Imperfect Competition and Prices in a Dynamic Trade Model with Comparative Advantage*

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Abstract

This paper shows how local currency pricing and law of one price deviations can occur as equilibrium phenomena in an international business cycle model extended with oligopolistic market structures. We look at a framework in which oligopolistic market structures occur in a "Ricardian type" set-up where countries have comparative advantages in a range of industries. Due to comparative advantages, producers in different countries have varying degrees of market power giving them the competitive edge if they have access to production technologies with lower costs than their competitors. Thus local firms will tend to be the market leaders in their home markets but less dominating in foreign markets. In this set-up prices will depend on average marginal costs of the firms that are competing in a particular industry. This implies that there will be deviations from the law of one price and that these deviations will be time varying so that traded goods prices vay over time and give rise to real exchange rate fluctuations. Furthermore, the oligopolistic structure gives rise to larger effects of "demand type" shock than standard competitive models. In general, the model gives rise to a mix of industries subject to specialization and industries with intra-industry trade. However, in the quantitative analysis we focus on settings with only intra-industry trade. We show that this framework can acount for substantial real exchange rate movements.

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1 Introduction

Explaining the large and persistent movements in real and nominal exchange rates and exploring their macroeconomic effects remain on the top of the agenda in international economics. It is empirically well established that PPP is violated in the short to medium run giving rise to real exchange rate movements that are both large and persistent over time. Why does PPP fail? The full answer to this question probably includes may different factors, but it seems beyond doubt that traded goods price differences is an important component. In other words, the Law of One Price (the LOP) is violated. The seminal contributions by Isard (1977) and Kravis and Lipsey (1977) both showed that (industry level) export prices differ across locations. Later investigations have looked at pricing-to-markets, i.e. whether mark-ups are location specific (see e.g. Krugman, 1987, Knetter, 1989, and Marston, 1990), and exchange rate pass-through, i.e. whether exchange rates affect export prices one-to-one (see e.g. Feenstra, 1989, Kasa, 1992, Harrison, 1993, and Goldberg, 1995), and most studies find firm evidence against the LOP. More direct evidence on the importance of LOP violations for accounting for real exchange rate movements is contained in Engel's (1999) analysis of the US real exchange rate where it is investigated whether real exchange rate changes are dominated by changes in relative traded goods prices or changes in relative non-traded goods prices. The results indicate strongly that relative traded goods prices is the most important source behind the fluctuations in real exchange rates. While it is perceivable that traded goods prices reflect also the price of inputs of non-traded factors, it seems somewhat speculative that such price fluctuations would be large enough to account for the observed relative traded goods price fluctuations.[1]

Thus, LOP violations are key to account for real exchange rate movements. This insight naturally begs one to ask the question why the LOP is violated. The LOP follows from a goods market arbitrage principle, but in practise there exists various frictions that hinders such instantaneous arbitrage. Such frictions includes costs of transportation, trade policies, such as tariffs, quotas and anti-competitive regulatory practices[2], as well as uncertainty and exchange rate fluctuations. In the presence of such frictions, firms with market power can exploit third degree price discrimination and set location specific prices. Empirically, it now seems clear that the degree of goods market competition is important when accounting for LOP violations (see e.g. Goldberg, 1995, Goldberg and Knetter, 1999, Harrison, 1993, Knetter, 1993, and Verhoven, 1996). However, it is yet to be empirically established how frictions and different forms goods market competition interact to allow for LOP violations that are of a size and variability that is comparable to what can be observed in the data.

This paper looks at this issue in a macroeconomic set-up of oligopolistic competition in the goods market. The paper combines together two strands of the literature, the international business cycle literature and the industrial organization based macroeconomic literature of the late 1980's and the early 1990's that examined the links between competition and real exchange rates. By combining these two literatures we are able to evaluate the quantitative importance of oligopolistic market structures yet retaining the rigor of analysis that the quantitative international business cycle literature has introduced. The objective of the paper is to investigate how oligopolistic competition might affect real exchange rate movements and the macroeconomic

[1] Interestingly, Engel (2000) finds firm evidence against this hypothesis for an analysis of US and Mexican prices.

[2] Usually one would think of competition policies limiting firms market power. However, in some cases, such as the recent case where Levi's succesfully blocked ASDA's parallel U.K. imports of Levi's jeans from the U.S., firms might make use of the regulation to exploit third degree price discrimination.

implications of such fluctuations in relative traded goods prices.

Following the large swings in the US dollar in the 1980's a literature developed looked into how various aspects of competition in goods markets might lead firms to charge location specific mark-up and the macroeconomic implications of such set-ups.[3] Krugman (1987) analyzed in detail how various market structures could lead to LOP violations stressing models with either marketing or distribution costs and models with customer-market effects. Dornbusch (1987) paid special attention to oligopolistic structures and how LOP violations are related to the demand side of the economy and product differentiation among producers. Froot and Klemperer (1989) extended Krugman's (1987) analysis and focused on models in which market shares matter for the demand for the good. Each of these studies showed how LOP violations can come about in imperfectly competitive market structures, and each paper also showed some empirical relevance of such models. However, these contributions also shared the fact that they were concerned with partial equilibrium analysis and none of them evaluated the quantitative contribution of the market structure.

The international business cycle literature, on the other hand, has focused on quantitative dynamic general equilibrium models. Backus, Kehoe and Kydland (1992) showed how these models can account for a number of interesting features of the data as far as real quantities are concerned. Backus, Kehoe and Kydland (1993) extended this work to the case of specialized production and showed that real competitive frictionless models with country specific shocks to technology can account not only for key features of movements in real quantities but also for certain aspects of relative prices such as J-curve (or S-curve) relationships. However, these authors also highlight that these models fail seriously on a number of accounts: For realistic parameter values, these models can account for only a small fraction of relative price movements and imply that across countries, consumption levels are strongly correlated while output and investment levels are negatively related, implications that are in stark contrast to the data.

Recently, a number of papers have addressed these shortcomings and focused attention on the importance of fluctuations in the real exchange rate. Betts and Devereux (1996, 2000), Kollman (1996), Chari, Kehoe and McGrattan (1998) study international business cycle models in which firms are monopolistically competitive and price discriminate across markets (see Lane, 1999, for an excellent survey of this and related literatures).[4] These models all built on the assumptions that exporters set their prices in the currency of the purchasers (commonly referred to as local currency pricing) and, importantly, that prices are sticky and do not adjust instantaneously. Thus, changes in the nominal exchange rate do not affect the prices faced by final purchasers in the short run. For that reason nominal and real exchange rates are linked over such horizons. These analyses have shown promising results as far as concerns the implications for (nominal and real) exchange rate movements, for national business cycles, and for international comovements.

In these models, firms, if they had the opportunity, would prefer to adjust their prices and, due to auxiliary assumptions made in this literature, set the same prices in all markets. Thus, any effects on the real exchange rate caused by LOP violations are due to *sub-optimal* imperfect pass-through. Adjustment costs of various sorts can help explain why economic agents decide not to adjust in the face of "small" deviations from their preferred policies, but since the aim is to reproduce large and persistent real exchange rate movements, the deviations from optimal

[3]Another strand of this literature, e.g. Baldwin, 1988, Baldwin and Krugman, 1989, and Dixit, 1989, looked at models in which sunk costs leads to so-called hysteresis effects, i.e. persistent effects, of nominal exchange rate movements.

[4]See also Devereux and Engel (1998) and Engel (2000) for analyses of the welfare properties of monetary policy regimes in such models.

policies will be large unless the effect of prices on profits is limited. This observation calls into question whether such models properly extended with transactions costs are able to reproduce real exchange rate fluctuations that are as large and persistent as can be observed in the data.

Thus, in contrast to the literature of the late 1980's and the early 1990's these models do not address the issue of why firms might *choose* to set different prices across markets. We combine these literatures and construct a dynamic general equilibrium model in which there is *optimal* imperfect pass-through and in which the LOP is violated *ex-ante*. The analysis is based on the contributions by Dornbusch (1987) and Krugman (1987) and assumes that firms engage in strategic interactions in the goods market. In particular, it is assumed that firms engage in oligopolistic competition, but in difference to the earlier literature we analyze this in a fully fledged dynamic general equilibrium set-up. This allows us to evaluate quantitatively the effects on such goods market structures.

We initially formulate the model in a continuum of sectors set-up in which output is produced using capital and labor and assuming that countries differ in sector specific levels of productivity. Thus, on the technology side, the model combines the Heckscher-Ohlin continuum of sectors model of Dornbusch, Fischer, and Samuelson (1980) with the Ricardian features as in Dornbusch, Fischer, and Samuelson (1977). However, we deviate from both of these papers on the specification of the competition in the goods market where we introduce oligopolistic competition. In particular, we assume perfect substitutability between domestic and foreign goods of any variety but assume that varieties themselves are imperfectly substitutable. This allows us to use a Cournot-Nash formulation of the strategic interaction between domestic and foreign firms that produce the same variety of goods. Due to the differences in productivity levels domestic and foreign firms, however, are asymmetric in the sense that they generally will have different marginal costs.

We also introduce explicitly costs of international trade. This feature works to reduce the scope for goods market arbitrage thus paving the way for differences in traded goods prices. However, we follow other papers in the literature and focus on the second moments of the data. Thus, the issue is not whether the LOP is violated, but whether traded goods price differences are time-varying and whether these gives rise to real exchange rate fluctuations of a size and persistence that comes close to what can be observed in the data and whether the implied real exchange rate movements gives rise other macroeconomic implications.

The combination of the imperfect competition in the goods market and cross-country differences in sector specific productivity levels has a number of consequences. First, in the general case, the model implies that the model gives rise to a mixture of specialization and intra-industry trade. In sectors where productivity differences are large, firms will specialize unless goods are sufficiently substitutable. In other sectors with less pronounced productivity differences firms will share the market. We constrain ourselves to settings in which all sectors are characterized by intra-industry trade and leave the analysis of settings with a mixed industrial structure to future research.

Secondly, as also stressed by Krugman (1987), this model implies "pricing to markets", i.e. the LOP is violated. The equilibrium pricing functions associates the price of each variety in domestic and foreign markets to a mark-up on the *average* of the marginal costs of domestic and foreign firms that produce this variety. This is a standard implication of duopoly models. Nevertheless due to the productivity differences and the transactions costs this leads to a number of interesting results.

Thirdly, firms always have a larger market share in their home market and firms exploit this to set relatively high prices of their goods in their domestic market. Fourthly, the elasticity of the price with respect to marginal costs differs across markets. In particular, foreign prices are more sensitive to variations in domestic marginal costs than domestic prices. The reason is that marginal costs associated with selling in overseas markets are higher than marginal costs of selling in the home market. Since prices are set as mark-ups over the average of domestic and foreign firms' marginal costs in each market, this implies that foreign prices react more to domestic marginal costs than domestic prices. The pricing rule also implies that mark-ups of each firm are "countercyclical": Marginal cost changes are not transmitted fully into prices. This implies a magnification of the effects of "demand type" shocks to the economy, see e.g. Rotemberg and Woodford (1992, 1995) for a discussion.

We then investigate the quantitative effects of this framework. The quantitative investigation is complicated by the fact that the model introduces a number of extra parameters that we need to calibrate. For that reason, the results of the quantitative investigation should be interpreted with some care but is still of interest. We limit ourselves to cases in which all sectors of the economy are subject to intra-industry trade in order to focus the attention on the effects of the oligopolistic market structure. We find that the model can account for a substantial fraction of the fluctuations in real exchange rates although it still leaves plenty of room for improvement. One main problem is that it does not give rise to as persistent real exchange rate movements as can be observed in the data. It also leads to non-standard results for the way in which productivity shocks affect the economy, and it does not provide as good a "fit" to the movements in real macroeconomic aggregates as standard competitive models. Nevertheless, since we do not introduce any nominal rigidities and since we do not allow for at least partial specialization in production, we believe that the results are encouraging and that they indicate that oligopolistic frameworks might have an important role to play in accounting for real exchange rate movements and for international business cycles.

The remainder of the paper is constructed as follows. The next section presents the standard parts of the model which relate to the household sector and the final goods sector. In Section 3 we then look at the intermediate goods sector. Sector 4 discusses the calibration of the model. Section 5 presents the quantitative results. Finally, we conclude in Section 6.

2 The Model

The main innovation of this paper is in the specification of how firms set prices. The other parts of the model are relatively standard. However, in order to aid the presentation, we first present the standard parts of the model and then turn to price setting.

The economy consists of two symmetric countries. In each country there is a large number of households, a large number of competitive firms each producing an identical final good, a government, and a large number of imperfectly competitive intermediate goods producing firms. Final goods, that are not traded internationally, are produced using inputs of domestic and foreign intermediate goods, but trade in these goods in costly due to transportation costs. Below we first present the households' problems. Next we turn to the final goods sector firms. The intermediate goods sector is described in detail in the next section.

2.1 Households and Governments

All households within each of the two countries are identical. Households have infinite planning horizons, have rational expectations and maximize the discounted expected present value of the stream utility. Utility depends on the consumption of goods, leisure and their holdings of real balances. We introduce money into the utility function in order to generate a demand for money, but the exact way that money is included is non-essential for the results that will be derived. For simplicity it is assumed that households hold only domestic currency.

Households supply labor services and productive capital to the domestic intermediate goods firms and take all prices for given. It is also assumed that the households own the claims to the profits of domestic firms and that they can borrow and lend freely in a complete set of contingent claims markets.

