Equilibrium exchange rates and supply-side performance

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Abstract

This paper develops a two-country, optimising, sticky price model of real exchange rate determination in the 'new open macroeconomics' tradition which allows several different forms of deviation from purchasing power parity (PPP), both along the adjustment path and in the steady state. The model has a rich structure, and is designed to provide a flexible tool for policy analysis. Unlike most other papers in the literature, both of the key components of the real exchange rate – the relative price of non-tradables, and the terms of trade – are made endogenous, allowing a more complete analysis of the impact of structural shocks. To illustrate one possible application, the model is calibrated to match key elements of the UK and euro-area economies, and used to examine the extent to which possible improvements in the United Kingdom's relative supply-side performance might account for the sharp and persistent appreciation in sterling since 1996. The results are not supportive of this hypothesis. In the model, improvements in productivity, goods market and labour market competitiveness are all associated with a depreciation in both the spot and the equilibrium real sterling exchange rates. Two potential supply-side sources of an equilibrium appreciation – a productivity improvement biased towards traded goods (Balassa-Samuelson effect), and an anticipated future productivity rise – are considered; however, each is insufficient to account for a long-run equilibrium appreciation; the latter may account for an initial appreciation of the real exchange rate. We conclude by considering further mechanisms that could affect our results.

Keywords: Real exchange rates, PPP, monopolistic competition.

JEL classification: E52, F41.

Summary

How do changes in supply-side behaviour and market structure affect equilibrium exchange rates? Much discussion of exchange rate movements in recent years has linked exchange rate appreciations with beneficial supply-side developments, but to date there has been relatively little careful evaluation of the proposition. To address this issue, we propose a two-country dynamic stochastic general equilibrium model of the real exchange rate building upon Obstfeld and Rogoff's 'New directions for stochastic open economy models' paper. Our model allows us to analyse the theoretical implications of steady-state shocks to the degree of monopolistic distortion in both the goods and the labour markets as well as improvements in total factor productivity. We model each of our two economies as having two production sectors, one producing traded goods and the other producing non-traded goods. We also assume that firms producing tradable goods are able to price discriminate between the home and the foreign market for their products. A further assumption that is crucial to our results is that agents are assumed to have a bias for traded goods produced in their own country. These three modelling choices allow us to isolate three commonly used concepts of the real exchange rate, the relative price of non-traded to traded goods, the law of one price for traded goods and the relative price of imports over exports. Our analysis shows that, depending on the source of the shock, deviations of these three definitions of the real exchange rate can move in opposite directions from one another, with the deviation of the consumption-based real exchange rate equal to the sum of the individual deviations.

Given the relative weight of the euro in the ERI, we calibrate our model to match some of the salient characteristics of the United Kingdom and euro-area economies. Conditional on our calibration, we find that increases in competitiveness, in either the goods or the labour market, brought about by a reduction in the degree of monopolistic distortion that pushes the affected sector closer towards a perfectly competitive allocation, results in a real exchange rate depreciation. This result holds for both economy-wide as well as sector-specific shocks. Increases in total factor productivity that shift the economy-wide production possibility curve outwards also result in a real depreciation. This result holds even in the case where the productivity improvement is concentrated in the traded goods sector. In this case, a model that assumes that all domestic producers of traded goods are price takers would predict a real appreciation. In our case, the fact that firms act monopolistically ensures that the domestic price of traded goods falls, resulting in a real depreciation working through the terms of trade, which, conditional on our calibration, outweighs the real appreciation that arises from our non-traded to traded goods price measure of the real exchange rate.

Having established that, for our calibration, the model predicts a real depreciation when supply-side improvements result in immediate increases in output, we examine the model's response to an anticipated future increase in total factor productivity concentrated in the United Kingdom's traded goods sector. Here, the anticipated increase in total factor productivity immediately raises the discounted value of the representative consumer's human wealth, while the productive capacity of the economy stays initially unchanged. Under certain conditions, we show that the transitional dynamics associated with such a shock result in an initial real exchange rate appreciation, followed by a real depreciation in the new equilibrium. Our paper concludes by

pointing towards possible extensions to our analysis that might offer interesting avenues for future research.

1 Introduction

How do changes in supply-side behaviour and market structure affect equilibrium exchange rates? Much discussion of exchange rate movements in recent years has linked exchange rate appreciations with beneficial supply-side developments, but to date there has been relatively little careful evaluation of the proposition. In order to address this proposition, we propose a two-country dynamic stochastic general equilibrium model building upon Obstfeld and Rogoff (2000).

A central issue in modelling equilibrium exchange rates is the extent to which the steady state of the model respects purchasing power parity (PPP). Essentially, PPP states that the real exchange rate should be constant in the long run as goods market arbitrage equalises prices across countries. Many of the most widely used exchange rate models in the literature impose PPP as an equilibrium condition. However, empirical support for PPP over policy-relevant horizons is relatively weak.

Our model incorporates three factors capable of generating deviations from PPP in the steady state. First, as in Obstfeld and Rogoff (2000), our model includes non-traded goods. Second, consumers can be given a taste bias towards home-produced traded goods. Third, we allow for the possibility of steady-state pricing-to-market in the sense that monopolistically competitive firms may set different prices at home and abroad in response to different demand elasticities. Since we model both countries explicitly, we are able to endogenise the key components of the real exchange rate (the relative price of non-traded goods, and the terms of trade). This is important because neither of these measures has been constant in recent years, and have moved in very different directions. In addition our framework allows us to encompass a number of previous results based on more partial models.[(1)]

Since 1996, sterling's effective nominal exchange rate has appreciated by over 25%. Given relative inflation rates, the rise in nominal sterling is more than accounted for by an appreciation in the real exchange rate. Furthermore, the appreciation seems to have been persistent. One possible explanation of this appreciation is that relative improvements in the United Kingdom's supply side have resulted in an appreciation of the United Kingdom's equilibrium real exchange rate. We use our model to analyse the real exchange rate effects of supply-side improvements in the steady state of changes to the degree of competition in the United Kingdom's product and labour market, as well as the equilibrium and transitional dynamics of permanent increases in total factor productivity.

To carry out this analysis, we calibrate the model to match key elements of the UK and euro-area economies, and use the model to examine the extent to which possible improvements in the United Kingdom's relative supply-side performance might account for the sharp and persistent appreciation in sterling since 1996. The results are not supportive of this hypothesis. In particular, we find that, for our model and calibration, reductions in the degree of monopolistic distortions in the goods and labour markets, as well as improvements to total factor productivity, cannot account for the real appreciation of sterling. Our transitional dynamics suggest that an

(1) The two-country set-up allows us to consider closed economy and small open economy models as limiting cases of our more general analysis.

initial appreciation following a permanent shock to total factor productivity is only likely if the shock is (a) concentrated in the traded goods sector and (b) anticipated to occur in the future.

The model is of course simplified in many respects: for example, the asset market structure is rather limited and we do not examine the implications of adding physical capital to the analysis.[(2)]

The remainder of the paper is organised as follows. Section 2 sets out the structure of the model in detail. Section 3 defines the three definitions of the real exchange rate analysed in the remainder of the paper, and shows how they are related to each other in the model. Section 4 describes the main elements of the model calibration for the UK / euro-area case. Section 5 illustrates application of the model to examine the possible links between supply-side improvements in the United Kingdom and the appreciation of sterling since 1996. Section 6 concludes by summarising these results, and suggests some alternative and additional mechanisms by which productivity shocks could affect the real exchange rate which constitute areas for further research.

2 Structure of the model

This section reviews the main building blocks of the model.

Our approach builds on a dynamic version of the small-scale general equilibrium model given in Obstfeld and Rogoff's (2000) 'New directions for stochastic open economy models'. The model is enriched in different dimensions, with the aim of offering a comprehensive framework that encompasses and generalises other previous contributions. Many of the elements of this model are individually already present in the literature,[(3)] but they have not been brought together in a single framework as is done here. The framework allows us to assess both (a) the determinants of the steady-state real exchange rate, and (b) the dynamic adjustment path to this long-run equilibrium. From a steady-state perspective we conduct an innovative analysis of the interaction between the degrees of imperfect competition in the goods and labour market and the real exchange rate. In terms of dynamics, key modifications from the original Obstfeld and Rogoff (2000) contribution are the explicit incorporation of a dynamic structure along with the incorporation of monetary policy reactions to shocks through nominal interest rate feedback 'rules'. In addition, we introduce goods and labour market imperfections, and a rich specification of nominal rigidities.[(4)]

An important implication of these key modifications is that the model incorporates several factors capable of generating deviations of the real exchange rate from PPP. First, as in Obstfeld and Rogoff (2000), the model includes non-traded goods. In general the 'law of one price' should hold for tradable goods to ensure that a commodity sells for the same price everywhere. For non-traded goods, however, nothing ensures that the law of one price holds and differences in non-traded goods' prices create deviations from PPP. Second, consumers in the model may have a taste bias towards home-produced traded goods. If preferences are asymmetric across countries,

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(2) Chari, Kehoe and McGrattan (2000) suggests that it is unlikely that the inclusion of physical capital would fundamentally alter the conclusions we come to here about the determinants of equilibrium rates.

(3) These contributions include Betts and Devereux (1996), Corsetti and Pesenti (2001), Chari, Kehoe and McGrattan (2000, 2001), Devereux and Engel (2000), Obstfeld and Rogoff (2000).

(4) The dynamic specification of our model does not incorporate any form of real rigidity but this would be an interesting subject for future research.

the price of consumption bundles will differ when expressed in a common currency.[5] Third, we allow for the possibility of international price discrimination. When the elasticity of demand is different across countries, this will imply steady-state pricing-to-market in the sense that monopolistically competitive firms may set different prices at home and abroad.[6]

In contrast to simpler models, we are able to examine simultaneously the behaviour of alternative channels of real exchange rate deviations. This matters since different shocks affect the real exchange rate through different channels. Previous work has mostly concentrated on deviations from PPP working through a single channel. In contrast, we generate three key channels through which the real exchange rate deviates from PPP.

- The relative price of non-traded to traded goods channel;
- the home bias channel, which is a function of the terms of trade; and
- the market segmentation channel resulting from international price discrimination, which captures the deviations from the law of one price for traded goods.

The main elements of the model below are for the most part quite familiar. In what follows we highlight our main simplifying assumptions and how these relate to the literature.

2.1 *Building blocks of the model*

2.1.1 Country size and household preferences

We consider a two-country economy where both 'home' and 'abroad' are explicitly modelled. The parameterisation of the model allows the relative size of the two countries to be varied. The home economy produces a continuum of differentiated tradable goods indexed on the interval $[0, n]$,[7] where n is the relative measure of country size. The foreign economy's tradable goods are indexed on the interval $(n, 1]$. In addition, we assume that each country produces a continuum of differentiated non-traded goods, indexed on the interval $[0, n]$ and $(n, 1]$ for the home and foreign country, respectively. In each country, there is a continuum of economic agents, with population size normalised to the range of tradable produced goods.[8] Consumers are infinitely lived, and behave according to the permanent income hypothesis. Each consumer, at home and abroad, consumes three types of goods: a domestically-produced traded good, a foreign-produced traded good and a non-traded good. Foreign agents are indexed by i^*. C_t^i denotes the level of consumption at period t for individual i, $\frac{M_t^i}{P_t}$ his real money holdings and L_t^i his labour supply. Each individual i maximises the following utility function which is separable in the three arguments:

$$U_t^i = \mathrm{E}_t \sum_{s=t}^{\infty} (\beta)^{s-t} \left[U\left(C_{t+s}^i\right) + N\left(\frac{M_{t+s}^i}{P_{t+s}}\right) - V\left(L_{t+s}^i, z_{t+s}^i\right) \right] \qquad \textbf{(1)}$$

(5) In the so-called 'New open macroeconomics' literature an earlier contribution that introduced home bias in goods preferences is due to Warnock (2000).

