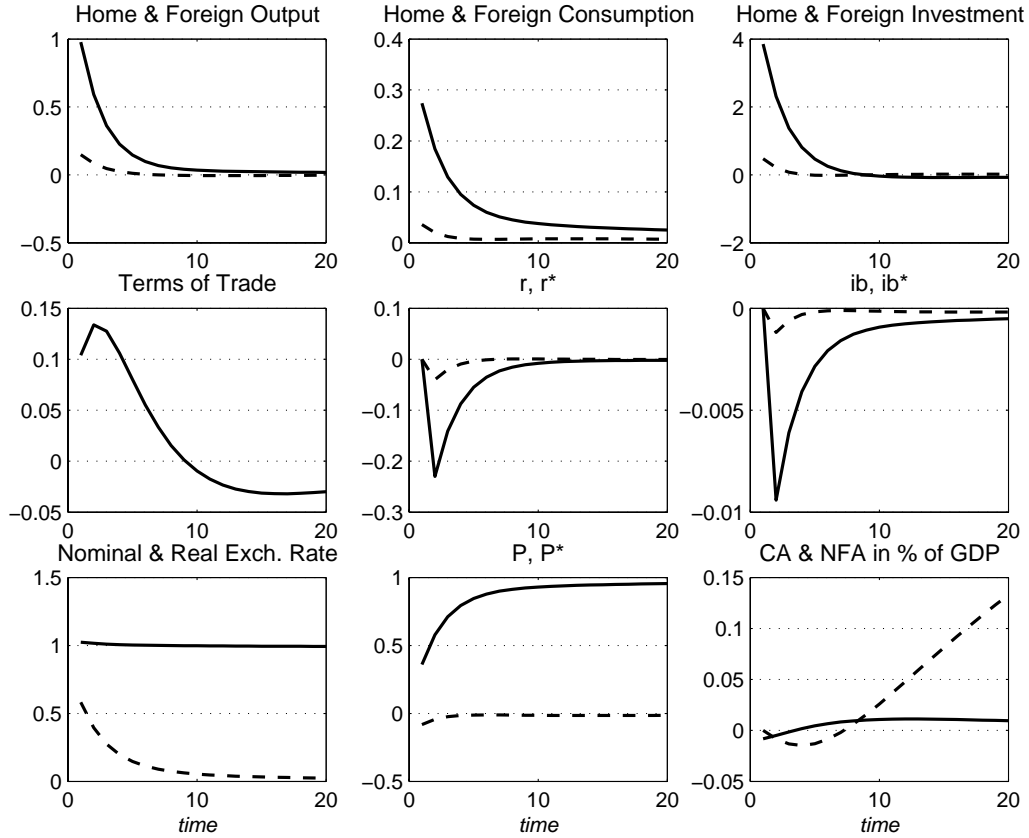
By the definition provided above, the complete asymmetric price-setting assumption implies that both home and foreign export goods are invoiced in the home currency, i.e. the U.S. dollar. Thus, a devaluation of the U.S. dollar induced by the U.S. monetary expansion reduces the foreign currency price of foreign country's imports as under the assumption of complete PCP. This in turn leads to a decline in the foreign overall consumer price level P^* as shown in Figure 5, which induces an increase in foreign real balances. The excess supply on the foreign money market allows for a decline in the foreign nominal and real interest rates, which brings forth an increase in foreign consumption and investment demand. This propagation mechanism corresponds with the one resulting for the assumption of complete PCP.

On the other hand, for home agents, import prices of foreign goods do not change on impact with the devaluation, as they are set in the home currency,

⁵⁸For a survey on the empirical results on pricing-to-market or local-currency-pricing the reader is referred to Goldberg and Knetter (1997).

⁵⁹I will illustrate the differences and similarities only for the first of the two sets of impulse responses, as the responses for the second sets are simply in between the responses for the PCP and the LCP assumption.

Figure 5: Impulse responses to a permanent increase in home money supply for the benchmark calibration and complete asymmetric price-setting behavior



the U.S. dollar. As there is no change in relative prices for home agents, they have no incentive to switch from foreign to home goods, and the expenditure-switching effect is clearly extenuated. Put differently, there is no exchange rate pass-through to U.S. import prices. Thus, the increase in home demand - which is far more important than the rise in foreign demand - is directed to both home and foreign goods in proportion to the expenditure shares of U.S. agents. Accordingly, foreign production, which is demand-determined in the short run, increases.

