9 The 3-equation model in the open economy

9.1 Overview

In this chapter, we extend the macro-model to the flexible exchange rate open economy. How does the openness of the economy to trade and financial flows affect the way an inflation-targeting central bank approaches its stabilization role? In the closed economy, the central bank diagnoses shocks hitting the economy and chooses their interest rate response, taking into account the implications of the shock for future inflation. The main insight when we extend the discussion to the open economy is that the forward-looking foreign exchange market and the central bank will simultaneously analyse shocks, and their responses will take into account the response of the other party.

Just as a great deal of resources are deployed in central banks to analyse economic developments and forecast inflation based on the diagnosis of the nature of shocks, the same is the case in financial institutions operating in global financial markets. Foreign exchange traders look at what is happening in the domestic and world economy and at how the central bank is likely to respond to economic developments.

The motives of the central bank and the foreign exchange traders for employing resources to forecast the future are, however, different. The central bank is attempting the stabilize the economy, whereas the foreign exchange traders are attempting to profit from arbitrage opportunities.

Expectations and the forward-looking foreign exchange market

In Chapter 4, we discussed the pervasiveness of uncertainty in the macroeconomy (predominantly in a closed economy context) and how this leads to agents forming expectations about the future so they can make better economic decisions today. In the baseline closed economy 3-equation model (introduced in Chapter 3), the central bank is forward looking with rational expectations. The central bank has to forecast both the *IS* and *PC* curves in the next period when setting interest rates in the current period. This is due to the assumption that interest rates can only affect economic activity with a one period lag.

When we move to the open economy, we introduce the foreign exchange market, where trades are also assumed to be forward looking and rational. We assume both interest rates and real exchange rates affect the economy with a one period lag. In the open economy 3-equation model, the central bank takes account of the reaction of the foreign exchange market when setting interest rates and the foreign exchange market moves when expectations about future central bank policy change.

Arbitrage opportunities, the foreign exchange market and the government bond market

When trade in financial assets across borders is possible, investors will want to take advantage of differences in rates of return on government bonds. In order to take advantage of arbitrage opportunities in the bond market, an agent must have the relevant national currency. For example, to buy US Treasury Bills, it is necessary to have US dollars; to buy German government Bunds, it is necessary to have euros. The exchange rate will depend on supply and demand in the foreign exchange market. An important source of demand and supply of foreign exchange arises from the desire of economic agents to buy and sell government bonds in order to take advantage of differences in interest rates.

Both the central bank and foreign exchange traders know that the extent of integration of international capital markets means that opportunities to make a profit from a difference in rates of return on bonds issued in different countries will be short-lived. Take the possibility of profiting from an interest rate differential opened up by a decision of one central bank to change its interest rate. This is a form of arbitrage opportunity. If, for example, the Bank of England increased the UK interest rate so that the return on UK bonds was higher than on US bonds, there would be a rush into UK pounds and out of US dollars until the chance of profiting from one rather than the other kind of bond has vanished.

Defining the nominal and real exchange rates

Let's take a step back for a moment and clarify the concept of the exchange rate. We need to define both the nominal and real exchange rates. Home's nominal exchange rate is 'the amount of home currency that can be bought with one unit of foreign currency'. For example, the nominal exchange rate for the UK pound (home economy) is defined in terms of the foreign currency (the US dollar) as the amount of UK pounds that can be bought with one US dollar (i.e. £/$). We use e to denote the nominal exchange rate of the home economy:

$$e \equiv \frac{\text{no. units of home currency}}{\text{one unit of foreign currency}}. \qquad \text{(home's nominal exchange rate)}$$

An increase in e means that one US dollar can buy more UK pounds, so that the pound has depreciated (or weakened). Note that since the nominal exchange rate is defined as the number of home currency units for one foreign currency unit, a depreciation of the pound is the same as $\uparrow e$.

The nominal exchange rate shows the rate at which the currencies of two economies can be exchanged for one another. To measure the rate at which domestic and foreign *goods and services* can be exchanged for each other, we also need to take into account the relative price level between the two economies. This is where we introduce the concept of the *real* exchange rate, which is defined as:

$$Q \equiv \frac{\text{price of foreign goods expressed in home currency}}{\text{price of home goods}} = \frac{P^*e}{P},$$

(home's real exchange rate, price competitiveness)

where P^* is the foreign price level and P is the home price level. The real exchange rate Q is a measure of price competitiveness between two economies. If Q increases, this reflects the fall in price of home goods relative to the price of foreign goods (when expressed in the same currency). This depreciation of the real exchange rate would make home's exports more attractive to foreigners and discourage the consumption of imports by domestic consumers. We assume throughout our modelling of the open economy that a depreciation of the real exchange rate (i.e. $\uparrow Q$)—an improvement in price competitiveness—will cause an increase in *net exports* (i.e. the real value of exports − the real value of imports).[1]

In the open economy model, aggregate demand not only consists of consumption, investment and government spending (as it does in the closed economy), but also net exports. This means that we assume an increase in competitiveness (a real depreciation) boosts aggregate demand through its effect on net exports.

Two stabilization channels in the open economy: interest rate and exchange rate

Given the central bank's stabilization objective and the way the nominal exchange rate will respond to arbitrage opportunities, the response to a shock will be a combination of a change in the interest rate by the central bank and a change in the exchange rate resulting from the actions of foreign exchange traders. For example, if a shock pushed inflation above target, the response in the closed economy is for the central bank to raise the interest rate in order to depress next period's level of output and bring inflation down.

In the open economy, it is also the case that a negative output gap is required to begin to bring inflation down. However, foreign exchange market operators know that the central bank will raise home's interest rate and this creates an arbitrage opportunity. In this example, we assume that the UK is the home economy and the US is the foreign economy. There will therefore be a rush out of US dollars and into UK pounds, due to the higher return on UK bonds. What happens to the exchange rate between UK pounds and US dollars as a result of this?

In this example, the interest differential in favour of UK bonds results in stronger demand for UK pounds, which forces the currency to appreciate. An appreciated currency will increase the price of the home economy's exports in terms of foreign currency, depressing demand for home-produced goods in foreign markets. It will also reduce the price of foreign-produced goods that are imported to the home economy (in terms of home currency), boosting demand for foreign goods.

In other words, it will make the British economy less competitive and depress aggregate demand for home-produced goods and services. We can therefore see that in addition to the *interest rate channel*, there is a second channel operating to produce the central bank's desired negative output gap: this is the *exchange rate channel*. With the higher interest rate in the UK and the appreciation of the UK pound both bearing down on output, the central bank will know that it needs to raise the interest rate by less than would be the case in the closed economy to achieve the same negative output gap.

Both parties solve the central bank's stabilization problem—this implies an assumption that both the central bank and the foreign exchange market form expectations rationally. Together their actions will place the economy on the stabilization path desired by the central bank.

[1] This result will be derived formally when we discuss the Marshall-Lerner condition in Chapter 10.

In short, we shall see that the presence of the foreign exchange market means that the work of stabilization is shared between exchange rate and interest rate adjustments. As with any rational expectations assumption, we have to be careful about its relevance for understanding real-world phenomena. In the case of the 3-equation closed economy model, we used the idea of the central bank solving the model in order to make its best judgement about how to respond to a shock; here we are assuming that the profit-seeking motivation of foreign exchange traders will produce an outcome that can be captured by the rational expectations assumption.

This is a more dubious assumption than is the case for the central bank, as we know that financial markets are affected by fads and manias (see Chapters 1, 4 and 6). However, we continue to work with the rational expectations model for the foreign exchange market as it provides a useful basic model of a very complex situation. In addition to helping us to understand the way interest rate and exchange rate changes interact following a shock to the economy, the open economy model also helps to explain exchange rate overshooting and highlights the trade-off between the contribution of exchange rate changes to stabilization and the potential for the foreign exchange market to be a source of volatility in the real economy.

How are the key aspects of the open economy reflected in the 3-equation model?

We now explore why central banks in flexible exchange rate economies are active in stabilization. Figure 9.1 shows that central banks frequently change the policy interest rate as they attempt to achieve their inflation target. We can think this through systematically by taking each of the three equations in the 3-equation model in turn.

IS relation

Beginning with the demand side of the economy, the *IS*, we need to amend the model to recognize that home's households, firms and government spend on imported as well as home-produced goods, and that foreigners buy goods produced at home. Since imports will depend on the level of activity in the home economy, some of the additional demand generated by higher incomes will leak abroad because of purchases of imports. This means

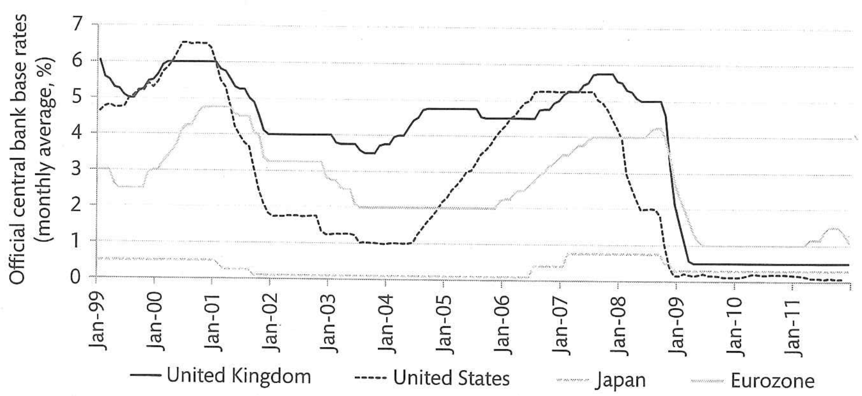

Figure 9.1 Official central bank interest rates, monthly averages, per cent: 1999–2011.

Source: Bank of England; Board of Governors of the Federal Reserve System (US); Bank of Japan; European Central Bank (data accessed January 2012).

the multiplier will be lower, the higher is the marginal propensity to import. The other major change to the *IS* relationship will come from the impact on imports and exports of changes in the competitiveness of home's production, as noted above. An improvement in home's competitiveness, i.e. a depreciation of the real exchange rate, boosts the demand for exports and dampens the demand for imports as home goods become relatively more attractive both abroad and at home.

In graphical terms, the presence of imports in reducing the multiplier makes the *IS* curve steeper because a given fall in the interest rate is associated with a smaller increase in output; and a depreciation of the real exchange rate shifts the *IS* curve to the right. An appreciation of the real exchange rate—a deterioration in home's competitiveness—shifts the *IS* to the left. These results are derived step by step in Chapter 10.

Phillips curve, PC

As in the closed economy, in this chapter, we shall assume that households use domestic inflation in their wage-setting calculations.[2] This means we can continue to work with a situation in which the equilibrium rate of unemployment is unique, i.e. it only shifts as a consequence of supply-side shifts in the *WS* curve (changes in the cost of job loss, wage-bargaining arrangements, employment regulation, etc.) or in the *PS* curve (changes in the degree of monopoly, the tax wedge, etc.).