(6) International price discrimination is a feature of some recent models, such as Benigno, G (2001) and Betts and Devereux (1996).

(7) The existence of differentiated goods is needed in order to give monopoly power to firms producing those goods.

(8) Home agents lie on the interval $[0, n]$, while foreign agents lie on $(n, 1]$.

where $U(.)$ and $N(.)$ represent flows of utility from consumption and real money balances respectively and $V(.)$ flows of disutility from supplying labour.[9] C is a consumption index defined as:

$$C = \frac{C_T^{\gamma} C_N^{1-\gamma}}{\gamma^{\gamma}(1-\gamma)^{1-\gamma}} \qquad \textbf{(2)}$$

where C_T and C_N are the two consumption sub-indices that refer, respectively, to the consumption of tradables and non-tradables. γ is a preference parameter that measures the relative weight that individuals put on traded goods. Since the consumption index is a Cobb-Douglas function of tradable and non-tradable consumption, γ also represents the share of total consumption expenditure that goes on traded consumption goods. We allow this parameter to vary across countries, and denote with γ^* the corresponding foreign variable. Money is deflated by a consumption-based price index that corresponds to the above specifications of preferences:

$$P = P_T^{\gamma} P_N^{1-\gamma} \qquad \textbf{(3)}$$

where P_T is the price sub-index for the traded goods expressed in the domestic currency and P_N is the price sub-index for the non-traded goods expressed in the domestic currency. Traded goods consumption is further sub-divided between Home and Foreign tradable goods:

$$C_T = \frac{C_H^{\upsilon} C_F^{1-\upsilon}}{\upsilon^{\upsilon}(1-\upsilon)^{1-\upsilon}} \qquad \textbf{(4)}$$

where υ represents the relative weight that a Home individual puts on domestically produced tradable goods. The price sub-index for traded goods implied by **(4)** is:

$$P_T = P_H^{\upsilon} P_F^{1-\upsilon} \qquad \textbf{(5)}$$

Foreign individuals have different tastes towards domestic versus imported goods, so that $\upsilon^* \neq \upsilon$. In Obstfeld and Rogoff (2000), υ is equal to the foreign correspondent, υ^*, and is equal to the relative size of Home, n. υ is an important parameter in characterising home bias in preferences. As in Warnock (2000), we define home bias as a situation where at *any given relative price*, Home consumers consume more home-produced tradable (relative to foreign-produced tradable) than do Foreign consumers:

$$\frac{C_H}{C_F} = \frac{\upsilon}{1-\upsilon}\left(\frac{P_H}{P_F}\right)^{-1}, \qquad \frac{C_H^*}{C_F^*} = \frac{\upsilon^*}{1-\upsilon^*}\left(\frac{P_H^*}{P_F^*}\right)^{-1} \qquad \textbf{(6)}$$

Home bias arises when $\frac{C_H}{C_F} > \frac{C_H^*}{C_F^*}$. At any given relative price, home bias requires $\upsilon > \upsilon^*$.

The last important element of our analysis is to allow for different elasticities of demand for the same good across countries. To this end, we need to introduce the following consumption

(9) We assume that U is increasing and concave in C_t, N is increasing and concave in $\frac{M}{P}$, and V is increasing and convex in L. E_t denotes the expectation conditional on information at time t, while β is the intertemporal discount factor $(0 < \beta < 1)$.

sub-indices:[10]

$$C^j = \left[\left(\frac{1}{n} \right)^{\frac{1}{\sigma^j}} \int_0^n c(z)^{\frac{\sigma^j - 1}{\sigma^j}} dz \right]^{\frac{\sigma^j}{\sigma^j - 1}}, \quad C^{j^*} = \left[\left(\frac{1}{1-n} \right)^{\frac{1}{\sigma^{j^*}}} \int_n^1 c(z)^{\frac{\sigma^{j^*} - 1}{\sigma^{j^*}}} dz \right]^{\frac{\sigma^{j^*}}{\sigma^{j^*} - 1}} \qquad \textbf{(7)}$$

where j and j^* denote the set of domestic and foreign production, specifically, $j = H, H^*, N$ and $j^* = F, F^*, N^*$ and where $\sigma^j > 1$ is the elasticity of substitution for goods produced within a country. If we denote with $p(i)$ and $p^*(i)$ the individual price of the single differentiated good in domestic and foreign currency respectively, then it can be shown that domestic and foreign demand for the same good are given respectively by:

$$c_H(i) = \frac{1}{n} \left(\frac{p(i)}{P_H} \right)^{-\sigma^H} C_H, \qquad c_H^*(i) = \frac{1}{n} \left(\frac{p^*(i)}{P_H^*} \right)^{-\sigma^{H^*}} C_H^*$$

2.1.2 Labour supply

Many models in the literature assume the existence of imperfect competition in either the goods or labour market.[11] Here, as in Chari, Kehoe and McGrattan (2001), Erceg, Henderson and Levin (2000), and Sbordone (2000) we consider labour and goods market imperfections together. Importantly, the introduction of simple labour market imperfections allows us to analyse the impact of changes in the efficiency of labour market institutions on the equilibrium exchange rate.

Labour is supplied by 'household unions' acting non-competitively in each sector (traded and non-traded). Each household supplies two types of labour services, one for the traded goods sector and one for the non-traded goods sector. The total labour supply of individual i is $L(i)$, which is divided between labour supplied to the domestic traded goods sector and the domestic non-traded goods sector:

$$L(i) = L_H(i) + L_N(i)$$

Here we have assumed that from the individual point of view, supplying labour to the traded or non-traded sector is equivalent (ie labour supply in the traded and non-traded sector are perfect substitutes). We assume that labour is immobile across countries. The Home 'household unions' combine individual households' supply according to:

$$L = \left[\frac{1}{n} \int_0^n L^j(i)^{\frac{\phi - 1}{\phi}} di \right]^{\frac{\phi}{\phi - 1}}$$

where $j = H, N$. We abstract from sectoral asymmetries in the labour market structure by assuming that the elasticity of substitution among labour is the same in the traded and non-traded

(10) The corresponding price indices for Home, Foreign and non-traded goods in the two economies are:

$$P_j = \left[\left(\frac{1}{n} \right) \int_0^n p(z)^{1-\sigma^j} dz \right]^{\frac{1}{1-\sigma^j}},$$

$$P_{j^*} = \left[\left(\frac{1}{1-n} \right) \int_n^1 p(z)^{1-\sigma^{j^*}} dz \right]^{\frac{1}{1-\sigma^{j^*}}},$$

where $j = H, H^*, N$ and $j^* = F, F^*, N^*$.

(11) For example Obstfeld and Rogoff (2000) focus on imperfect competition in the labour market while Chari, Kehoe and McGrattan (2000) focus on goods market imperfections.

sectors. If we denote with W^j the price index for labour inputs in sector j, and with $W^j(i)$ the nominal wage for worker i in sector j, then total demand for household i's labour is given by:

$$L^j(i) = \left[\frac{W^j(i)}{W^j}\right]^{-\phi} L^j \qquad \textbf{(8)}$$

'Household unions' will take into account the labour demand curve in setting their wages.

2.1.3 The asset market and the households budget constraint

The asset market structure in the model is relatively standard in the literature; there are, however, several important simplifications — for example, there are no cross-border equity transactions as all equities are held domestically. Individuals are, however, assumed to be able to trade internationally two nominal risk-less bonds denominated in the domestic and foreign currency.[(12)] These bonds are issued by residents in both countries in order to finance their consumption expenditure. Home households face a cost (ie transaction cost) when they take a position in the foreign bond market (see Benigno, P (2001)). This cost depends on the net foreign asset position of the whole economy.[(13)] Domestic firms are assumed to be wholly owned by domestic residents, and profits are distributed equally across households. This structure is almost identical to the one proposed in Obstfeld and Rogoff (2000).

Formally the Home households' budget constraint is given by:

$$P_{T,t}C^i_{T,t} + P_{N,t}C^i_{N,t} + M^i_t - M^i_{t-1} + \frac{B^i_{H,t}}{(1+i_t)} + \frac{S_t B^i_{F,t}}{(1+i^*_t)\Theta\left(\frac{S_t B_{F,t}}{P_t}\right)} \leq B^i_{H,t-1} \qquad \textbf{(9)}$$

$$+S_t B^i_{F,t-1} + T^i_t + W^i_{H,t}L^i_{H,t} + W^i_{N,t}L^i_{N,t} + \frac{\int_0^n \Pi^i_{N,t} di}{n} + \frac{\int_0^n \Pi^i_{H,t} di}{n}$$

where M is the household's stock of nominal money balances at the beginning of period and T^i are lump-sum government transfers. Π^i_N, Π^i_H are nominal profits from domestic firms. $B^i_{H,t}$ and $B^i_{F,t}$ are the individual's holdings of domestic and foreign nominal risk-less bonds denominated in the local currency. S_t is the nominal exchange rate expressed as units of domestic currency needed for one unit of foreign currency. The maximisation problem of the Home individual consists of maximising **(1)** subject to **(9)** in determining the optimal profile of consumption and bond holdings.

2.1.4 Firms' price-setting behaviour

Each firm is a monopolistic producer of a single differentiated good. Monopoly power is an important assumption of the model since it allows a rigorous justification of the assumption that

(12) More precisely we assume that there are 'incomplete markets' in the sense that agents do not have access to a complete set of markets in which to insure against all possible events. Other contributions, like Bergin and Feenstra (2001) and Chari, Kehoe and McGrattan (2000) assume that international financial markets are complete.
(13) Here we follow Benigno, P (2001) in assuming that the cost function Θ (.) assumes the value of 1 only when the net foreign asset position is zero, ie $B_{F,t} = 0$, and is a differentiable decreasing function in the neighbourhood of zero. This cost function is convenient because it allows us to log-linearise our economy properly since in steady state the desired amount of net foreign assets is always zero. On the other hand, in this way we are precluding any wealth effects. In this model, in steady state, there is no reason to have a position in foreign bonds since there is a cost. Cavallo and Ghironi (2001) use an overlapping generations approach to analyse the relationship between the net foreign assets and the nominal exchange rate.

output is demand determined when prices are fixed. Firms use labour as their primary input and total factor productivity can be varied independently in each sector, both at home and abroad.(14) An important dynamic element in our model consists of modelling the price-setting behaviour according to a partial adjustment rule *à la* Calvo (1983).(15) At each point in time, each firm can change its price with probability $1-\alpha_p$. This probability is independent of the time elapsed since the last price change, so the average time over which a price is fixed is given by $\frac{1}{1-\alpha_p}$. For example, $\alpha_p = 0.75$ in a quarterly model implies that prices are fixed on average for one year. In what follows, we allow for this parameter to vary within sectors and countries. Moreover we allow firms to price discriminate across countries. This means that, in its pricing decision, a Home tradable firm will choose a price for the domestic market and one for the foreign market, both expressed in the local currency.(16) (17)

If we denote with $p_t^{Hf}(i)$ the price chosen at time t and with $\widetilde{y}_{t,t+k}^{Hd}(i)$ the demand of the individual good H produced by producer i at time $t+k$, conditional on keeping the price fixed at the level chosen at time t, the first-order condition for the domestic producer of traded goods selling in the domestic market is given by:

$$\mathrm{E}_t \left\{ \sum_{k=0}^{\infty} (\alpha_p^H \beta)^k U_C(C_{t+k}) P_{H,t+k} P_{t+k}^{-1} \widetilde{y}_{t,t+k}^{Hd}(i) [(1-\Phi^H) p_t^{Hf}(i) - mc_{t+k}^H] \right\} = 0 \qquad \textbf{(10)}$$

where α_p^H is the Calvo parameter for the domestic firm selling tradable goods in the home market and mc^H is the real marginal cost for the producer of the Home tradable goods. We can define the overall degree of monopolistic distortions in the domestic tradable sector as:

$$1-\Phi^H \equiv \frac{\sigma^H - 1}{\sigma^H}$$

As in Gali and Gertler (1999), we depart from the original Calvo specification by assuming that two types of firms coexist. In every period, a fraction $1-\epsilon$ of firms set prices in a forward-looking manner while a fraction ϵ of firms set prices in a backward-looking manner. In

(14) As a result of having constant returns to scale in both production sectors, the relative price of non-traded to domestically produced traded goods P_N/P_H is, in the steady state, independent of the demand side of the economy given the linear production possibility frontier that results from this structure.