Let $s^t = (s_0, s_1, .., s_t)$ denote the history of events up to date t where s_m is the event at m and each event belongs to a finite countable set S. The probability of observing s^t at date t conditional on s^0 is denoted by $\pi(s^t|s_0)$. We follow Chari, Kehoe and McGrattan (1998) and assume that preferences for households in country i are given by:

$$\begin{aligned} U_{i0} &= E_0 \sum_{t=0}^{\infty} \sum_{s^t} \pi\left(s^t|s_0\right) \beta^t [\frac{1}{1-\sigma} \left(\gamma \left(c_i\left(s^t\right)\right)^{\theta} + (1-\gamma)\left(M_i\left(s^t\right)/Q_i\left(s^t\right)\right)^{\theta}\right)^{(1-\sigma)/\theta} \\ &\quad + \frac{\chi}{1-\kappa}\left(1-n_i\left(s^t\right)\right)^{1-\kappa}] \end{aligned} \tag{1}$$

where β is the subjective discount factor, $c_i(s^t)$ denotes the consumption of final goods in country i when the state at date t is equal to s^t, M_i denotes holdings of domestic currency, Q_i is the general price level, and n_i denotes hours worked. We have normalized the time endowment to one every period.

There is a complete set of asset markets. Households can purchase a set of bonds, $B(s^t)$, at the price $R(s^t|s^{t-1})$ (denominated in the domestic currency). Such a bond pays out one unit of the domestic currency if the realized state at date t is equal to s^t. The budget constraint faced by domestic agents is:

$$\begin{aligned} &Q_1\left(s^t\right)\left(c_1\left(s^t\right)+x_1\left(s^t\right)\right)+M_1\left(s^t\right)+\sum_{s^{t+1}} R\left(s^{t+1}|s^t\right) B_1\left(s^{t+1}\right)+T_1\left(s^t\right) \leq \\ &Q_1\left(s^t\right)\left(r_1\left(s^t\right)k_1\left(s^t\right)+w_1\left(s^t\right)n_1\left(s^t\right)\right)+M_1\left(s^{t-1}\right)+B_1\left(s^t\right)+\Pi_1\left(s^t\right) \end{aligned} \tag{2}$$

and foreign households' budget constraints are given by:

$$\begin{aligned} &Q_2\left(s^t\right)\left(c_2\left(s^t\right)+x_2\left(s^t\right)\right)+M_2\left(s^t\right)+\sum_{s^{t+1}} R\left(s^{t+1}|s^t\right) \frac{B_2\left(s^{t+1}\right)}{e\left(s^t\right)}+T_2\left(s^t\right) \leq \\ &Q_2\left(s^t\right)\left(r_2\left(s^t\right)k_2\left(s^{t-1}\right)+w_2\left(s^t\right)n_2\left(s^t\right)\right)+M_2\left(s^{t-1}\right)+\frac{B_2\left(s^t\right)}{e\left(s^t\right)}+\Pi_2\left(s^t\right) \end{aligned} \tag{3}$$

where x_i denotes real investment. T_i are nominal net transfers from the domestic government. k_i is the households holdings of productive capital and r_i and w_i denote the real capital rental rate and the real wage rate, respectively. Finally, Π_i denotes the households receipts of profits.[5]

Capital accumulates according to:

[5] This formulation subsumes that households of country hold all the equity of the firms of country i. We can easily allow for holdings of foreign equity but the complete markets assumption makes this in-consequential.

$$k_i\left(s^t\right)=(1-\delta)\,k_i\left(s^{t-1}\right)+\phi\left(x_i\left(s^t\right)/k_i\left(s^{t-1}\right)\right)k_i\left(s^{t-1}\right) \tag{4}$$

where δ is the capital depreciation rate, and $\phi\left(x_i\left(s^t\right)/k_i\left(s^{t-1}\right)\right)k_i\left(s^{t-1}\right)$ captures capital adjustment costs. This latter function is assumed to be increasing and concave in $x_i\left(s^t\right)/k_i\left(s^{t-1}\right)$ and to be consistent with a steady-state Tobin's Q of 1.

The first order necessary optimality conditions are derived in the appendix. It is worth pointing out two properties of this model. First, the model gives rise to the following simple money demand function:

$$\frac{M_1\left(s^t\right)}{Q_1\left(s^t\right)}=\left(\frac{\gamma}{1-\gamma}\right)^{1/(\theta-1)}\frac{c_1\left(s^t\right)}{\left(1-R\left(s^t\right)\right)^{1/(1-\theta)}} \tag{5}$$

where $R\left(s^t\right)=\sum_{s^{t+1}}R\left(s^{t+1}|s^t\right)$.

secondly, the model yields the following risk sharing condition:

$$MU\left(c_1\left(s^t\right)\right)=\xi\frac{MU\left(c_2\left(s^t\right)\right)}{q\left(s^t\right)} \tag{6}$$

where ξ is a time and state-invariant constant reflecting initial wealth differences, $MU(c)$ denotes the marginal utility of consumption and q is the real exchange rate defined as $q\left(s^t\right)=e\left(s^t\right)Q_2\left(s^t\right)/Q_1\left(s^t\right)$. This condition states that marginal utilities of consumption are equalized across countries and states of nature apart from the wedge that is introduced by the real exchange rate. This wedge is one of the main channels through which real exchange rate movements affect the real economy and is important for driving down the almost perfect correlation of consumption levels that arise in standard models based on PPP.[6]

Finally, governments purchase final goods and finance their purchases by lump-sum taxation and by money issues. They face the following sequence of budget constraints:

$$Q_i\left(s^t\right)g_i\left(s^t\right)-T_i\left(s^t\right)=M_{it}\left(s^t\right)-M_i\left(s^{t-1}\right) \tag{7}$$

where $g_i\left(s^t\right)$ denotes real government purchases of goods and services.

We now turn to the final goods sector an, in order to save on notation, we will from now on denote any variable $h\left(s^t\right)$ by h_t.

2.2 The Final Goods Sector

There is a large number of identical final goods producing firms in each country that produce an identical good taking all input and output prices for given. Final goods are not traded among countries. The production of final goods depends on the input of a continuum of different intermediate goods, indicated by $z\in[0,1]$, which are substitutes. Each of these goods can be purchased from either domestic producers or from foreign producers but domestic and foreign goods of any type z are perfect substitutes. The technology is given by the following CES-function:

$$V_{it}=\left[\int_0^1\omega_i(z)\,v_{it}(z)^{(\rho-1)/\rho}\,dz\right]^{\rho/(\rho-1)} \tag{8}$$

[6]Ravn, 2000a, tests this version of the risk sharing condition empirically, and disappointingly finds limited support for it in the data. The reasons for limited risk sharing still has to be explored fully. Kehoe and Perri, 1999, claim that imperfect enforcability of international loan contracts can explain the risk sharing puzzle.

where $\omega_i(z)$ is the weight that is associated with intermediate input of type z, $v_{it}(z)$ denotes the input of intermediate good of type z, and ρ is the elasticity of substitution.

The output of final goods are used for consumption, investment and government consumption and the resource constraints are given by:

$$V_{it} = c_{it} + x_{it} + g_{it} \tag{9}$$

It is worth noting that, due to the use of the CES function above, one can re-interpret the model as one in which there is trade in final goods and in which all final uses of the goods are specified by identical CES functions of the domestic and the foreign goods (this is the specification used e.g. by Obstfeld and Rogoff, 1995). The present formulation is used only because it is more economical in terms of presentation.

The choices of inputs can be summarized by the demand functions:

$$v_{it}(z) = \left[\frac{\omega_i(z) Q_{it}}{p_{it}(z)}\right]^{\rho} V_{it} \tag{10}$$

where $p_i(z)$ is the price of intermediate good of type z in country i denominating in currency i. Q_{it} is the general price level in country i which, given the CES structure, follows as:

$$Q_{it} = \left[\int_0^1 \omega_i(z)^{\rho} p_{it}(z)^{1-\rho} dz\right]^{1/(1-\rho)} \tag{11}$$

3 The Intermediary Goods Firms

We model the intermediate goods sector by introducing imperfect competition into the continuum of sectors Heckscher-Ohlin model of Dornbusch, Fischer and Samuelson (1980) extended with cross-country differences in technological efficiency as in Dornbusch, Fischer and Samuelson (1977). The continuum of sectors aspect is simply a neat way of presenting the multi-sector model and is mainly meant as an illustrative. Indeed, when later analyzing the model's quantitative implications we will work with a finite number of sectors. The general case of a continuum of sectors, however, is informative since it highlights the way in which the model might lead to specialization in production.

The Ricardian aspect, however, *is* important. It implies that countries differ in their technological opportunities and gives rise to marginal cost differences across sectors and across countries. This aspect allows us to model the fact that the industrial structure of countries differ but without having to make to assume that factor supplies differ. We do not necessarily want to rule out factor supply differences, but in our model, capital and labor supplies are determined endogenously and cannot be imposed exogenously as in standard in static trade theory. Indeed, in the absence of shocks, the two economies are symmetric, and thus, the pattern of specialization and trade would be indeterminate.[7] Furthermore, such technological differences has recently attracted substantial attention in the empirical international trade literature, see e.g. Trefler (1993, 1995), Dollar and Wolff (1993), Harrigan (1997, 1999), and, for an excellent survey of this an related literatures, Helpman (1998). These contributions either document problems with

[7] A model with a similar industrial structure but with competitive firms is analyzed in Ravn (2000b) where it is shown that the extension to a model with an endogenous pattern of specialization itself leads to interesting implications but does not radically improve the performance of the model as far as the standard "puzzles" in international business cycle models is concerned.

existing trade models based on factor endowment differences and/or estimate differences in technologies across countries. Harrigan (1999) is particularly interesting because his results to some extent support the modelling of technological differences that will be applied below, although his results cannot be directly applied here because of differences in auxiliary assumptions.

3.1 Technology and Input Choices

In each of the two countries there is exactly one firm that has the technological opportunity of producing intermediary good of variety $z \in [0, 1]$.[8] The technologies are specified as Cobb-Douglas functions with inputs of labor and capital. The production function for a firm that has the opportunity to produce good z and is located in country i is given by:

$$y_{it}(z) = \lambda_{it} a_i(z) (k_{it}(z))^{1-\alpha} (n_{it}(z))^{\alpha} \tag{12}$$

where λ_{it} is a country specific level of productivity that affects all sectors within each country equally. $n_{it}(z)$, denotes input of labor and $k_{it}(z)$ denotes input of capital.

The important variable to notice in this production function is $a_i(z)$ which is a sector and country specific level of productivity. We assume that this productivity factor is constant over time, but that it differs across sectors within each of the two countries. As a normalization we assume that $a_1(z)$ is decreasing in z while $a_2(z)$ is increasing in z. This implies that country 1 (2) has a comparative advantage in the production of goods indexed by "low" ("high") values of z. It will be assumed that the technological opportunities are symmetric in the sense that $a_1(z) = a_2(1-z)$. Figure 1 gives a graphical illustration of an example of the sector specific productivity levels might look like.

Input markets are assumed to be competitive and it is straightforward to derive the following factor demand functions and cost functions:

$$n_{it}^d(z) = \frac{1}{\lambda_{it}} \frac{1}{a_i(z)} \left[\frac{\alpha}{1-\alpha} \frac{r_{it}}{w_{it}} \right]^{1-\alpha} y_{it}(z) \tag{13}$$

$$k_{it}^d(z) = \frac{1}{\lambda_{it}} \frac{1}{a_i(z)} \left[\frac{\alpha}{1-\alpha} \frac{r_{it}}{w_{it}} \right]^{-\alpha} y_{it}(z) \tag{14}$$

$$D_{it}(z) = \frac{1}{\lambda_{it}} \frac{1}{a_i(z)} w_{it}^{\alpha} r_{it}^{1-\alpha} \left[\left(\frac{1-\alpha}{\alpha} \right)^{\alpha} + \left(\frac{\alpha}{1-\alpha} \right)^{1-\alpha} \right] y_{it}(z) \tag{15}$$

For future use, we will denote the unit cost by:

$$d_{it}(z) = \frac{1}{\lambda_{it}} \frac{1}{a_i(z)} w_{it}^{\alpha} r_{it}^{1-\alpha} \left[\left(\frac{1-\alpha}{\alpha} \right)^{\alpha} + \left(\frac{\alpha}{1-\alpha} \right)^{1-\alpha} \right] \tag{16}$$

3.2 Quantity and Price Determination

Standard models in the international business cycle literature assume that countries are specialized in production and that firms are either competitive or engage in monopolistic competition. Here we instead assume that firms engage in oligopolistic competition and we derive the pattern

[8] Alternatively, we can assume that there are many firms that can produce each of the varieties but that all firms within each country that produce the same variety perfectly coordinate their actions.

of specialization endogenously. All firms assume that they have no impact on what firms in other industries do and, thus, take the aggregate price level for given. The domestic and the foreign firm of the intermediary good of variety z take part in Cournot-Nash games. Here we assume the strategic games that the firms engage in are static and repeated every period and leave dynamic games for future research.

A firm located in country i that produces an intermediate good of variety z might be selling its good both in the domestic market and in the foreign market. Selling in the two markets is associated with different marginal costs due to the presence of costs of transportation as in e.g. Ravn and Mazzenga (1999) or Obstfeld and Rogoff (2000). The costs can also be thought of as reflecting tariffs or other frictions that makes trade costly. We include these costs explicitly so as to allow for frictions in goods markets arbitrage. As we will later discuss, however, the implications of our model in the presence of such costs are different from those that occur in other models.

