

Medium Term Exchange Rate Dynamics

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Highly provisional – not to be quoted but comments welcome. My thanks to Peter Westaway for first encouraging me to develop the 'Three Term' model outlined in this paper.

1. Introduction

The behaviour of exchange rates for some of the major currencies over the last few years have highlighted our lack of understanding of medium term exchange rate dynamics. Although sterling has depreciated during this year, its large appreciation in 1997 and the subsequent five-year substantial overvaluation relative to PPP remains something of a mystery. A number of ingenious explanations have been put forward for the weakness of the Euro at the end of the nineties, but none has received widespread acceptance. A common explanation for the strength of the dollar over this period is that it is a response to a favourable productivity shock, but there has been little qualitative analysis of this hypothesis. (Bailey, Millard and Wells (2001) is one exception.)

In this paper we examine whether certain basic macroeconomic shocks, including technology shocks, can in principle generate large and highly persistent (medium term) deviations from PPP. We assume that international trade is characterised by the sale of differentiated goods in imperfectly competitive markets, so that medium term changes in capital flows will lead to corresponding swings in international competitiveness and hence the real exchange rate.

To examine this issue, section 2 outlines a model that explicitly distinguishes between the short, medium and long term (provisionally called the Three Term Model). The model is calibrated to represent either an economy like the UK, or a less open economy like the US. Section 3 presents the response of the model to various demand shocks coming from the private or public sector. Section 4 looks at an improvement in technical progress. Section 5 draws some general conclusions. In Appendix A, the model's response to some shocks is compared to the UK econometric model COMPACT.

2. Theoretical framework

A basic model we teach students to enable them to start thinking about exchange rate behaviour combines UIP, rational expectations and PPP. UIP implies

$$\begin{aligned}e_t &= E[e_{t+1} | I_t] + rd_t \\ rd_t &= r_t - rw_t\end{aligned}\tag{1.1}$$

where e is the log of the real exchange rate (where an increase is an appreciation), E is the expectations operator, r is the domestic real interest rate and rw the corresponding overseas rate. Using this equation one period ahead, taking expectations and applying the Law of Iterated Projections allows us to express UIP in terms of the expected exchange rate two periods ahead, and the current and one period ahead expected real interest rate differential. Repeating this $n-1$ times implies

$$e_t = E[e_{t+n} | I_t] + rd_t + E[rd_{t+1} + rd_{t+2} + \dots + rd_{t+n-1} | I_t]\tag{1.1'}$$

Assume that in the long run (i.e. for large n) the real exchange rate tends to some constant value given by PPP ($=e_{PPP}$). The equation

$$e_t = e_{PPP} + rd_t + E[rd_{t+1} + rd_{t+2} + \dots + rd_{t+n-1} | I_t]\tag{1.1''}$$

then provides a complete model of the exchange rate once expected rd and e_{PPP} are known.

If we are in a Keynesian world where governments or central banks can attempt to influence real interest rate differentials in the short run, then we can use (1.1'') to do various experiments examining short term exchange rate dynamics. In doing this, we may leave students with the impression that the long run begins when the short run ends, so that deviations from PPP are entirely due to monetary policy. However evidence suggests this is not the case: deviations from PPP appear to be more long lasting than the Keynesian short run (e.g. Rogoff (1997)). This is the period of the medium term.

One of the best known attempts to model the real exchange rate over the medium term is John Williamson's FEER analysis. A number of related models have subsequently been developed (e.g. Stein's NATREX approach), and it is now possible to talk about DEERs, BEERs, PEERs etc. Wren-Lewis (2003) argues that these approaches differ more in their method of calculating equilibrium exchange rates than in their theoretical standpoint. A rather more useful demarcation from a theoretical point of view is between models that assume imperfectly competitive goods markets, and those that combine a perfectly competitive traded goods sector with a non-traded sector. In the remainder of this section I will outline a model of the former variety, whereas Bailey, Millard and Wells (2001) consider a model of the latter type.

Although it may be possible to derive the model presented here formally from microfoundations (along the lines of Obstfeld-Rogoff, 1995, for example), for clarity we move immediately to aggregate relationships.¹ In some cases we distinguish between different variants of the model's equation, if different relationships apply over the short run, medium run or long run. In our simulations, we can show paths for any particular variable over all three time frames (although, for permanent shocks, the steady state model involves no dynamics).

It is useful to show the steady state response to shocks, as the dynamics implied by intertemporal consumption can be long lasting. It is more unusual to explicitly distinguish short term and medium term dynamics. However, I have argued elsewhere that a key element of the FEER approach ('internal balance') is its abstraction from Keynesian effects and therefore monetary policy (see Driver and Wren-Lewis, 1998, for example). The medium term part of the Three Term model is therefore a FEER type model. Distinguishing between the medium and short term allows us to examine the relative importance of nominal inertia in determining short term exchange rate paths. No other dynamic elements are introduced into the short term model, so it is not designed to be a realistic description of the actual response to shocks. The data period is quarterly throughout, and constants in equations are omitted for clarity. We also assume perfect foresight.

One of the shortcomings of the traditional implementation of the FEER approach is that it is normally static. A judgement is made about the level of medium term capital flows, and a trade model is used to calculate the real exchange rate that will deliver the current account counterpart to those capital flows. However, as we shall see, the response of medium term capital flows to macroeconomic shocks is likely to vary significantly over the medium term, and so any attempt to 'average out' such paths may be problematic.

In the Three Term model, real exports and imports are determined using standard demand curves, but with one non-standard element.

$$\ln(x_t / k_t) = \ln(yw_t) - \alpha e_t \quad (1.2)$$

$$\ln(m_t) = \ln(c_t + i_t + g_t) + \beta e_t \quad (1.3)$$

where x and m are real exports and imports, yw is 'world demand', c is domestic private consumption, g public consumption and i investment. α and β (and all subsequent Greek letters) are parameters. The non-standard element is the presence of the capital stock in the export equation. This is designed to capture the idea that any increase in capital will also involve the production of new varieties of goods.

If new capital produces new varieties rather than simply more of existing varieties, then generating a demand for these new goods will not require any reduction in price. Krugman (1989) suggests that this distinction may help explain some puzzling features of traditional aggregate export equations. Proxying the production of new varieties using the capital stock is

¹ This statement is qualified because of the trade relationships used in the model, for reasons discussed below.

far from ideal, but we show below how important it is to allow for this effect in some way when considering technical progress.

Consumption comes from a Blanchard/Yaari constant probability of death model, so it is a constant proportion of total wealth.

$$c_t = \chi(h_t + wpn_t) \quad (1.4)$$

Here h is human wealth and wpn personal financial wealth. Human wealth in the short and medium term is given by

$$h_t = (h_{t+1} + w_t n_t e_t^\delta - tax) / (1 + r_t + \varepsilon) \quad (1.5sm)$$

where wn is labour income, and the real exchange rate appears to reflect terms of trade gains. In steady state we can simply write

$$h_t = (w_t n_t e_t^\delta - tax) / (r_t + \varepsilon) \quad (1.5)$$

The government's budget constraint is

$$d_t = d_{t-1}(1 + r_t) + g_t - tax_t \quad (1.6sm)$$

where d is government debt, which in steady state is

$$d_t = (tax_t - g_t) / r_t \quad (1.6l)$$

We assume that government spending is a constant proportion of output

$$g_t = \phi y_t \quad (1.7)$$

but taxes are a constant proportion of wage income plus a debt feedback term.