(15) Obstfeld and Rogoff (2000) consider the case in which prices are all fixed for one period. Considering a dynamic adjustment of prices is obviously important for our purposes, since we are interested in characterising the adjustment path following a shock. The choice between quadratic adjustment costs and the Calvo adjustment rule is made for analytical convenience. From a quantitative point of view the two adjustment mechanisms are identical.

(16) The assumption of a linear production function simplifies the analysis here. In this way, the firm's pricing decisions in the two markets are independent because a rise in demand in the Home market does not affect the marginal cost of production for the Foreign market.

(17) This assumption is known in the literature as local currency pricing (see Betts and Devereux (1996) and Chari, Kehoe and McGrattan (2000)). On the other hand, Obstfeld and Rogoff (2000) assume that prices are set in producers' currency so that prices for consumers change one-to-one with changes in the nominal exchange rate. In a different version of our paper, we consider the existence of a pass-through function which governs how changes in nominal exchange rates are passed on to domestic consumers by importers. This function (which has been proposed by Corsetti and Pesenti (2001)) lets us vary the degree of pass-through from local currency pricing (zero pass-through) to producer currency pricing (complete pass-through). In the current version of the paper we set the parameter in such a way as to imply local currency pricing.

this way, we introduce structural persistence in inflation[18] and increase inflation inertia which appears to be an important feature of the data. We denote with $\overline{\overline{p}}_t$ an index of the prices set at date t as a weighted average of the forward-looking price, p_t^f and the backward-looking price, p_t^b :

$$\overline{\overline{p}}_t = (1 - \epsilon)\, p_t^f + \epsilon\, p_t^b$$

We assume that a backward-looking firm at time t sets its price equal to the price set in the most recent round of adjustment, $\overline{\overline{p}}_{t-1}$, with a correction based on lagged inflation (ie these firms use lagged inflation to forecast current inflation):

$$p_t^b = \overline{\overline{p}}_{t-1} \frac{P_{t-1}}{P_{t-2}}$$

2.1.5 Wage-setting

We now specify more formally the wage-setting process. Given the monopolistically competitive structure of the labour market, if household unions have the chance to change their wage every period, they will set it as a mark-up over the marginal rate of substitution between consumption and labour. In addition to this monopolistic distortion we also allow for a partial adjustment of wages again using a Calvo-type contract. Household unions are able to adjust wages at each period with a probability of $(1 - \alpha_w^j)$ where $j = N, H$. In any period in which the household union is able to reset its wage contract, it maximises utility **(1)** with respect to the wage rate, taking into account the labour demand curve **(8)**. The first-order condition for setting the nominal wage in the tradable sector is then:

$$\mathrm{E}_t \left\{ \sum_{k=0}^{\infty} (\alpha_w^H \beta)^k \left[(1 - \Phi_W) \frac{\widetilde{W}(i)_{H,t}}{P_{t+k}^H} - mrs_{t+k}^H \right] U_C \left(C_{t,t+k} \right) L(i)_{t+k} \right\} = 0 \qquad \textbf{(11)}$$

where $\widetilde{W}(i)_{H,t}$ is the nominal wage set in period t and mrs_t^H is marginal rate of substitution between consumption and labour in the domestic traded good sector. Condition **(11)** tells us that the nominal wage depends on the current and expected value of the marginal rate of substitution. We define the overall degree of monopolistic distortions in the labour market as:

$$1 - \Phi^W \equiv \frac{\phi - 1}{\phi}$$

2.1.6 Government budget constraint and the current account

Given our representative agent assumption, Ricardian equivalence holds in the model. The budget constraint at date t for the fiscal authority of the Home country is given by:

$$\int_0^n \left[M_t(i) - M_{t-1}(i) \right] dh = G_t^H + G_t^N + \int_0^n T_t(i) di \qquad \textbf{(12)}$$

The government finances public expenditure on home tradables and non-tradable, G^H and G^N, by seigniorage revenues.[19] What is left is rebated to households in the form of transfers, $T_t(i)$.

(18) This means that in our Phillips curve current inflation will depend on lagged inflation as long as the proportion of backward-looking firms is non-zero.

(19) Even though government spending shocks are outside the scope of the present analysis, the model is readily used for shocks to fiscal spending.

To determine the resource constraint for our economy, we need to consider the private and public sector together. The public sector is described by the government budget constraint, **(12)**, and the behaviour of the private sector is given by aggregating individual budget constraints, **(9)**, across all individuals belonging to the Home country. In an open-economy framework, the difference between total income and domestic consumption is defined as the current account:

$$\frac{S_t B_{F,t}}{P_t(1+i_t^*)\Theta\left(\frac{S_t B_{F,t}}{P_t}\right)} = \frac{S_t B_{F,t-1}}{P_t} + \frac{P_{H,t} Y_H^d}{P_t} + \frac{S_t P_{H,t}^* Y_{H,t}^{d^*}}{P_t} - \frac{P_T C_T}{P_t} \qquad \textbf{(13)}$$

where we have denoted with Y_H^d and $Y_{H,t}^{d^*}$ the aggregate demand for domestic goods coming from home and abroad. Equation **(13)**, which follows Benigno, P (2001), describes the evolution of foreign assets, which will be important in determining the equilibrium exchange rate.[20] In this way, it is possible to relate the evolution of the current account to movements in the exchange rate.

2.1.7 Monetary policy

In this model, as in many other recent contributions, we make the simplifying assumption that monetary policy is characterised in terms of interest rate feedback rules. Each monetary authority sets the nominal interest rate according to current economic conditions. A common example of this specification is the Taylor rule, under which the nominal interest rate reacts to current inflation and the output gap. This does not imply that Taylor rules are an accurate description of monetary policy in either the United Kingdom or the euro area, but they do offer a convenient way in which to capture an active monetary policy.[21] A very general way of characterising this behaviour is to express these rules as:

$$\frac{1+r_t}{1+\overline{r}} = \Psi\left(\overline{\mathsf{z}}_t, \varepsilon_t^M\right)$$
$$\frac{1+r_t^*}{1+\overline{r}^*} = \Psi^*\left(\overline{\mathsf{z}}_t^*, \varepsilon_t^{M^*}\right)$$

where $\overline{\mathsf{z}}_t$ ($\overline{\mathsf{z}}_t^*$) is the set of target variables for the Home (foreign) country, given the information set at time *t*. ε_t^M and $\varepsilon_t^{M^*}$ are monetary policy shocks that in this setting represent deviation from the systematic component of the interest rate rule.

2.1.8 Log-linear equilibrium

The model is log-linearised around the steady state. Importantly in this framework the steady state is well defined (ie the model is stationary so the log-linearisation procedure is consistent). We have normalised the steady state so that the equilibrium values of the variables do not affect the elements of the matrices in the log-linearised system.[22] The log-linearisation yields a system of linear difference equations which can be expressed as a singular dynamic system of the form:

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(20) Many models in this recent literature assume that markets are complete internationally and characterise the equilibrium dynamics without the need to refer to the current account equation (see for example Bergin and Feenstra (2001) and Chari, Kehoe and McGrattan (2000)). When markets are complete an optimal risk-sharing condition links the real exchange rate to the ratio of marginal utilities of income in the two countries and determines, along with other equations, the equilibrium value of the real exchange rate.

(21) An alternative way of closing the model is to derive a money demand function from the representative agent's first-order conditions.

(22) The programming routine that we use allows us to explore the implications of permanent shocks for our equilibrium.

$$\mathrm{A}E_t y(t+1 \mid t) = \mathrm{B}y(t) + \mathrm{C}x(t)$$

where $y(t)$ is ordered so that the non-predetermined variables appear first and the predetermined variables appear last, and $x(t)$ is a martingale difference sequence. We then solve this system using the Reds/Solds algorithms of King and Watson.

3 The real exchange rate and deviations from PPP

Some definitions

Before presenting our experiments we focus on alternative definitions of the real exchange rate and relate them to the various sources of PPP deviations highlighted at the start of Section 1. We do so from a long-run perspective by focusing on steady-state relationships.

The purest form of the theory of purchasing power parity predicts that the real exchange rate, expressed as the relative cost of a common basket of goods, should be equal to 1. In our framework the basket of goods we use, which through the presence of non-traded goods and through home bias may vary in composition across countries, is expressed in terms of the consumption index C and its price, in local currency, is given by P. The real exchange rate is then defined as:

$$RS \equiv \frac{SP^*}{P}$$

where we have used the nominal exchange rate, S, to express everything in terms of the domestic currency. In what follows, we say that the real exchange rate depreciates (appreciates) when RS rises (decreases).

The terms of trade, ie the relative price of home imports in terms of home exports, is defined as:

$$ToT = \frac{P_F}{SP_H^*}$$

When ToT falls, the terms of trade are said to 'improve', since imports are relatively cheaper.

We now use the price indices, **(3)** and **(5)**, to express the real exchange rate as a function of the relative prices of non-traded to traded goods, $\frac{P_N}{P_T}$ and $\frac{P_{N^*}}{P_T^*}$, and the relative price of traded goods.

$$RS = \frac{SP^*}{P} = \frac{SP_T^*}{P_T} \frac{\left(\frac{P_{N^*}}{P_T^*}\right)^{1-\gamma^*}}{\left(\frac{P_N}{P_T}\right)^{1-\gamma}} \qquad \textbf{(14)}$$

There are now two components or channels in explaining real exchange rate deviations from PPP. One is given by the real rate of exchange for the traded goods, ie $\frac{SP_T^*}{P_T}$, while the other is the relative prices of non-traded goods in the two countries, ie $\left(\frac{P_{N^*}}{P_T^*}\right)^{1-\gamma^*} / \left(\frac{P_N}{P_T}\right)^{1-\gamma}$. The latter of these channels is what we define as the 'internal real exchange rate' channel. The internal real exchange rate is said to depreciate (appreciate) when the internal real exchange rate increases (decreases). The former channel, given by $\frac{SP_T^*}{P_T}$, can be split into two separate components: one deriving from deviations from the law of one price of traded goods, and the other from differences in the preferences of home and foreign consumers.