The demand in market i for goods of variety z is given by:

$$v_{it}(z) = x_{it}^{i}(z) + x_{it}^{j}(z) \tag{17}$$

where $x_n^s(z)$ is the demand for good z stemming from market n and s indexes the origin of the producer. The inverse demand for $v_i(z)$, derived in the previous section, is given by:

$$p_{it}(z) = [\omega_i(z) Q_{it}] V_{it}^{1/\rho} v_{it}(z)^{-1/\rho} \tag{18}$$

Consider a firm located in country 1. This firm sets quantities of its' output in the domestic market and in the foreign market on the basis of conjectures on the foreign firm's supply. We let these conjectures be given by $\overline{x}_{1t}^2(z)$ and $\overline{x}_{2t}^2(z)$. The firm's profit maximization problem is given by:

$$\max p_{1t}(z) x_{1t}^1(z) + e_t p_{2t}(z) x_{2t}^1(z) - Q_{1t}\left(x_{1t}^1(z) d_{1t}(z) + x_{2t}^1(z) d_{1t}(z) \frac{1}{1-\tau}\right) \tag{19}$$

The first term is the nominal revenue from selling in the domestic market $(p_{1t}(z) x_{1t}^1(z))$. The second term is the nominal revenue from selling in the foreign market, $e_t p_{2t}(z) x_{2t}^1(z)$. The last term is sum of $Q_{1t} x_{1t}^1(z) d_{1t}(z)$ which is the nominal costs of supplying $x_{1t}^1(z)$ to the home-market, and $Q_{1t} x_{2t}^1(z) d_{1t}(z) \frac{1}{1-\tau}$ which is the cost of supplying x_{2t}^1 to the foreign market. In this expression $\frac{1}{1-\tau} \geq 1$ denotes the transactions costs..

It is straightforward to derive the following condition for the rational expectations Cournot-Nash equilibrium:

$$\frac{\frac{\rho-1}{\rho} x_{it}^1(z) + x_{it}^2(z)}{\frac{\rho-1}{\rho} x_{it}^2(z) + x_{it}^1(z)} = \frac{MC_{it}^1(z)}{MC_{it}^2(z)}$$

where $MC_{1t}^1(z) = Q_{1t} d_{1t}(z)$ and $MC_{2t}^1(z) = Q_{1t} d_{1t}(z) \frac{1}{1-\tau} \frac{1}{e_t}$. Define also $MC_{1t}^2(z) = Q_{2t} d_{2t}(z) \frac{1}{1-\tau} e_t$ and $MC_{2t}^2(z) = Q_{2t} d_{2t}(z)$. Rearranging this expression yields the condition that:

$$x_{it}^1(z) = \frac{MC_{it}^1(z) - \frac{\rho-1}{\rho} MC_{it}^2(z)}{MC_{it}^2(z) - \frac{\rho-1}{\rho} MC_{it}^1(z)} x_{it}^2(z) \tag{20}$$

from which we see that an interior solution (for both firms' output levels) must be subject to the following two conditions:

$$MC^1_{it}(z) > \frac{\rho-1}{\rho} MC^2_{it}(z) \tag{21}$$

$$MC^2_{it}(z) > \frac{\rho-1}{\rho} MC^1_{it}(z) \tag{22}$$

These conditions assure that the Cournot-Nash equilibrium is consistent. If equation (21) is violated, the firm of country 1 will be a monopolist in market i and sets a monopoly price of $p^{1m}_{it}(z) = \frac{\rho}{\rho-1} MC^1_{it}(z)$. This price will be below the marginal costs of the firm located in country 2 which, accordingly, will leave the market. Equivalently for the second condition which assures that the firm located in country 2 will not become a monopolist.

Assuming that (21) – (22) holds, we can derive the equilibrium oligopoly price by inserting the reaction functions in the equilibrium condition (equation (17)):

$$p_{it}(z) = \left[\frac{2\rho}{2\rho-1}\right] \frac{\left(MC^1_{it}(z) + MC^2_{it}(z)\right)}{2} \tag{23}$$

Thus, the equilibrium oligopoly price is set as a mark-up on the average marginal costs of the firms that operate in the market, and the mark-up is constant due to the assumption of isoelastic demand functions.

It is instructive to look at the equilibrium outcome graphically. In the absence of costs of international trade the law of one price will hold in equilibrium. Figure 2 illustrates the equilibrium prices together with the marginal cost schedules and the prices that would have applied if either the domestic or the foreign firm was a monopolist (or more precisely, the price of brand z if firms engage in monopolistic competition). In Diagram A firms share the market for all varieties of the intermediary goods end up as duopolists in the markets for all individual brands. Given the negative correlation between domestic and foreign sector specific productivity levels, the price stabilizes across goods relative to what would be the case if there was either perfect competition in the intermediate goods market or monopolistic competition.

In Diagram B there is a range of goods for which either the domestic suppliers or the foreign suppliers are monopolists and the price is a mixture of the oligopoly price and the monopoly price schedules. Thus, there is some specialization in production, although the model still implies intra-industry trade for a subset of the industries. Whether all markets will be shared or not depends on (i) the marginal costs differences, and (ii) the elasticity of demand. If marginal costs differences are big, it is likely that the low cost firm will end up as a monopolist. Similarly, the higher the price elasticity of demand the more likely it is that the low cost firm ends up as a monopolist. In the latter case, this is explained by the fact that the higher is the price elasticity, the lower is the equilibrium mark-up.

Figure 3 illustrates the oligopoly pricing schedules for the case where trade is costly. For brevity, we show only the case where the oligopoly outcome applies to the whole range of intermediate goods. We see that the LOP holds for only a single good at any point in time. Next, we see that goods in which a given country has the largest comparative advantage are also the goods for which the LOP deviations are the largest and that are relatively more expensive in the country that has the competitive edge. This is a result of the fact that the low cost firms take advantage of the high cost firms and implements a relatively high equilibrium price.

Given the pricing schedule derived above, and assuming that the duopoly price relates to the whole range of intermediate goods, we get the following solutions to the aggregate levels of intermediate goods supply and each producer's supply:

$$
\begin{aligned}
v_{it}(z) &= [\omega_i(z) Q_{it}]^{\rho} V_{it} \left[\frac{2\rho}{2\rho-1}\right]^{-\rho} \left(\frac{MC_{it}^1(z)+MC_{it}^2(z)}{2}\right)^{-\rho} \\
x_{it}^1(z) &= \rho \frac{MC_{it}^2(z) - \frac{\rho-1}{\rho} MC_{it}^1(z)}{MC_{it}^1(z)+MC_{it}^2(z)} v_{it}(z) \\
x_{it}^2(z) &= \rho \frac{MC_{it}^1(z) - \frac{\rho-1}{\rho} MC_{it}^2(z)}{MC_{it}^1(z)+MC_{it}^2(z)} v_{it}(z)
\end{aligned}
$$

In case the consistency requirements, equations (21) – (22), are violated for a subset of the industries, we get that for these industries:

$$
\begin{aligned}
v_{it}(z) &= [\omega_i(z) Q_{it}]^{\rho} V_{it} \left[\frac{\rho}{\rho-1} MC_{it}^1(z)\right]^{-\rho} \\
x_{it}^1(z) &= v_{it}(z)
\end{aligned}
$$

if (21) is violated or:

$$
\begin{aligned}
v_{it}(z) &= [\omega_i(z) Q_{it}]^{\rho} V_{it} \left[\frac{\rho}{\rho-1} MC_{it}^2(z)\right]^{-\rho} \\
x_{it}^2(z) &= v_{it}(z)
\end{aligned}
$$

if (22) is violated.

3.3 Discussion

The model as presented is a dynamic general equilibrium version of the duopoly models in Dornbusch (1987) and Krugman (1987) and is also similar to contributions to the industrial organization literature by Kirman and Schueller (1990) and, in particular, by Hens, Jäger, Kirman and Phlips (1999). Dornbusch (1987) also studies the implications for more general demand functions and for other goods market models based on product differentiation. Krugman (1987), instead, puts special attention on dynamic settings in which pricing-to-markets occur either because of marketing and distribution costs, or because of customer-market effects. Hens, Jäger, Kirman and Phlips (1999) allow for both general demand and general cost functions. They show that the properties of the equilibrium duopoly depend quite crucially on the properties of the cost functions and the demand functions. The difference between those papers and the present one is, first, that we use a stochastic general equilibrium framework in which, among other things, marginal costs are endogenous; Secondly, the Ricardian framework that we apply puts some restrictions on the relative cost functions that do not easily fit into a partial equilibrium framework. Thirdly, we use particular assumptions on the parametric modeling of demand and cost functions. Fourthly, we incorporate directly a goods market friction that allow for pricing-to-markets.

The present model has the implication that the LOP is violated ex-ante. This result, however, relies on the existence of transactions costs. In the face of transactions costs, models based on either competition or imperfect competition will share this implication, so one might question whether the model has a convincing case to make to LOP violations.[9] When firms are price takers (and countries are specialized in production), costs of international trade will be reflected one-to-one in the prices faced by the final purchasers. Similarly, if firms engage in monopolistic competition, prices will differ by the transactions costs multiplied by the mark-up that firms add to marginal costs.[10] In the present set-up, generally, the traded goods price differences will be smaller than the transactions costs (so that there are no opportunities for goods market arbitrage). Thus, in contrast to other model, the present set-up does not imply that the marginal cost differences associated with international trade are directly reflected in international price differences.

A more fundamental difference, however, is associated with the way that prices will differ across countries over time. Models based on competitive firms will only lead to variations over time in traded goods price differences if transactions costs are time-varying. While there might be good reasons to expect some time-varying transactions costs, such variations would have to be counterfactually large to be consistent with the observed magnitude of the variations in real exchange rates (see Ravn and Mazzenga, 1999). Assuming instead that firms engage in monopolistic competition (or a monopoly structure) leads to the same problem if one assumes that firms face iso-elastic demand functions for their goods.

Betts and Devereux (1996, 2000), Chari, Kehoe and McGrattan (1998), and Kollman (1996) assume instead that firms cannot change prices continuously and that prices are sticky in the currency of the consumer. These models allow for price discrimination across markets, but the LOP holds ex ante.. Ex post, however, the LOP might be violated because any fluctuations in nominal exchange rates will be reflected in traded goods prices over the horizon where prices are sticky. Thus, these models give rise to sub-optimal imperfect pass-through. Chari, Kehoe and McGrattan (1998) show that if prices are sticky for 3 years, these models can generate real exchange rate movements of a size and persistence that is comparable to the data. A questionable aspect of this is that it relies on the existence of non-specified frictions that lead firms not to adjust their prices. Unless profits are insensitive with respect to changes in prices, such frictions would have to be very severe in order to prevent firms from adjusting their prices in the face of as large variations in traded goods prices.

The present model does not introduce nominal rigidities, but the oligopolistic competition structure introduces a real rigidity that endogenously leads to variations in traded goods prices across locations. In the present model, money is neutral but persistent changes in the money growth rates have real effects.[11] Money is, however, not super-neutral and when money-supply changes are correlated over time, they will have real effects.[12]

[9] Krugman (1987) stresses the same point.

[10] Strictly speaking, the latter outcome also requires that final purchasers cannot exploit goods market arbitrage opportunities since the prices faced by purchasers in this case differ by more than the transactions cost itself.

[11] Neutrality follows from the absence of nominal rigidities and can easily be derived from inspecting the first order condition for money demand $\frac{M_1(s_t)}{Q_1(s_t)} = \left(\frac{\gamma}{1-\gamma}\right)^{1/(\theta-1)} \frac{c_1(s_t)}{\left(1-\sum_{s^{t+1}} R(s^{t+1}|s^t)\right)^{1/(1-\theta)}}$ A once and for all increase in the money-supply will leave $\sum_{s^{t+1}} R\left(s^{t+1}|s^t\right)$ unaltered giving rise to a proportional increase in the price level and a devaluation of the exchange rate leaving all real quantities and prices constant.

[12] This follows because under these circumstances $\sum_{s^{t+1}} R\left(s^{t+1}|s^t\right)$ will be affected by changes in the money supply. This implies that real money-demands will change. An increase in domestic money supply will then increase domestic real money demand and domestic consumption. As long as money-supply shocks do not transmit perfectly abroad, this will mean that domestic consumption will rise relative to foreign consumption. From the risk sharing condition, equation (6), this implies that the real exchange rate has to depreciate. Since the price level and the exchange rate no longer change one for one, this also means that the relative competitiveness of domestic and foreign firms is altered. We can easily see that this gives rise to time-

3.4 Equilibrium Definition

We are now in a position to define the equilibrium of the model formally. We assume that the stochastic processes for aggregate productivity shocks, government expenditure, and money growth rates, are given by Markovian processes. In particular, we assume that:

$$\begin{bmatrix} \lambda_{1t+1} \\ \lambda_{2t+1} \end{bmatrix} = A_\lambda + B_\lambda \begin{bmatrix} \lambda_{1t} \\ \lambda_{2t} \end{bmatrix} + \varepsilon_{t+1}^{\lambda} \quad (24)$$

$$\begin{bmatrix} g_{1t+1} \\ g_{2t+1} \end{bmatrix} = A_g + B_g \begin{bmatrix} g_{1t} \\ g_{2t} \end{bmatrix} + \varepsilon_{t+1}^{g} \quad (25)$$

and:

$$M_{it+1} = \varrho_{it+1} M_{it}$$

where:

$$\begin{bmatrix} \varrho_{1t+1} \\ \varrho_{2t+1} \end{bmatrix} = A_\varrho + B_\varrho \begin{bmatrix} \varrho_{1t} \\ \varrho_{2t} \end{bmatrix} + \varepsilon_{t+1}^{\varrho} \quad (26)$$

where $\varepsilon_{t+1}^{\lambda}$, ε_{t+1}^{g}, and $\varepsilon_{t+1}^{\varrho}$ are mutually independent n.i.d. variables with covariance matrices Ω_λ, Ω_g, and Ω_ϱ.