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

The impulse responses in Figure 5 suggest that international asymmetries in the price-setting behavior of firms might partly be responsible for the documented positive international transmission effects of U.S. monetary policy shocks to output and demand in the non-U.S. G7-countries. Nonetheless, it remains to be analyzed whether this result is robust to variations in other parameter values, where I focus on the role of money demand elasticities.

4.4 Robustness check: Money Demand Elasticities

Two other parameters present in the model are likely to influence the international transmission effects of monetary policy on the foreign economy: both money demand elasticities with respect to consumption and to the nominal interest rate. As pointed out in the discussion of the calibration values in the previous chapter, there seems to be little agreement on the magnitude of these elasticities, which proposes a close examination of the sensitivity of the results to variations in these parameters. For this purpose, however, I need to adopt preferences that are non-separable in real money balances and consumption. As outlined earlier, this feature allows to determine the parameter of risk aversion, i.e. the intertemporal elasticity of substitution, independent of money demand elasticities. The explicit form of the non-separable preferences considered is

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

which is also used in Kollmann (2001a).⁶⁰ The resulting money demand equation is

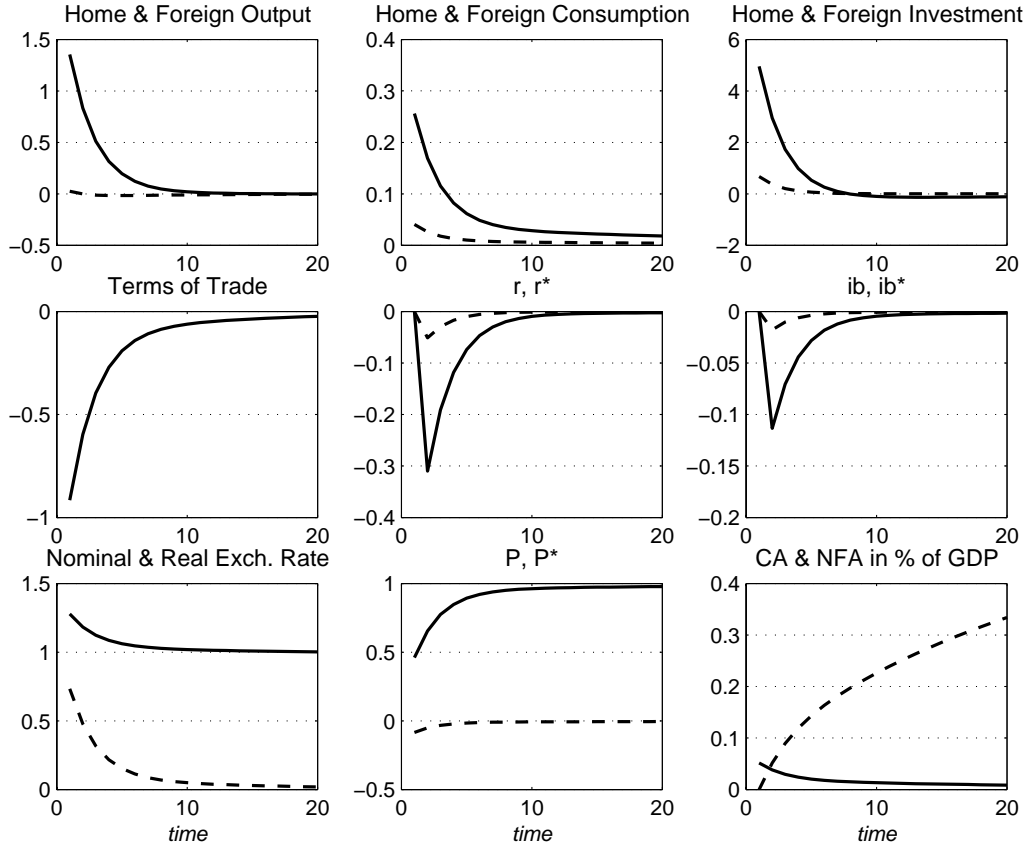
$$\frac{M_t}{P_t} = \left[\frac{\nu}{\epsilon \chi} C_t^{\nu-1} \left(\frac{i_{t+1}}{1+i_{t+1}} \right) \right]^{\frac{1}{\epsilon-1}}. \quad (23)$$