$$tax_t = \varphi w_t n_t + \gamma(\hat{d}_t / \hat{y}_t) \quad (1.8)$$

where a $\hat{\ }^{\wedge}$ symbol indicates deviations from steady state. Personal wealth combines the value of equities (wco), government debt and overseas assets (wos)

$$wpn_t = wco_t + d_t + wos_t \quad (1.9)$$

Changes in overseas assets equal to current account in the short and medium term

$$wos_t = (1 + r_w)wos_{t-1} + x_t - m_t + gl(r_t - r_w) \quad (1.10sm)$$

where gl is a fixed gross stock. The corresponding steady state value of overseas assets is

$$wos_t = (m_t - x_t - gl(rw_t - r_t)) / rw_t \quad (1.10l)$$

Overseas assets are assumed to be denominated in domestic currency.
Investment is given by a q model in the short and medium term

$$i_t = \eta k_{t-1} + l(wco_{t-1} / k_{t-1} - 1) \quad (1.11)$$

where k is the capital stock (the first term reflects replacement investment), and wco is the value of the company sector. In steady state the second term disappears, as q equals one. The value of the company sector is given by discounted future profits

$$wco_t = (wco_{t+1} + y_t - w_t n_t) / (1 + r_t + \eta + \kappa) \quad (1.12sm)$$

which in steady state is simply

$$wco_t = (y_t - w_t n_t) / (r_t + \eta + \kappa) \quad (1.12l)$$

Here η is the depreciation rate, and κ represents a risk premium. In the short and medium term, the capital stock is related to investment

$$k_t = (1 - \eta)k_{t-1} + i_t \quad (1.13sm)$$

In steady state, this equation is identical to (1.11). Instead, the steady state capital stock comes from a first order condition for profit maximisation (see below).

The model is based on firms maximising profits subject to a Cobb-Douglas production function. As a result, we can write hours worked as

$$\ln(n_t) = \ln(y_t) - \ln(w_t) \quad (1.14)$$

In steady state, there will be a similar condition for the capital stock

$$\ln(k_t) = \ln(y_t) - \ln(r_t + \eta + \kappa) \quad (1.13l)$$

The real wage is determined in an imperfectly competitive labour market according to

$$\ln(w_t) = \ln(y_t / n_t) - \bar{\omega}(pop - n_t) \quad (1.14)$$

where pop is a fixed labour force. (This is therefore not a real business cycle model.)

Output supply (y_s) is given by the production function

$$\ln(y_s_t) = v \ln(n_t) - (1 - v) \ln(k_t) \quad (1.15)$$

In the medium and long run, output is equal to output supply:

$$y_t = y^s_t \quad (1.16m)$$

In the short term, we allow output to be demand determined, and the difference between output and supply to influence inflation.

$$y_t = c_t + i_t + g_t + x_t - m_t \quad (1.17)$$

$$\text{inf}_t = o \text{inf}_{t+1} + (1-o) \text{inf}_{t-1} + \pi(y_t - y^s_t) \quad (1.18s)$$

Here inflation can either be backward or forward looking, depending on the o parameter, In the simulations presented here we set o to zero (i.e inflation is backward looking).

What role does (1.17) play in the medium and long run, given (1.16m)? It can be thought of as determining the real exchange rate, via the equations for net trade. In the short run, the real exchange rate is given by UIP (1.1). In the medium and long run, UIP determines the domestic real interest rate, given world rates. Of course in the long run steady state this implies domestic and overseas real rates are identical, but this will not be true in the medium term. The real interest rate in the short term is determined by a monetary policy rule

$$r_t = \theta(\text{inf}_t - \text{target}) + r^w_t \quad (1.19s)$$

where target is the inflation target.

The calibrated parameter values are as follows

Table 2.1 Calibrated parameter values

Export competitiveness elasticity	α	1.0
Import competitiveness elasticity	β	1.0
Propensity to consume from total wealth (p.a.)	χ	0.06
Human wealth mark-up on interest rates (p.a.)	ε	0.02
Income effect from real exchange rate	δ	0.2
Fiscal feedback from debt to taxes (p.a.)	γ	0.1
Depreciation rate for investment (p.a.)	η	0.06
Response to Tobin's q (p.a.)	ι	0.20
Risk premium (p.a.)	κ	0.02
Wage equation unemployment effect	$\bar{\omega}$	0.2
Cobb-Douglas labour share	ν	0.7
Phillips curve parameter	π	0.1
Monetary policy inflation feedback on real rates	θ	0.5

The trade competitiveness elasticities are lower than microfounded studies using demand curves would suggest (e.g. Rotemberg and Woodford (1998)), but are much closer to empirical evidence at the aggregate level. If all exchange rate changes were fully passed through into imported goods prices, then δ would be equal to the share of imports in total demand (see below). However we modify this by two thirds to reflect strong empirical evidence of less than full pass through. In the most simple Blanchard/Yaari model, ε is the probability of death, and χ combines this with the rate of time preference, implying that the latter is 4% pa. The risk premium parameter κ is in fact derived from steady state relationships (see Appendix B).

Table 2.2 Steady state values

Share of exports/imports in total output (main case)	0.3 (0.1)
Gross overseas assets to output (annual)	2.5 (1.0)
Net overseas asset stock	0
Share of government spending in total output	0.2
Capital output ratio (annual)	2.5
Real interest rate (annual)	4%
Government debt to output (annual)	0.4
Inflation (annual)	4%
Population/Employment	1.05

The base case calibration for trade (which determines the first two rows, plus the δ parameter above) is designed to characterise a developed open economy like the UK, France or Germany. However for a productivity shock, we also look at a US/Euro case, which is given by the figures in brackets. In this case we assume only 50% pass through (so $\delta=0.05$).

The capital output ratio and the depreciation rate give the steady state investment share, which is 0.15. This, together with the assumed government spending share and zero net exports, implies a consumption share of 0.65. The assumptions about real interest rates and government debt imply taxes are 21.6% of output, but 31% of wage income. Human wealth is post-tax wage income divided by the $r+\varepsilon$, which is about 8 times the size of annual output.²

² In practice, both mark up parameters (ε and κ) are derived by residual. κ is determined by the need for the value of the firm to equal the capital stock in steady state. ε is solved out to ensure the real interest rate is equal to its steady state value. Appendix B presents the details.

3. Demand shocks

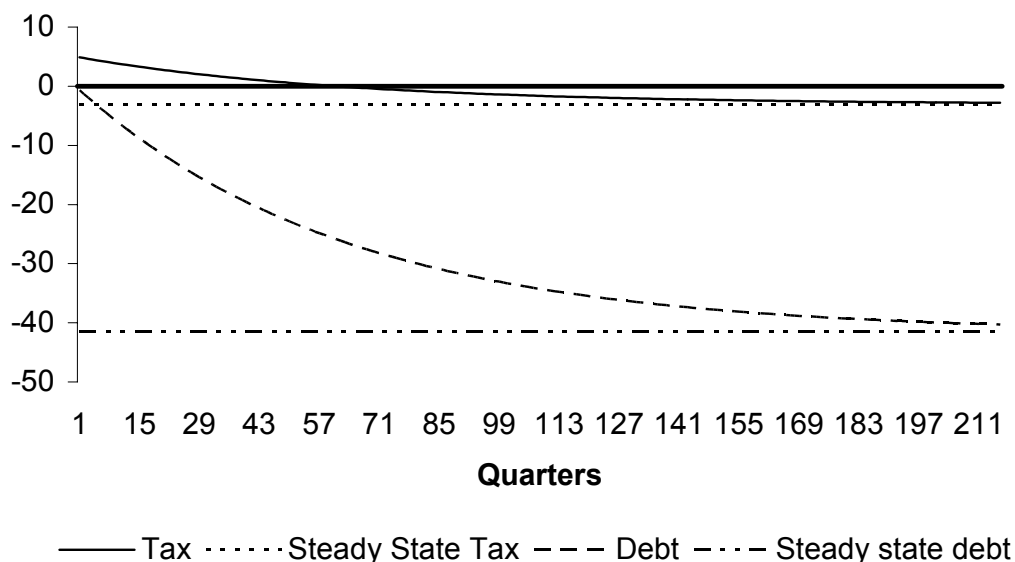
Fiscal shocks

Although fiscal policy has not been seen as an important determinant of recent medium term swings in real exchange rates, they have in the past, so in this section we begin by examining the impact of various fiscal shocks.