Definition: An equilibrium is a set of functions: $\mathcal{T} = (TR_i)$, $\mathcal{P} = (r_i, w_i, R, e, p_i(z), Q_i)$, $\mathcal{S} = \left(c_i, x_i, n_i, k_i', B_i, M_i, v_i(z), n_i(z), k_i(z), x_i^j(z), \pi_i(z)\right)$ such that given the taxes $\mathcal{T}$, and the laws of motion given by equations (24)-(26), (i) the households choose $(c_i, n_i, x_i, k_i', B_i, M_i)$ to solve their maximization problems given the prices $\mathcal{P}$, (ii) the final goods firms choose $v_i(z)$ to solve their maximization problems given the prices $\mathcal{P}$, (iii) the intermediate goods firms choose $\left(n_i(z), k_i(z), x_i^j(z), \pi_i(z)\right)$ to solve their maximization problems and these choices are consistent with the prices $\mathcal{P}$, (iv) the government's budget constraint (7) is satisfied, and (v) all markets clear.

The market clearing conditions here consists of (i) a set of bonds market clearing conditions that require that (i) $B_1(s^t) = -B_2(s^t)$, (ii) final goods market clearing conditions that require that $V_i(s^t) = c_i(s^t) + x_i(s^t) + g_i(s^t)$, (iii) intermediate goods market clearing conditions that $v_i(z)(s^t) = x_i^1(z)(s^t) + x_i^2(z)(s^t)$, (iv) labor and productive capital market clearing conditions that require:

$$\begin{aligned} n_i\left(s^t\right) &= \int_0^1 n_i^d(z)\left(s^t\right) dz \\ k_i &= \int_0^1 k_i^d(z)\left(s^t\right) dz \end{aligned}$$

varying violations of the LOP. Define the relative traded goods price for good z as $q_{1t}(z) = e_t p_{2t}(z)/p_{1t}(z) = \left(MC_{1t}^1(z)\frac{1}{1-\tau} + e_t MC_{2t}^2(z)\right) / \left(MC_{1t}^1(z) + e_t MC_{2t}^2(z)\frac{1}{1-\tau}\right)$. From this we see that the deviations from the LOP will be time varying unless $MC_{1t}^1(z) = e_t MC_{2t}^2(z)$, a condition that holds under two scenarios (i) $\tau = 0$, or (ii) monetary neutrality.

where the labor and capital demand functions have been defined in equations (13)-(14). Notice also that the profit levels that enter into the households budget constraints are given by $\Pi_i(s^t) = \int_0^1 \pi_i(z)(s^t)\,dz$.

The problem as stated is non-stationary because nominal supplies are growing over time. This gives rise to growth in the nominal variables of the model. To get around this non-stationarity, we deflate all nominal variables by the money stock.

4 Calibration

The present model is more cumbersome to calibrate than standard models due to a number of aspects. Given the number of new parameters that are introduced due to the multi-sector aspect of the economy and the scant empirical evidence on which to base these parameters, the calibration is, admittedly, somewhat speculative, and the numerical results should be interpreted with some care. However, we still believe that it is worthwhile to analyze, for as closely matched parameter values as possible, whether the model gives rise to important quantitative implications for the variables of our main interest. Whenever possible, we try to use standard parameter values and follow the conventions in the literature in order to make our results comparable to those in other studies. The model is calibrated to match two large regions, the United States and Europe. For that reason, the moments of the actual data are the same as those reported by Chari, Kehoe and McGrattan (1998).

The following table reports our baseline parameterization and below we discuss how these parameters were determined.

parameter	value	comments
β	$1/(1.04)^{1/4}$	Based on 4 percent annual real interest rate
δ	2.5 percent	
g_M	$1.06^{1/4}$	Based on 6 percent growth in M1 per annum
σ	3	
κ	6	
s_g	0.2	Steady state output share of gov. spend.
θ	-1.59	Interest rate elasticity of money demand
γ	0.961	Matches ratio of M1 to nominal consumption
τ	10.5 percent	
$a_1(2)/a_1(1)$	0.5	
ρ	1.45	
$\omega_1(1)$	0.79	
$\omega_1(2)$	0.21	
χ	2.15	

We set the real interest rate equal to 4 percent annually and assume that capital depreciates at a rate of 2.5 percent per quarter. We use the standard parameter values for α and set this parameter equal to 0.60. Along with Chari, Kehoe and McGrattan (1998) assume that the $\varkappa = 6$ while we use a lower value than these authors for σ which we set equal to 3.

Recall that the model gives rise to the following money demand function:

$$\frac{M_{1t}}{Q_{1t}} = \left(\frac{\gamma}{1-\gamma}\right)^{1/(\theta-1)} \frac{c_{1t}}{(1-R_t)^{1/(1-\theta)}}$$

where $R_t = \sum_{s^{t+1}} R\left(s^{t+1}|s^t\right)$ is the unconditional nominal discount rate, i.e. $1/\left(1+R_t^{nom}\right)$ where R_t^{nom} is the nominal interest rate which in the steady state is equal to $(1+R)\, g_M$ (R is the steady state real interest rate and g_M is the mean growth rate of $M1$). We follow the calibration of Chari, Kehoe and McGrattan (1998) and set $\theta = -1.59$ which is based on matching the interest rate elasticity of real US money demand. We set the mean nominal money supply growth rate equal to 6% per annum. Assuming that the ratio of money supply to nominal consumption is equal to 1.2 (the mean ratio for the US) implies that $\gamma = 0.961$.[13]

We choose to formulate the model as a two-sector economy which makes the computation considerably easier. The two sector model reflects the main aspects of the many-sector model given that we restrict ourselves to the case where the duopoly outcome is realized for all sectors of the economy. Thus, we will assume that this is the case so that the inequalities in $(21)-(22)$ hold.

We set the steady state share of nominal imports (or exports) to nominal GDP is equal to 10.5 percent. Trade shares for the US have been trending significantly upwards in the post war period. For example, in the period 1946-2000, the ratio of imports to GDP has risen from 3.1 percent to 14.6 percent. For that reason, we use the mean of the import share for the period 1974.1-2000.2. Furthermore, we base the parameter on total foreign trade in order not to downward bias the estimate on the openness of the economy.[14]

We assume that transportation costs are equal to 25 percent. This is a quite high estimate but is based on a number of considerations. Harrigan (1993) estimates the average transportation costs to around 20 percent using IMF data. Ravn and Mazzenga (1999) look at the average transportation costs for 4 digit US bilateral import data and finds these to equal to approximately equal to 10 percent. However, as stressed by Hummels (1999) this estimate probably suffers from a negative bias and the "true" costs of transportation might be quite a lot higher. Furthermore, actual transactions costs are higher due to tariffs and red taping. For these reasons, we choose the rather higher estimate of 25 percent transportation costs, but we examine the sensitivity of the results to this number.

We know of no direct estimates of the elasticity of substitution , ρ, this parameter in terms of the model as specified in this paper. We calibrate this parameter so that it is consistent with empirical estimates of the ratio of price to marginal costs. Domowitz, Hubbard and Petersen (1988) estimates the ratio to be between 1.4 and 1.7 while Morrison (1990) finds it to be between 1.2 and 1.4. We use an estimate of 1.7 which is in the higher end of the empirical evidence but again look at the sensitivity of the results to this parameter.

Harrigan (1999) estimates sectorial TFP levels for a cross-section of OECD countries. In principle we might be able to use these for the calibration of the relative productivities. However, those of his estimates that relates the closest to the parameters that we are interested in are based on the assumption that prices equal marginal costs which is contrary to our assumptions. For that reason, we use a more pragmatic approach and look at the outcomes for different values of the relative productivity levels. In our baseline case we assume that the productivity of sector 2 in country 1 is equal to 50 percent of the productivity level in sector 1.

Given these assumptions we obtain the estimates for the preference parameters, steady state prices, and steady state activity levels for the various sectors of the economy. The implied elasticity of substitution is equal to 1.55, and the implied preference weights are $\omega_1(1) = \omega_2(2) =$

[13]In other words, $\gamma = (1.2)^{-2.59} / \left(1 - 1/R^{nom} + (1.2)^{-2.59}\right)$ where $R^{nom} = (1.06 * 1.04)^{.25}$.

[14]This number is considerably higher than the estimate used by Chari, Kehoe and McGrattan (1998) who set this value equal to 1.6 percent. Their estimate is based on the GDP share of US trade with Europe.

0.79 and $\omega_1(2) = \omega_2(1) = 0.21$.[15] We find that $p_1(1)/p_1(2) = p_1(1)/(ep_2(1)) = 1.10$ so that the LOP violation is equal to 10 percent, a price difference that is considerably smaller than the transportation cost so that there are no arbitrage opportunities.[16]

This leaves us only to calibrate the preference weight χ. Combining the first order conditions for the choice of leisure, money and consumption yields the following condition:

$$\chi (1-n)^{-\kappa} = \vartheta c^{-\sigma} w$$

where $\vartheta = \gamma \left(\gamma + (1-\gamma) \left(\left(\frac{\gamma}{1-\gamma} \right)^{1/(\theta-1)} (1-R)^{1/(\theta-1)} \right)^{\theta} \right)^{(1-\sigma-\theta)/\theta}$. Combining this condition with the labor market clearing condition gives us that $\chi = 2.15$.

We assume that government spending takes up 20 percent of steady-state output and that shocks to this process are unrelated across countries, that their persistence is equal to 0.95, and that their standard deviation is equal to 2 percent of the steady-state value of government spending. We follow Chari, Kehoe and McGrattan's (1998) calibration and assume that money growth rate shocks are independent across countries as well. We set the first order autoregressive parameter equal to 0.57 and the standard deviation of the innovations is equal to 0.92 percent. The calibration of the technology shocks is more problematic. The problem is that existing estimates are based on one-sector models and on prices equal to marginal costs. In particular, Backus, Kehoe and Kydland (1992) estimate for the US-Europe case that:

$$B_{\varrho} = \begin{bmatrix} 0.906 & 0.08 \\ 0.088 & 0.906 \end{bmatrix}$$

and that the standard deviation of ε^{ϱ} is equal to 0.852 percent while correlation between these innovations across countries is equal to 0.258. The problem here is that because prices are different from marginal costs, the Solow residuals do not correspond to the technology shocks. However, we will still use this specification.[17]

5 Quantitative Results

In this section we will look at the quantitative implications of the model. We will first discuss the results from the baseline calibration of the model and then look at a sensitivity analysis.

5.1 The Baseline Model - Impulse Response Analyses

It is useful to start with an examination of the reaction of the variables of the economy to the structural shocks. We show the effect on the money stock (in the case of an increase in the

[15]In principle, we can also assume that there is no preference for home goods thereby doing away with preference differences as suggested by Helpman (1998). In this case, however, we need an extra degree of freedom to match the parameters that we are interested in.

[16]In the steady state, sector 1 accounts for 94.5 percent of total activity, for 80.3 percent of total exports, and for 89 percent of total factor inputs. Thus, each country is close to being specialized. These results, however, are sensitive to the parametrization. For example, raising the export share to 20 percent, doubles the size of sector 2. However, we will look into these sensitivity results later on.

[17]The endogeneity problem will in general give rise to a bias in the estimates since part of the movement in the Solow residuals are due to movements in aggregate demand. In principle we could apply a technique similar to Hornstein (1993) and Rotemberg and Woodford (1995) and adjust the variance of the technology shocks so as to match the standard deviation of the measured Solow residuals and the Solow residuals implied by the model.

money growth rate), the domestic price level, the foreign price level measured in the domestic currency, the nominal and the real exchange rate, and on a number of real variables. The real variables are consumption, hours, and real output. Before proceeding, we need to define real output. We define real output as:

$$y_{it} = \sum_{s=1}^{2} \left(p_i(s) x_{it}^i(s) + e p_j(s) x_{jt}^i(s) \right)$$

where $p_i(z)$ denotes the steady-state price of good z sold in country i. The nominal variables, the money stock, prices, and the nominal exchange rate, are shown relative to their level in the absence of any shocks to the economy. Real variables are shown as percentage deviations from their steady-state level.

First, we look at the impact of an increase in the growth rate of domestic money supply. The results are shown in Figure 4. An increase in the domestic money supply growth rate increases domestic output while leaving foreign output almost unchanged. It also increases domestic hours worked (and, not shown) domestic investment. Furthermore, the effects on output and hours are quite large. To understand this, it is useful to recall that because of the imperfectly competitive goods markets, real factor rental rates do not equal marginal products. Furthermore, the elasticity of prices to marginal costs is less than one (since the price is related to a constant times the average of the suppliers marginal costs). In other words, the mark-up of prices over marginal costs is negatively related to the level of the marginal costs. This countercyclical behavior of marginal costs implies that the effects of demand shocks are amplified relatively to what would occur under perfect competition (see e.g. Rotemberg and Woodford, 1995, for a discussion of this in a dynamic monopolistic competition set-up).[18]

The increase in domestic hours and output give rise to increases in domestic consumption and investment. Foreign consumption, however, decreases. From the risk sharing condition, we see that the differential response of domestic and foreign consumption can only come about due to fluctuations in the real exchange rate. Since relative domestic consumption rises, the domestic real exchange rate must depreciate. We see from the lower two diagrams that both domestic and foreign prices rise in response to the increase in the domestic money supply. Measured in the domestic currency, foreign prices, however, increases more than domestic prices and there is a real depreciation and nominal of the domestic currency. The reason for this is that - due to the transactions costs - the elasticity of foreign prices wrt. domestic marginal costs is higher than the same elasticity of domestic prices.