Using the expression that defines P_T, **(5)** and the foreign correspondent for P_T^*,(23) we can express the real exchange rate for traded goods to obtain:

$$\frac{SP_T^*}{P_T} = \frac{SP_H^{*\upsilon^*} P_F^{*1-\upsilon^*}}{P_H^{\upsilon} P_F^{1-\upsilon}} = \left(\frac{SP_H^*}{P_H}\right)^{\upsilon^*} \left(\frac{SP_F^*}{P_F}\right)^{1-\upsilon^*} \left(\frac{P_F}{P_H}\right)^{\upsilon-\upsilon^*} \qquad \textbf{(15)}$$

There are two elements that affect this component. The first is given by the extent to which firms price discriminate across countries, ie $\frac{SP_H^*}{P_H}$ and $\frac{SP_F^*}{P_F}$. If the law of one price holds, the price of the same commodity will be equalised across countries once expressed in a common currency and $\frac{SP_H^*}{P_H}$, $\frac{SP_F^*}{P_F}$ will be equal to 1. Since we allow for different elasticities of demand for the same good across countries, firms will charge a different price in the two markets. We define this channel as the 'market segmentation channel'.(24) The second element depends on the existence of home bias,(25) $\upsilon > \upsilon^*$, through the relative price of foreign versus home produced goods, $\frac{P_F}{P_H}$.(26) In general a deterioration in the terms of trade, ie an increase in T, will lead to a bigger real exchange rate depreciation the higher is the degree of home bias, ie the difference $\upsilon - \upsilon^*$ (see **(15)**). This is our 'home bias channel'.

Using the nomenclature thus defined, we can express the real exchange rate in terms of its three channels of deviation from PPP:

$$RS = \underbrace{\left(\frac{SP_H^*}{P_H}\right)^{\upsilon^*} \left(\frac{SP_F^*}{P_F}\right)^{1-\upsilon^*}} \left(\frac{P_F}{P_H}\right)^{\upsilon-\upsilon^*} \frac{\left(\frac{P_{N^*}}{P_T^*}\right)^{1-\gamma^*}}{\left(\frac{P_N}{P_T}\right)^{1-\gamma}}$$

$$RS = \begin{array}{c}\text{Market}\\ \text{segmentation}\end{array} \times \begin{array}{c}\text{Home}\\ \text{bias}\end{array} \times \begin{array}{c}\text{Internal real}\\ \text{exchange rate}\end{array}$$

Without international price discrimination the market segmentation channel is equal to one, without home bias (when $\upsilon = \upsilon^*$) the home bias channel is equal to one, and, if all goods at home and abroad are traded, ie $\gamma = \gamma^* = 1$, the internal real exchange rate channel is also equal to one. In the absence of any of these channels the real exchange rate is unity, as PPP suggests.

Determination of the equilibrium real exchange rate

In a general equilibrium model, the interaction between household behaviour, the supply side and monetary policy determines the equilibrium value of the real exchange rate. Our previous

(23) In decomposing the real exchange rate for traded goods we are using definitions introduced before. The resulting relationship also holds in the dynamic equilibrium.

(24) In the steady state, this channel works through different substitution elasticities between varieties of home and foreign produced traded goods in the home and foreign goods market. In the transitional dynamics, when these elasticities remain constant, this channel operates through a lack of complete pass-through from the exchange rate to prices.

(25) In general it depends on asymmetric preferences, ie the fact that $\upsilon \neq \upsilon^*$, where υ (υ^*) represent the weight that Home (Foreign) consumers put on the domestically produced goods.

(26) This ratio is, in steady state, proportional to the terms of trade, ie the relative price of home imports in terms of home exports, ie $ToT = \frac{P_F}{SP_H^*}$. In what follows we refer to the ratio $\frac{P_F}{P_H}$ as the terms of trade and use the same terminology in describing their changes.

decomposition has shown that we can understand changes in the real exchange rate by examining the behaviour of the terms of trade and the internal real exchange rate.

In what follows we will briefly focus on the steady-state analysis in order to highlight the variety of potential determinants of (various definitions of) the steady-state real exchange rate. In particular we are interested in examining whether productivity shocks, preference shocks and demand shocks affect our variables of interest.

The private sector behaviour is described by the consumption-leisure trade-off equations for the Home and Foreign representative consumers:[27]

$$U_C\left(\frac{C_T^{\gamma}C_N^{1-\gamma}}{\gamma^{\gamma}(1-\gamma)^{1-\gamma}}\right)\frac{W}{P}\left(1-\Phi^W\right)=V_L\left(\left(\frac{Y_H}{A_H}\right)+\left(\frac{Y_N}{A_N}\right)\right) \quad \textbf{(16)}$$

$$U_C\left(\frac{C_{T^*}^{\gamma^*}C_{N^*}^{1-\gamma^*}}{\gamma^{*\gamma^*}(1-\gamma^*)^{1-\gamma^*}}\right)\frac{W^*}{P^*}\left(1-\Phi^{W^*}\right)=V_L\left(\left(\frac{Y_F}{A_F}\right)+\left(\frac{Y_{N^*}}{A_{N^*}}\right)\right) \quad \textbf{(17)}$$

Where U_C (.) and V_L (.) denote the partial derivatives of U (.) and V (.) with respect to consumption and labour supply respectively. Y_H and Y_N denote aggregate production in the Home country for the home tradable and non-tradable goods. Y_F and Y_{N^*} denote the corresponding foreign variable. The resource constraints link production to total demand. For the Home and foreign tradables we have:

$$Y_H=\frac{\upsilon}{n}\left(\frac{P_H}{P_T}\right)^{-1}nC_T+\frac{\upsilon^*}{n}(1-n)\left(\frac{P_H^*}{P_T^*}\right)^{-1}C_T^*+G_H \quad \textbf{(18)}$$

$$Y_F=\frac{(1-\upsilon)}{1-n}n\left(\frac{P_F}{P_T}\right)^{-1}C_T+\frac{(1-\upsilon^*)}{1-n}(1-n)\left(\frac{P_F^*}{P_T^*}\right)^{-1}C_T^*+G_F \quad \textbf{(19)}$$

In both countries, output of non-traded goods has to be domestically consumed by private and public agents.

$$Y_N=C_N+G_N,\qquad Y_{N^*}=C_{N^*}+G_{N^*} \quad \textbf{(20)}$$

From **(2)**, we can obtain the allocation of consumption among traded and non-traded goods in the Home and Foreign economy:

$$\frac{C_T}{C_N}=\frac{\gamma}{1-\gamma}\frac{P_N}{P_T},\qquad \frac{C_{T^*}}{C_{N^*}}=\frac{\gamma^*}{1-\gamma^*}\frac{P_{N^*}}{P_{T^*}} \quad \textbf{(21)}$$

The interaction between the real exchange rate and the rest of the economy occurs through the current account equation, **(13)**. In steady state there is no accumulation of net foreign assets and the holding of foreign assets is zero:

$$0=\frac{P_HY_H^d}{P}+\frac{SP_H^*Y_H^{d*}}{P}-\frac{P_TC_T}{P} \quad \textbf{(22)}$$

(27) Equations **(16)** and **(17)** are obtained by maximising consumers' utility with respect to the nominal wage.

The system given by the previous equilibrium conditions (equations **(16)**, **(17)**, **(18)**, **(19)**, **(20)**, **(21)** and **(22)**) determines the equilibrium real exchange rate in the long run.

Among the various determinants of the real exchange rate we highlight the following:

- Productivity shocks in different sectors and countries (traded and non-traded, at home and abroad, as well as current and expected future shocks).
- Preference shocks to the consumption and labour components of the households' utility function.
- Demand shocks in terms of government spending in the different sectors.
- Different degrees of monopolistic distortion in the different markets (goods and labour).
- Different elasticities of demand across countries and the parameters of home bias in the consumers' preferences.

Along the adjustment path, all these elements interact with nominal rigidities and the reaction of monetary policy rules.

4 Calibration

In the application presented in this paper, we calibrate the model assuming that 'Home' is the United Kingdom and that 'Abroad' is the euro area. No feature of this model is, however, specific to either economy. Our calibration strategy proceeds as follows: first, for parameters where there is reasonable consensus, we have used values from the existing literature. In particular, we follow Batini, Harrison and Millard (2001) and Neiss and Nelson (2001) for the United Kingdom. For the euro area the main references are Smets and Wouters (2001) and Kollmann (2001). For parameters where there is less consensus in the literature, we choose values that allow us to capture key business cycle properties of the real exchange rate. In particular, we focus on the volatility of the real exchange rate relative to GDP and the persistence of the real exchange rate fluctuations for the UK economy.

Table A summarises the parameters of our preferred calibration.

Table A: Calibrated parameters

Parameters/Country		United Kingdom	Euro area
Structural parameters			
β	Discount factor	0.99	0.99
n	Relative country size	0.14	0.86
ρ	Intertemporal rate of substitution	5	5
σ	Elasticity of substitution (goods)	6.88 (NT), 6.459 (H)	7.88
ϕ	Elasticity of substitution (labour)	5.061	4
γ	Share of traded goods in total consumption	0.301	0.4835
υ	Share of UK traded goods in traded goods consumption	0.513	0.09
α_p	Probability of not changing prices	0.75	0.9
α_w	Probability of not changing wages	0.7	0.7
ϵ	Proportion of backward-looking firms	0.15	0.4
η_L	Elasticity of labour supply	0.8	0.8
η_z	Elasticity of labour supply preference shock	0.2	0.2
δ	Cost of intermediation in foreign bond market	10^{-3}	10^{-3}
Interest rate rules			
Γ_π	Coefficient on current inflation	0.406	0.4104
Γ_y	Coefficient on the output gap	0.046	0.05
Γ_{i-1}	Coefficient on lagged interest rate	0.605	0.76

The following parameters are taken from the literature. We set the discount factor so as to yield a steady-state annual real interest rate of 4%. We proxy the size of the United Kingdom relative to the sum of the euro area and the United Kingdom by relative GDP; for the period 1995-2000, we find an average of 0.14.[28] The elasticity of substitution between differentiated goods, σ, in the

(28) It could be argued that the United Kingdom / euro-area calibration exaggerates the size of the United Kingdom relative to the foreign country in the model. We find, however, that our results are robust for values of n closer to the United Kingdom's share of world output (about 4%).

United Kingdom follows Batini, Harrison and Millard (2001) (BHM) who differentiate between traded goods (sector F) and non-traded goods (sector N). Given that in BHM domestic consumers have preferences only over non-traded and imported goods, we restrict $\sigma^F = \sigma^H$. Studies for the euro area, such as Smets and Wouters (2001) (SW), do not offer a specific estimates of σ, instead they follow Rotemberg and Woodford (1997) (RW), who find a value of σ for the US economy predicated on a one-sector economy. For want of better data, we follow their approach.(29) The elasticity of substitution between individual types of labour, ϕ, is also determined following BHM. Again a lack of studies on the euro area poses a problem. We arbitrarily choose ϕ in such a way as to make the UK labour market more price competitive.(30)

The share of non-traded goods in total consumption in the euro area, $1 - \gamma^*$, is proxied by services' average share in household final consumption expenditure taken from the 1985 Eurostat input-output tables for France, Germany and Italy (the EU3). The UK share is calculated using the 1990 domestic-use matrix of the ONS input-output table. The share of UK versus euro-area consumed traded goods in the euro area, υ^*, is also an EU3 average taken from the 1985 Eurostat input-output tables.(31) The UK estimate of υ is derived from input-output tables.(32) The fraction of backward-looking agents, ϵ, follows unpublished Bank of England work for the United Kingdom and SW for the euro area. The interest rate rule coefficients are taken from BHM for the United Kingdom and SW for the euro area.(33) In setting the cost of intermediation in the foreign goods market, we follow Benigno, P (2001), who assumes a value of 10^{-3}, which implies a 10 basis point spread of the domestic rate (in the foreign goods market) over the foreign rate.

(29) BHM's estimates imply a mark-up over unit costs of 17% for the non-traded sector, and 18.3% for the traded sector. The RW estimate suggests a mark-up of 14.5% for the euro area. Kollmann also refers to US studies, but chooses a higher mark-up of 20% implied by Martins *et al* (1996).

(30) This accords with evidence of a less unionised labour market in the United Kingdom relative to the euro-area countries. Specifically we assume a mark-up of 33%. Our sensitivity analysis also found that the model's behaviour and performance in terms of matching moments are not greatly influenced by ϕ.