Central bank behaviour, MR

Finally, we turn to the policy maker, which is the central bank. There is no reason why opening up the economy to international trade and capital flows should affect the policy maker's preferences, and hence, the *MR* curve. We continue to assume that the central bank suffers a loss of utility according to how far away it is from its inflation target and from equilibrium output. But what is the inflation rate the central bank targets? It could target consumer price inflation, which includes the price changes of imported goods or it could target domestic inflation. In this chapter, we keep to the simple case where the central bank targets *domestic* inflation.

To summarize, in the open economy we need to modify the *IS* curve, making it steeper to reflect the lower multiplier, and noting that it will shift with a change in the real exchange rate. If the central bank targets domestic inflation and we assume wage setters use domestic inflation in their wage-bargaining calculations, we do not need to modify the *PC* or the determinants of equilibrium unemployment, y_e. Equilibrium employment remains determined in the same way as in the closed economy. In the *PC* – *MR* diagram, the vertical axis is domestic inflation and the *MR* curve is derived in the same way as in the closed economy: from the tangencies of the Phillips curves with the loss circles, which capture the preferences of the central bank.

How does capital market openness affect stabilization policy?

Two elements of global flows of capital play a crucial role: the foreign exchange market and the ability of home and foreign economic agents to buy home and foreign assets. This ties

[2] We shall explore the effects of imports on wage setting in the next chapter.

together the foreign exchange market and the money market where government bonds are bought and sold.

In a world without global financial markets, the supply and demand for foreign exchange and therefore exchange rates are driven by exports and imports (i.e. by the need to finance trade in goods and services). By the late 1980s, values traded in international markets for financial assets far exceeded the value of international trade in goods and services. As a consequence, it is trade in international financial markets that dominates the foreign exchange market. Market participants buy and sell currencies to take advantage of differences in rates of return on financial assets. Just as in the closed economy, we continue to assume there is just one asset, namely government bonds. Foreigners seeking to buy home bonds, need home currency in order to do this and vice versa. As market participants seek to take advantage of differences in interest rates on government bonds issued by different countries, this trading is a key determinant of exchange rate fluctuations. To understand the essential aspects of international financial markets, it is useful to make some simplifying assumptions.

1. There is *perfect international capital mobility*. This means that home residents can buy or sell foreign bonds with the fixed nominal world interest rate, i^*, in unlimited quantities at low transactions costs.

2. The home country is assumed to be *small* in the sense that its behaviour cannot affect the world interest rate.

3. Just as in the closed economy, we assume there are just *two assets* that households can hold—bonds and money. But now they can hold foreign or home bonds. We assume that they hold only home money.

4. There is *perfect substitutability* between foreign and home bonds. This assumption means that the riskiness of foreign and home bonds is identical, so the only relevant difference between them is the expected return.

The last assumption means we rule out differences in the risk of default of bonds issued by different governments and we assume that investors do not care about the balance between home and foreign bonds in their portfolio. Cross-country differences in default risk have always been highly relevant for the analysis of emerging and developing economies but much less so in developed economies, where bond yields converged at low levels during the Great Moderation. Default risk has, however, reemerged as a pertinent issue for developed economies with the Eurozone crisis in 2010–11, which centred on the diverging default risk on Eurozone government bonds. In this chapter, we assume away issues related to differences in default risk. We return to them when we discuss the Eurozone in Chapter 12.

How do foreign exchange traders respond to interest rate differences? The uncovered interest parity (*UIP*) condition

If home households can hold home and foreign bonds in their portfolio, what will influence their choice? Assumption 4 (above) means there is no difference in risk between the bonds issued by the two governments. In this case, the only difference is the expected return on the two bonds and that will depend on two factors:

1. any expected difference in interest rates over a specific time horizon; and
2. a view about the likely development of the exchange rate over the same time horizon.

The second of these factors emphasizes the importance of forming expectations about the exchange rate in future periods. In this model, agents are therefore fully forward looking and take all available information into account when making decisions. How does this tally with our view that households form expectations of inflation in a backward-looking manner (i.e. the assumption that underlies the Phillips curve)?

Just as in Chapter 5, we assume that households save in the money market through pension funds or other sophisticated agents who are acting on their behalf. It is these agents that act in a forward-looking manner and are collectively referred to in our model as participants in the *foreign exchange market*. In contrast, workers are assumed to handle their wage negotiations personally or through a union, both of which form expectations in a backward-looking manner. To make this distinction clearer, when discussing households buying and selling home and foreign bonds we will refer to this as the actions of foreign exchange market participants. Following the definitions introduced in Chapter 4, the foreign exchange market participants are therefore assumed to have rational expectations.

Example

Suppose the UK is the 'home' economy and the US is the 'foreign' economy. As discussed earlier, if the interest rate on home bonds is higher than on foreign ones, that will make home bonds more attractive. This would be followed by appreciation of home's currency (i.e. UK pounds) as people sold US dollars in order to buy UK pounds, which they need to buy the UK bonds. But, we need a model to explain by how much the UK pound appreciates.

Suppose that initially the interest rate on both bonds is 4%. Now let us see what happens if the Bank of England suddenly raised the UK interest rate to 6.5%. This case is shown in Fig. 9.2, where e is used to denote the UK pound nominal exchange rate (i.e. £/$), t is used to denote the time period, i is used to denote the home interest rate and i^* is used to denote the world (or foreign) interest rate. The interest rate change makes UK bonds more attractive and investors will sell US dollars and buy UK pounds in order to take advantage of the higher expected return. But the move out of dollars and into UK pounds leads the US dollar to depreciate (weaken) and the UK pound to appreciate (strengthen).

As investors try to maximize their returns, the UK pound will appreciate by exactly 2.5% so that the expected return on UK and US bonds is identical. An American investor holding UK bonds for the duration of the interest differential (i.e. one year) gets 2.5% more in interest receipts than he would holding US bonds. On the flipside, however, the American investor loses 2.5% as the UK pound depreciates back to its 'normal' level over the course of the year. We assume that the underlying expected level of the exchange rate is exogenous and remains constant. The American investor will have to buy UK pounds at the start of the year in order to purchase the UK bonds, but wants US dollars at the end of the year to spend in the US (Assumption 3). Figure 9.2 shows how this process of arbitrage in the international bond markets works to equalize the expected return on bonds.

A survey of foreign exchange dealers in the UK asked: 'How fast do you think the market can assimilate the new information when the following economic announcements from

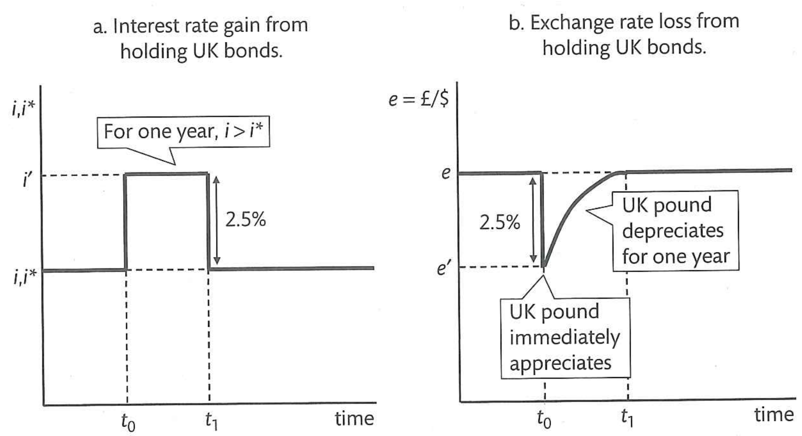

Figure 9.2 Arbitrage in the international bond market.

the major developed economies differ from their market expectations?'[3] For an unexpected interest rate announcement, over 60% of the traders said 'less than ten seconds' with most of the rest saying less than one minute. According to this survey, speedy reaction is most common for news about interest rates, which also has a bigger impact on foreign exchange markets than announcements about inflation, unemployment, the trade deficit, the money supply or GDP. The survey findings suggest that any arbitrage opportunities that arise as a result of interest rate differentials (or expected interest differentials) are exhausted extremely quickly. This results in jumps in the exchange rate. In the example shown above, as soon as the interest differential is announced, the UK pound would immediately appreciate by 2.5%.

The result that the exchange rate will jump so as to eliminate differences in expected returns on bonds is called the uncovered interest parity condition (*UIP*). It is derived in detail in the modelling section (9.2) that follows. We can write it like this:

Interest gain from holding home currency (UK pounds) rather than US dollar bonds	=	Loss from the expected depreciation of home currency (UK pounds) against the US dollar

(UIP condition)

With home's interest rate above the world (US bond) interest rate for one period between t_0 and t_1, the *UIP* condition states that the exchange rate will jump immediately to eliminate the arbitrage opportunity. Applying this to our example in Fig. 9.2, the *UIP* condition states that: the UK pound exchange rate will appreciate by exactly 2.5% so that the loss from the expected depreciation of the UK pound over this period is equal to the interest gain from holding the higher yielding UK bonds over the same period. All market participants are assumed to believe that the exchange rate will return to its initial level at the end of the period.

[3] See Cheung et al. (2004).

The *UIP* condition tells us that the 'unwinding' of the initial change in the exchange rate must be equal to the interest rate differential; hence we know that the interest differential pins down the size of the jump. The arbitrage condition also tells us that the exchange rate at any time during the period between t_0 and t_1 will be as shown on the path in the right-hand panel of Fig. 9.2. As the time comes closer to when the interest differential will disappear, the size of the interest gain from a UK bond shrinks and hence the matching expected depreciation of the pound must be smaller. The exchange rate must therefore be closer to its expected level of *e*. If this was not the case, there would be unexploited opportunities for profit-making by buying or selling pounds to buy or sell UK bonds. An important distinguishing characteristic of financial markets (as compared with goods and labour markets) is that *jumps* in prices are commonly observed.

The reaction of the central bank and the foreign exchange market to an inflation shock

We have now discussed the key components and mechanisms driving the 3-equation model in the open economy. This allows us to use the model to think about the adjustment of a small open economy to an inflation shock. We will set out detailed, period-by-period adjustment paths to an inflation shock and a range of other shocks later in the chapter. This initial simple example aims to provide an overview of how the model works and to highlight the key differences from the closed economy model presented in Chapter 3.

We assume a flexible exchange rate economy, which is initially at equilibrium output and target inflation, is hit by an inflation shock. In this case, just as in the closed economy, the central bank will raise the interest rate in order to reduce output and dampen inflation. However, the foreign exchange market will also react to the knowledge that home's interest rate will be kept above that of the rest of the world for some time. The *UIP* condition tells us that home's exchange rate will therefore appreciate, as there will be increased demand for home's currency. This occurs as investors buy home currency to buy home bonds so as to take advantage of their higher yields.