It is useful to contrast these implications with the local currency pricing literature. In that literature, similar implications derive for real and nominal exchange rates and for real variables. There, however, the results are due to sticky prices: An increase in nominal money supply leads to a nominal exchange rate depreciation and, since local currency prices are sticky, to a real depreciation of the currency. This leads to the same divergence of consumption levels as what we derived above and to even more pronounced output and investment comovements. In the present model prices are fully flexible but the oligopolistic market structure and the transactions costs interact to create similar implications as in the local currency pricing models. One important

[18] In a sense, the "static" oligopolistic framework applied in the present paper gives rise to similar effects to the supergame theoretic based model of Rotemberg and Woodford (1992) in that the mark-up is countercyclical. The reason, however, is that in our case, when money has real effects, the firms are subject to asymmetric marginal costs shocks. In Rotemberg and Woodford (1992) the countercyclical mark-up works as a deterrent for deviating from the co-operative solution for members of a dynamic cartel since it lowers the profit from single handedly lowering prices in times of high demand.

difference is that prices are quite volatile in the present model. More fundamentally, we derive these results without assuming that marginal cost variations cannot be passed on to consumers. In other words, in the present model, the traded goods price variations are due to what we (with some mis-use of terminology) might phrase "optimal LOP violations" whereas these violations are sub-optimal in the local currency pricing literature.

In the present model, the initial impact on output is around 0.45 percent of its steady-state value while the effect on the real exchange rate is around 1.2 percent. Thus, if money shocks accounted for all the output variability, the real exchange rate would fluctuate around 2-3 times more than output. This is not far from what can be observed in the data. However, as far as the absolute variability is concerned, the picture might look less promising since we have yet to answer the amount of output variability that the model generates. This will be analyzed in detail below. Nevertheless, in terms of the relative variability, the model does seem to perform quite well in spite of the fact that we clearly have neglected important phenomena such as sticky prices and wages. This being said, the impulse responses also point towards a major problem: The persistence of the exchange rate movements appears to be quite low: One year after the increase in the money growth rate, the real exchange rate has approximately returned to its long run steady-state level. This might indicate that nominal rigidities are needed even in this set-up if we are to be able to successfully account for the persistence of the real exchange rate.

Figure 5 shows the impact one the economy following a domestic technology shock of 1 percent. Following the increase in domestic productivity, which gradually spills-over to the foreign economy, domestic output rises while real foreign output decreases. This pattern persists over the four year horizon that we look at, but most effects have worn out three years after the shock. Interestingly, the increase in output is smaller than 1 percent on impact which implies that domestic hours decrease, an implication that is confirmed in the second panel of the figure. This is in contrast to standard models based on price taking behavior in which output rises more than productivity because of intertemporal substitution in labor supply (and, over time, due to capital accumulation). This diminished output effect is due to the combination of a number of factors. First, the price elasticity of demand is relatively low in the baseline parametrization. This implies that although the rise in productivity leads to a decrease in prices, the associated demand effect is small. Furthermore, the elasticity of prices wrt. the decrease in marginal costs is smaller than one dampening further the effects of technology shocks.[19] Another implication of this is that productivity shocks are likely to be less dominating in this framework than in standard competitive models such as Backus, Kehoe and Kydland (1992, 1993) or Ravn (1997).

The second diagram shows that consumption increases very smoothly and persistently after the increase in domestic productivity. In contrast to the other variables of the economy, the effect on consumption 4 years after the shock are still large relatively to the initial impact. This smooth and persistent effect is due to, first, the relatively low intertemporal elasticity of substitution. Secondly, it is caused by the lack of impact on the real exchange rate. We see from the last two diagrams that, as expected, prices at home and abroad decrease in response to the productivity shock. Foreign prices, measured in the domestic currency, fall marginally more than domestic prices, but the difference is very small. In other words, although the currency is subject to a real and a nominal appreciation, the real exchange rate is hardly affected and the initial appreciation is around 0.06 percent. This has the implication that domestic and foreign agents are able to share almost perfectly the risk of technology shocks and we see that domestic and foreign consumption rises almost exactly by the same amount. This perfect risk sharing

[19] Finally, the decrease in hours is partially due to the assumption made on preferences. For standard non-separable preferences, hours decrease less.

implication is partially due to the separability between consumption and leisure that we have assumed, but allowing for non-separabilities does not change this implication significantly: It is mainly due to the lack of impact on real exchange rates.

In summary, technology shocks that in standard competitive models have large real effects have much smaller real effects in this economy and imply countercyclical fluctuations in hours and lack of real exchange rate movements as well as to very counterfactual cross-country comovements in output components.

Finally, Figure 6 shows the response of the economy to a 1 percent increase in domestic government spending. This increase in government demand increases aggregate activity at home and abroad. The increase in domestic output is larger than the increase in foreign output mainly because we have assumed a "taste for home-goods". The increase in output comes about through an increase in hours worked. The effects are, as discussed above, larger than in competitive frameworks due to the countercyclical variations in mark-ups. Recall that government spending accounts for 20 percent of steady-state output. In the present model, a one percent increase in government spending increases output on impact with around 0.14 percent. In competitive models, the corresponding output effect is around one third of this. Thus, the oligopolistic competition framework leads to an amplification of the real effects of changes in government spending.

The lower two diagrams show that domestic and foreign prices both increase after the increase in government spending. Again, since the elasticity of foreign prices wrt. domestic marginal costs is higher than the elasticity of domestic prices, foreign prices (measured in the domestic currency) rise more than domestic prices. Thus, the real exchange rate depreciates. There is also a small nominal depreciation of the currency. All the price effects, however, are very small. The effect on the real exchange rate is just above 0.01 percent and the effect on the nominal exchange rate is even smaller than this. The reason for this is the countercyclical movements in mark-ups coupled with the fact that the increase in government spending is financed through taxes rather than through money issues.

In sum, movements in real and nominal exchange rates are dominated by monetary shocks. Furthermore, such shocks lead to negative international comovements in consumption. Changes in country specific productivity levels and in government spending have limited effects on real and nominal exchange rates. Productivity shocks have also smaller real effects than in standard competitive models while the real effects of government spending are magnified.

5.2 The Baseline Model - Simulation Results

In order to look into the quantitative implications of the model we simulate it for a period of 150 quarters. We follow the business cycle literature and detrend the data using the Hodrick-Prescott filter. We conduct 100 experiments and report the average of the simulated moments over these 100 experiments. We report the results for the variables discussed above as well as for real exports and imports and the ratio of the trade balance to nominal output. We measure real exports and imports along the same lines as real output:

$$\begin{aligned} ex_{it} &= ep_j(1)\, x^i_{jt}(1) + ep_j(2)\, x^i_{jt}(2) \\ im_{it} &= p_i(1)\, x^j_{it}(1) + p_i(2)\, x^j_{it}(2) \end{aligned}$$

where ex_{it} denotes real exports and im_{it} denotes real imports. Net exports are then defined as:

$$
\begin{aligned}
nxy_{it} &= \frac{EX_{it} - IM_{it}}{Y_{it}} \\
Y_{it} &= \sum_{s=1}^{2} \left(p_{it}(s)\, x_{it}^{i}(s) + e_t p_{jt}(s)\, x_{jt}^{i}(s) \right) \\
EX_{it} &= e_t p_{jt}(1)\, x_{jt}^{i}(1) + e_t p_{jt}(2)\, x_{jt}^{i}(2) \\
IM_{it} &= p_{it}(1)\, x_{it}^{j}(1) + p_{it}(2)\, x_{it}^{j}(2)
\end{aligned}
$$

Before proceeding let us quickly summarize the properties of the actual data.[20] The standard deviation of Hodrick-Prescott filtered US quarterly real GDP is around 1.75 percent. The US-Europe real exchange rate has a standard deviation that is around 4.75 times higher than this (its absolute standard deviation is around 8.3 percent per quarter). Real and nominal exchange rates are both very persistent with first order autocorrelations close to 0.85. At this frequency nominal and real exchange rates are almost perfectly correlated, while the cross-correlation between real exchange rates and output is small but positive with a point estimate of 0.1. Consumption is slightly smoother than output in the US with a standard deviation of 80 percent of the standard deviation of output, while the corresponding number for investment, which is volatile, is 3.3. Both of these series are strongly procyclical with a correlation with output not far below 0.9. Employment has a standard deviation relative to output of 72 percent and are very procyclical. Across countries, output levels and employment are strongly positively correlated. Net exports are countercyclical in the US, and this is due to more procyclical behavior of imports than exports. At the quarterly frequency, the correlation between detrended US and European output is around 0.5 as is the correlation between US and European employment. Consumption and investment levels are less strongly related with correlation coefficients close to 0.25.

The results of the simulations of the model are reported in Tables 1 and 2. Table 1 gives the moments of the exchange rate movements while Table 2 reports the moments of output and its components. In each table we report the results from four different experiments. The first experiments sets the variance of technology shocks and government spending shocks equal to 0 and the only shocks to the economy relate to changes in the domestic and foreign money supply growth rates. The next experiment is similar but allows only for technology shocks. The third is associated with shocks to government spending. The last experiment allows for all three different types of shocks simultaneously.

When there are only monetary shocks, the implied output variability is 0.45 percent. The nominal exchange rate variability is 3.75 percent, or around 8 times more than output. The real exchange rate variability is 1.27 percent per quarter, i.e. 3 times more than output. The output variability is one fourth of the variability of US real GDP. Nominal exchange rates vary too much relative to output in the model economy while the relative real exchange rate variability is relatively close to what can be observed in the data. Thus, the model does quite well in generating extensive movements in relative prices but seems to imply too little absolute variability in output if money shocks were the only impulses to the economy.

The first order autocorrelation of the nominal exchange rate is 0.71 which is slightly below empirical estimates but not very far off the mark. Real exchange rates, however, are much smoother in the model than in the data: We find a first order autocorrelation of 0.43 which is around 50 percent of the persistence of the US-Europe real exchange rate. This probably

[20]These numbers are based on Chari, Kehoe and McGrattan's (!998) calculations.

indicates that nominal rigidities are a necessity if we want fully to account for the persistence and variability of real exchange rates. A further indication of this is that the model implies a too low short run correlation between real and nominal exchange rates. In the data, real and nominal exchange rates are close to perfectly correlated at the one quarter horizon. The model implies a correlation of 0.64 which is high yet below the empirical estimates.

These results, we believe, should be positively viewed. Our analysis abstracts from nominal rigidities which would increase the persistence and variability in relative price movements. What we have shown is that substantial real exchange rate volatility can be generated even in the absence of such rigidities. Introducing nominal rigidities, including sticky wages, would lead to higher persistence of real exchange rates and, possibly, also increase the real exchange rate volatility. These results should therefore not be taken to be interpreted that such rigidities are not important nor that they are not needed in order fully to account for the exchange rate movements. Rather they indicate that real rigidities re important as well.

Where the model is less successful is at accounting for the output components. Consumption is too smooth and investment too volatile relative to output in the model. The investment volatility is related to the value we have assumed for the capital adjustment costs. Increasing this parameter will lower investment volatility and increase, but only slightly so, consumption volatility. This comes, however, at the cost of lower output volatility.

However, an even greater problem is the implied behavior of exports and imports. Although the model implies a volatile and countercyclical trade balance just as can be observed in the data, the countercyclical behavior of the trade balance is caused by counterfactual comovements of these variables with output. In the data, both real exports and real imports are quite strongly procyclical but imports are more procyclical than exports thus leading to countercyclical movements in net foreign trade. In the model, the negative correlation between net-exports and output, in contrast, is due to a strong countercyclical behavior of exports.

As far as international comovements are concerned, the model implies that consumption levels are negatively related across countries, that output levels are almost unrelated, and strong positive comovements of hours worked. In a sense, this reverses the "output puzzle" of Backus, Kehoe and Kydland, (1995). The "output puzzle" which occurs in standard competitive models relate to the fact that in the data, output comovements are relatively strong as are employment comovements while consumption comovements are much weaker related across OECD countries. Standard competitive models, in contrast implies negative comovements of output and employment but almost perfect positive comovements of consumption due to risk sharing, see Ravn (1997) for an extensive analysis. Here, due to the movements in real exchange rates, consumption is negatively related and hours are positively related. The low real output correlation (in contrast to the positive comovement of hours) is due to a negative comovement of investment and due to changes in the sectorial composition. Nevertheless, as above, we think of these results as "successes" in the sense that the new aspects introduced here serve to move these correlations in the right direction, and in a sense they do it too well.

The column "T" reports the results from simulating the model setting all shocks but technology shocks equal to 0. This leads to an output variability of 0.49 percent. This is bigger than the effects of monetary shocks but much lower than the output variability implied by productivity shocks in competitive settings. As discussed above, the countercyclical movements in mark-ups that increase consumption variability also lowers the output variability and this is the main reason why this model implies such a low elasticity of output to changes in productivity. As we have already discussed such shocks leads to almost no variations in exchange rates. But on top of this, consumption is almost perfectly smoothed over time and perfectly correlated across countries. One reason for this is that we have assumed that utility is additively separable over consumption and leisure. Non-separabilities lower cross-country consumption correlations and increase the volatility of these fluctuations, so the extreme form of these phenomena in the present model is partially due to our assumptions on preferences.