We look at three types of shock. The first is a permanent increase in tax rates, holding government spending fixed. Although in the short term this obviously raises the tax take, and therefore reduces disposable income, the long run impact is in fact to lower taxes. This is because, with fixed spending, the reduction in debt reduces interest payments, requiring lower taxes to balance the budget. In the long term, therefore, this shock represents a reduction in the stock of government debt. This is the kind of policy that appears to be implied by the fiscal rules of the Stability and Growth Pact, for example.

The specific shock we examine is a sustained shift in taxes worth 1% of GDP. Chart 3.1 plots the time path of taxes in government debt, with the horizontal lines representing their steady state values.

Chart 3.1 Permanent Tax Rate increase

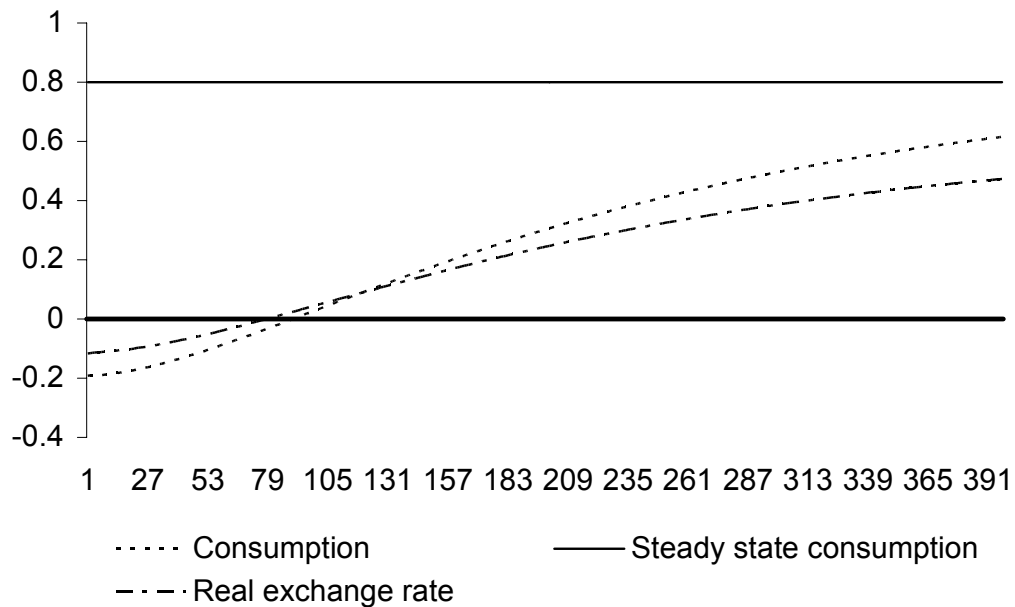


Although the increase in tax rates initially raises taxes rise by about 5%, the reduction in the stock of debt steadily reduces taxes, so that in the long run they fall by over 3%. Debt falls to a new steady state of about 40% below base. In both cases the steady state is reached after over 50 years.

Lower steady state taxes raise steady state consumption by just under 0.8%. As Chart 3.2 shows consumption initially falls, reflecting a decline in

human wealth: future tax cuts are discounted relative to higher current taxes. Although consumption is positive relative to base after about 25 years, its convergence on steady state is very gradual. The path of the real exchange rate reflects that of consumption: with virtually no change in the capital stock and output supply, changes in consumption are reflected in net trade, and movements in net trade are brought about by changes in competitiveness. However the size of the movements in the real exchange rate are small compared to the size of the shock: in steady state it appreciates by 0.6%.³

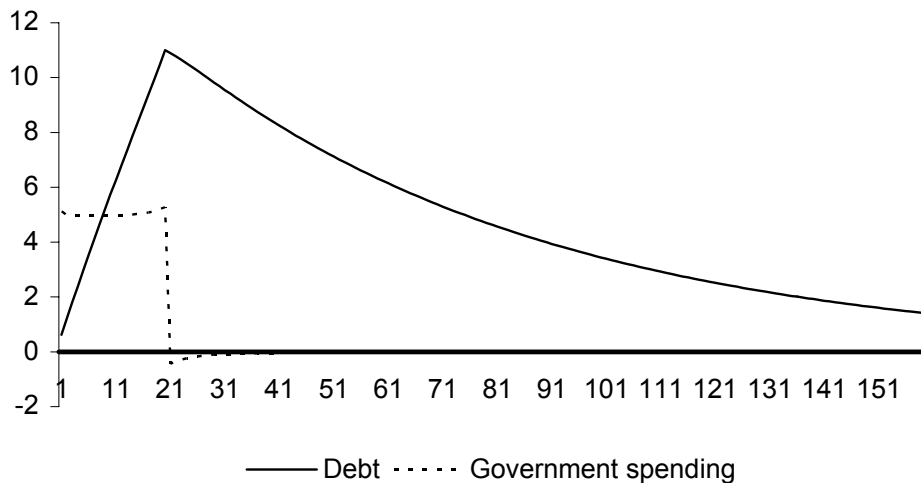
Chart 3.2 Permanent Tax Rate Increase



³ The impact on steady state wealth is negative. Although lower taxes would imply higher wealth (reflecting higher income), an appreciation has the opposite (and dominant) effect, reflecting the fact that the purchasing power of income and wealth is now higher. See Appendix B.

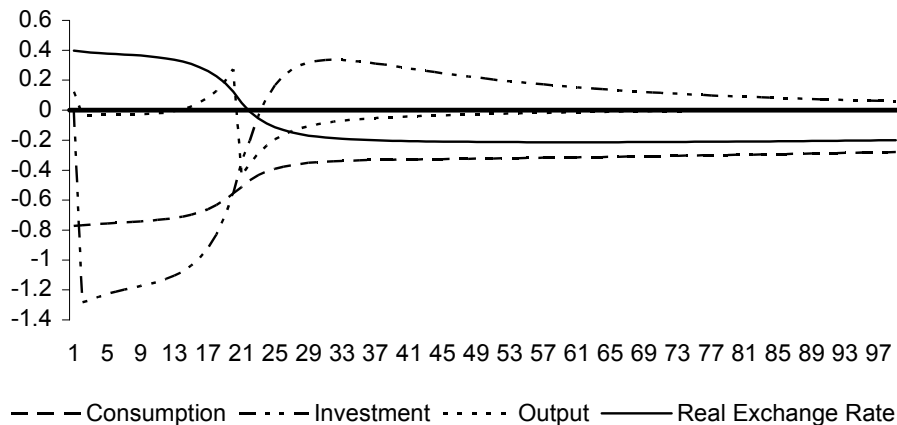
Our second fiscal shock involves a temporary increase in government consumption. This is likely to have a more noticeable impact on the real exchange rate because the extra spending feeds straight through into demand. (The model assumes that there is no direct offset by consumers through their spending.) Although taxes will have to rise to bring debt back down to base, this tax increase will be delayed compared to the spending increase. Chart 3.3 shows the impact on debt of a shift in spending worth 1% of GDP lasting for 5 years. (Government spending is not completely exogenous, but follows GDP.)

Chart 3.3 5 year government spending increase



The impact of the tax increase on consumption is also smoothed, so that for five years domestic demand for domestic output is significantly increased. Chart 3.4 plots percentage changes in consumption, investment, output and the real exchange rate.