We know from the *IS* curve that the appreciation of the exchange rate will depress demand by reducing net exports. This means the central bank will not have to raise the interest rate as much as they would in the closed economy, as they correctly anticipate some of the adjustment will take place through the foreign exchange market. In other words, in the open economy, the dampening of demand needed to get the economy back onto the *MR* curve occurs through a combination of a higher interest rate and exchange rate appreciation.

Forward-looking behaviour of central banks and foreign exchange markets—real-world examples

The interaction between a forward-looking central bank and a forward-looking foreign exchange market is at the heart of the model of stabilization policy in the open economy. This is reflected in the publications of central banks and the financial press.

The link between the exchange rate and the monetary policy of the central bank in a flexible exchange rate regime is highlighted in Obstfeld and Rogoff (2009):[4]

[4] See p. 32 of Obstfeld and Rogoff (2009).

> Under the pressure of very loose US monetary policy after the dot-com crash and 9/11, however, the dollar depreciated by more than 16% from early 2002 through the start of 2007, with a significant (but temporary) reversal over 2005 as the Fed tightened.

In the wake of the 9/11 attacks on the US, the Federal Reserve cut interest rates more aggressively than other developed economy central banks (e.g. the European Central Bank; see Fig. 9.1). This saw the emergence of an interest rate differential that contributed to the depreciation of the dollar over that period.

One of the main lessons of this chapter is the way a forward-looking foreign exchange market anticipates the actions of the central bank and facilitates the adjustment of the economy to a shock. On a minute-by-minute basis, the foreign exchange market is assimilating the latest macroeconomic data and making forecasts about how this could affect the interest rates set by the central bank. In light of this, changes in interest rate expectations are often built into the foreign exchange market a long time before the interest rate changes actually take place, as illustrated by this Bloomberg News article from mid-2004:[5]

> The dollar rose the most against the euro in a month on speculation government reports tomorrow will show faster inflation in the US, underscoring the potential for the Federal Reserve to raise interest rates more than some traders had expected.

In uncertain economic times, such as the UK's stop-start recovery from the 2008-09 financial crisis, it is harder to predict the path of the economy, and consequently of interest rate decisions. Mansoor Mohi-uddin, UBS's managing director of foreign exchange strategy alluded to this point in early 2011:[6]

> But do not pity the Sterling [i.e. UK pound] bulls. Foreign exchange investors have bolstered the pound this year on expectations interest rates would soon be raised. Yet it remains far from clear whether the Bank's Monetary Policy Committee will take such a step.

Foreign exchange traders make their best estimate with the information they have available in each time period but can be wrong, which might subject the market to corrections and jumps in the exchange rate. This could happen if the market anticipated a smaller (or larger) interest rate change than was actually observed. The extra unanticipated change would likely cause a jump in the exchange rate, as the market quickly takes advantage of the unexpected interest rate differential. In short, because the future is uncertain, basing current actions on forecasts and predictions can lead to volatility in the exchange rate.

Foreign exchange markets are complex and are influenced by a whole host of macroeconomic variables. The *UIP* condition is often hard to observe in exchange rate data, because these other factors influence the future expected exchange rate. In the recent economic downturn, the Bank of England kept a close eye on interest rate differentials and the sterling (i.e. UK pound) exchange rate and found a number of other factors contributing to the depreciation of the UK pound over this period:[7]

> Sterling had lost over a quarter of its value since mid-2007. To some degree, that depreciation had probably reflected the need to rebalance the UK economy away from domestic towards external demand. In addition over the past year, the global outlook had deteriorated with resultant downward revisions to interest rate expectations worldwide. But the downward revision to forecasts of the UK economy appeared to have been greater than for some other countries. And those perceptions may have contributed to sterling's decline. Another factor in sterling's decline over the past eighteen months could have been increased risk premia.

As discussed in Chapter 7, the recent recession of 2008-9 saw the limits of conventional monetary policy reached and central banks had to resort to unconventional monetary policy, such as quantitative easing, to avoid a deflation trap. These policies also affect the foreign exchange market. Quantitative easing aims to influence long term interest rates and therefore to affect interest rate differentials. An article in the *Financial Times* from autumn 2011 attributed moves in the pound exchange rate to changes in expectations about quantitative easing:[8]

> The pound dropped to an eight-month low against the dollar on Wednesday as expectations heightened that the Bank of England would engage in further quantitative easing in an effort to boost the UK economy.

Summary

In this chapter, we extend the core 3-equation model introduced in Chapter 3 to set out a framework for analysing stabilization policy in the flexible exchange rate open economy. This involves opening up the economy to both international trade (i.e. imports and exports) and international capital flows (i.e. home and foreign bonds). The two main effects on the model of introducing the forex market are that:

1. following an economic shock, the central bank and foreign exchange market react to the shock, which means adjustment occurs through both exchange rate and interest rate channels; and
2. the forex market bases its actions partly on its expectations of the future, which can lead to jumps in the exchange rate and increased macroeconomic volatility.

9.2 Modelling

In the previous section, we provided an overview of how the 3-equation model works in the open economy. In this section, we get into the mechanics of the model. The first part of

[5] Excerpt taken from: Heather Bandur and Vivanne Rodrigues, June 9th 2004, 'Dollar Surges Against Euro as Traders Anticipate Fed Rate Moves,' *Bloomberg News*.

[6] Excerpt taken from: Mansoor Mohi-uddin, February 7th 2011, 'Pound Remains Vulnerable to Abrupt Reversal of Fortune,' *Financial Times*.

[7] Excerpt taken from: Bank of England, *Minutes of the Monetary Policy Committee Meeting, 4 and 5 March 2009*, published 18th March 2009.

[8] Excerpt taken from: Peter Garnham, September 21st 2011, 'Dovish Bank Minutes Weigh on Pound,' *Financial Times*.

the section formalizes the *UIP* condition. In the second part, we explain what is meant by medium-run equilibrium in the open economy. We combine these components to build the open economy 3-equation model and use them to analyse the period-by-period adjustment of the economy to shocks. The new *RX* curve combines the interest rate and exchange rate channels through which the central bank's interest rate decision affects aggregate demand. Section 9.3 discusses the role of exchange rate overshooting in the open economy.

9.2.1 The foreign exchange market and the *UIP* condition

In Section 9.1, we introduced the concept of the *UIP* condition, which is central to the behaviour of the foreign exchange market in the open economy 3-equation model. In this subsection, we will set out the equation for the *UIP* condition and use a graphical analysis to explore the concept in more detail.

The *UIP* condition

The *UIP* can be represented as:

$$\underbrace{i_t - i^*}_{\text{interest gain (loss)}} = \underbrace{\frac{e^E_{t+1} - e_t}{e_t}}_{\text{expected depreciation (appreciation)}},$$

where i is the home interest rate, i^* is the foreign interest rate, e is the nominal exchange rate of the home country and e^E is the expected exchange rate of the home country. The equation says that given the values for i_t, i^* and e^E_{t+1}, we can work out the value to which the exchange rate will jump, e_t.

In the example we introduced in Section 9.1, the initial shock is the rise in i_t. The world (i.e. US) interest rate, i^*, and the view of the exchange market traders about the expected exchange rate in a year's time, e^E_{t+1}, remain unchanged. From the point of view of the UK as the home country, there is an interest gain on the left hand side, which in the presence of arbitrage must equal the expected depreciation of the pound (on the right hand side). For the equation to hold therefore, the UK pound exchange rate e_t must immediately appreciate (as people sell US dollars to buy UK pounds): it will appreciate by exactly 2.5% so that its subsequent expected depreciation just offsets the interest gain incurred by holding UK rather than US bonds (see Fig. 9.2 in Section 9.1).

So far we do not have a model of what determines the expected exchange rate: we simply assume it is expected to return to its previous value after one period. In Section 9.2.2, we introduce a model that pins down the equilibrium exchange rate and hence provides an anchor for exchange rate expectations. For the moment, we assume the expected exchange is constant.

We make use of the fact that we can approximate the percentage growth of the exchange rate by the change in the (natural) log of the exchange rate, i.e.

$$\frac{e^E_1 - e_0}{e_0} \approx \log e^E_1 - \log e_0 \text{ and in our example, } \log e^E_1 - \log e_0 \approx 2.5\%.$$

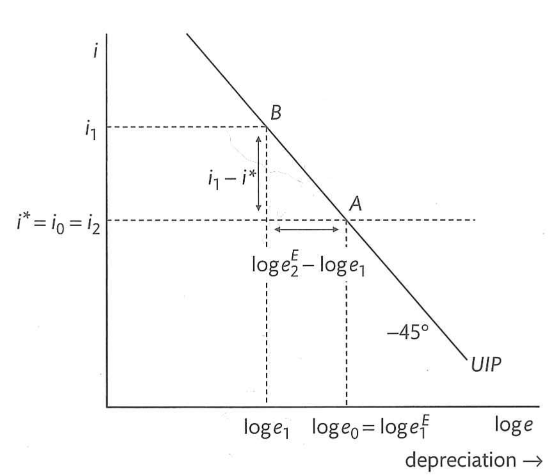

Figure 9.3 The uncovered interest parity condition: $i_t - i^* = \log e^E_{t+1} - \log e_t$.

The great advantage of using the log formulation is that we now write the *UIP* condition as

$$\underbrace{i_t - i^*}_{\text{interest gain (loss)}} = \underbrace{\log e^E_{t+1} - \log e_t,}_{\text{expected depreciation (appreciation)}}$$

and we can draw this as a line with a $-45°$ slope as shown in Fig. 9.3 with the interest rate on the vertical axis and the log of the nominal exchange rate on the horizontal axis.[9] The *UIP* curve is pinned down by the world interest rate and the expected exchange rate.

Our understanding of the model is helped by looking at two points on the *UIP* curve. The first is point *A* in Fig. 9.3: this is where the home interest rate equals the world interest rate ($i = i^*$) and exchange rate expectations are fulfilled ($\log e_0 = \log e^E_1$) and the exchange rate does not change.

We now look at a second point on this *UIP* curve at *B*. This represents the situation where home's interest rate of i_1 above the world interest rate is expected to prevail for one year. Assuming the expected exchange rate remains fixed at $\log e^E_1$, then since home's interest rate is now above the world interest rate, there must be a change in the *actual* exchange rate away from $\log e_0$. According to the *UIP* condition, as soon as the interest rate differential opens up, home's exchange rate will appreciate immediately (jump) to $\log e_1$ so that its expected depreciation over the year is equal to the interest rate differential. In the diagram, the two double-headed arrows are equal.

[9] Natural logs often allow equations to be displayed and manipulated in a simpler manner. Taking the natural log of a variable is an example of a monotonic transformation, that whilst changing the values in the series preserves the order of the underlying variables. This ensures that taking natural logs does not change the meaning of the original data. Another useful property of natural logs is that (when percentages are small) the percentage change between two variables is approximately equal to the difference in the natural logs of those two variables. In the case of the *UIP* condition, using this property of natural logs allows us to represent the *UIP* condition as a $-45°$ degree line, which makes the graphical analysis less complex. In general, this property makes calculating percentages changes or growth rates easier and is often used when analysing time series data. We look at natural logs in more detail in the discussion on long-run growth in Chapter 8.