(31) The share of traded goods for each of the EU3 economies is calculated from Table T33 of the 1985 Eurostat table on final consumption expenditure of households. The share of non-EU import in total consumption is derived using the total traded consumption of households from Table T33 and final household consumption of imports from non-EU economies in Table T09. We do this calculation for France, Germany and Italy and take a non-weighted average.

(32) γ is the fraction of consumer expenditure that is traded relative to total consumer expenditure. 1-ν is the ratio of imports to total traded consumption. We define agriculture, manufacturing and imports as traded, and energy, construction, distribution, transport, business services as well as 'other services' as non-traded sectors. (1-υ) is imports divided by total consumer expenditure on traded goods. See Table 2 on page viii of the 1990 input-output tables.

(33) It is of course not suggested that either the Monetary Policy Committee or the ECB set interest rates according to any mechanical rule. Moreover, estimation is particularly difficult in the United Kingdom because the sample period, 1985-1998 in the BHM study encompasses monetary frameworks different from the current one, and for the euro area because there was no single monetary policy prior to 1999. Among other considerations, there is no 'forward-looking' component in these 'rules'. From BHM, we take the coefficients on the lagged interest rate, the output gap and inflation. BHM's regression also includes terms for the depreciation as well as two dummy variables. For now, we ignore these extra terms. For the euro area SW estimate some of their structural parameters, including the interest rate rule coefficients, by using maximum likelihood methods as suggested by Sargent (1989).

The remaining parameters are calibrated with the aim of matching the particular set of the moments of the data referred to above. The main characteristics of these data are shown in Tables B and C.(34)

Table B: Real exchange rates moments: data and model

Statistics	Data	Model
Standard deviations relative to GDP		
Internal real exchange rate*	0.653	0.868
Terms of trade**	1.200	1.759
Real exchange rate**	3.733	3.722
Autocorrelations		
Internal real exchange rate	0.801	0.795
Terms of trade	0.554	0.857
Real exchange rate	0.758	0.630
Cross-correlations with GDP		
Internal real exchange rate	-0.288	-0.137
Terms of trade	0.470	0.694
Real exchange rate	0.284	0.351

Note: The statistics of the data are based on logged Hodrick-Prescott filtered data with λ=1,600.

*Sample: 1987:1 - 2001:1.

**Sample: 1979:1 - 2000:4.

As in Chari, Kehoe and McGrattan (2001) we express the standard deviations of the real exchange rate measures relative to the standard deviation of GDP. By this measure, the real exchange rate is 3.7 times as volatile as GDP, the terms of trade 1.2 times as volatile and the relative price of traded to non-traded goods only about two-thirds as volatile. We also note that all three measures of the real exchange rate are highly persistent, with autocorrelations ranging from 0.554 for the terms of trade to 0.801 for the relative price of traded to non-traded goods. The real exchange rate and the terms of trade are positively related to GDP, whereas the relative price of traded to non-traded goods is negatively related to GDP. In column 2 of Table C we present further business cycle statistics for the United Kingdom.

(34) The data are obtained from the Organisation for Economic Co-operation and Development (OECD), are of quarterly frequency, and range from 1962:2 to 2000:1. Unfortunately, not all series are available over the entire sample period. In the table we specify the data range for each variable.

In Table C we focus more on the usual business cycle statistics.

Table C: Business cycle statistics: United Kingdom

Statistics	Data	Model
Standard deviations		
Nominal interest rate†	0.017	0.016
CPI inflation‡	0.010	0.014
Consumption‡	0.017	0.006
GDP‡	0.015	0.011
Current account relative to consumption‡	0.004	0.005
Autocorrelations		
Nominal interest rate	0.795	0.853
CPI inflation	0.571	0.991
Consumption	0.789	0.675
GDP	0.794	0.709
Current account relative to consumption	0.794	0.633
Cross-correlations with GDP		
Nominal interest rate	0.157	-0.714
CPI inflation	0.021	-0.341
Consumption	0.785	0.189
Current account relative to consumption	-0.335	0.358

Note: The statistics of the data are based on logged Hodrick-Prescott filtered data with λ=1,600, except for CPI inflation, which is reported in levels.

†Sample: 1978:1 - 2001:1.

‡Sample: 1962:2 - 2000:4.

Having presented the main features of the data, we now proceed to calibrate the remaining model parameters so as to match the volatility of the real exchange rate relative to that of GDP, the persistence of the real exchange rate and the correlation between the current account and GDP for the Home economy. In Table D, we summarise the properties of the shock processes used as an input in calibrating our model and generating the moments of interest.

Table D: Shock processes

Shock to:	Autocorrelation	Variance
A^H	0.705	0.0000319
A^N	0.784	0.0000704
A^F	0.81	0.0000292
A^{N^*}	0.81	0.0000292
ε	0	0.0000674
ε^*	0	0.0000674

We simulate the model using two kinds of shocks: sector-specific productivity shocks, and monetary policy shocks. The stochastic properties of A^H, A^N and ε are taken from BHM and A^F and A^{N^*} from Kollmann, we assume that the properties of ε^* are the same as ε.[35]

The intertemporal elasticity of substitution ρ is assumed to be the same in both economies. The outcome of our sensitivity analysis[36] suggests a choice of 5, which is the value suggested by Chari, Kehoe and McGrattan (2001). The elasticity of the labour supply is subject to considerable uncertainty. BHM assume logarithmic labour supply, thus constraining η to unity. RW choose 0.47. Following our sensitivity analysis, we set η to 0.8.[37]

Regarding the degrees of nominal rigidities for the United Kingdom, BHM find values for α_H, α_F and α_N of 0.67, 0.67 and 0.57 respectively. Neiss and Nelson (2001), on the other hand, choose 0.75. We find that we are better able to match the moments in the data by choosing a higher degree of price stickiness. Price stickiness raises the persistence of the real exchange rate and its volatility relative to GDP. We follow Neiss and Nelson in choosing a value of 0.75 for all three domestic sectors. For the euro area, we rely on the estimates by SW: the average duration of price contracts is longer than two and a half years, which implies that $\alpha_p = 0.9$.

We choose α_w, the degree of wage stickiness, to be 0.7 for the United Kingdom and set $\alpha_w^* = 0.7$ for the euro area. These are similar to the values suggested in the literature. BHM choose $\alpha_w = 0.75$ arbitrarily for the United Kingdom, and Kollmann (2001) also sets $\alpha_w^* = 0.75$ for an aggregate of France, Germany and Italy.[38]

Given the set of parameters in Table A the model matches the volatility of the real exchange rate relative to the volatility of GDP reasonably well. In the data, this ratio is 3.733 for the United

(35) We use the values of the variance of the shocks in Table D to construct the variance-covariance matrix of our shock vector. We use this matrix to calculate the stationary variance-covariance matrix as well as the one-period lag autocovariance matrix of the vector of jump variables $\{y_t\}$. We then use these two matrices to calculate variances, covariances, autocorrelation coefficients and cross-correlations in the standard way.

(36) Here we examine the autocorrelation of the real exchange rate and the volatility of the real exchange rate relative to GDP. We derived the parameters summarised in Table A by repeatedly running sensitivity analysis exercises, changing one parameter at a time so as to match best our set of moments.

(37) Raising η increases the ratio of volatilities of the real exchange rate and GDP as well as the persistence of the real exchange rate. Since the persistence is not very responsive to η, we choose η in such a way as to match best the relative volatility of the real exchange rate relative to GDP.

(38) Our sensitivity analysis indicates that increasing α_w increases both the persistence and the relative volatility of the real exchange rate.

Kingdom; our model generates values of 3.722 for the ratio of unconditional variances.[39] Our model comes close to matching the persistence of the relative price of traded to non-traded goods while generating a lower volatility of the real exchange rate than is found in the data. Our model generates a higher persistence of the terms of trade than is found in the data.

For completeness, Table C summarises the volatilities, autocorrelations and cross-correlations with GDP for the nominal interest rate, CPI inflation, consumption, GDP and the current account-consumption ratio. Our model performs reasonably well in terms of volatilities, but as with the exchange rate measures, does not fully capture the persistence of the data.

5 Policy experiments

Having analysed the moments generated by our model, this section uses the calibrated model to carry out a number of policy experiments. In particular, we ask if positive supply-side shocks would be consistent with an appreciation of the equilibrium sterling exchange rate since 1996. We first analyse the steady-state real exchange rate response to productivity shocks and to a change in the competitive environment of the goods and labour markets. Having analysed the steady state, we then consider the dynamic adjustment of the economy towards this new steady state. In the analysis of both the steady state and the dynamic adjustment, we refer to the real exchange rate and the three channels that cause it to deviate from unity; in terms of levels they are the market segmentation channel: $\left(\frac{SP_H^*}{P_H}\right)^{\upsilon^*}\left(\frac{SP_F^*}{P_F}\right)^{1-\upsilon^*}$, the home bias channel: $\left(\frac{P_F}{P_H}\right)^{\upsilon-\upsilon^*}$ and the internal real exchange rate channel: $\left(\frac{P_{N^*}}{P_T^*}\right)^{1-\gamma^*}\left(\frac{P_N}{P_T}\right)^{\gamma-1}$.

In recent years, policy-makers have taken account of the possible impact of perceived supply-side improvements in the economy.[40] These changes can be characterised as shocks to potential output and divided into improvements in product market competition,[41] total factor productivity shocks and structural changes in the labour market. This paper does not attempt to quantify the extent of any such changes. In this section we use our model to examine whether any or all of these shocks might be consistent with the observed behaviour of sterling.

In our model, firms use labour as their primary input and total factor productivity can be varied independently in each sector, both at home and abroad. The model allows us to explore the impact of improvements in product market competition by varying the degree of monopolistic distortion, Φ^j, in different sectors and markets. The overall degree of monopolistic distortion in any given sector depends on the elasticity of demand for the correspondent good. In modelling structural changes in the labour market, we focus on changes in the degree of monopolistic competition in the labour market designed to capture the possibility of a shift in 'bargaining power'.[42]

(39) We find that this ratio increases with the monetary authority's interest rate response to changes in the output gap, which reduces the volatility of output while increasing the volatility of the real exchange rate.
(40) See, for example, Section 1 of the May 2000 *Inflation Report*, and John Vickers' speech on 'Monetary policy and the supply side' in *Bank of England Quarterly Bulletin*, May 2000, pages 199-206.
(41) See Wadhwani (1999).
(42) In this paper, we do not try to model an increase in labour supply (participation) or a change in the equilibrium level of average hours worked. A plausible way to capture such shifts in consumers' preferences would be to modify the elasticity of labour supply.

5.1 The supply side and the steady-state real exchange rate

5.1.1 Permanent total factor productivity shock

In this section we investigate the implications of the United Kingdom experiencing a permanent improvement in TFP.(43) We consider two possibilities: an economy-wide shock and a sector-specific shock (to either the non-tradable or tradable sector). The distinction is important since sector-specific shocks alter relative productivity not only among the two countries but also among different sectors in one economy, inducing changes in the relative price of non-tradables. Tille, Stoffels and Gorbachev (2001) argue that much of the recent appreciation of the US dollar can be explained by an increase in productivity of the US traded sector. According to the Balassa-Samuelson proposition, countries with faster traded-sector TFP growth are associated with appreciating real exchange rates.

We first consider the case in which there is a permanent TFP improvement in all sectors. For a given 1% increase in TFP in the steady state, Table E decomposes the depreciation (negative as the exchange rate appreciates) of the real exchange rate into its component channels, the internal real exchange rate channel, the home bias channel and the market segmentation channel, all three of which add up to the overall effect on the real exchange rate.