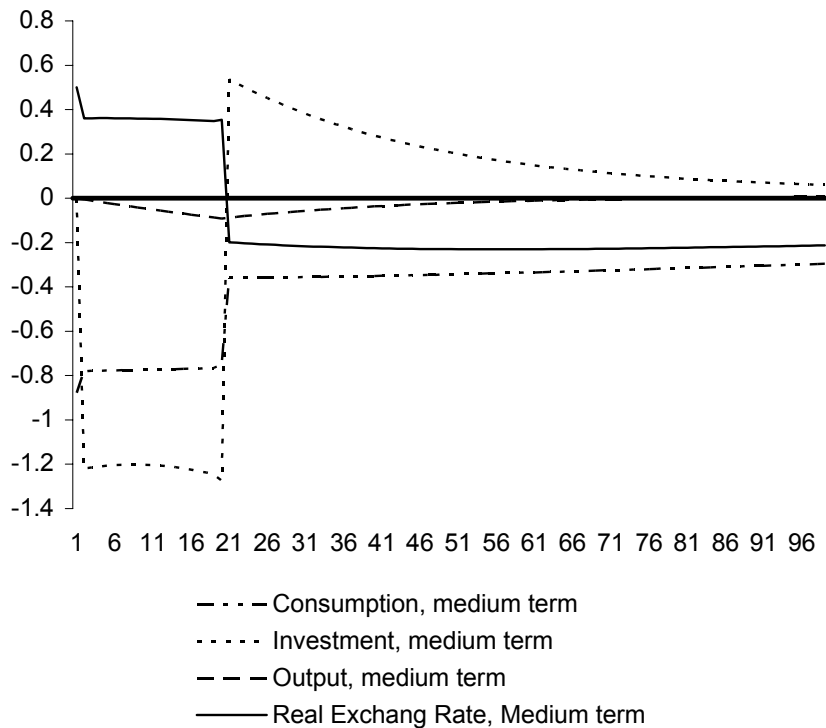
Chart 3.4 5 year government spending increase



Output is above output supply for most of the first five years, because output supply declines as investment falls. As a result, inflation rises. There is an initial appreciation in the real exchange rate of about 0.4%. However, once the government spending increase ends, the real exchange rate depreciates sharply. Higher interest rates are also why both consumption and investment fall. (There is a one period delay for investment.)

It would be wrong, however, to infer that the appreciation was the result of anti-inflationary monetary policy. Chart 3.5 plots the same variables for the medium term model.

Chart 3.5 5 year G increase, medium term



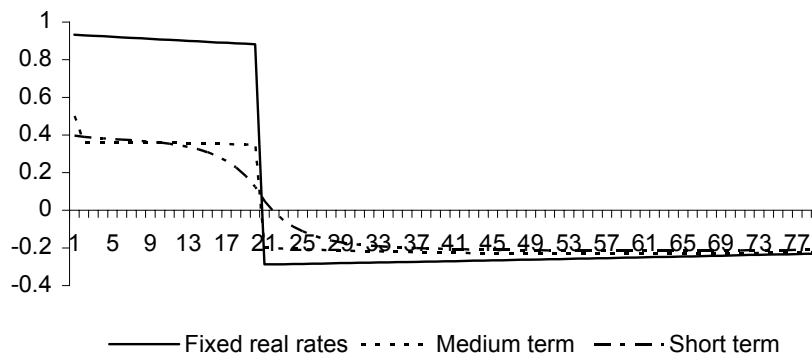
In this case output falls, following lower investment. The exchange rate still appreciates, because government spending raises demand, requiring a decline in net trade. In fact the appreciation is very similar to that in the short term model. As a result, UIP generates similar increases in real interest rates, producing similar profiles for investment and consumption. The main difference is that the medium term paths are less smooth.

We can also demonstrate the importance of the medium term effects on the exchange rate by reducing the coefficient on excess inflation in the monetary policy reaction function from 0.5 to 0.2. This has very little impact on the path for the real exchange rate. The main difference is that output is slightly higher, and inflation rises by almost twice as much. The impact of this fiscal expansion on the real exchange rate is therefore not large, whatever the stance of monetary policy. This is essentially because the movement in real

interest rates implied by the exchange rate path and UIP dampens the impact on demand, and therefore the real exchange rate.⁴

To see how important this last influence is, we can rerun the medium term model with fixed real interest rates. Chart 3.6 compares the real exchange rate response in the short term model, the medium term model, and then the medium term model with fixed real rates. (With fixed real rates, inflation would be uncontrolled in the short term.) The initial appreciation in the real exchange rate is almost doubled as a result of fixing real interest rates.

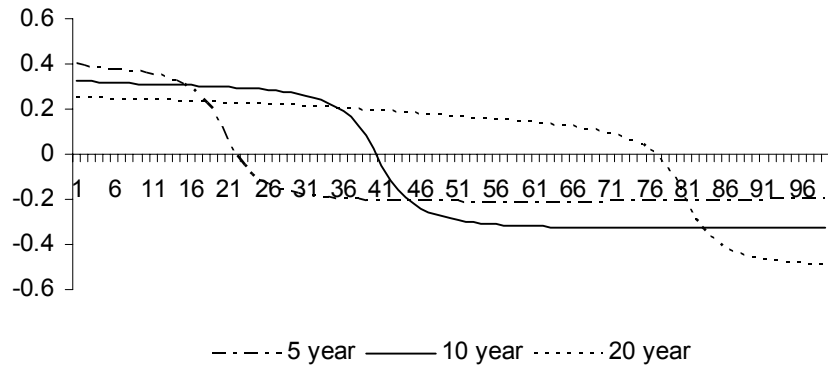
Chart 3.6 Five year G increase. The impact of endogenous and fixed real rates on the real exchange rate.



⁴ This UIP effect is partly offset by an income effect on consumption: an appreciation raises real incomes, adding to consumption. However as this effect works through human capital, the (discounted) exchange rate change over the future will influence current consumption

Chart 3.7 shows the path of the real exchange rate for shocks to government spending lasting 5 years, 10 years and 20 years. In each case the extra spending is initially bond financed, debt is higher as a result, and taxes have to rise to bring debt back to base.

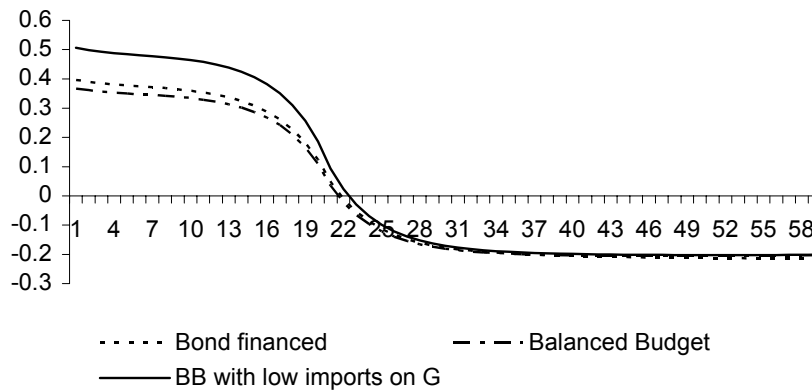
Chart 3.7 Impact of government spending increases lasting different periods on real exchange rate



The initial appreciation of the real exchange rate is smaller the longer the increase in spending lasts, because the tax burden involved is also increased, which reduces initial consumption. In the case of a twenty year rise in government spending, the real depreciation after twenty years is much greater than the appreciation beforehand. The reason is the same: the stock of debt built up for a twenty year increase in spending is much greater than for a five year increase, so the tax burden of servicing it is also greater.

The final fiscal shock we consider is a temporary balanced budget increase in spending. Taxes are raised by 1% of GDP at the same time as government spending, but only for 5 years. Chart 3.8 compares the real exchange rate path for this shock to the bond financed case: the differences are small, essentially because the departure from Ricardian Equivalence implied by Blanchard/Yaari is small. It is worth noting that if the balanced budget fiscal expansion was permanent, the exchange rate would actually show a very small depreciation (-0.03%). This is because lower consumption implies lower desired personal wealth, which means the total decline in private consumption implied by higher taxes is slightly larger than the increase in public consumption.