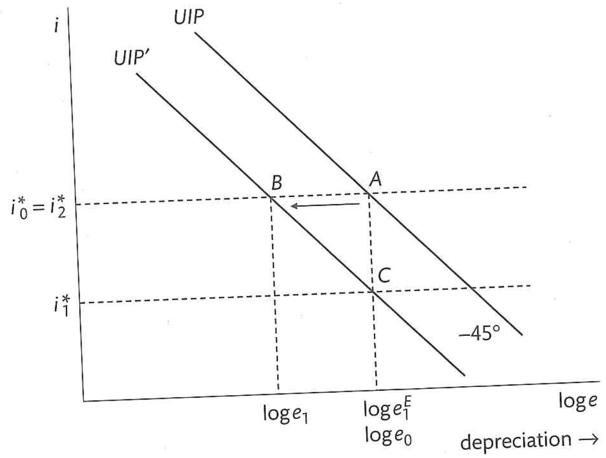

Figure 9.4 The uncovered interest parity condition: a fall in the world interest rate leads to an immediate appreciation of the home exchange rate.

The key features of the *UIP* diagram with i and $\log e$ on the axes are:

1. each *UIP* curve has a slope of −45° and must go through the point ($\log e^E$, i^*);
2. a change in home's interest rate causes a *movement along* the *UIP* curve (for a given $\log e^E$ and i^*);
3. for a given expected exchange rate, any change in the world interest rate *shifts* the *UIP* curve;
4. for a given world interest rate, any change in the expected exchange rate *shifts* the *UIP* curve.

To illustrate how the *UIP* curve works, suppose there is a fall in the world interest rate that will last for one period. What is the implication for the home country's exchange rate assuming that there is no change in the home interest rate? To answer this question, we assume there is no change in the expected exchange rate. The shift in the *UIP* curve from *UIP* to *UIP'* due to the fall in the world interest rate is shown in Fig. 9.4.

The economy is initially at point *A* on the *UIP* curve. With the expected exchange rate equal to $\log e^E$ and with home's interest rate unchanged and now above the world interest rate of i_1^*, arbitrage in the financial market will lead to an immediate appreciation of the home exchange rate as shown by point *B* on the new *UIP* curve, *UIP'*. At the end of the period, i^* reverts to its initial level (and the *UIP* curve reverts to the original one). There is no interest differential and the exchange rate is back at its initial level.

If the home country is the UK, the pound depreciates continuously over the period during which the interest rates differ. As the *UIP* condition makes clear, for example, just before the US interest rate is raised at the end of the period, there is little to be gained by switching to UK bonds: the tiny expected interest gain would be matched by a tiny expected depreciation of the pound: hence e_t would be very close to its expected level.

The diagram also illustrates that there will be no change in the exchange rate at all if the central bank in the home country immediately follows the interest rate move by the foreign central bank. The economy would shift from *A* to *C*. At the end of the period, if home again follows the interest rate move of the foreign central bank, then the move is from *C* back to *A* and the exchange rate does not change.

A final exercise is the analysis of a change in sentiment in the foreign exchange market. If traders suddenly change their view about the likely exchange rate in a year's time, the *UIP* curve will shift. If a depreciated home exchange rate is expected, the *UIP* curve will shift to the right. With the home and world interest rates equal, such a change in sentiment will have the effect of leading to an immediate depreciation of the actual exchange rate to its new expected value (so that the *UIP* condition holds). This illustrates that expectations about future developments are incorporated into today's exchange rate. Drawing the diagram for this case is left as an exercise for the reader.

9.2.2 Medium-run equilibrium in the open economy and the *AD-ERU* model

Before we can bring the foreign exchange market together with the 3-equation model, we need to analyse the characteristics of the constant inflation equilibrium of the open economy. This entails discussion of the supply side and the demand side.

We saw in Chapter 2 that the closed economy is in medium-run equilibrium when inflation is constant. For inflation to be constant, there must be equilibrium on the supply side, which occurs when wage and price setters have no incentive to change their behaviour—i.e. at the intersection of the *WS* and *PS* curves (see Chapter 2). The intersection between the *WS* and *PS* curves pins down the *equilibrium rate of unemployment*, which is why we shall call the supply-side schedule in the medium-run model the *ERU* curve. The use of the term *ERU* is a reminder that the supply side, and in particular the labour market, lies behind the determination of the constant inflation equilibrium.

In the open economy, the real exchange rate plays a central role and it is useful to present the medium-run model in a diagram with output on the horizontal axis and the real exchange rate on the vertical axis. The full medium-run model, which includes the trade balance, is introduced in the next chapter. Here we focus on the demand- and supply-side relationships, and we use the simplest model that allows us to understand stabilization policy problems in the open economy.

As we shall see in this section, the *ERU* curve captures the supply side of the economy. On the *ERU* curve, inflation is constant. The demand side in the open economy is represented by the *aggregate demand* curve (the *AD* curve). On the *AD* curve, the goods market is in equilibrium and the real interest rate is equal to the world real interest rate (i.e. $r = r^*$).

The medium-run equilibrium (MRE) in the open economy is defined by values of output, unemployment and the real exchange rate. In a MRE, which we shall see is at the intersection of the supply-side (*ERU*) curve and the demand side (*AD*) curves, output and the real exchange rate are at their equilibrium levels and inflation is constant. The medium-run model applies irrespective of the exchange rate regime. The type of exchange rate regime (i.e. fixed or flexible) affects the dynamics of adjustment to shocks, the available policy instruments and how the medium-rate inflation rate is determined. In this chapter, we concentrate on flexible exchange rate regimes and leave a discussion of fixed exchange rate regimes until Chapters 10 and 12. We look at the *ERU* and the *AD* curves in turn.

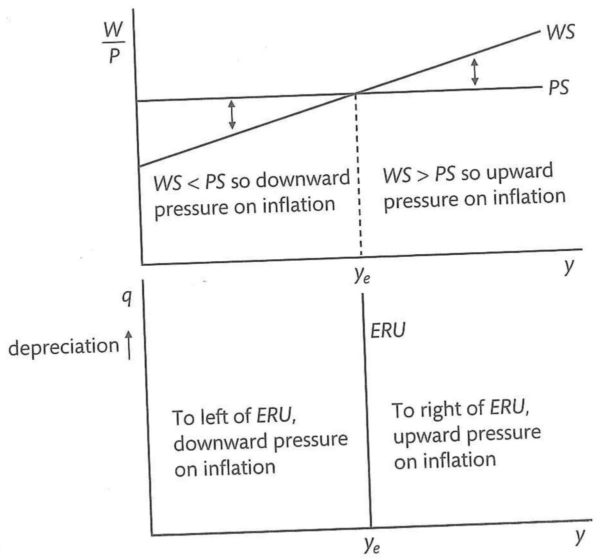

Figure 9.5 Supply-side equilibrium and the *ERU* curve.

Supply-side equilibrium: the *ERU* curve

The *ERU* curve is defined by the intersection of the wage- and price-setting curves. It shows the combinations of the real exchange rate and output at which there is supply-side equilibrium (i.e. constant inflation).

In this chapter, we continue to work with a single price level, P, which means the *WS* and *PS* curves are exactly the same as in the closed economy. Figure 9.5 shows the equilibrium output level, y_e, associated with supply-side equilibrium. At an output level to the right of y_e, the real wage defined by the *PS* curve is too low for wage setters given that unemployment is below equilibrium. This puts upward pressure on inflation. Similarly, an output level below y_e where unemployment is higher than equilibrium means that the real wage (on the *PS*) is too high given the weakness of workers in the labour market: there is downward pressure on inflation. Although not shown in the diagram, the short-run Phillips curves are derived graphically from the *WS* and *PS* curves in exactly the same way as in the closed economy.

The *WS* − *PS* intersection defines the *ERU* curve, which is vertical in the real exchange rate-output diagram at y_e.[10] For reasons that will become clear, we use the log of the real exchange rate rather than its level on the vertical axis in Fig. 9.5. We use q to denote the natural logarithm of Q—i.e. $q \equiv \log Q$. We can write the *ERU* curve as:

$$y = y_e(z^W, z^P), \qquad \text{(ERU curve)}$$

where z^W is the set of supply-side factors that shift the *WS* curve such as unionization, labour market regulations and unemployment benefits. z^P is the set of factors that shifts the *PS* curve, such as the tax rate, the level of technology (i.e. labour productivity) and the degree

10 In the next chapter, we shall see why the *ERU* may be downward sloping.

of product market competition. As we saw in Chapter 2, for example, a rise in unionization shifts the *WS* curve upwards and reduces equilibrium output. In the open economy diagram, this is represented by a leftward shift in the vertical *ERU* curve to the new lower level of equilibrium output.

The ERU curve is defined as the combinations of the real exchange rate and output at which the wage-setting real wage is equal to the price-setting real wage. At any point on the ERU curve, inflation is constant.

9.2.3 *AD* curve

The *AD* curve incorporates the demand side and the *UIP* condition in the medium-run equilibrium. To derive the *AD* curve, we use the version of the *IS* curve introduced in Chapter 3. This formulation captures the fact that aggregate demand responds negatively to the real interest rate (r) and positively to a depreciation in the real exchange rate (q), both with a one period lag. Hence

$$y_t = A_t - ar_{t-1} + bq_{t-1}, \qquad \text{(open economy IS curve)}$$

where A includes the multiplier and demand shift variables in the open economy, such as world trade, as well as government spending (G) and the variables that shift the consumption and investment functions such as wealth and Tobin's Q. The open economy *IS* curve is discussed in detail in the next chapter.

The second step in deriving the *AD* curve is to incorporate financial integration. In medium-run equilibrium, the real exchange rate is constant and equal to its expected value. We shall see that this implies that $r = r^*$. We are considering a small open economy, which cannot affect the world real interest rate. To see why $r = r^*$ in a medium-run equilibrium, we begin by recalling the *UIP* condition:

$$i_t - i^* = \log e^E_{t+1} - \log e_t. \qquad \text{(UIP condition)}$$

From this, we know that for the nominal exchange rate to be unchanged (i.e. $\log e^E_{t+1} = \log e$), then $i_t = i^*$. We can derive the *UIP* condition in terms of the real rather than the nominal exchange rate (see Section 9.5.1 of the Appendix for the derivation):

$$r_t - r^* = q^E_{t+1} - q_t. \qquad \text{(real UIP condition)}$$

The real *UIP* condition says that if home's real interest rate is higher than the world's, then its real exchange rate is expected to depreciate. Since for a medium-run equilibrium, we require the real exchange rate to be constant, i.e. that the actual real exchange rate is at its expected level, then it is also the case that $r = r^*$. This produces the aggregate demand equation:

$$y = A - ar^* + bq. \qquad (AD \text{ curve}, r = r^*)$$

Note, there are no time subscripts on the equation for the *AD* curve, because to be on the *AD* curve, r has to be equal to r^* and the real exchange rate must be constant. The *AD* curve is upward sloping in the exchange rate-output space (as shown in Fig. 9.6). This means a more depreciated exchange rate is associated with a higher level of output.