Nevertheless, introducing non-separabilities do not fundamentally change these implications since another factor is the other main counterfactual implication of such shocks in the present setting: Acyclical movements in hours worked. This acyclicality arises, once, again due to the effects of the oligopolistic structure of the goods market.

But the model subjected to only technology shocks lead to a number of other counterfactual implications. For example investment is close to being acyclical and imports are countercyclical, implications that are both very counterfactual. On top of this the pattern of international comovements is completely at odds with the data. Thus, in this model, not only do technology shock not help much to account for relative price movements, but they also lead to very counterfactual movements in output and its components. What this might indicate is that the impact of imperfect competition is simply to strong as we have formulated it here. One way in which this might be accomplished would be to generalize the industrial structure along the lines that we derived in Section 3. There we showed that, in general, the model will give rise to a mixture of sectors in which each country becomes specialized and sectors in which intra-industry trade takes place. Allowing for this more general industrial structure could potentially be important because sectors in which countries specialize would be more affected by technology shocks than intra-industry trade sectors. The reason is that, in the specialized sectors, firms would not be pricing to markets and mark-ups would be constant. However, we leave this issue for future research.

The next column reports the results for the case where only government spending shocks are allowed for. If there were only these types of shocks, the standard deviation of output would be equal to 0.38 percent. This implied variability of output is much higher than in standard competitive models for reasons already discussed. As in the case of technology shocks, however, the relative price effects are very limited. The reason is simply that these shocks work indirectly to change marginal costs and these indirect effects are very limited. For the same reason, although consumption decreases following an increase in government spending as in standard models, the crowding out of consumption is limited and countries are able to insure well against these shocks leading to low impacts on consumption and high correlations across countries.

The more interesting experiment is where we allow for all three different types of shocks simultaneously as reported in the last column. This generate a standard deviation of output of around 0.79 percent per quarter, or approximately half of what can be observed for the US economy. The moments of the exchange rate movements are very similar to those for the case where there are only monetary shocks since these are the shocks that have much the biggest impact on relative prices. Thus, the standard deviation of the real exchange rate is close to 1.3 percent per quarter or around 60 percent higher than the output volatility. The autocorrelation of the real exchange rate remains at around 40 percent and the correlation of real and nominal exchange rates at just above 60 percent. Both the persistence and the variability of the real exchange rate are substantially lower than what we observe in the data, but this is not very surprising given the lack of nominal rigidities and other transmission mechanisms that lead to more substantial and long-lived effects of monetary disturbances. We think that it is interesting that this model which excludes all these aspect can still account for considerable relative price movements.

The movements in the output components also reveal that, perhaps, the effects of imperfect competition are too strong in this economy. In particular, while competitive models can successfully account for the procyclical movements in consumption, exports and imports, the present model implies countercyclical movements in the latter two variables and almost acyclical movements in consumption. The lack of procyclical movements in consumption is due to the strong effects of productivity shocks combined with the strong risk sharing effect in response to such shocks.

However, the model does provide a better, although imperfect, fit to the international comovements that standard competitive models. In particular, although the international consumption correlation is still high it is substantially below unity, and hours comovements are (too) large and positive in contrast to the negative comovements that competitive models give rise to.

In sum, the model does leave substantial room for improvement, but we do not regard this necessarily as neither very surprising nor as very disappointing. We have on purpose abstracted from a number of aspects that without much doubt would improve the performance of the model and we have investigated how imperfect competition by itself affects the movements in relative prices and fluctuations in main macroeconomic aggregates. The results seem to indicate that two amendments are needed. First, we disregarded any nominal rigidities such as nominal wage contracts as in Obstfeld and Rogoff (1999) or sticky prices as in the local currency pricing literature or other mechanisms that leads to transmissions of nominal rigidities. Secondly, the model provides too strong effects of imperfect competition and generalizing the industrial structure which would work to re-instate some of the standard effects of real shocks to the economy.

6 Summary and Conclusions

In this paper we have constructed an international business cycle model with an oligopolistic market structure. Our aim was to investigate the extent to which this leads to deviations from the law of one price and the effects on real exchange rates and main macroeconomic aggregates. In contrast to most other papers in the international business cycle literature, the framework that we have proposed does not rely on sub-optimal imperfect pass-through due to e.g. (usually un-modeled) nominal price rigidities. We looked at the way in which the economy leads to a mixture of specialization and intra-industry trade and the effects on pricing across markets. In the general case, the model has quite rich implications for production and pricing-to-markets but we limited ourselves to the investigation of a special case - where all industries are characterized by intra-industry trade - in the quantitative investigation. Although this analysis indicated that this framework cannot account for all of the observed real exchange rate movements nor for key moments of the fluctuations in real macroeconomic aggregates, we think that it is interesting that the oligopolistic market structure by itself does seem to provide at least some potential for accounting for the movements in real exchange rates.

Clearly, the model leaves ample room for improvement and we will look at such in future research. In particular we think that it would be interesting to generalize the model along two main lines. First, we would like to allow for a more general industrial structure. Secondly, we would like to introduce some nominal rigidities or other aspects that lead to a propagation of nominal disturbances over time. One possibility would be to allow for customer-market effects as in Krugman (1987) or Froot and Klemperer (1989). Another possibility would be to introduce product differentiation as in the international trade literature. We believe that extensions along these lines would leave to richer insights and this will be pursued in future research.

7 Appendix

We can formulate the households' problems as:

$$\begin{aligned} & V_i\left(k_i\left(s^{t-1}\right), B_i\left(s^t\right), M_i\left(s^t\right), s^t\right) \\ = & \max\left(u_i\left(c_i\left(s^t\right), M_i\left(s^t\right)/Q_i\left(s^t\right), n_i\left(s^t\right)\right) + \beta \sum_{s^{t+1}} \pi\left(s^{t+1}|s^t\right) V_i\left(k_i\left(s^t\right), B_i\left(s^{t+1}\right), M_i\left(s^{t+1}\right), s^{t+1}\right)\right) \end{aligned}$$

subject to the budget constraint and the capital accumulation constraint. Using the envelope conditions and re-arranging, gives us the following set of first order conditions:

$$\gamma\left(c_i\left(s^t\right)\right)^{\theta-1}\left(\gamma c_i\left(s^t\right)^\theta + (1-\gamma)\left(M_i\left(s^t\right)/Q_i\left(s^t\right)\right)^\theta\right)^{(1-\sigma)/\theta-1} = \psi_i\left(s^t\right) Q_i\left(s^t\right)$$

which equalizes the marginal utility of consumption (the left hand side) with the shadow prices of consumption (the right hand side). The shadow price is composed of the nominal price and the multiplier on the budget constraint, $\psi_i\left(s^t\right)$. The condition for labor supply is:

$$\chi\left(1-n_i\left(s^t\right)\right)^{-\kappa} = \psi_i\left(s^t\right) Q_i\left(s^t\right) w_i\left(s^t\right)$$

which equalizes the marginal dis-utility of work with the nominal wage evaluated at its shadow price. The investment condition is:

$$\psi_i\left(s^t\right) Q_i\left(s^t\right) = \xi_i\left(s^t\right) \phi'\left(x_i\left(s^t\right)/k_i\left(s^{t-1}\right)\right)$$

where the left hand side is the shadow price of investment. The right hand side includes the marginal effect on the capital stock and the multiplier on the capital accumulation equation, $\xi_i\left(s^t\right)$. The condition for capital accumulation is given by:

$$\begin{aligned} \xi_i\left(s^t\right) = & \beta \sum_{s^{t+1}} \pi\left(s^{t+1}|s^t\right) \xi_i\left(s^{t+1}\right) [(1-\delta) + \phi\left(x_i\left(s^{t+1}\right)/k_i\left(s^t\right)\right) \\ & -\phi'\left(x_i\left(s^{t+1}\right)/k_i\left(s^t\right)\right) \frac{x_i\left(s^{t+1}\right)}{k_i\left(s^t\right)}] \\ & +\beta \sum_{s^{t+1}} \pi\left(s^{t+1}|s^t\right) \psi_i\left(s^{t+1}\right) Q_i\left(s^{t+1}\right) r_i\left(s^{t+1}\right) \end{aligned}$$

Here the left hand side is the price of this expression is the cost of acquiring one unit of capital today which we see from the preceding expression is equal to $\psi_i\left(s^t\right) Q_i\left(s^t\right)/\phi'\left(x_i\left(s^t\right)/k_i\left(s^{t-1}\right)\right)$. The right hand side is the sum of two terms. The first term is the net addition to tomorrows capital stock which includes two components, the capital that is left after depreciation (given by $1-\delta$), and the savings in capital adjustment costs (or the capital gain), the difference between $\phi\left(x_i\left(s^{t+1}\right)/k_i\left(s^t\right)\right)$ and $\phi'\left(x_i\left(s^{t+1}\right)/k_i\left(s^t\right)\right)\frac{x_i\left(s^{t+1}\right)}{k_i\left(s^t\right)}$. These terms are all evaluated at their expected shadow value tomorrow discounted at the rate of β. Finally, the capital stock also gives a direct nominal return of $Q_i\left(s^{t+1}\right) r_i\left(s^{t+1}\right)$ which is evaluated at its expected shadow price and discounted by β. The first order condition for nominal money holdings is given by:

$$\begin{aligned} & \frac{(1-\gamma)}{Q_i\left(s^t\right)}\left(M_i\left(s^t\right)/Q_i\left(s^t\right)\right)^{\theta-1}\left(\gamma c_i\left(s^t\right)^\theta + (1-\gamma)\left(M_i\left(s^t\right)/Q_i\left(s^t\right)\right)^\theta\right)^{(1-\sigma)/\theta-1} \\ = & \psi_i\left(s^t\right) - \beta \sum_{s^{t+1}} \pi\left(s^{t+1}|s^t\right) \psi_i\left(s^{t+1}\right) \end{aligned}$$

where the left hand side is the marginal utility of real money balances, and the right hand side is the expected costs of real money holdings which is given by the difference between today's shadow price of money and its discounted expected future price. Finally, the conditions for bond purchases are given by:

$$\begin{aligned}\psi_1\left(s^t\right)R\left(s^{t+1}|s^t\right) &= \beta\pi\left(s^{t+1}|s^t\right)\psi_1\left(s^{t+1}\right)\\ \psi_2\left(s^t\right)R\left(s^{t+1}|s^t\right)/e\left(s^t\right) &= \beta\pi\left(s^{t+1}|s^t\right)\psi_1\left(s^{t+1}\right)/e\left(s^{t+1}\right)\end{aligned}$$

The first of these is the condition for domestic households. This condition sets the price of bonds today, evaluated at its shadow value, equal to the expected return tomorrow, discounted by β and evaluated at its shadow price. The second condition is for foreigners' bond purchases which differs only from the condition for domestic agents in that the nominal return of the bonds is denominated in the domestic currency.

References

[1] Armington, P., 1969, "A Theory of Demand for Products Distinguished by Place of Production", *IMF Staff Papers*, vol.27, 488-526.

[2] Backus, David K., Patrick J. Kehoe and Finn E. Kydland, 1992, "International Real Business Cycles", *Journal of Political Economy*, vol.101, 745-775.

[3] Backus, David K., Patrick J. Kehoe and Finn E. Kydland, 1994, "Dynamics of the Trade Balance and the Terms of Trade: The J-Curve?", *American Economic Review*, vol.84, 84-103.

[4] Baldwin, 1988, "Hysteresis in Import Prices: the Beachhead Effect", *American Economic Review*, 78.

[5] Baldwin, Richard, and Paul Krugman, 1989, "Persistent Trade Effects of Large Exchange Rate Shocks", *Quarterly Journal of Economics*, 104(4), 635-54.

[6] Betts, Caroline, and Michael Devereux, 1996, "The Exchange Rate in a Model of Pricing-to-Markets", *European Economic Review*, 40, 1007-22.

[7] Betts, Caroline, and Michael Devereux, 2000, "Exchange Rate Dynamics in a Model of Pricing to Markets", *Journal of International Economics* vol.50, 215-44.

[8] Chari, V., Patrick Kehoe, P. and Ellen McGrattan, 1998, Monetary Shocks and Real Exchange Rates in Sticky Price Models of the International Business Cycle, Fed of Minneapolis, Staff Report 223.

[9] Devereux, Michael B., and Charles Engel, 1998, "Fixed vs. Floating Exchange Rates: How Price Setting Affects the Optimal Exchange-Rate Regime", NBER working paper no.6867.

[10] Dixit, Avinash, 1989, "Hysteresis, Import Penetration, and Exchange Rate Pass-Through", *Quarterly Journal of Economics*, 104, 205-28.

[11] Dollar, D. and E.N. Wolff, 1993, "**Competitiveness, Convergence and International Specialization"**, MIT Press: Cambridge, MA.

[12] Dornbusch, Rudiger, 1987, "Exchange Rates and Prices", *American Economic Review*,77, 93-106.

[13] Engel, Charles, 1999, "Accounting for U.S. Real Exchange Rates", *Journal of Political Economy*, 107(3), 507-38.

[14] Engel, Charles, 2000, "Optimal Exchange Rate Policy: The Influence of Price Setting and Asset Markets", manuscript, University of Washington.