Chart 3.8 Impact of a 5 year Balanced Budget fiscal expansion on the real exchange rate



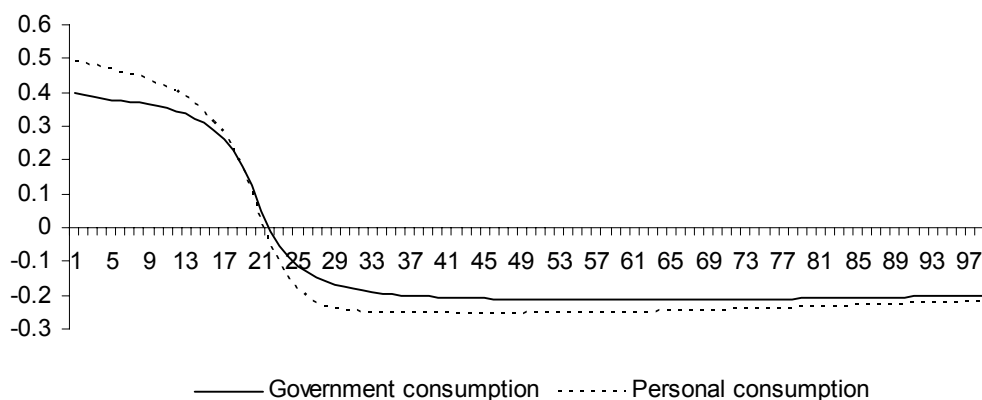
The impact of a permanent balanced budget fiscal expansion on the real exchange rate is discussed at length in Wren-Lewis et al (1996). There the possibility that public consumption may have a lower import content than private consumption is discussed. Chart 3.8 repeats the balanced budget shock, but using an import propensity for G that is half that for C. The initial impact on the real exchange rate is noticeably larger for obvious reasons. In this case a permanent balanced budget fiscal expansion would lead to an appreciation of about 0.15%.

These results suggest two general conclusions. First, although an increase in government spending may induce an initial appreciation, it is not that large in our model. Second, the subsequent depreciation once government spending returns to base may be just as large.

Consumption shocks

Suppose we shock consumption temporarily for 5 years, by applying a positive residual to the equation worth 1% of GDP. The results are very similar to the same shock to public consumption. The initial increase in the real exchange rate is about 0.5%, compared to 0.4% for the fiscal shock. The subsequent profile is very similar.

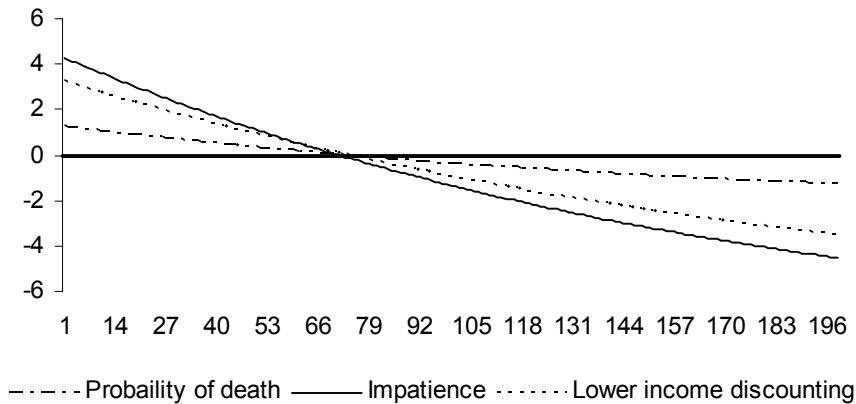
Chart 3.9 Real Exchange Rate response to 5 year consumption shocks



This may seem odd: surely we would expect more of an appreciation, because the impact of the fiscal shock was damped by lower consumption? However, although the shock to consumption is worth 1% of GDP, consumption actually increases by considerably less than this. Just as with the fiscal shock, higher real interest rates reduce human wealth, and consumer's financial wealth begins to decline. In both cases borrowing finances an identical increase in demand. The only difference is that the government raises taxes by more than would be required simply to finance the extra debt, which depresses consumption to some extent with non-Ricardian consumers.

A more interesting simulation involves changing the structural parameters in the consumption model. The Blanchard Yaari framework involves two: impatience (the rate of time preference) and the probability of death. The former only influences the rate at which utility is discounted over time and therefore the propensity to consume out of total wealth, but the latter influences both this and the rate at which income is discounted in forming human wealth. In Chart 3.10 we examine the path of consumption following a 0.001 increase in both impatience (from 0.015 to 0.016 ρ) and the probability of death (from 0.00525 to 0.00625 ρ), and also a 0.001 decrease in the rate at which income is discounted (from 0.00525 to 0.00425 ρ).

Chart 3.10 Response of consumption to parameter changes



The largest impact comes from increasing impatience: consumption jumps up by over 4%, but then gradually declines as wealth falls. Steady state consumption is 8.6% lower. Increasing the probability of death (i.e. raising both the discounting of utility and income) raises consumption on impact by much less (1.2%), because discounted income also falls. Reducing the rate at which income is discounted with no change in utility discounting raises consumption on impact by over 3%. The impact effects on the real exchange rate are proportionate, ranging from a maximum of 2.3% for the change in impatience to 0.7% for the change in the probability of death.

Of course the size of these numbers are fairly arbitrary. More interesting is the length of time it takes before consumption is lower: between 15 and 20 years, so the half life of higher consumption is between 8 and 10 years.

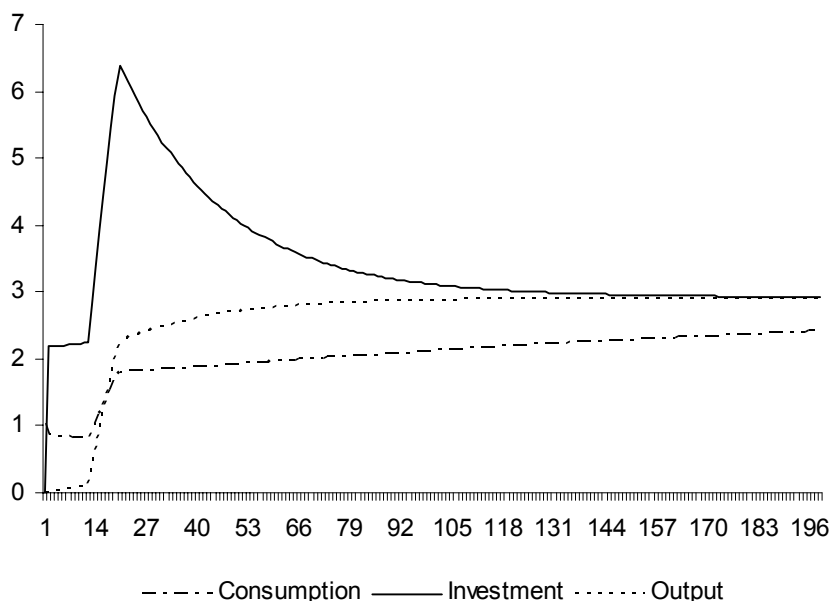
4. Supply shocks

In the context of the US dollar, there has been some discussion of the possibility that a technical progress shock in the US may account for the recent appreciation. Bailey, Millard and Wells (2001) analyse this in the context of a trade/non-traded two sector model. In this paper we assume that a technical progress shock occurs in the domestic economy that is never matched overseas. While this extreme case is analytically convenient, in reality the international transmission of technical improvements could be quite rapid. While there is clear evidence that a good part of the growth experienced in the US in the second half of the 1990s was due to the IT sector, there are also indications that this sector had a positive impact on European growth rates over this period (Jorgenson et al, 2003).