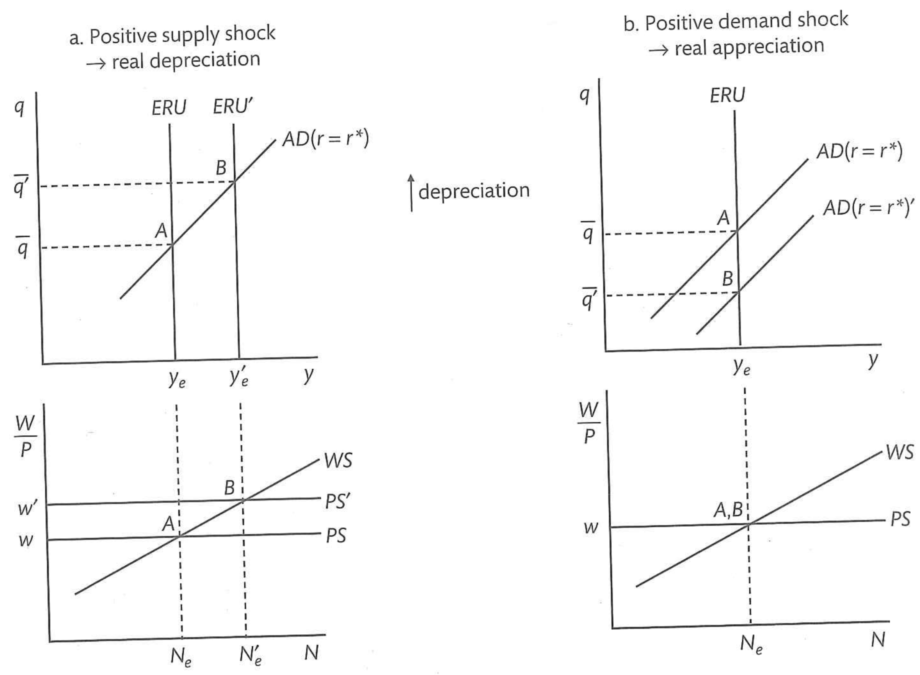

Figure 9.6 What determines the medium-run real exchange rate?

The AD curve shows the medium-run combinations of the real exchange rate, q, and level of output, y, at which the goods market is in equilibrium with the real interest rate equal to the world real interest rate (i.e. $r = r^*$).

The medium-run model (*AD-ERU* model)

The basic medium-run model for analysis in the small open economy consists of:

- The demand side represented by the *AD* curve. On the *AD* curve, the goods market is in equilibrium and $r = r^*$.
- The supply side represented by the *ERU* curve. On the *ERU* curve inflation is constant.
- In medium-run equilibrium, the economy is at the intersection of an *AD* curve with the *ERU* curve: $r = r^*$; $y = y_e$; $q = \bar{q}$; and inflation is constant. Being on the *AD* curve implies that the real exchange rate is equal to its expected value and hence, constant; being on the *ERU* curve means $y = y_e$ and hence, inflation is constant.

What determines the medium-run real exchange rate?

In modelling the *UIP* condition, exchange rate expectations played a key role. The *AD* – *ERU* model helps to explain those expectations by showing how the real exchange rate is determined in the medium-run equilibrium.

Table 9.1 Supply and demand shocks: implications for medium-run equilibrium.

	Shock		
	Rise in productivity	**Fall in union bargaining power**	**Increase in autonomous consumption**
Equilibrium unemployment	↓	↓	no change
Real exchange rate	depreciation	depreciation	appreciation
Real wage	↑	no change	no change

Note: ↑ means the variable is higher in the new medium-run equilibrium, ↓ means it is lower and 'no change' means it is unchanged. We assume a flat PS curve throughout.

In the closed economy, there is a new stabilizing real interest rate at medium-run equilibrium following a permanent demand or supply shock. In the small open economy, the real interest rate is pinned down by the world real interest rate in medium-run equilibrium (i.e. $r = r^*$) and it is therefore the real exchange rate that varies in response to demand and supply shocks.

We assume the economy is initially at medium-run equilibrium on the *AD* and *ERU* curves, and look at the implications for the real exchange rate of a supply shock and a demand shock.

A supply shock A positive supply shock such as a wave of new technology raises productivity and the *PS* shifts up (assuming it takes time for the change in trend productivity to make its way into wage-setters' behaviour). This shifts the *ERU* curve to the right. At the new equilibrium, the real exchange rate has depreciated to $\bar{q}'$. Equilibrium output is higher (see point *B* in Fig. 9.6a). The intuition for this result is that for the level of output demanded to increase to the higher equilibrium level, the real exchange rate must be depreciated. All the other components of aggregate demand are unchanged.

A demand shock A positive demand shock such as an investment boom shifts the *AD* curve to the right and at the new equilibrium, there is an appreciated real exchange rate, $\bar{q}'$ (point *B* in Fig. 9.6b). Output is unchanged in the new equilibrium. In this case, an investment boom raises *A* in the *AD* equation; r^* is fixed and therefore an appreciated real exchange rate is required to reduce aggregate demand such at $y = y_e$.

Table 9.1 compares the implications of a variety of permanent supply and demand shocks for unemployment, the real exchange rate and real wages in the new constant inflation equilibrium.

9.2.4 Stabilization under flexible exchange rates: 3-equation model and *RX* curve

To model stabilization policy in the open economy, we use the *AD* – *ERU* model to characterize the medium-run equilibrium and extend the 3-equation model to explain how the central bank responds to a shock. To do this, we introduce a new curve, the *RX* curve, explained below, which gives the central bank's best interest rate response taking into account the reaction of the foreign exchange market.

To simplify the modelling, we assume the central bank targets domestic inflation. In reality, central banks target consumer price inflation, which includes the effect of changes in import prices.

In the closed economy, the central bank minimizes its loss function, which expresses its objective of keeping inflation close to target, π^T, subject to the constraint from the supply side, which is the Phillips curve (*PC*). This produces the monetary rule function (*MR*), which pins down the best response output gap $(y_t - y_e)$. This is in turn implemented through the choice of the real interest rate (r) using the *IS* equation.

Why should openness of the economy affect the central bank's inflation targeting behaviour? The answer is that the central bank will need to take account of the forward-looking behaviour in the foreign exchange market and the effect of changes in the exchange rate on aggregate demand. The examples in Section 9.1 highlighted why the central bank will need to build into its decision making the anticipation of the foreign exchange market response.

In the open economy, the central bank minimizes its loss function, which just as in the closed economy expresses its objective of keeping inflation close to its target, π^T

$$L = (y_t - y_e)^2 + \beta(\pi_t - \pi^T)^2, \qquad \text{(central bank loss function)}$$

1. Subject to the constraint from the supply side, which (again, just as in the closed economy) is the adaptive expectations Phillips curve (*PC*),

$$\pi_t = \pi_{t-1} + \alpha(y_t - y_e). \qquad \text{(Phillips curve, } PC\text{)}$$

2. Again this produces the monetary rule function (*MR*), which pins down the best response output gap $(y_t - y_e)$,

$$(y_t - y_e) = -\alpha\beta(\pi_t - \pi^T). \qquad \text{(monetary rule, } MR\text{)}$$

3. But now this is implemented through the central bank's choice of r using the *open economy IS curve* and *taking account of the reaction of the forward-looking forex market*,

$$y_t = A_t - ar_{t-1} + bq_{t-1}. \qquad \text{(open economy } IS \text{ curve)}$$

Earlier in the chapter, we introduced the *UIP* condition, which showed how the exchange rate jumps in response to any news about home or foreign interest rates. When a shock hits the economy, this is news and both the central bank *and* the foreign exchange market will respond to it (see Fig. 9.7, starting at the top, for a summary of the dynamic adjustment of the economy to an inflation shock).

Instead of adjusting back to equilibrium along the *IS* curve as in the closed economy, the central bank will adjust along a flatter 'interest rate – exchange rate' curve called *RX*. Smaller interest rate changes will be needed because the exchange rate channel operates as well.

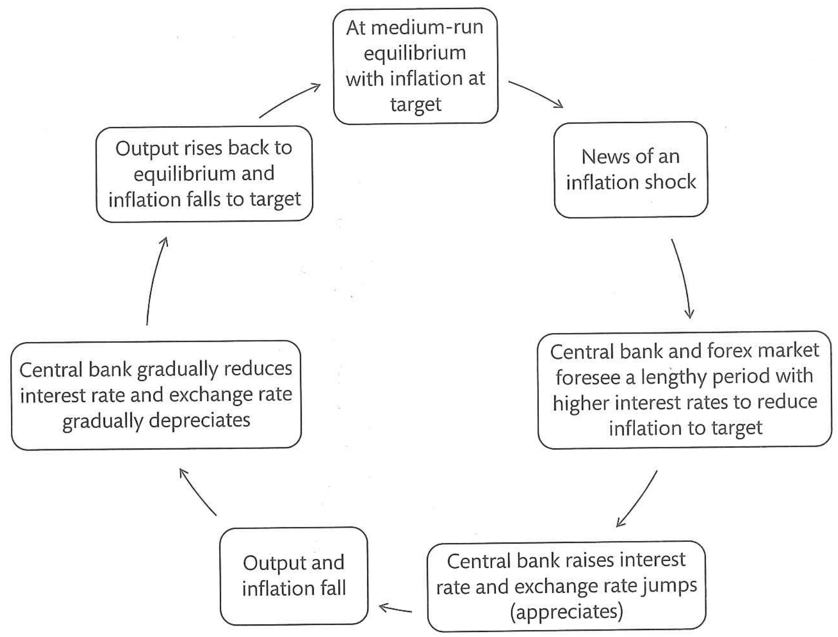

Figure 9.7 Dynamic adjustment to an inflation shock under flexible exchange rates and inflation targeting.

9.2.5 Inflation shock: comparing closed and open economies

The first step is to recall that a temporary inflation shock shifts the Phillips curve for one period. The problem for the inflation-targeting central bank is to get inflation back to its target and in order to do that, it must push output below and unemployment above equilibrium by raising the interest rate. This is because of the persistence in the inflation process (indicated by π_{t-1} in the *PC* equation): once inflation has been pushed up by the shock, it is built in to the behaviour of wage and price setters. For example, if food prices were pushed up by the effects of a drought, wage setters will expect in the next round of wage setting to get a wage increase that compensates them for the higher prices they face. In turn, firms will increase their prices to maintain their profit margins in the face of higher labour costs. This feature of inertia in wage and price setting means the central bank faces the constraint of the Phillips curve indexed by the inflation shock even though the shock was a temporary one.