[15] Engel, Charles, and John Rogers, 1996, "How Wide is the Border?", *American Economic Review*, 86(5),

[16] Feenstra, Robert, 1989, "Symmetric Pass-Through of Tariffs and Exchange Rates under Imperfect Competition: An Empirical Test", *Journal of International Economics*, 27, 25-45.

[17] Froot, Kenneth a., and Paul D. Klemperer, 1989, "Exchange Rate Pass-Through When Market Share Matters", *American Economic Review*, 79(4), 637-54.

[18] Froot, Kenneth A., and Kenneth Rogoff, 1995, "Perspectives on PPP and Long Run Real Exchange Rates", in: Gene M. Grossman and Kenneth Rogoff (eds.), **Handbook of International Economics**, vol.3, Amsterdam: North Holland.

[19] Goldberg, Pinelopi K., 1995, "Product Differentiation and Oligopoly in International Markets: the Case of the US automobile Industry", *Econometrica*, 63, 891-951.

[20] Goldberg, Pinelopi K., and Michael M. Knetter, 1999, "Measuring the Intensity of Competition in Export Markets", *Journal of International Economics*, 47, 27-60.

[21] Harrigan, James, 1993, "OECD Imports and Trade Barriers in 1983", *Journal of International Economics*, vol.35, no.1-2, 91-111.

[22] Harrigan, 1997, "Technology, Factor Supplies and International Specialization: Estimating the Neoclassical Model", *American Economic Review*, 87, 475-94.

[23] Harrigan, James, 1999, "Estimation of Cross-Country Differences in Production Functions", *Journal of International Economics*, vol.47, pp. 267-93.

[24] Harrison, A., 1993, "Imperfect Explanations for Imperfect Pass-Through: Market Power and Exchange Rates in the US Steel Industry", manuscript.

[25] Helpman, Elhanan, 1998, "The Structure of Foreign Trade", NBER working paper no.6752.

[26] Hens, Thorsten, Eckart Jäger, Alan Kirman, and Louis Phlips, 1999, "Exchange Rates and Duopoly", *European Economic Review*, 43, 621-48.

[27] Hornstein, Andreas, 1993, "Monopolistic Competition, Increasing Returns to Scale, and the Importance of Technology Shocks", *Journal of Monetary Economics*, vol.31. 299-316.

[28] Hummels, David, 1998, "Toward a Geography of Trade Costs", manuscript, University of Chicago.

[29] Hummels, David, 1999, "Transport Costs and the Growth of World Trade", manuscript, University of Chicago.

[30] Kasa, Kenneth, 1992, "Adjustment Costs and Pricing-to-Markets: Theory and Evidence", *Journal of International Economics*, 32(1/2), 1-27.

[31] Kehoe, Patrick J., and Fabrizio Perri, 1999, "International Business Cycles with Endogenous Imperfect Markets", working paper, Research Department, Federal Reserve Bank of Minneapolis.

[32] Kirman, Alan, and Nathalie Schueller, 1990, "Price Leadership and Discrimination in the European Car Market", *Journal of Industrial Economics*, XXXIX, 69-91.

[33] Knetter, Michael M, 1993, "Price Discrimination by US and German Exporters", *American Economic Review*, 83, 473-86.

[34] Kollmann, Robert, 1995, "Consumption, Real Exchange Rates, and the Structure of International Capital Markets", *Journal of International Money and Finance,* 14, 191-211.

[35] Kollmann, Robert, 1996, "The Exchange Rate in a Dynamic Optimizing Current Account Model with Nominal Rigidities", CentER Discussion Paper no.9667.

[36] Kravis, Irving, and Richard Lipsey, 1977, "Export Prices and the Transmission of Inflation", *American Economic Review*, 67(1), 155-63.

[37] Krugman, Paul, 1987, "Pricing to Markets when the Exchange Rate Changes", in: Arndt, S.W., Richardson, J.D. (eds.): Real Financial Linkages in Open Economies, MIT Press: Cambridge.

[38] Lane, Philip R., 1999, "The New Open Economy Macroeconomics: A Survey", CEPR Discussion Paper no. 2115.

[39] Marston, Richard, 1990, "Pricing to Market in Japanese Manufacturing", *Journal of International Economics*, 29, 217-36.

[40] Obstfeld, Maurice and Kenneth Rogoff, 1995, "Exchange Rate Dynamics Redux", *Journal of Political Economy*, 103, 624-40.

[41] Obstfeld, Maurice and Kenneth Rogoff, 1999, "New Directions for Stochastic Open Economy Models", NBER working paper no. 7313.

[42] Obstfeld, Maurice and Kenneth Rogoff, 2000, "The Six Major Puzzles in International Macroeconomics: Is There a Common Cause?", NBER working paper no.7777.

[43] Ravn, Morten O., 1997, "International Business Cycles in Theory and in Practise", *Journal of International Money and Finance*, vol. 16 (2), 255-83.

[44] Ravn, Morten O., 2000a, "Consumption Dynamics and Real Exchange Rates", working paper, London Business School.

[45] Ravn, Morten O., 2000b, "International Business Cycles in a Dynamic Ricardian Model: Specialization and Relative Price Determination", working paper, London Business School.

[46] Ravn, Morten O., and Elisabetta Mazzenga, 1999, "Frictions in International Trade and Relative Price Movements", working paper, London Business School.

[47] Rotemberg, Julio J. and Michael Woodford, 1992, "Oligopolistic Pricing and the Effects of Aggregate Demand on Economic Activity", *Journal of Political Economy* 100(6), 1153-1207.

[48] Rotemberg, Julio J., and Michael Woodford, 1995, "Dynamic General Equilibrium Models with Imperfectly Competitive Product Markets", chapter 9 in Thomas F. Cooley (ed.), **Frontiers of Business Cycle Research**, Princeton University Press: New Jersey.

[49] Trefler, D., 1993, "International Factor Price Differences: Leontief was Right!", *Journal of Political Economy*, vol.101, 961-87.

[50] Trefler, D., 1995, "The Case of Missing Trade and Other Mysteries", *American Economic Review*, vol.85, 1029-46.

[51] Verboven, F., 1996, "International Price Discrimination in the European Car Market", *Rand Journal of Economics*, 27(2), 240-68.