For our calibration, an increase in productivity across all sectors implies a depreciation of the real sterling exchange rate.(44) Following a TFP improvement, it is possible to produce more at any given price (ie national supply rises). As a consequence, the relative price of home-produced goods must fall. The terms of trade, which are proportionate to the home bias channel, will deteriorate ($\frac{P_F}{P_H}$ will increase) to induce a shift in demand towards UK-produced goods. The internal real exchange rate also depreciates since domestic non-traded goods will now be relatively cheaper than the basket of imported and domestically-produced traded goods.(45) Note that in the steady state, the law of one price holds in relative terms for both traded goods, hence we have a zero contribution from the market segmentation channel.

Table E: Steady-state TFP shocks

		% depreciation of:		
	Internal RS	Home bias	Market segmentation	RS
1% increase in:				
Traded and non-traded TFP	0.138	0.151	0	0.289
Traded sector TFP	-0.346	0.386	0	0.040

Table E also shows that a domestic productivity shock confined to the traded sector results in an

(43) This is not to assert that there has been any permanent improvement in UK productivity growth over the relevant period, relative to the euro area. But this hypothesis is widely discussed.
(44) If TFP falls, then the real exchange rate would appreciate in an analogous manner.
(45) Note that the relative price of domestic traded to domestic non-traded goods, (P_H/P_N), does not change since both domestic sectors are affected in the same way. The movement in RER results from P_H being only one component of P_T.

appreciation in the internal real exchange rate (a negative depreciation), as domestic traded goods become cheaper relative to non-traded goods. This channel reflects the well-known Balassa-Samuelson proposition, which states that under certain circumstances, a domestic productivity increase biased toward traded goods may cause the domestic currency to appreciate in real terms. But unless domestic traded goods firms have no pricing power in home and foreign markets, a rise in productivity in the domestic sector will also lower the price of home-traded output relative to that abroad (ie $\frac{P_F}{P_H}$ will increase). This effect, which we capture through the home bias channel, works in the opposite direction to the Balassa-Samuelson effect in determining the net effect on the real exchange rate expressed in terms of the consumption price index. For our calibration, the home bias channel dominates, so we observe a small real exchange rate depreciation in steady state.

In general, the net effect on the real exchange rate depends on the weight on home-produced tradable goods, υ, and the overall weight on tradables, γ, in the consumption index. Intuitively when the weight on traded goods increases the Balassa-Samuelson effect tends to become less relevant. This occurs as γ increases.

Table F: Steady-state TFP shocks: sensitivity analysis

Variation in υ	$\upsilon = 0.513$	$\upsilon = 0.6$	$\upsilon = 0.9$
% Real depreciation from initial steady state:	0.040	0.048	0.074
Variation in γ	$\gamma = 0.301$	$\gamma = 0.2$	$\gamma = 0.8$
% Real depreciation from initial steady state:	0.040	0.020	0.162

Table F illustrates the net effect on the real exchange rate following a 1% increase in the level of home-traded goods sector TFP when we vary the relative weight on traded goods γ and the relative weight on the home-produced goods, υ. The larger is the share of home-produced traded goods in the consumption basket, γ and υ, the larger will be the depreciation. As υ rises, the home bias channel becomes more important and the internal real exchange rate channel becomes less important, thus increasing the depreciation.

To summarise our results:

- Conditional on our model and calibration, the steady-state real exchange rate always depreciates following a TFP improvement, though the quantitative dimension of this change is modest. For a 1% increase in TFP across all sectors, the real exchange rate depreciates by 0.289%.
- The internal real exchange rate appreciates following a rise in productivity in the domestic traded sector (Balassa-Samuelson effect), but the overall real exchange rate depreciates.

5.1.2 Permanent product market competition shock

In this section, we examine the effect on the equilibrium real exchange rate of a permanent shock to the degree of product market competition.[46] A substantial amount of recent work suggests that developments in information and communication technology, ICT, together with increased openness may affect consumers' price sensitivity, resulting in increased competition and lower mark-ups for firms. In our model, we capture this effect by analysing a permanent increase in the elasticity of substitution between differentiated goods, which determines the degree of monopolistic distortion.

In these experiments,[47] we assume that the degree of monopolistic distortion, measured by Φ^j for $j = N, H, F$ is reduced so as to make the UK product market more competitive.[48] Specifically, we initially assume starting values for the degree of monopolistic competition of $\Phi^H = \Phi^F = 0.1548$ and $\Phi^N = 0.1453$, implying a mark-up over unit costs of 17% in the non-traded sector and 18.3% in the traded sector. In our policy experiment we reduce the degree of monopolistic distortions faced by UK consumers by a reduction in the mark-up by 10%. Table G summarises the effects of reducing the degree of monopolistic competition in the product and labour markets. Starting with an overall reduction in the degree of monopolistic distortions in both domestic markets for traded goods on the real exchange rate and its components, we find that the real exchange rate depreciates by 0.71%. As in the previous experiment where we analysed the steady-state response to productivity improvements, we again decompose this real depreciation into its individual components. The internal real exchange rate channel appreciates as the relative price of home-produced non-traded to traded goods increases. Unlike in the previous experiment, the market segmentation channel is affected. An increase in the domestic market's competitive environment not matched in the foreign market causes the absolute law of one price to fail, and the relative price of traded goods sold at home to fall, contributing to a real depreciation. The increase in the degree of competitiveness of the domestic market for traded goods implies that the price of imports relative to that of exports rises marginally. This deterioration in the terms of trade affects the real exchange rate via the home bias channel which pushes the real exchange rate in a depreciation direction. Overall, the market segmentation channel dominates, resulting in a quantitatively modest depreciation of the real exchange rate.

Our sensitivity analysis carried out for all plausible values of γ and υ suggests that the real exchange rate depreciation is robust over the parameter range.

Assuming a sectoral increase in competition confined to the UK markets for UK-produced traded goods also yields a real depreciation of the exchange rate (see second row of Table G), though of a lower magnitude (around 0.25% for a 10% decrease in Φ^H) than in the previous experiment. The home bias channel via the terms of trade depreciates as output of domestically-produced traded

(46) The type of shock analysed in this and in the next section reduces the degree of monopolistic distortions. Such a shock drives the relevant market closer to its competitive optimum in terms of supply and price.
(47) In Tables E and F, as well as in the dynamic analysis below, all deviations of the real exchange rate are deviations from a steady state that is normalised around $P^F/P^H = 1$. For this steady-state analysis, all deviations are from the initial non-normalised steady state.
(48) Recall that *H*,*F* and *N* refer to the goods consumed in the Home country, ie the domestically-produced traded good, the foreign-produced traded good and the domestic non-traded good respectively.

goods expands. The internal real exchange rate channel appreciates. Since the shock is asymmetric, the internal real exchange rate appreciates less than in the previous example (around 0.66%) as the price of home-produced traded goods falls relative to non-traded goods prices. In this experiment, only the steady-state relative price of home-produced goods at home and abroad changes. Given that home tradables are only a small share of the foreign consumption of traded goods, the market segmentation channel only contributes a small amount to the overall real depreciation.

Table G: Steady-state shocks to product and labour market competition

	% depreciation of:			
	Internal RS	Home bias	Market segmentation	RS
Product market distortions				
10% reduction in:				
Φ^H and Φ^F	-1.194	0.073	1.831	0.710
Φ^H	-0.664	0.753	0.163	0.252
Φ^N	1.118	-0.074	0	1.044
Labour market distortions				
10% reduction in:				
Φ^w	0.693	0.763	0	1.458

Turning to the case in which only the market for non-traded goods (third row of Table G) experiences an increase in competitiveness, we find, as before, that the real exchange rate depreciates, this time by around 1.0%. The intuition for this is that if the market for domestic non-traded goods becomes more competitive, output of non-traded goods rises, hence the relative price of traded to non-traded goods rises. This time, there is no market segmentation channel affecting the real exchange rate; instead we observe a depreciation of the internal real exchange rate caused by a fall in the price of non-traded goods. The terms of trade decline because as the relative price of non-traded to traded goods falls, consumers switch demand from domestic and foreign-produced traded goods towards non-traded goods. Since consumers have a bias for home-produced traded goods, P^F falls by more than P^H, causing the terms of trade to appreciate. This appreciation of the terms of trade affects the real exchange rate via the home bias channel. The appreciation via the home bias channel is, however, less than the depreciation working through the internal real exchange rate channel, thus the net result is a real depreciation.

In summary we have found that:

- Conditional on our model and calibration, the real exchange rate always depreciates following an increase in UK product market competition. The quantitative dimension of the real depreciation is again fairly modest at about 1.0% for a 10% reduction in monopolistic distortions to the domestic non-traded goods sector.

- For sectoral increases in competitiveness, the internal real exchange rate displays more variability than the real exchange rate since its change is needed in order to redirect demand between domestic sectors.

5.1.3 Permanent labour market competition shock

In this experiment, we attempt to capture the effects of increased labour market competition, modelled by a decline in the mark-up of wages over the marginal rate of substitution of consumption for labour. As this mark-up falls the labour market moves closer towards a competitive market structure where individual suppliers of labour face a horizontal labour demand curve at the given wage. The fourth row in Table G shows the effects on our real exchange rate measures of a reduction in the degree of monopolistic distortion in the labour market by 10%. Recall that we assume the same degree of monopolistic distortion in both sectors, so a reduction affects both domestic production sectors in the same way. The terms of trade via the home bias channel deteriorate because a fall in Φ^{w} reduces the economy-wide wage level which, given that firms set prices as mark-ups over unit costs, lowers the price of home-produced exports relative to foreign-produced imports. A second channel affecting the real exchange rate is the internal real exchange rate channel. A depreciation of the terms of trade, *ceteris paribus*, causes our internal real exchange rate channel to depreciate. The market segmentation channel does not affect the real exchange rate in this scenario. In summary, the real exchange rate depreciates in response to a reduction in the degree of monopolistic distortion to the labour market.

5.2 The supply side and the adjustment towards the steady state

The main conclusion of our analysis so far is that in this model and for our calibration, realised supply-side improvements will imply a long-run depreciation of the real exchange rate. In this section, we examine the dynamic adjustment following a supply-side improvement by looking at the impulse response of the variables of interest. In particular, we want to see if a short-run appreciation of the real exchange rate is compatible with its long-run depreciation.

When prices and wages are sticky, the real exchange rate and the other macroeconomic variables will adjust differently from the case in which prices and wages were fully flexible. We emphasise these differences by using the concepts of gaps which represent the difference between the sticky-price adjustment and the 'shadow' flexible price adjustment. In what follows we will introduce and use the concepts of output gap, terms of trade gap, real exchange rate gap and current account gap.[(49)]

5.2.1 Current TFP shocks

We start by considering a 1% permanent increase in total factor productivity in the United Kingdom affecting only the traded goods sectors. In Charts 1 and 2 we plot the response of all three real exchange rate measures, the current account, domestic nominal interest rates, CPI

(49) Whereas an output gap is straightforward to identify in theory, we recognise that in practice it may be extremely difficult to observe and measure, and monetary policy makers are therefore likely to examine a range of different indicators of demand pressure on inflation.

inflation and the output gap, defined as the difference between real output under sticky and under flexible prices, following a 1% permanent increase in total factor productivity localised in the traded goods sector. In addition to these we also plot the consumption gap differential between the United Kingdom and the euro area, the real interest rate gap differential between the two economies. These two gap measures are used in analysing the dynamics of the real exchange rate. Throughout, the dotted lines represent the flexible price equilibrium (ie the equilibrium value of our variables when prices and wages are perfectly flexible).