Once inflation is back at target, the economy will be back at the initial equilibrium. This means that in the *AD – ERU* model the new equilibrium coincides with the initial equilibrium—i.e. there is no change in the medium-run equilibrium real exchange rate.

A good way of introducing the open economy aspects of the problem faced by the central bank is to make a direct comparison with the closed economy. Figure 9.8 shows the *IS* and Phillips curve diagrams for the cases of the open and closed economies following an inflation shock.

Closed economy

Figure 9.8a (the left-hand panel of Fig. 9.8), shows the adjustment of a closed economy to a temporary inflation shock, repeating the analysis from Chapter 3.

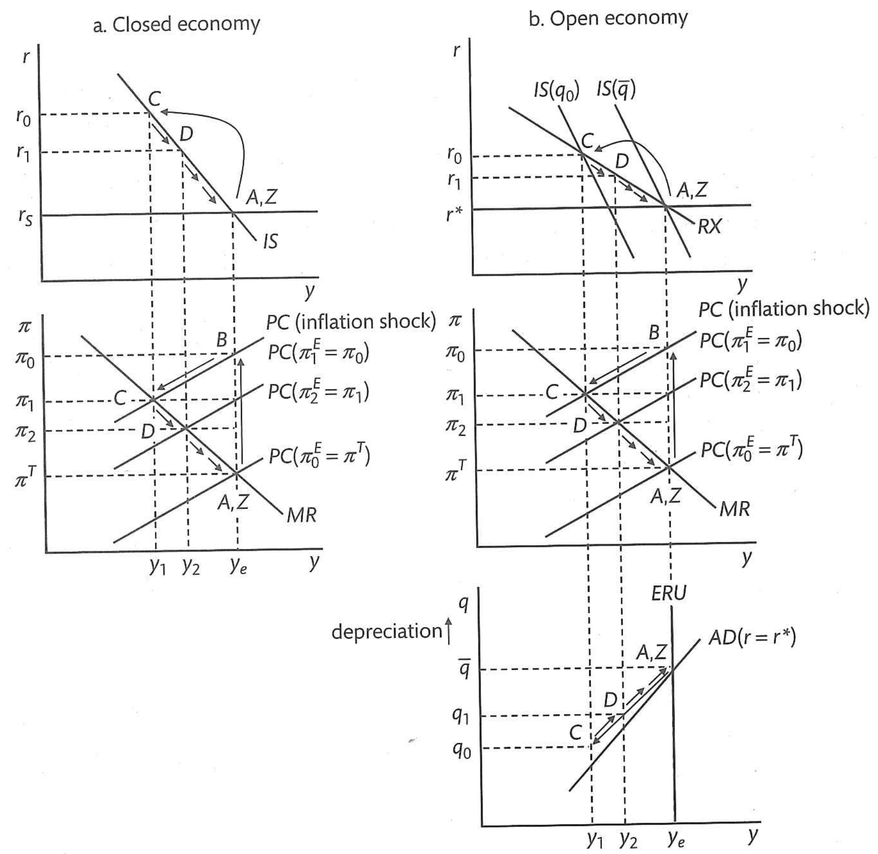

Figure 9.8 Inflation shock: closed and open economies.

Period 0 The economy starts at *A*—the central bank's bliss point. The economy is hit by an inflation shock which shifts the *PC* to *PC*(inflation shock) and the economy moves from *A* to *B*. Point *B* is not on the central bank's *MR* curve. The central bank forecasts the *PC* in the next period. This is $PC(\pi_1^E = \pi_0)$. Faced with this *PC*, the central bank would like to locate at point *C*, back on their *MR* curve. They therefore set the interest rate at r_0. The interest rate can only affect economic output with a one period lag, however, so the economy ends period 0 with inflation at π_0, output at y_e and interest rates at r_0.

Period 1 The new interest rate has had time to affect aggregate demand. The higher rate of interest dampens investment. This reduces output and the economy moves to point *C*, with output below equilibrium at y_1 and inflation at π_1. The central bank forecasts the *PC* in the next period. Based on last period's inflation, the *PC* it faces is $PC(\pi_2^E = \pi_1)$ and the central bank would like to locate at point *D*, back on their *MR* curve. They therefore reduce the interest rate to r_1. The interest rate can only affect economic output with a one period lag however, so the economy ends period 1 with inflation at π_1, output at y_1 and interest rates at r_1.

Period 2 onwards In period 2, the economy moves to point *D*, as the lower interest rate stimulates demand. This increases output to y_2 and inflation falls to π_2. The same process now repeats itself until the economy is back at equilibrium at *Z*. The economy will move gradually down the *MR* curve, as the central bank slowly adjusts the interest rate down from r_1 to r_S. The adjustment to the inflation shock ends when the economy is back at point *Z*, with output at y_e, inflation at π^T and the interest rate at r_S.

Open economy: introducing the *RX* curve

Figure 9.8b shows the adjustment of a small open economy to a temporary inflation shock.

Period 0 The economy starts at *A* and the central bank's reasoning is the same as in the closed economy to locate its best response output gap at point *C*, on their *MR* curve. The foreign exchange market foresees that the central bank will keep interest rates above world interest rates for a number of periods in order to squeeze inflation out of the system. The *UIP* condition implies this will cause an immediate appreciation of home's currency, so that it can depreciate for the *whole period* during which there is a positive interest differential between home and foreign bonds. To get the economy back on the *MR* curve in the next period, the central bank therefore sets the interest rate at r_0 on the *RX* curve—taking into account the appreciation in the exchange rate that will occur since the IS curve will shift to the left to IS(q_0). The interest rate and the exchange rate can only affect economic output with a one period lag however, so the economy ends period 0 with inflation at π_0, output at y_e, the interest rate at r_0 and the exchange rate at q_0.

Period 1 The new interest rate and exchange rate have had time to affect aggregate demand. The higher rate of interest dampens investment and the appreciated exchange rate reduces net exports. These forces combine to reduce output and the economy moves to point *C*, with output below equilibrium at y_1 and inflation at π_1. The *IS* curve has shifted to the left on account of the more appreciated exchange rate. The central bank forecasts the *PC* in the next period, $PC(\pi_2^E = \pi_1)$. Faced with this *PC*, the central bank would like to locate at point *D*, back on their *MR* curve. In setting the interest rate, they again take into account the response of the foreign exchange market. The central bank foresees that a depreciation of the exchange rate will follow any reduction in the interest rate, as the *UIP* condition needs to hold in every period. They therefore reduce the interest rate to r_1 and the exchange rate depreciates to q_1 (point D on the *RX* curve). The interest rate and the exchange rate can only affect economic output with a one period lag however, so the economy ends period 1 with inflation at π_1, output at y_1, the interest rate at r_1 and the exchange rate at q_1.

Period 2 onwards In period 2, the economy moves to point *D*, as the lower interest rate and depreciated exchange rate stimulate demand. This increases output to y_2 and inflation falls to π_2. The *IS* curve has shifted to the right (back towards the initial equilibrium), due to the depreciation in the exchange rate. The economy is travelling down the curve labelled *RX* curve, which is flatter than the *IS* curve. It shows the adjustment path of a small open economy (with flexible exchange rates) after an economic shock. Along the *RX* curve the *UIP* condition always holds—i.e. it shows the central bank the interest rate to set to achieve a given output gap, taking into account the reaction of the forex market. The same process now repeats itself until the economy is back at equilibrium at Z.

The adjustment from D to Z will take a number of periods. The *IS* curve will gradually shift to the right and the economy will move gradually down the *RX* and *MR* curves, as the central bank slowly adjusts the interest rate down from r_1 to r^* and the exchange rate depreciates from q_1 to $\overline{q}$. The interest rate needs to be back at the world interest rate for there to be no pressure on the exchange rate to change and for the economy to be in medium-run equilibrium. The movements in r and q reinforce each other, causing output to rise slowly from y_2 to y_e and inflation to fall slowly from π_2 to π^T. The adjustment ends when the economy is back at point Z, with output at y_e, inflation at π^T, the interest rate at r^* and the exchange rate at $\overline{q}$.

To complete the discussion of the open economy adjustment, the bottom panel of Fig. 9.8b shows the *AD − ERU* diagram. In the case of an inflation shock, the positions of the *AD* and *ERU* curves are unaffected by the shock. For the whole of the adjustment process the economy is to the left of the *ERU* curve and as we saw in Fig. 9.5, this leads to downwards pressure on inflation. This causes inflation to fall until the economy is back at target inflation and once again on the *ERU* curve in medium-run equilibrium. From the top panel, we know that the real interest rate is above the world interest rate during the adjustment process. This means the adjustment along the *MR* curve from C to Z will lie to the left of the *AD* curve as shown in the bottom panel: at each level of q, $r > r^*$ so output is below the level shown by the *AD* curve on which $r = r^*$. The economy will only be back on the *AD* curve when it is once more in medium-run equilibrium with $r = r^*$.

Comparing the closed and open economy cases

There are clear differences between the closed and open economy adjustment paths in Fig. 9.8:

1. The initial interest rate hike (to r_0) in response to the inflation shock is greater in the closed economy. This is because the appreciation of the exchange rate shoulders some of the burden of adjustment in the open economy.

2. The *IS* curve shifts in each period in the open economy but remains fixed in the closed economy. The open economy *IS* curve includes net exports, which are dampened by any appreciation of the real exchange rate and boosted by any depreciation. Net exports are part of the intercept term of the open economy *IS* curve, so the *IS* curve shifts if the real exchange rate changes. In contrast, a change in the real interest rate causes a movement along the *IS* curve (in both the closed and open economies).

3. The closed economy moves along the *IS* curve on its path back to equilibrium. This curve shows the interest rate the central bank must set to achieve their desired output gap on the *MR* curve. The open economy moves along the flatter *RX* curve on its path back to equilibrium. This curve shows the interest rate the central bank must set to achieve its desired output gap, whilst also taking into account the response of the forex market to any differential between home and world interest rates. The *UIP* condition holds at all points on the *RX* curve.

Figure 9.8 also highlights the important role played by expectations in the adjustment of the economy to an inflation shock in an open economy. The adjustment process relies heavily on the central bank and forex market foreseeing that a lengthy period with higher interest rates will be required to reduce inflation to target (see the third step in the flow diagram in Fig. 9.7). The central bank and foreign exchange market solve the dynamic adjustment problem simultaneously using the same model, which is an example of rational expectations modelling.

In Section 9.5.2 of the Appendix, we show in more detail how to calculate the initial jump in the exchange rate and therefore how to derive the *RX* curve mathematically and geometrically.