Within an imperfectly competitive goods market model, the direction of the initial effect of a technical progress shock is clear. First, technical progress will require additional investment, and the additional demand for domestic output that this creates will generate an appreciation. (We can put the same point a different way, by describing the reduction in net saving requiring a current account deficit.) In addition, to the extent that consumption rises anticipating future increases in income, then this will add to the demand for domestic output and the appreciation.

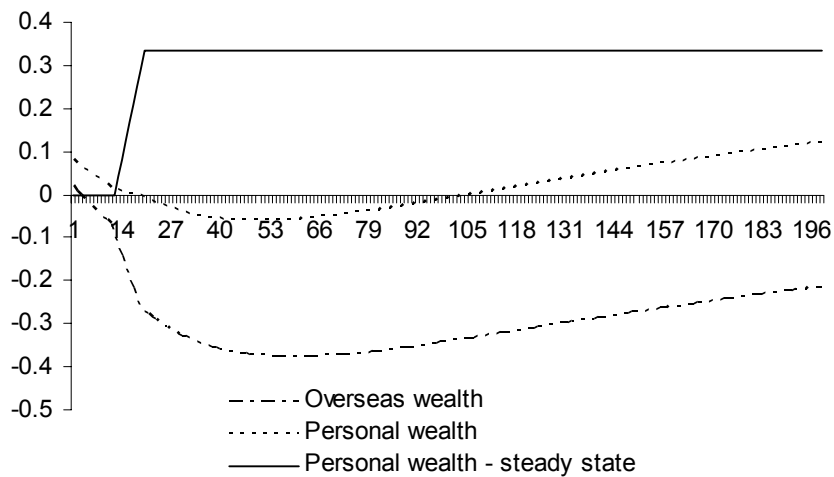
Chart 4.1 plots the impact on output, investment and consumption of a technical progress shock using the medium term model. (Paths in the short term model are fairly similar, but slightly less transparent.) The shock starts 3 years after the run, which is the main element of anticipation. Output supply rises over the next two years, giving a total increase in supply of almost 3%.

Chart 4.1 Anticipated technical progress shock - medium term model



Investment increases substantially, and before the shock occurs, reflecting the rise in share prices anticipating future profits. Consumption also rises ahead of the shock. However, whereas both output and investment converge to their steady state values quite quickly, consumption remains below its steady state. This important last effect can be understood by comparing medium term and steady state values of both consumption and wealth.

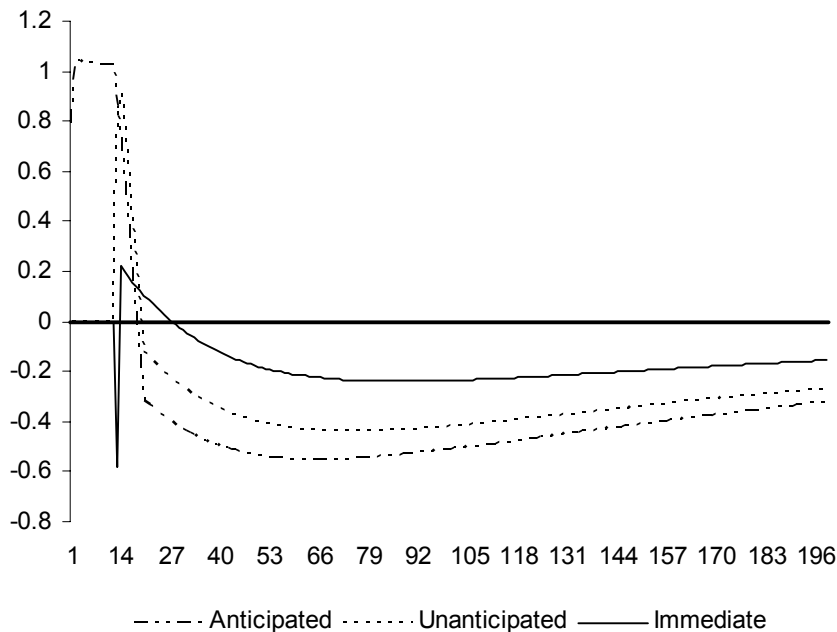
Chart 4.2 Anticipated Technical Progress Shock - medium term and steady state



Steady state personal wealth rises with the increase in technical progress. However medium term personal wealth, although it increases at first following the rise in share prices, subsequently declines. The chart shows that this is due to a decline in overseas asset holdings, associated with the current account deficits generated by consumption and investment rising ahead of and (for investment) beyond the increase in supply. The dynamics of wealth are very long lived: even after 50 years wealth is a long way from its steady state value.

The net effect on the real exchange rate is shown in Chart 4.3.

Chart 4.3 Technical Progress Shocks and the Real Exchange Rate: Anticipated, Unanticipated and Immediate



The initial appreciation is about one percent. (The impact effect is lower, because of the one period start delay before investment increases.) This appreciation is sustained until the shock begins. As technical progress begins to occur, the appreciation declines rapidly, because the additional demand for domestic output is now being met by additional supply. When the shock is complete, the real exchange rate is back to its base value. Thereafter, we observe a depreciation, reflecting lower consumption as wealth is built up.

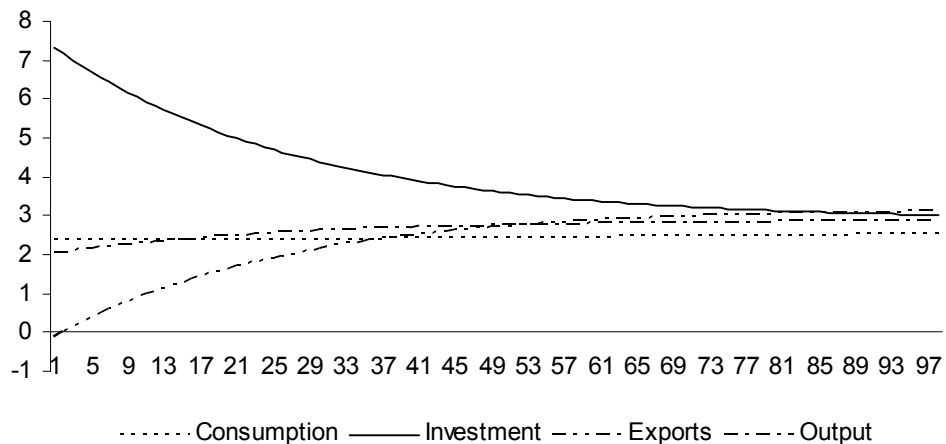
This path for the exchange rate has second round effects on demand. The marked depreciation associated with the technical improvement implies higher domestic interest rates during this period (i.e. while the technical progress is happening), which depresses both consumption and investment at the time and beforehand. This accounts for why the peak effect on investment shown in Chart 4.1 occurs once the technical progress shock is over.

This simulation suggests that it is the anticipation of the technical progress shock that leads to a sustained appreciation, rather than the shock

itself. This is confirmed by Chart 4.3, which shows the path for the real exchange rate for the same shock, but unanticipated. In this case the initial appreciation is a bit less, but the depreciation sets in immediately. However, because the shock builds up steadily over two years, there is still an element of anticipation in this simulation. Chart 4.3 also shows a third simulation, where the technical improvements is no longer phased in, but occurs immediately.

In this case the exchange rate jump is a depreciation, because of the one quarter delay in investment. (Supply rises, but an important element of demand - investment - is static.) Thereafter there is only a small appreciation. The reason for this can be seen in Chart 4.4, which plots the key components of demand for the immediate technical improvement. (The chart starts after the one quarter investment delay.)