The consumption elasticity of money demand is easily derived as $\frac{\nu-1}{\epsilon-1}$, whereas the interest elasticity is $\frac{\beta}{\epsilon-1}$. Note that the coefficient of intertemporal risk aversion σ does not enter the money demand equation. Hence, money demand elasticities can be calibrated independent of the calibration of the intertemporal elasticity of substitution and vice versa.

Figure 6 depicts the impulse responses adopting the non-separable preferences with calibration values for the interest elasticity of -0.051 and a

⁶⁰The same exercise has also been conducted employing the preferences from Chari et al. (2002). As the main findings are similar, I will only show the results for the preferences adopted by Kollmann.

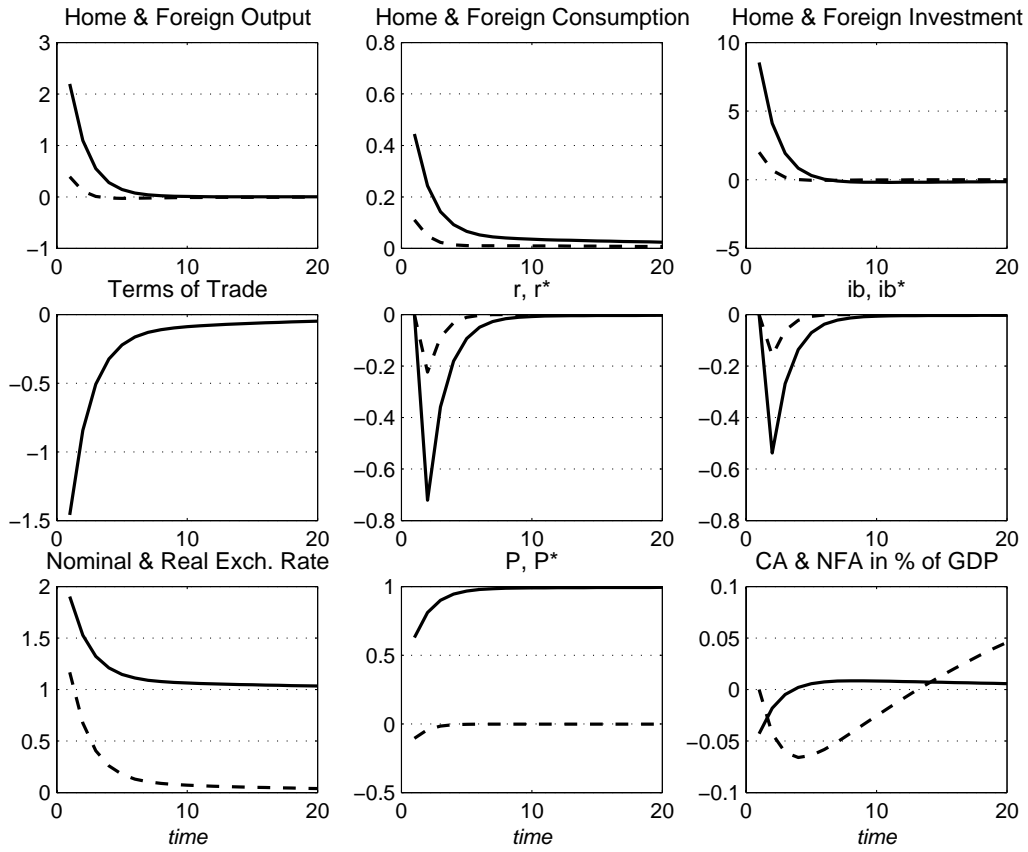
Figure 6: Impulse responses to a permanent increase in home money supply for Kollmann preferences, low interest elasticity of money demand (-0.051) and complete PCP