The top panel of Chart 1 shows the impulse response of the real exchange rate and the different real exchange rate channels that add up to the real exchange rate. The three channels we analyse are: the internal real exchange rate channel, the home bias channel and the market segmentation channel. The real exchange rate depreciates on impact, continues to depreciate for a further period, before appreciating towards its new steady state analysed in Section 5.1. The increase in TFP in the domestic traded goods sector raises domestic inflation and price stickiness results in a negative output gap. Given the weights on inflation and the output gap on our assumed interest rate 'rule', the domestic monetary authority responds by reducing the nominal interest rate. The real interest rate gap differential is negative. Real uncovered interest rate parity thus requires an expected real appreciation, which is achieved by an initial over-depreciation. The excess supply in our model is accommodated domestically by a rise in the terms of trade as can be seen by the response of the home bias channel which is proportionate to the terms of trade. The internal real exchange rate channel contributes towards a real appreciation as the relative price of non-traded goods rises, as the Balassa-Samuelson proposition suggests. As we saw in our calibration exercise the current account gap is pro-cyclical implying that output rises initially by more than domestic consumption of traded goods. Whereas the real interest rate gap differential helps to explain the dynamics of the real exchange rate, the initial impact of the real exchange rate following a shock can be analysed with the consumption gap differential. Throughout, we observe that, on impact, the consumption gap differential is positively correlated with the real exchange rate gap. The reason is that real exchange rates and marginal utilities of consumption at home and abroad are approximately related in expected first difference terms.[50] Changes in the real exchange rate are then related to expected changes in the consumption path differential. The real exchange rate adjusts to close this gap differential. A positive gap differential is closed by a shift in consumption from home to foreign consumers, which is achieved through a real depreciation which raises the price of imported goods in the United Kingdom.

When the productivity increase occurs in the non-traded goods sector (see Charts 3 and 4) we also find a real depreciation. The depreciation comes about from a strong depreciation of the internal real exchange rate channel. The remaining two of our real exchange rate channels move in the opposite direction. The home bias channel, which is proportional to the terms of trade, appreciates as the relative price of home-produced traded goods increases, the same effect results

(50) To be precise this relationship depends also on the term δb_t, for very low values of δ as we assume this term does not have a significant quantitative effect.

Chart 1: Permanent TFP shock to the domestic traded goods sector

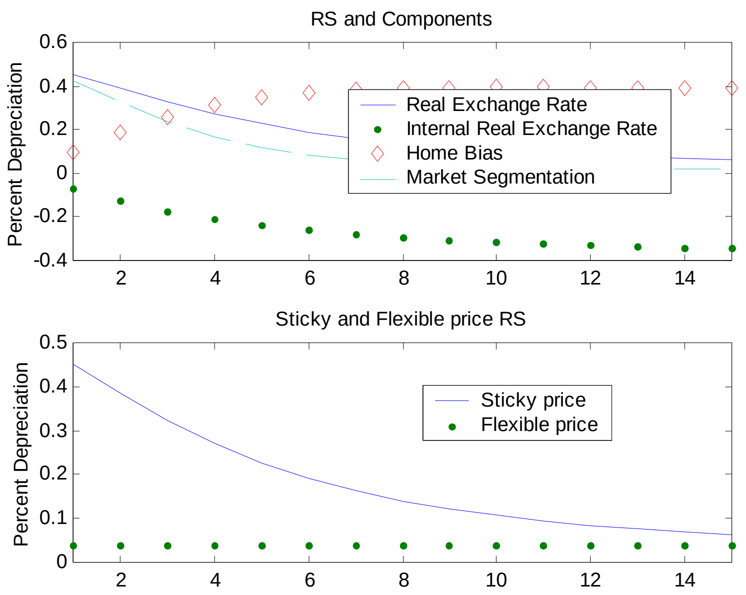
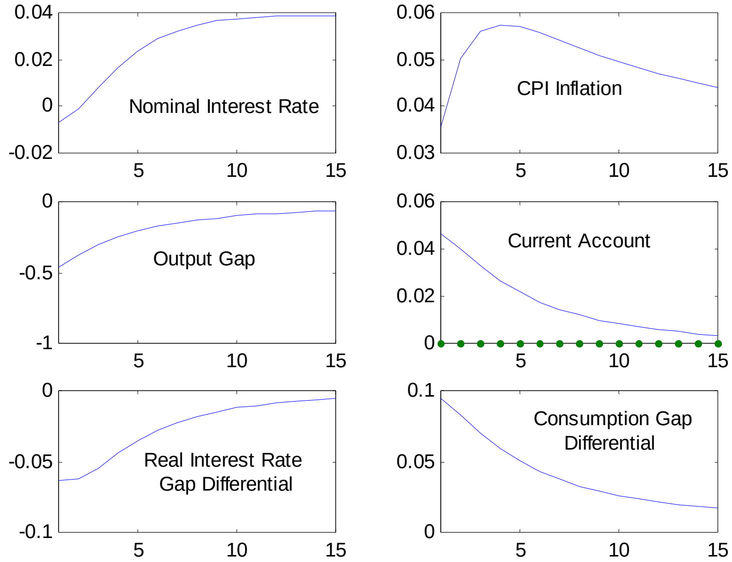


Chart 2: Permanent TFP shock to the domestic traded goods sector



in an appreciation via the market segmentation channel. Given that firms set different prices for different markets, the law of one price for domestic traded goods does not hold; in particular the UK price of UK tradables is greater than the euro-area price of UK goods expressed in sterling. This causes the market segmentation channel to appreciate. Given that the domestic non-traded goods sector is much larger in terms of consumption share than the domestic traded goods sector, a proportional reduction in the price of non-traded goods will have a larger impact on the overall price level and thus the real exchange rate will depreciate by more than in the previous policy experiment. Given the relative size of the domestic non-traded goods sector and the real depreciation, overall UK inflation falls.[51] Unlike in the previous policy experiments, the output gap is positive throughout the transition. The output gap of the non-traded sector is negative (due to sticky prices) but as the relative price of domestic traded goods increases, firms in that sector expand output above the flexible price level. Given that this real depreciation is associated with an increase in the non-traded goods sector's productivity, the shift in demand towards the home-produced goods results in a positive output gap. Conditional on the weights on inflation and output gap, in the assumed monetary policy reaction function, the nominal interest rate falls.

Since the real exchange rate continues to appreciate in the first few periods of the transition, we observe a corresponding positive real interest rate gap differential during that stage of the transition. Note that we observe a negative real exchange rate gap, so that in real terms the exchange rate is initially over-valued, thus the current account moves into deficit.[52] The negative real exchange rate gap is associated with a negative consumption gap differential. To close this gap domestic consumers must consume relatively more. To achieve this, the real exchange rate must initially undershoot its new steady-state level.

Given the linearity of our model, the initial response to a permanent shock to total factor productivity affecting both production sectors can be analysed by summing the initial responses of the previous two simulation exercises. Given that in both of the previous exercises the real exchange rate depreciates on impact, the initial response of the real exchange rate to an economy-wide TFP shock is also to depreciate.

Summarising the experiments we note that:

- Given our model and calibration, for plausible parameter values, realised supply-side improvements are associated with a real exchange rate depreciation in the short run as well as in the long run.
- The sectoral origin of the shock is important quantitatively, and in determining the response of the different real exchange rate channels.

(51) Specifically, inflation falls in the non-traded and imported goods sectors and rises in the home produced traded goods sector.
(52) Also, since the productivity improvement takes place in the non-traded goods sector, any initial increase in overall domestic consumption that does not fall on non-traded goods tends to worsen the current account balance.

Chart 3: Permanent TFP shock to domestic non-traded goods sector

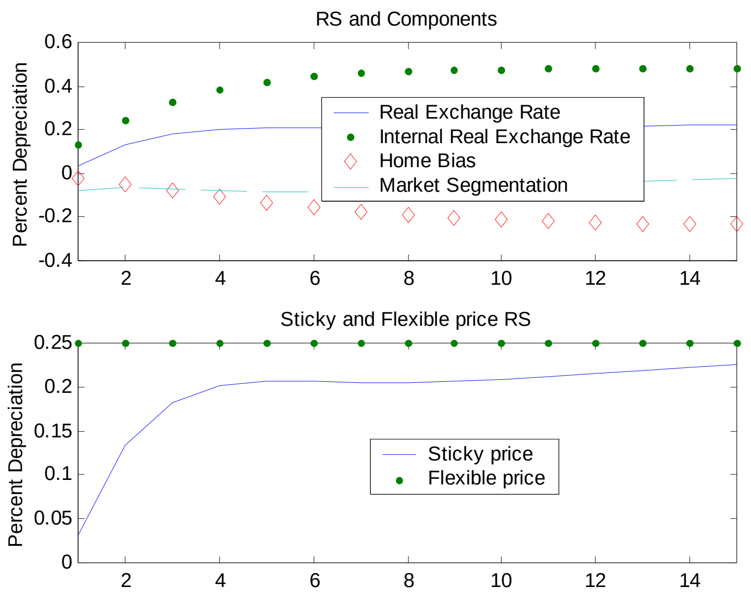


Chart 4: Permanent TFP shock to domestic non-traded goods sector

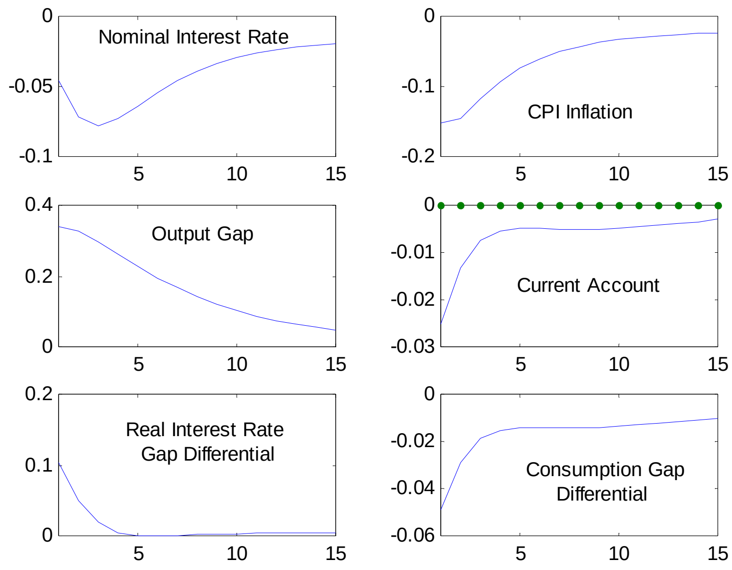
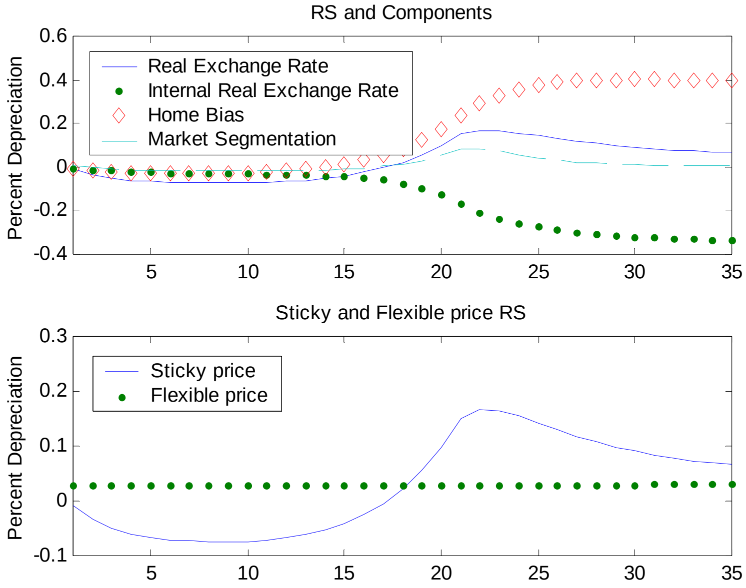