To use the *RX* curve, its key features are:

1. It goes through the intersection of r^* and y_e and therefore shifts only when either of these changes.
2. Its slope reflects the interest and exchange rate sensitivity of aggregate demand, the central bank's preferences and the slope of the Phillips curves:
   (a) it is flatter than the *IS* curve;
   (b) it is flatter, the flatter is the *IS* curve (i.e. when a is higher indicating higher interest sensitivity of aggregate demand) and the higher is b (i.e. the more sensitive is aggregate demand to the real exchange rate). When there is a larger aggregate demand response to a given change in the interest rate or exchange rate (i.e. a higher a or b), the central bank has to change the interest rate by less, ceteris paribus;
   (c) it is flatter, the steeper is the *MR* curve (i.e. the lower is α, flatter Phillips curves; or the lower is β, steeper loss circles). For example, when the central bank is less 'hard-nosed' the return to equilibrium following a shock will be slower and the central bank will raise the interest rate by less.

The response of the economy and the central bank to an inflation shock in both a small open economy with flexible exchange rates and a closed economy can be shown using the Macroeconomic Simulator available from the Carlin and Soskice webpage.[11] Figure 9.9 shows the impulse response functions after the economy experiences a 2% inflation shock in period five. We can see that the behaviour of inflation and GDP is the same in both cases, which is analogous to the bottom panels being identical in Fig. 9.8. The key difference in the

[11] The impulse reponse functions shown in Fig. 9.9 show the effect of a 2% positive inflation shock. To re-create these graphs, open the Macroeconomic Simulator available from the Carlin and Soskice website http://www.oup.com/uk/orc/carlin_soskice and choose the closed economy version. Then take the following steps:
(1) Click on the *reset all shocks* button on the left hand side of the main page. (2) Set a 2% positive inflation shock and change the sensitivity of expenditure with respect to interest rate to 0.5. (3) Click on the *inflation, income and interest rates figures* button on the left hand side to view the impulse response functions. (4) Return to the main page and click on the *save* button on the left hand side. This will store these graphs in memory. (5) Click the *change to a different simulator version* on the main page to switch to the open economy (with flexible exchange rates) version of the simulator and then apply the same shock, remembering to adjust the sensitivity of the exchange rate with respect to the real exchange rate to 1. (6) Save this data, then click on the *go to saved data* button on the main page to compare the two scenarios.

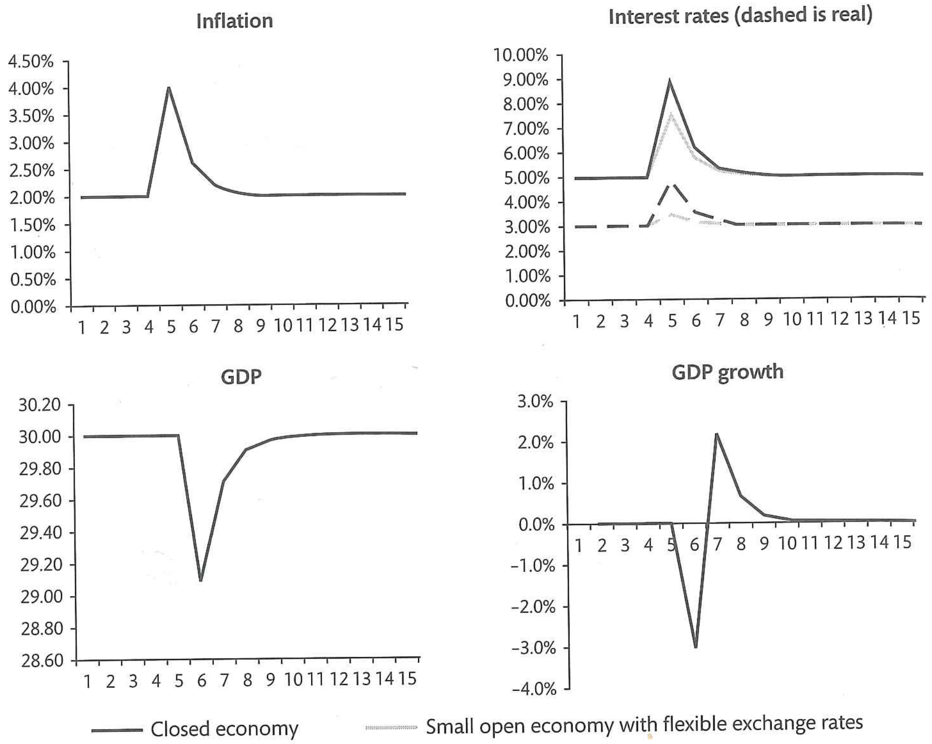

Figure 9.9 Macroeconomic simulator example—Impulse response functions after an inflation shock (in period 5) in a closed economy and a small open economy with flexible exchange rates.

impulse reponse functions is the behaviour of interest rates. In the closed economy case, the central bank has had to raise the interest rate by more to stabilize the economy after the inflation shock. This is because in the open economy, some of the adjustment takes place through an appreciation of the real exchange rate.

9.3 Applications

9.3.1 Demand and supply shocks: the 3-equation and *AD-ERU* models

As we have seen in the closed economy (Chapter 3), it is only necessary for the central bank to manage the adjustment of the economy to an aggregate demand shock when it is unable to respond quickly enough to prevent any consequences of the shock for inflation from occuring. If it could act quickly enough by changing the interest rate to offset the effect of the demand shock on inflation, it could avoid the need to get the economy on to the *MR* curve. This is also the case in the open economy, where we have defined the *IS* curve such that output in period t depends on the real interest rate and the real exchange rate in period $t-1$:

$$y_t = A_t - ar_{t-1} + bq_{t-1}. \qquad \text{(open economy } IS\text{)}$$

This *IS* curve assumes it takes one period for the decisions of the central bank and the foreign exchange market to affect the real economy: a shock to y_t cannot be offset by a change in r or in the real exchange rate q within the period. The fact that interest rates typically affect the economy with a lag is taken into account when monetary policy is formulated in the UK. The Bank of England's mandate when making interest rate decisions is to target inflation two years ahead. If the real economy responded immediately to changes in the real interest rate and the real exchange rate, then the economy would return to equilibrium within the period, there would be no chance for the output gap to affect inflation and no need for the central bank to intervene to bring inflation back to target along the *MR* curve.

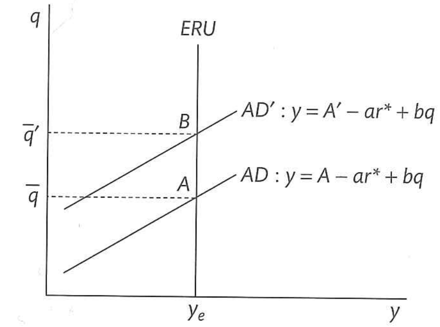

Figure 9.10 Medium-run equilibrium: negative demand shock.

From Section 9.2.2 we know that demand and supply shocks change the medium-run exchange rate. The first step is therefore to look at the implications of the demand (or supply) shock for the medium-run equilibrium using the $AD - ERU$ model (Fig. 9.10). As our example, we take a permanent negative aggregate demand shock due, for example, to a fall in investment demand, which reduces the term A in the *AD* equation (shown in Section 9.2.3). This shock shifts the *AD* curve to *AD*′. Since we know that in the small open economy the real interest rate in the new equilibrium is at the world real interest rate, it is clear that there will be a depreciated *real exchange rate* in the new equilibrium: for output to be equal to y_e, higher net exports must offset the lower investment. This contrasts with the closed economy, where a permanent negative demand shock implies a lower stabilizing *real interest rate* in the new medium-run equilibrium.

Dynamic adjustment to the shock

Next, we analyse the dynamic adjustment of the economy to the shock using the 3-equation model, as shown in Fig. 9.11:

Period 0 The economy starts at *A*—the central bank's bliss point. The economy is hit by a negative permanent demand shock which shifts the *IS* curve to $IS(A', \bar{q})$. Output in the economy falls to y_0 and inflation falls to π_0. The economy moves from *A* to *B*. Point *B* is not on the central bank's *MR* curve. The central bank forecasts the *PC* in the next period. The *PC* will move to $PC(\pi_1^E = \pi_0)$ next period. Faced with this *PC*, the central bank would like to locate at point *C*, back on their *MR* curve. At point *C*, output is above equilibrium, so in order to reach this point, the central bank will need to reduce interest rates to stimulate investment and boost output. The foreign exchange market foresees that the central bank will keep interest rates *below* world interest rates for a number of periods in order to boost demand and return inflation to target. The *UIP* condition implies this will cause an immediate

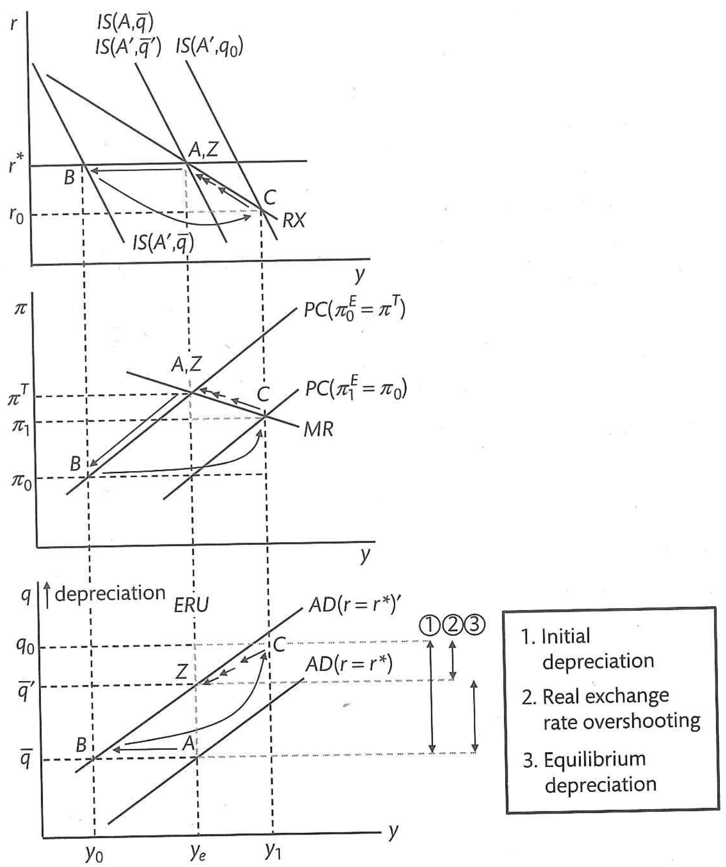

Figure 9.11 Dynamic adjustment to a negative permanent demand shock.

depreciation of home's currency, so that it can appreciate for the whole period where home's interest rates are below world rates. The central bank therefore sets the interest rate at r_0—taking into account the immediate depreciation in the exchange rate that will occur—to get the economy back on the *MR* curve *in the next period*. The interest rate and the exchange rate can only affect economic output with a one period lag however, so the economy ends period 0 with inflation at π_0, output at y_0, interest rate at r_0 and exchange rate at q_0.