unitary consumption elasticity of money demand. These values are the estimates obtained by Mankiw and Summers (1986), using consumption in the money demand equation and they are at the lower end of the values employed in the literature. Further, complete PCP is presumed and σ is set to 2 as in Kollmann (2001a). Compared to impulse responses for the benchmark calibration in Figure 1, the decline in both the real and foreign interest rate depicted in Figure 6 is more pronounced. As money demand reacts less to a decline in the nominal interest rate, the drop in the nominal interest rates to equilibrate money markets in the two countries is stronger, which reinforces the resulting spread between the home and foreign nominal interest rate. Therefore, the overshooting of the nominal exchange rate is increased compared with Figure 1. Whereas the consumption responses in the two

countries are hardly affected by the change in the interest elasticity, both the increase in home and foreign investment are noticeably larger. Accordingly, the rise in aggregate world demand is augmented. However, the resulting increase in foreign production is hardly noticeable. It is obvious from Figure 6, that no positive spill-over effect on foreign output occurs for the calibrated values of money demand elasticities employed.

Figure 7: Impulse responses to a permanent increase in home money supply for the utility function and calibration used in Kollmann (2001a)



Yet, as demonstrated in Kollmann (2001a), perceivable international co-movements in output and aggregate demand in response to a monetary shock can be obtained if money demand elasticities are set ‘sufficiently’ low. For illustration, I calibrate the model analogous to Kollmann (2001a), including the assumption of complete PCP. The interest elasticity of money demand is set to -0.01 , which implies an ϵ of about -98 . Consumption elasticity is

assumed to be 0.2, which implies $\nu = 18.8$. Besides the calibration of small values for money demand elasticities, Kollmann employs a rather low elasticity of substitution between home and foreign goods of unity. As in Kollmann (2001a), the import share is set to 10% and $\sigma = 2$. The resulting impulse responses for Kollmann's benchmark calibration are depicted in Figure 7. For the Kollmann calibration, the model features positive international transmission effects of monetary policy shocks on foreign aggregate demand and aggregate production. Accordingly, in this setup – which ignores wage rigidities but is otherwise similar to Kollmann (2001a) – the results with respect to foreign output in Figure 7 depend vitally on money demand elasticities in combination with the cross-country substitutability.⁶¹ Comparing the depicted impulse responses to the ones in Figure 6, it is obvious that the lower calibration values for money demand elasticities enlarge the drop in the real interest rate which is twice as large. Hence, very high consumption and investment responses are generated. With a low cross-country substitutability of 1, the expenditure-switching effect is reduced, and the higher increase in aggregate world demand is also directed towards foreign goods. Hence, the magnitude of money demand elasticities vitally influences the international transmission effects in the presence of PCP. However, it remains open to question whether the values adopted by Kollmann are justifiable. The positive transmission effects on output for complete PCP in Kollmann (2001a) are not robust to the commonly employed range of money demand elasticities, which casts doubt on the relevance of Kollmann's model to explain the international transmission effects of monetary policy.

5 Conclusion

In this paper, I show that the stylized facts - in terms of positive international transmission effects of U.S. monetary policy on foreign (non-U.S. G-7) output and aggregate demand - can be reproduced in a two-country dynamic general equilibrium model with sticky prices, if we allow for international asymmetries in the price-setting behavior of producers. Empirical evidence and optimality considerations seem to suggest 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, because of the dominance of the U.S. market, foreign producers from Europe and Japan seem more likely to set the prices for their exports to the U.S. in U.S. dollars and hence to pursue a local-currency pricing strategy. This asymmetric

⁶¹In his paper, Kollmann (2001a, p. 1561) claims that the positive spill-over effect on output is robust for different assumptions about these elasticities.

price-setting behavior of firms allows for positive spill-over effects of a U.S. monetary shock on the non-U.S. G-7 countries, as the expenditure-switching effect is eliminated in the U.S., while a decline in import prices (and hence the overall price level) in the foreign country remains present, which induces foreign consumption and investment to rise.

Different authors - especially Betts and Devereux (2001,2000,1996) and Engel (2000) - have shown that the currency of pricing for export goods plays a decisive role for the international transmission of monetary shocks. The contribution of this paper is to point out that it is equally important to consider international differences in the choice of currency denomination. As demonstrated, allowing for asymmetries in the price-setting behavior of firms across countries seems promising for better understanding the international transmission of business cycles induced by monetary policy.

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