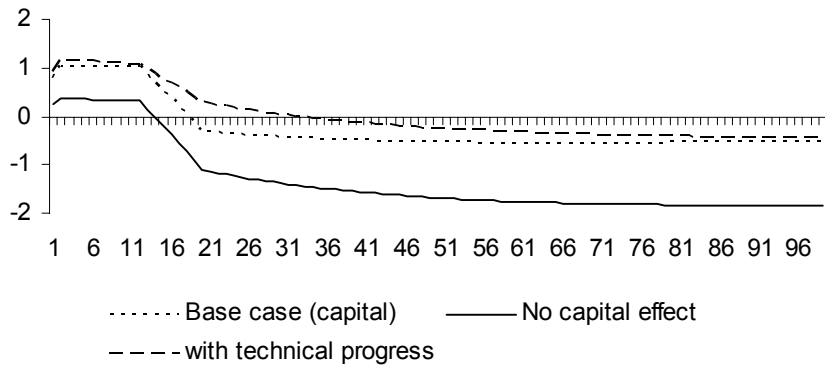
Chart 4.4 Immediate Technical Improvement



Although investment rises substantially, exports only rise gradually, as the capital stock slowly increases. The net result is only a moderate increase in demand required to be offset by an appreciation.

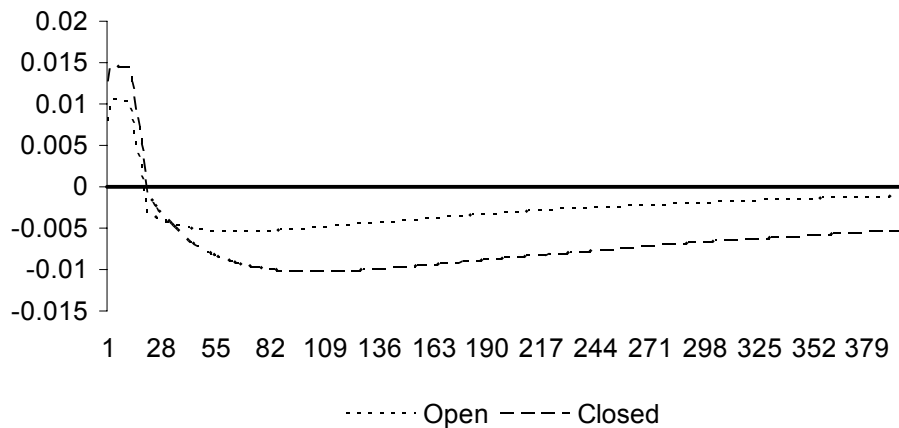
It is possible to argue that the export response to technical improvement might be more rapid than this. Suppose, for example, that exports rose - ceteris paribus - in line with increase in technical progress itself. Chart 4.5 shows the impact (for an anticipated shock) on the real exchange rate: compared to the previous case, the initial appreciation is slightly greater (reaching a peak of 1.2%), and the subsequent depreciation rather more gradual. These differences are minor, however, compared to the simulation with a conventional demand curve specification for exports. Here there is no increase in the demand for exports to match higher supply, so the real exchange rate profile shifts downwards throughout.

Chart 4.5 Real Exchange Rate response to Anticipated Technical Progress: alternative export specifications



The simulations so far have used a model calibrated to roughly correspond to an open economy like the UK. The changes described in switching to a more closed economy like the US were described in section 2: in particular, trade is now 10% rather than 30% of GDP, and the ratio of gross overseas assets to GDP is reduced from 2.5 to 1. Chart 4.6 plots the real exchange rate path for an anticipated technical progress shock for the two cases.

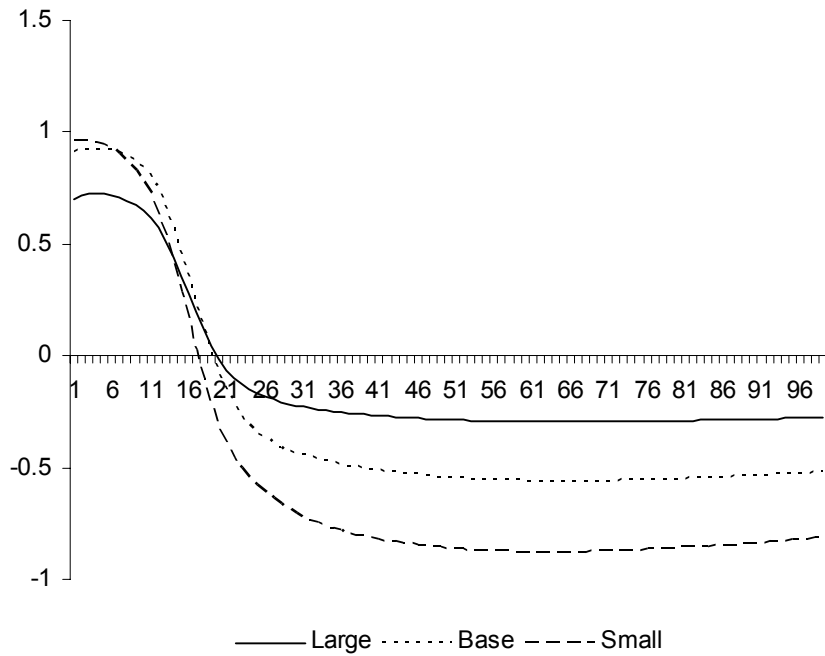
Chart 4.6 Real Exchange Rate Response to Anticipated Technical Progress for Open and Less Open Economies



For any given capital flows, a reduction in the size of net trade will require a correspondingly larger movement in the real exchange rate. We can see this clearly in the two paths after the shock, where the 'US' depreciation is much greater than in the 'UK'. The initial appreciation is also larger in the 'US' (after one quarter, about 1.5% compared to 1.0%), but not three times as large. The reason is the behaviour of interest rates. The larger depreciation in the 'US' generates higher interest rates, which reduces the initial increase in investment and consumption. Of course it would be legitimate in the case of the US to argue that world real interest rates might respond to domestic real interest rates to some extent, which would moderate this effect.

A similar effect operates if we reduce the size of the trade competitiveness elasticities, in this case for the open economy. Chart 4.7 looks at three cases: the base case, where elasticities are unity for both exports and imports, a 'large' case where they are both two, and a low case where they are both 0.6.

Chart 4.7 Real Exchange Rate Paths for Anticipated Technical Progress with varying trade competitiveness elasticities



Both the initial increase and subsequent decline in the exchange rate is smaller for large elasticities, as we would expect. The more interesting case is where elasticities are low (but not uncommon in the empirical literature), where the depreciation is magnified but the initial appreciation is not. The explanation is again that the larger depreciation generates higher initial real interest rates, which dampens the initial increase in demand.

5. Conclusions

In this paper we have explored the implications of demand and supply shocks for the real exchange rate in models where trade involves differentiated goods sold under imperfect competition. Two general conclusions emerge.

First, the size of movements in the exchange rate in response to reasonably large shocks is not great. An anticipated technical improvement that raises GDP by 3%, for example, generates an appreciation of around 1%. A positive demand shock worth around 1% of GDP generates a real appreciation of less than 0.5%. In both cases a key moderating influence is the impact of higher real interest rates on demand. Higher interest rates are implied by UIP: if UIP were not to operate, the magnitude of the appreciation would be much greater. Exchange rate responses would also be magnified if trade elasticities or trade shares were very low, although even here this is likely to impact more on the subsequent depreciation rather than the initial appreciation.

Second, if the shock produces an initial appreciation, this appreciation is relatively short lived in some cases. The main appreciation associated with technical progress comes from its anticipation. While higher investment may lead to an appreciation after the technical improvement has taken place, anticipation of the technical improvement will have led to increased borrowing which will have a depressing influence on consumption. Any appreciation could also be reduced or eliminated if export demand does not increase in line with supply. Appreciations associated with shifts in structural consumption parameters may be more long lasting.

Overall, while standard shocks can generate movements in real exchange rates that are quite persistent in this type of model, producing large movements appears to be rather more difficult.

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Appendix A Technical Progress and Consumption Shocks in COMPACT

The UK econometric model COMPACT has many similarities to the model examined in this paper. (See Darby et al, 1999 , and Wren-Lewis et al, 1996, for descriptions of the model.) There are of course many differences, as Compact is theoretically much richer. In addition, most parameters are derived from econometric estimation, and so there may be differences with the calibrated parameters of the Three Term model. For example, estimated competitiveness elasticities are closer to the 'small' case analysed in chart 4.7.