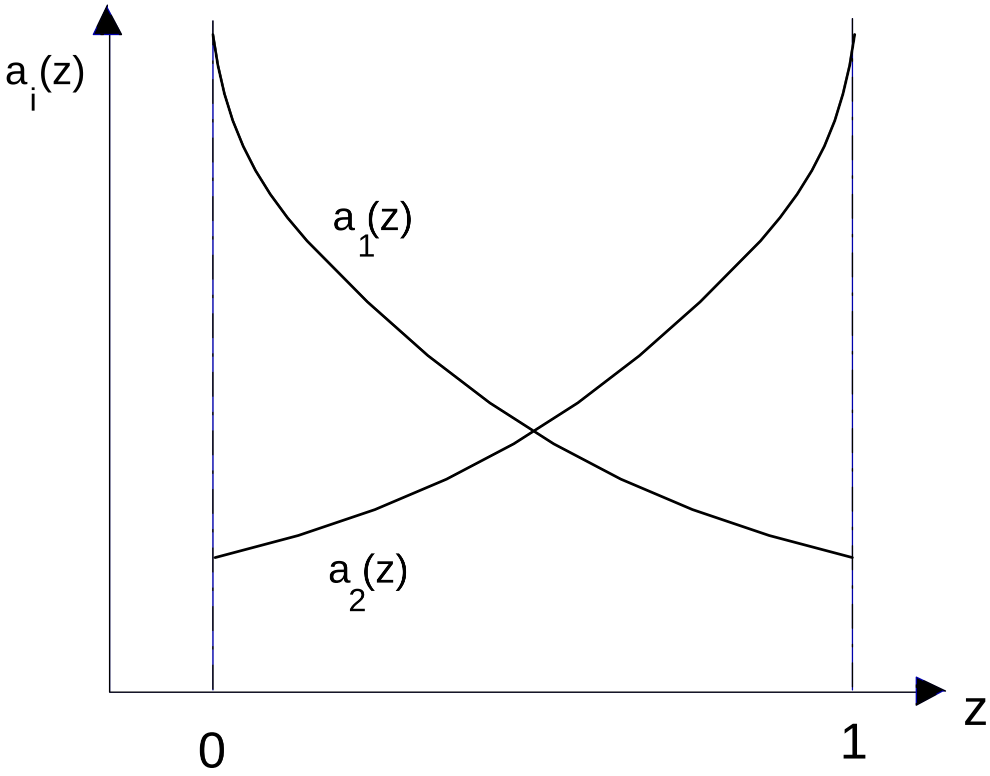

Figure 1. The Sector Specific Productivities in the Two Countries

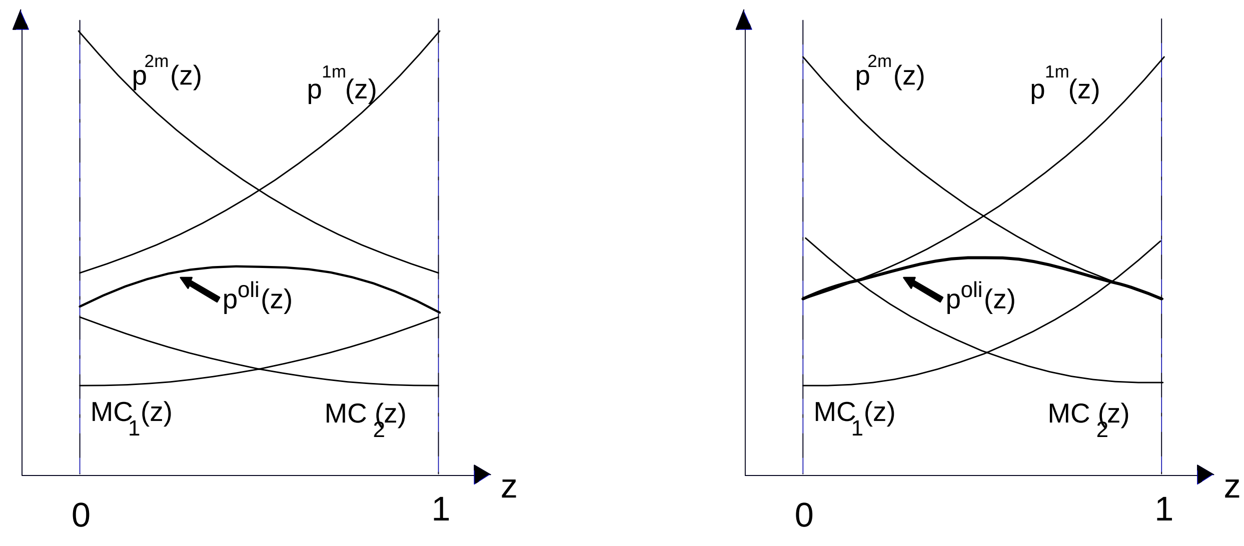

Figure 2. Equilibrium Oligopoly Price Schedules Small and Large Cost Differences

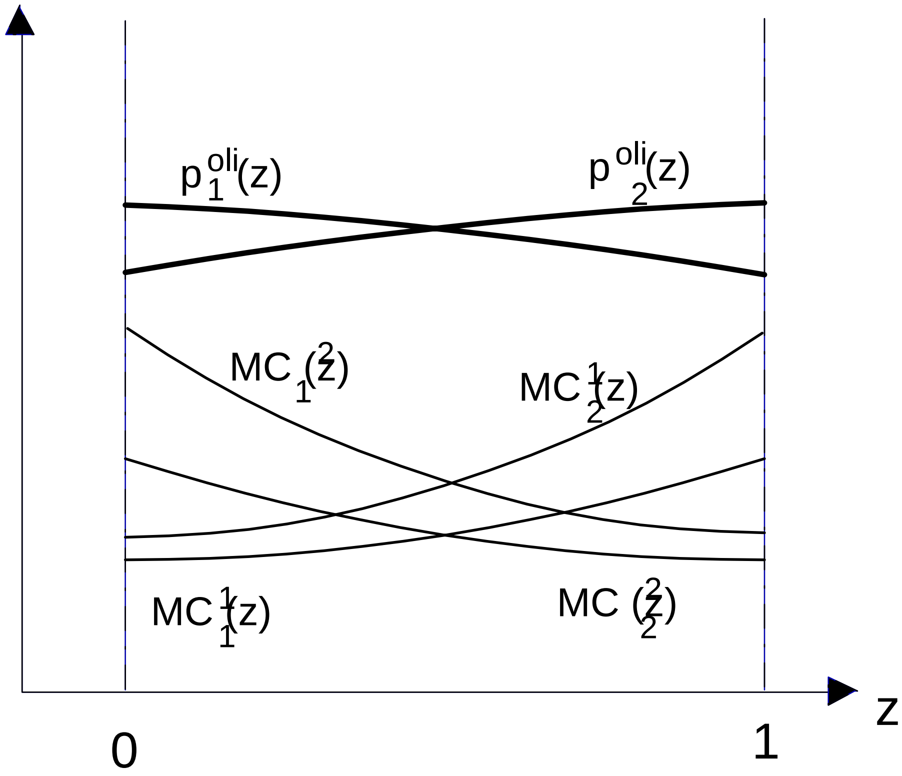

Figure 3. Oligopoly Pricing Schedules When Trade is Costly

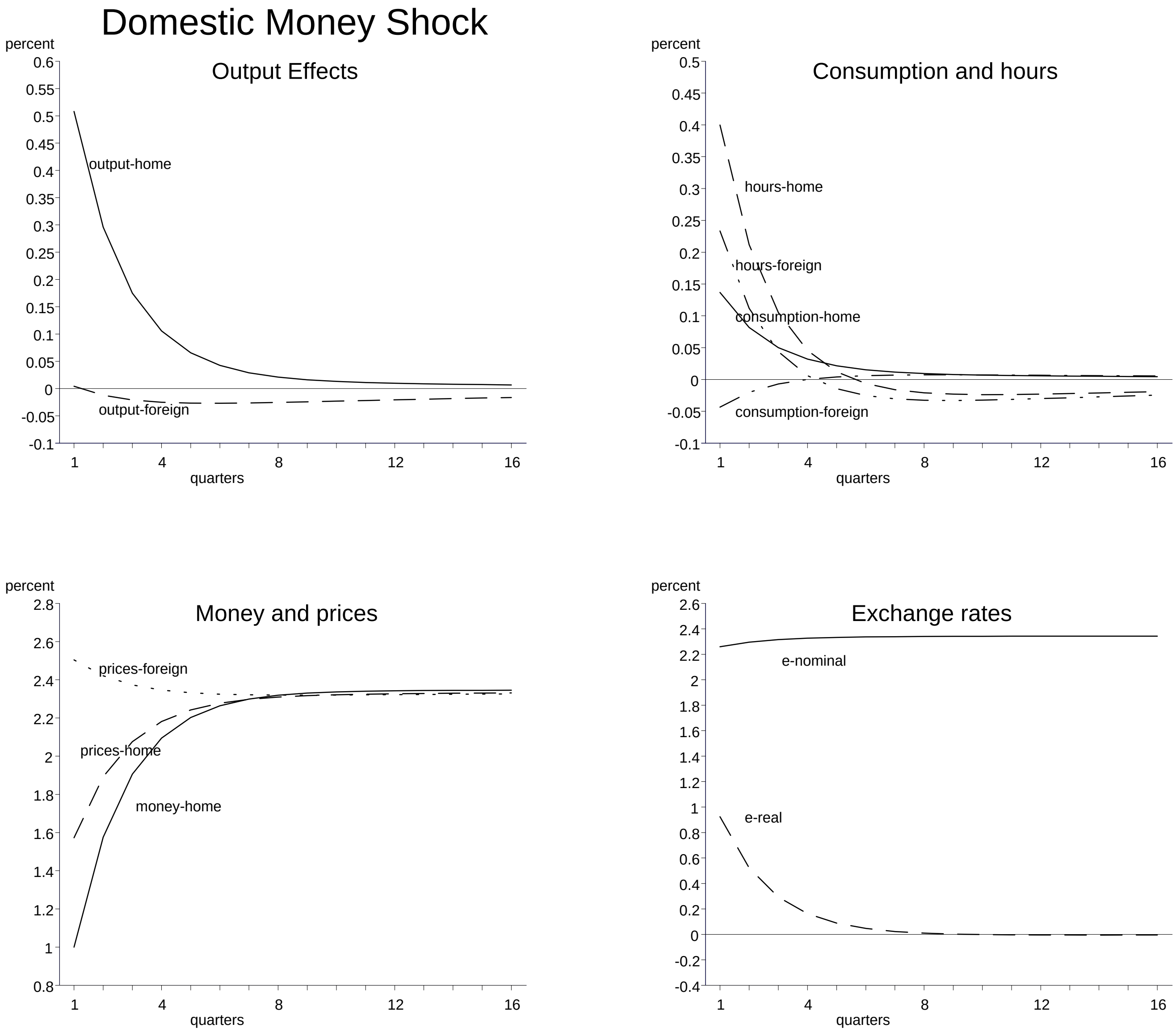

Figure 4. Effects of Domestic Money Shock: Baseline Economy

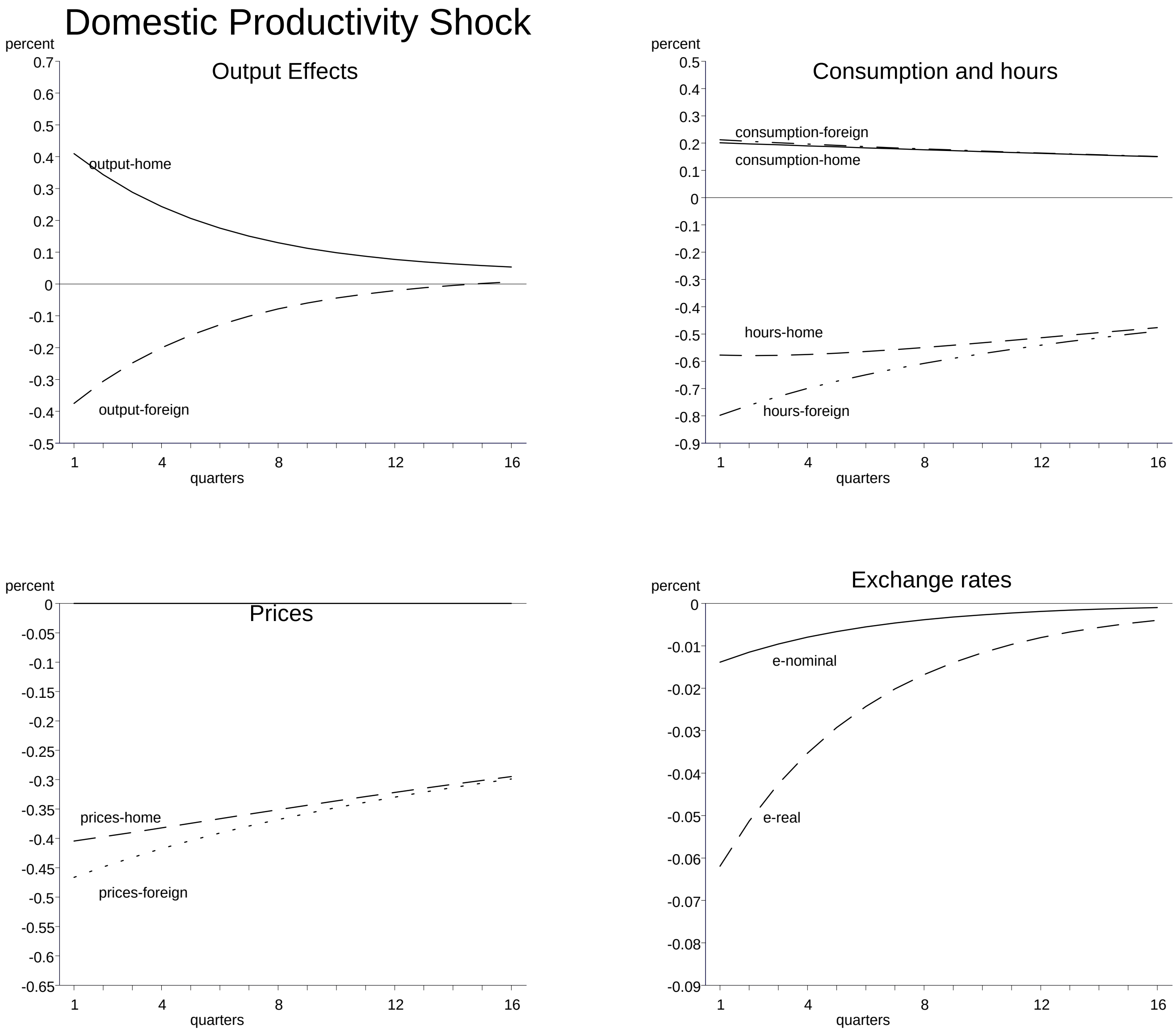

Figure 5. Effects of Domestic Productivity Shock: Baseline Economy

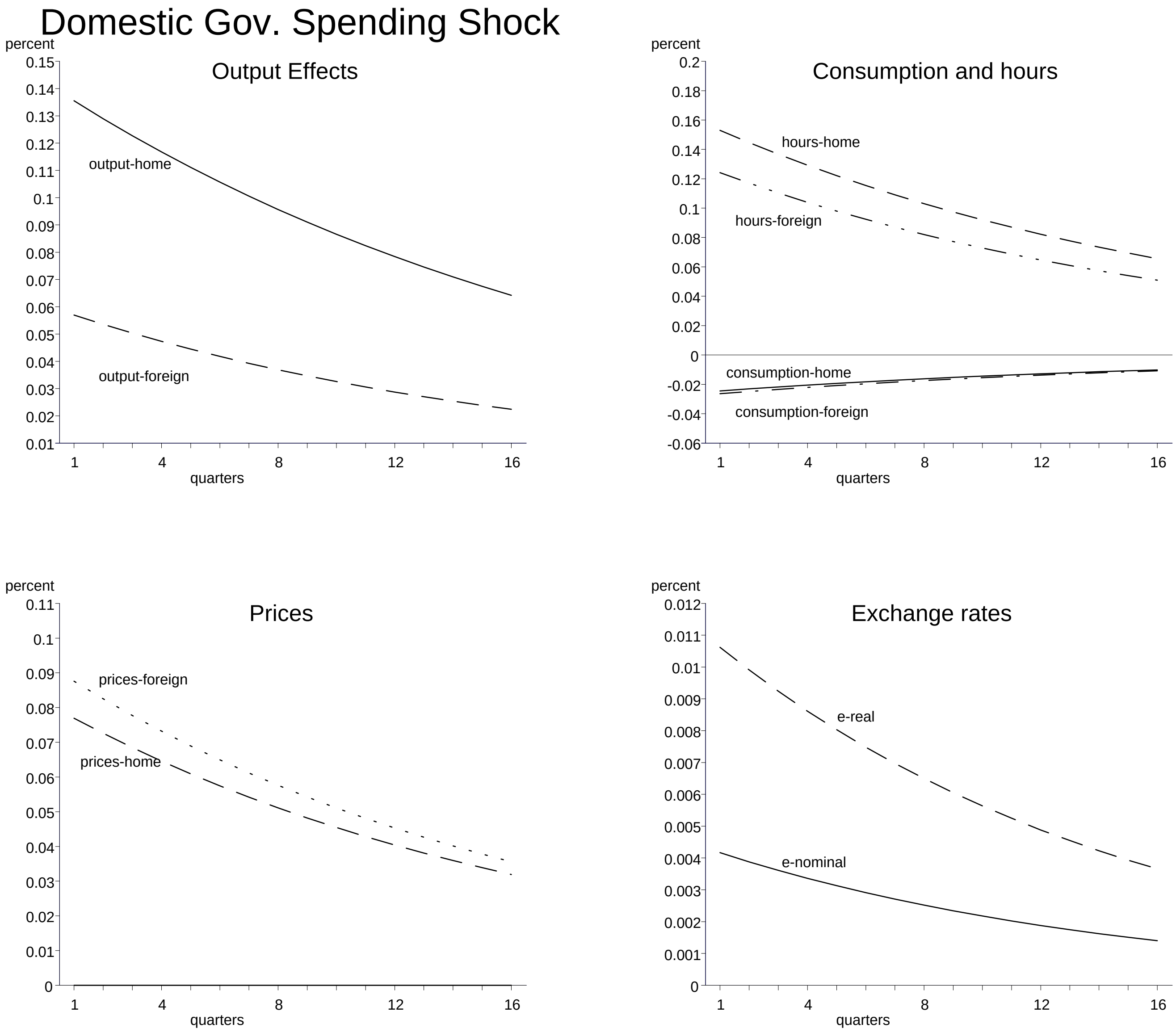

Figure 6. Effects of Domestic Government Spending Shock: Baseline Economy

Table 1. Simulation Results for the Baseline Economy: Exchange Rate Movements

	M	T	G	A
% standard deviations				
output	0.45	0.49	0.38	0.79
nominal exh. rate	3.75	0.02	0.02	3.75
real exchange rate	1.27	0.08	0.04	1.28
Autocorrelation				
Nominal exch. rate	0.71	0.63	0.68	0.71
real exchange rate	0.42	0.63	0.68	0.42
Correlations				
Nom. exch. rate and output	0.49	-0.97	0.37	0.29
Real each. rate and output	0.69	-0.99	0.38	0.39
Nom. and real exchange rate	0.64	0.98	0.97	0.64

Notes: Results relate to the average of 100 simulations. The data were Hodrick-Prescott filtered. In column "M" the economy is exposed to only "money shocks", in column "T" there are only "technology shocks", in column "G" there are only "government spending shocks", in column "A" all shocks are allowed for.

Table 2. Simulation Results for the Baseline Economy: Real Variables

	M	Z	G	A
Standard deviation of output				
	0.45	0.49	0.38	0.79
Std. dev. relative to output				
Cons.	0.28	0.74	0.24	0.50
Inv.	6.62	1.38	0.87	4.27
Gov. Spend.	-	-	6.83	3.25
Exports	5.33	6.40	3.96	5.51
Imports	5.32	6.41	3.95	5.54
Net exports	1.07	1.05	1.74	1.63
Hours	0.93	2.46	1.34	1.75
Correlation with output				
Cons.	0.94	0.04	-0.91	0.13
Inv.	0.91	0.06	0.75	0.60
Gov. Spend.	-	-	0.92	0.43
Exports	-0.94	0.76	-0.66	-0.12
Imports	0.24	-0.67	0.06	-0.21
Net Exports	-0.67	0.99	-0.39	0.06
Hours	0.86	0.05	0.96	0.37
International correlations				
Output	0.03	-0.99	0.71	-0.21
Cons.	-0.58	0.99	0.99	0.79
Investm.	-0.69	0.97	-0.58	-0.62
Hours	0.87	0.97	0.98	0.96

See notes to Table 1.