Chart 5: Anticipated TFP shock to domestic traded goods sector



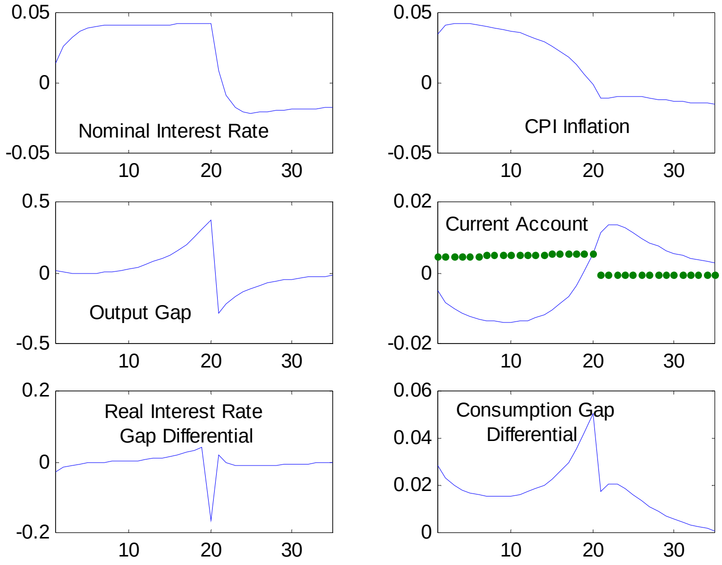
5.2.2 *Anticipated TFP shocks*

Our analysis has so far explored the dynamic implications of realised productivity shocks for our variables of interest. In short, an unexpected realised increase in productivity leads to a depreciation of the real exchange rate. One possible way to reconcile the observed persistent real appreciation of sterling with the possibility of a positive relative supply-side shock is to consider the implications of an anticipated productivity shock.

In general an expected increase in productivity will induce higher consumption because households anticipate that they will be richer in the future and will smooth their consumption over time. Since the domestic supply improvement has not yet occurred, this will generate a current account deficit coupled with a real exchange rate appreciation in order to redirect demand towards foreign-produced goods. Specifically, we consider the case of a 1% expected permanent increase in the total factor productivity in the UK traded goods sector. This TFP improvement is expected to occur five years (20 quarters) from the initial period. We assume that agents can correctly anticipate a future technical innovation and that they are only surprised by its announcement. In Charts 5 and 6 we plot the impulse response of our variables of interest.

There are two parts to the adjustment path. After the shock occurs, the dynamic behaviour of the main variable is similar to that described in the realised productivity shock case above. What is more interesting is the period between the announcement of the shock and its occurrence. Domestic agents anticipate the higher production and consume more. This will generate a current account deficit and capital inflows. Along this adjustment path the real exchange rate will appreciate.

Chart 6: Anticipated TFP shock to the domestic traded goods sector



Although there is an initial real exchange rate appreciation, we observe a positive consumption gap differential.(53) The path of the real exchange rate can be explained using the real interest rate gap differential. A negative gap is associated with an appreciating real exchange rate, while a positive gap is associated with a depreciating real exchange rate.

Summarising this experiment:

- For expected future productivity improvements, our model suggests a quantitatively modest appreciation of the real exchange rate in the initial periods before the productivity increase occurs, followed by a depreciation of the real exchange rate in the long run.

6 Conclusions

We have analysed the implications of supply-side shocks for the equilibrium real exchange rate in a two-country dynamic general equilibrium model with nominal rigidities. In our model, current supply-side improvements lead to a real exchange rate depreciation. In particular, we show that for our UK-euro calibration, equilibrium improvements in the degree of both product and labour market competition lead to real depreciations. Steady-state increases in total factor productivity also lead to a depreciation of the equilibrium real exchange rate, regardless of which sector the TFP increase is concentrated in. These results suggest that the mechanism suggested by the Balassa-Samuelson proposition that link a real appreciation to productivity improvements in the

(53) The link between the consumption gap differential and the real exchange rate breaks down because the transaction cost associated with foreign bond holdings are not small enough for the relationship to hold for all levels of foreign bond holdings.

traded goods sector can, for a plausible calibration, be insufficient to offset the impact of increased supply in an imperfectly competitive market. The impulse response associated with such a permanent shock indicates an exchange rate that over-depreciates in the initial period. When the same shock is expected to occur in the future, however, the model predicts a quantitatively modest real appreciation in the short to medium run, followed by the same equilibrium depreciation. In this case the anticipated supply shock is initially offset by a positive demand shock creating an excess demand for home-produced goods.

Our model is of course based on a number of simplifying assumptions that facilitate our analysis considerably. We have emphasised throughout the paper that the results of our experiments are contingent on the model, and to some extent on the chosen calibration. Various additional or alternative channels by which the shocks examined could affect the exchange rate may be suggested.

The shocks to technology that we have analysed assume that enhanced TFP increases potential output of all existing firms within the affected sector, thus shifting the economy's production productivity frontier outwards. Bowman and Henderson (1999) show that, in a deterministic overlapping-generations model, such a TFP increase can have temporary demand effects working through changes in the government's debt to GDP ratio, thus making it more likely that the initial response of the real exchange rate is an appreciation. An alternative modelling strategy would be to analyse a technological innovation that results in a new variety of goods as suggested by Grossman and Helpman (1991). This causes a shift in demand towards the innovating economy, as in models of creative destruction. In such a model, the demand effect of the technology shock might well result in a different conclusion to ours.

The transitional dynamics could be enriched by modelling capital accumulation subject to adjustment costs, which might also improve the model's ability to match the moments of the data. Allowing agents to hold both foreign and domestic equities would also permit the analysis of interesting cross-border equity flows that are commonly associated with asymmetric TFP growth.

Our analysis of shocks to the degree of competitiveness in the goods and labour is at present confined to the steady state. Giannoni (2000) shows how shocks to mark-ups can be analysed in a dynamic closed-economy framework. Incorporating such an extension into our framework would allow us to analyse the dynamics of shocks to the degree of competition and compare these with impulse responses associated with TFP shocks.

References

Batini, N, Harrison, R and Millard, S (2001), 'Monetary policy rules for open economies', *Bank of England Working Paper no. 149.*

Benigno, G (2001), 'Real exchange rate persistence and monetary policy rules', London School of Economics, unpublished.

Benigno, G and Benigno, P (2000), 'Monetary policy rules and the exchange rate', LSE and New York University University, unpublished.

Benigno, P (2001), 'Price stability with imperfect financial integration', *CEPR Working Paper*, No. 2854.

Bergin, P R and Feenstra, R C (2001), 'Pricing-to-market, staggered contracts, and real exchange persistence', *Journal of International Economics*, forthcoming.

Betts, C and Devereux, M (1996), 'The exchange rate in a model with pricing-to-market', *European Economic Review*, Vol. 40, pages 1,007-21.

Bowman, D H and Henderson, D (1999), 'Productivity improvements and fiscal reactions in a two-country world', Federal Reserve Board, unpublished.

Calvo, G A (1983), 'Staggered prices in a utility-maximising framework', *Journal of Monetary Economics*, Vol. 12, pages 383-98.

Cavallo, M and Ghironi, F (2001), 'Net foreign assets and the exchange rate: redux revived', New York University and Boston College, unpublished.

Chari, V V, Kehoe, P J and McGrattan, E R (2000), 'Monetary shocks and the real exchange rates in sticky price models of international business cycles', *NBER Working Paper*, No. 7869.

Chari, V V, Kehoe, P J and McGrattan, E R (2001), 'Can sticky price models generate volatile and persistent real exchange rates?', *Federal Reserve Bank of Minneapolis Research Department Staff Report No. 277*.

Corsetti, G and Pesenti, P (2001), 'International dimension of optimal monetary policy', Yale University, unpublished.

Devereux, M B and Engel, C (2000), 'Monetary policy in the open economy revisited: price setting and exchange rate flexibility', *NBER Working Paper*, No. 7655.

Erceg, C J, Henderson, D W and Levin, A T (2000), 'Optimal monetary policy with staggered wage and price contracts', *Journal of Monetary Economics*, Vol. 46(2), pages 381-413.

Faust, J and Rogers, J (1999), 'Monetary policy's role in exchange rate behavior', International Finance Division, Federal Reserve Board, unpublished.

Gali, J and Gertler, M (1999), 'Inflation dynamics: a structural econometric analysis', *Journal of Monetary Economics*, Vol. 44, October, pages 195-222.

Giannoni, M P (2000), 'Optimal interest-rate rules in a forward-looking model, and inflation stabilisation versus price-level stabilisation', Federal Reserve Bank of New York, unpublished.

Grossman, G M and Helpman, E (1991), 'Quality ladders in the theory of growth', *Review of Economic Studies*, Vol. 58(1), January, pages 43-61.

Inflation Report, Bank of England, various issues.

Kollmann, R (2001), 'Macroeconomic effects of nominal exchange rate regimes: new insights into the role of price dynamics', University of Bonn, unpublished.

Martins, J S *et al* (1996), 'Mark-up pricing, market structure and the business cycle', *OECD Economic Studies*, Vol. 27, pages 71-105.

McCallum, B T and Nelson, E (1999), 'Nominal income targeting in an open-economy optimizing model', *Journal of Monetary Economics*, Vol. 43, pages 553-78.

Neiss, K S and Nelson, E (2001), 'The real interest rate gap as an inflation indicator', *Bank of England Working Paper no. 130*.

Obstfeld, M and Rogoff, K (1996), *Foundations of international macroeconomics*, MIT Press, Cambridge, MA.

Obstfeld, M and Rogoff, K (2000), 'New directions for stochastic open economy models', *Journal of Internationl Economics*, Vol. 50(1), pages 117-53.

Rogers, J (1998), 'Monetary shocks and real exchange rates', *International Finance Discussion Papers*, No. 612, Board of Governors of the Federal Reserve System.

Rogoff, K (1996), 'The purchasing power parity puzzle', *Journal of Economic Literature*, Vol. 34, pages 647-68.

Rotemberg, J J and Woodford, M (1997), 'An optimization-based econometric framework for the evaluation of monetary policy', in Bernanke, B S and Rotemberg, J J (eds), *NBER Macroeconomic Annual* 1997, MIT Press, Cambridge, MA.

Rotemberg, J J and Woodford M (1998), 'Interest rate rules in an estimated sticky price model', in Taylor, J B (ed), *Monetary policy rules*, University of Chicago Press for NBER.

Sargent, T J (1989), 'Two models of measurements and the investment accelerator', *Journal of Political Economy*, Vol. 97(2), pages 251-87.

Sbordone, A (2000), 'An optimising model of US wage and price dynamics', Rutgers University, unpublished.

Smets, F and Wouters, R (2001), 'Monetary policy in an estimated stochastic dynamic general equilibrium model of the euro area', European Central Bank, unpublished.

Tille, C, Stoffels, N and Gorbachev, O (2001), 'To what extent does productivity drive the dollar?', *Current Issues in Economics and Finance*, Vol. 7, No. 8, Federal Reserve Bank of New York.

Turnovsky, S J (1997), *International macroeconomic dynamics*, MIT Press, Cambridge, MA.

Wadhwani, S B (1999), 'Sterling's puzzling behaviour', *Bank of England Quarterly Bulletin*, November, pages 416-27.

Warnock, F E (2000), 'Idiosyncratic tastes in a two-country optimizing model: implications of a standard presumption', *International Finance Discussion Paper*, No. 631, Board of Governors of the Federal Reserve System.