Chart A1 Real Exchange Rate response to an Anticipated Technical Progress shock: 3 term model and COMPACT, modified

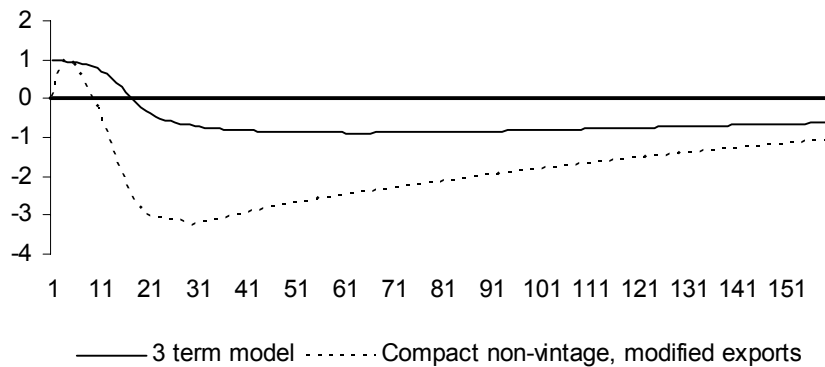
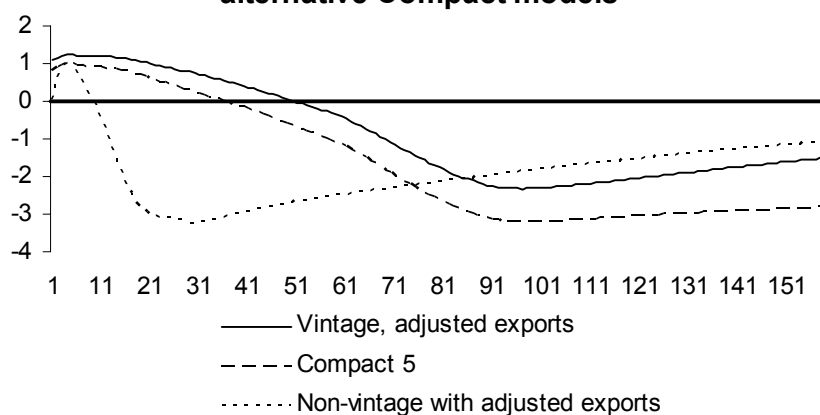


Chart A.1 compares the exchange rate response from chart 4.7 (small) with a modified version of Compact 5.

The initial appreciation in the exchange rate is of the same broad magnitude in each case (i.e. about 1%), although in Compact it takes a few quarters to reach this peak. The major difference between the two models is that the subsequent depreciation in Compact is much larger, reaching a peak of 3% compared to less than 1% in the Three Term model. The main reason for this is behaviour of investment, the capital stock and exports. The empirically estimated investment equation responds more gradually to share prices in Compact than in the calibrated model. This in turn leads to a slower build up in the capital stock, and therefore lower exports. Once the shock is over, therefore, key components of demand are lower than supply, and so a large depreciation is required.

Chart A.2 Real Exchange rate response to anticipated technical progress shock: alternative Compact models



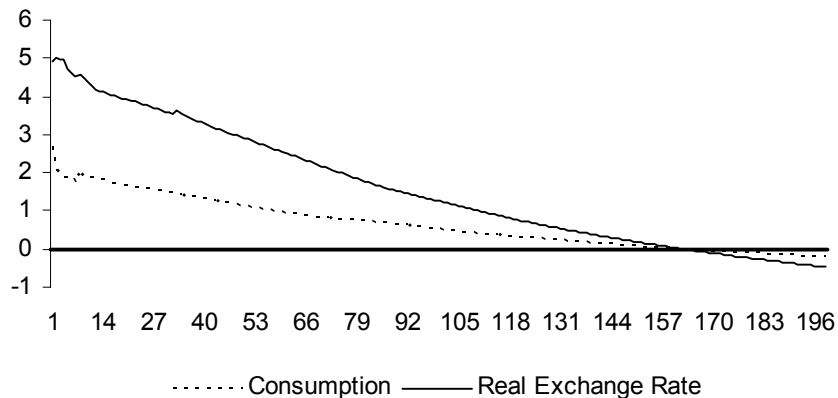
Compact has been modified in two major ways for this simulation. First, the model's vintage production technology has been replaced by a putty/putty set-up, similar to the 3 term model. Chart A.2 shows what happens when the vintage model is reinstated. A technical progress shock in a vintage model has a quite different character, as technical improvements are only embodied once new investment occurs. As a result, the impact of the shock is much more drawn out, and consequently there is much more scope for anticipation effects. This means that the appreciation, although initially of a similar size, is much more persistent.

The second modification adds a capital stock term to the export equation in a similar way to the equation in the Three Term model. Chart A.2 shows the effect of replacing this with the estimated export equation (and retaining the vintage technology): export demand is lower throughout, so the required depreciation in the medium term is greater. The impact of this change is not quite as great as in Chart 4.6, because Compact does contain a cumulated investment term in the estimated export equation designed to capture variety

and quality effects. However its estimated value is not large enough to provide as much additional demand as the increase in supply.⁵

As the consumption function in COMPACT is based on Blanchard/Yaari, it would be possible to repeat the simulations shown in the main text. However COMPACT also has a unique characteristic: the proportion of income going to consumers who are credit constrained (and therefore do not behave as Blanchard/Yaari consumers) depends explicitly on a financial liberalisation variable. Chart A3 plots the effects of an increase in financial liberalisation. Liberalisation increases by roughly 5% of the size that liberalisation is estimated to have increased over the 1980s. Apart from the magnitude of the effect, it is interesting that consumption is higher for longer than in Chart 3.10, and here the percentage change in the exchange rate is about double the change in consumption, compared to about 50% in Chart 3.10. Smaller trade elasticities in Compact are important in explaining this latter result.

Chart A3 Financial Liberalisation increase in COMPACT



⁵ The simulations makes a few additional, less interesting, adjustments to the model, to do with the oil sector and residential investment.

Appendix B Steady State Values and Comparative Statics

The Cobb-Douglas technology determines the labour and profit share in national income. In steady state, the value of the company sector (wco) must equal the capital stock (k). Using (1.12I) we have

$$(y - wn) / k = (r + \eta + \kappa) \quad (\text{A2.1})$$

In calibration, using this equation with a given capital stock, real interest rate and depreciation rate will determine κ . In behavioural terms, this equation determines the capital stock in an open economy where world interest rates determine domestic interest rates (in steady state).

Combining the consumption function (1.4) with the steady state relationship for human wealth (1.5I) and the government budget constraint implies

$$c = \chi(k + wos + d + \frac{wne^\delta - g - rd}{r + \epsilon}) \quad (\text{A2.2})$$

Combining this with the national income identity and (1.10I), we obtain

$$1 - g - \eta k + r wos = \chi(k + wos + d + \frac{wne^\delta - g - rd}{r + \epsilon}) \quad (\text{A2.3})$$

For a given labour income share and values for d , r and net overseas assets, this equation determines ϵ . In behavioural terms (A2.3) determines the steady state value of financial wealth ($d+wos$). To see this, replace $(g+rd)$ by tax , and rearrange to give

$$(d + wos)(\chi - r) = 1 - tax - k(\chi + \eta) - \chi(\frac{wne^\delta - tax}{r + \epsilon}) \quad (\text{A2.4})$$

In Blanchard/Yaari, the marginal propensity to consume must be greater than the real interest rate, but less than the income discount rate. Thus a rise in taxes reduces financial wealth as well as human capital, and an appreciation (rise in e) will also reduce steady state financial wealth.