Period 1 onwards The new interest rate and exchange rate have had time to affect aggregate demand. The lower rate of interest boosts investment and the depreciated exchange rate increases net exports. The economy moves to point *C*, with output above equilibrium at y_1 and inflation at π_1. The *IS* curve has shifted to the right to $IS(A', q_0)$ due to the depreciation of the exchange rate. This is further to the right than the original *IS* curve. The adjustment process from point *C* back to point *Z* (not shown in the diagram) follows the process described for an inflation shock in Section 9.2.5 and will take a number of periods. The *IS* curve will gradually shift to the left and the economy will move gradually up the *RX* and *MR* curves, as the central bank slowly adjusts the interest rate up from r_0 to r^* and the exchange rate appreciates from q_0 to $\overline{q}\prime$. The exchange rate appreciates from period 1 onwards to take account of the fact

that home interest rates are below world interest rates. This ensures the *UIP* condition holds in every period. The interest rate needs to be back at the world interest rate for there to be no pressure on the exchange rate to change and for the economy to be in medium-run equilibrium. Adjustment to the demand shock ends when the economy is back at point *Z*, with output at y_e, inflation at π^T, the interest rate at r^* and the exchange rate at $\overline{q}\prime$.

In the new medium-run equilibrium, the *IS* curve is indexed by lower autonomous demand (as a result of the permanent negative demand shock) and a depreciated real exchange rate (i.e. $IS(A', \overline{q}\prime)$). This is because the permanent fall in autonomous demand needs to be offset by higher net exports for the economy to return to equilibrium output after the shock.

The bottom panel of Fig. 9.11 shows the $AD - ERU$ diagram. A permanent negative demand shock causes a leftward shift of the *AD* curve. The arrows plot the adjustment path of the economy. They show that the initial depreciation of the real exchange rate (from $\overline{q}$ to q_0) was greater than the equilibrium depreciation (from $\overline{q}$ to $\overline{q}\prime$). The label ② on the $AD - ERU$ diagram shows the difference between the initial and equilibrium movements in the real exchange rate, which is referred to as *real exchange rate overshooting*. We discuss real and nominal exchange rate overshooting in Section 9.3.2.

At point *C* on the $AD - ERU$ diagram, the exchange rate is q_0 and is expected to appreciate back to $\overline{q}\prime$: this is just what we would expect, given that during the period of expected appreciation, home's interest rate is below the world interest rate. Holders of home bonds are losing out in terms of the interest return on home bonds, but are gaining from the expected appreciation of home's exchange rate.

It is important to note that point *C* is not on the new *AD* curve, because at this point home's interest rate is below the world interest rate (r must be below r^* to produce the desired boost to demand to offset the shock, whereas r must equal r^* to be on the *AD* curve). Since $r < r^*$, y must be greater than it is on the $AD(r = r^*)'$ line because the lower r will stimulate higher interest-sensitive spending. Hence, point *C* is to the right of AD'.

Summing up

The examples of an inflation shock (as shown in Section 9.2.5) and an aggregate demand shock (as shown in this section) highlight the similarities and differences between the way the 3-equation model works in the closed and open economies. The analysis of a supply shock is left as an exercise. Remember that in the case of a supply shock, the *ERU* curve will shift. In the $AD - ERU$ diagram, there will be a new equilibrium real exchange rate and a new equilibrium output level. Just as in the closed economy, a supply shock means the *MR* curve and the Phillips curves shift. In the open economy, the *RX* curve will shift to intersect the new equilibrium output level and r^*.

The new element in the open economy is the way the behaviour of the foreign exchange market interacts with that of the central bank. Table 9.2 contrasts the decision-making process in the central bank and the foreign exchange market in the closed and open economies using the example of a permanent demand shock.

9.3.2 Exchange rate overshooting

Exchange rate overshooting refers to the phenomenon of the nominal and real exchange rate jumping by more than the equilibrium adjustment in response to shocks. In the case of

Table 9.2 Decision-making process of central bank and foreign exchange market after a permanent demand shock.

Period	Closed economy	Small open economy
0	CB works out stabilizing interest rate in the new equilibrium, r^S.	CB and forex market work out real exchange rate in the new equilibrium, $\overline{q}$; $r = r^*$. Use *AD-ERU* model.
	CB works out implications of the shock for the Phillips curve and for its choice of output in period one on the *MR* curve.	
		CB and forex market work out the path over time of the CB's desired output level along the *MR* to the new equilibrium.
	CB sets r_0 using the *IS* curve to achieve its desired output gap in the next period.	CB sets r_0 using the *RX* curve to achieve its desired output gap in the next q jumps to q_0, as the forex market take advantage of the arbitrage opportunities brought about by the interest rate differential. Both parties take into account the response of the other when formulating their best response.
1	r_0 affects the real economy, shifting output to y_1, which is on the *MR* curve and minimizes the CB's loss function.	r_0 and q_0 affect the real economy. This shifts output to y_1 on the *MR* curve, which minimizes the CB's loss function. The *IS* curve shifts as the real exchange rate affects demand for net exports.
2+	CB adjusts r to move economy along *MR* (and *IS*) to equilibrium.	CB adjusts r (and forex market adjusts q) to move economy along *MR* (and *RX*) to equilibrium.

an inflation shock, there is no change in the equilibrium real exchange rate, which means that all of the initial jump from $\overline{q}$ to q_0, which shifts the *IS* curve to the left in Fig. 9.8, is real exchange rate overshooting. In the case of a permanent demand shock, the new equilibrium real exchange rate is depreciated, but initially the depreciation overshoots this equilibrium as shown in Fig. 9.11.

Overshooting is integral to the 3-equation model of inflation targeting. It exists because of the combination of:

1. an internationally integrated financial market;
2. rational expectations in the foreign exchange market, which leads to jumps in the exchange rate; and
3. sluggish adjustment of wages and prices in the economy, which requires the central bank to keep the interest rate above (or below) the world interest rate until inflation returns to target.

When financial markets are integrated, the real *UIP* condition,

$$r_t - r^* = q^E_{t+1} - q_t, \qquad \text{(real \textit{UIP} condition)}$$

holds each period. When $r > r^*$, the real exchange rate, q must jump relative to its expected value. The greater the cumulative deviation of home's interest rate is expected to be above (e.g. in the case of a positive inflation shock) or below (e.g. in the case of a negative demand shock or a positive supply shock) the world interest rate, the more the real exchange rate must

overshoot initially in order that it can adjust back to the equilibrium exchange rate during the period of the interest rate differential. Overshooting will be greater when shocks are larger.

We can define the *equilibrium change* as the difference in the real exchange rate between the inital equilibrium and the new medium-run equilibrium. Hence the initial jump in the exchange rate equals the equilibrium change plus the exchange rate overshooting. If the interest rate differential was expected to prevail for just one year, the initial jump will be $[(r_0 - r^*)+$ equilibrium change]; if it is expected to prevail for three years, the initial jump will be $[(r_0 - r^*) + (r_1 - r^*) + (r_2 - r^*)+$ equilibrium change].[12] In Section 9.3.1, we showed exactly how the initial jump in q is determined in the case of inflation targeting, where the interest rate is gradually adjusted back to the world interest rate. This is shown by point *C* on the *RX* curve in Fig. 9.11.

Although exchange rate overshooting is an integral part of the modern modelling of a flexible exchange rate economy, this was not always the case. The German-American economist Rudiger Dornbusch developed the theory of exchange rate overshooting as a way of explaining the volatility of exchange rates following the end of the Bretton Woods system of fixed exchange rates at the end of the 1960s.[13] The idea of overshooting centres on the fact that the exchange rate is a variable that can jump easily—as we discussed when introducing the *UIP* condition in Section 9.1, within seconds of news arriving that changes the views of traders about the future, transactions take place and the exchange rate jumps. This is also true of the prices of other financial assets like shares and bonds. By contrast, the prices of most goods and services, and of labour, do not jump. Only the prices of goods that are homogeneous and traded on commodity exchanges, such as oil and wheat, behave like those of financial assets. It is the interaction of prices that jump with those that do not that produces exchange rate overshooting. It is because prices and wages *do not change immediately* to wipe out an inflation shock and return the economy to target inflation, or change to bring about the new equilibrium exchange rate to wipe out an aggregate demand shock, that overshooting occurs.

Box 9.1 Dornbusch overshooting and the Thatcher recession

In 1979, Margaret Thatcher became Prime Minister of the UK and her government introduced an anti-inflationary monetary policy referred to as the Medium-Term Financial Strategy. Prime Minister Thatcher announced a reduction in the growth of the money supply with the objective of reducing inflation. Theory suggests that if no overshooting takes place, then a 10% reduction in the money supply produces a 10% fall in prices and output would remain unchanged. The nominal exchange rate would appreciate by 10%, leaving the real exchange rate unchanged.

[12] For example: $(r_0 - r^*) + (r_1 - r^*) + (r_2 - r^*) = (\overline{q}' - q_0)$. Add $(\overline{q} - \overline{q}')$ to both sides: $(r_0 - r^*) + (r_1 - r^*) + (r_2 - r^*) + \underbrace{(\overline{q} - \overline{q}')}_{\substack{\text{equilibrium}\\ \text{change}}} = \underbrace{(\overline{q} - q_0)}_{\text{initial jump}}$.

[13] The initial model of overshooting was developed by Rudiger Dornbusch (1976). For a very readable introduction to the Dornbusch model, see Rogoff (2002), who also describes the atmosphere in Dornbusch's PhD class at MIT when he first explained the model.

Dornbusch pointed out that if the foreign exchange market expects that a period with output below its equilibrium level is required to bring prices down, then they will also expect a prolonged period where real interest rates will remain high. This is because the central bank is expected to keep nominal interest rates high until they can see evidence that prices are adjusting downwards. The expectation of higher interest rates leads to an immediate appreciation of home's real exchange rate (i.e. overshooting of the real as well as the nominal exchange rate since the nominal exchange rate appreciates by more than 10%).

Applying this to the Thatcher case, an announcement of a lower money supply growth rate did not produce an immediate fall in inflation. In anticipation that a period of high interest rates was needed to push up unemployment and squeeze inflation out of the system, the UK pound appreciated sharply following the announcement of the tight money policy in 1979. Unemployment rose as a consequence of the appreciated real exchange rate and the higher real interest rates. The fall in inflation *followed* the rise in unemployment. Figure 9.12 shows the path of the real and nominal exchange rates, unemployment and inflation over the Thatcher period. Although some of the exchange rate appreciation was attributable to the discovery of North Sea oil, exchange rate overshooting in response to the tight monetary policy was an important part of the story. Exchange rate overshooting was viewed as having led to lasting damage to the UK's manufacturing industry.

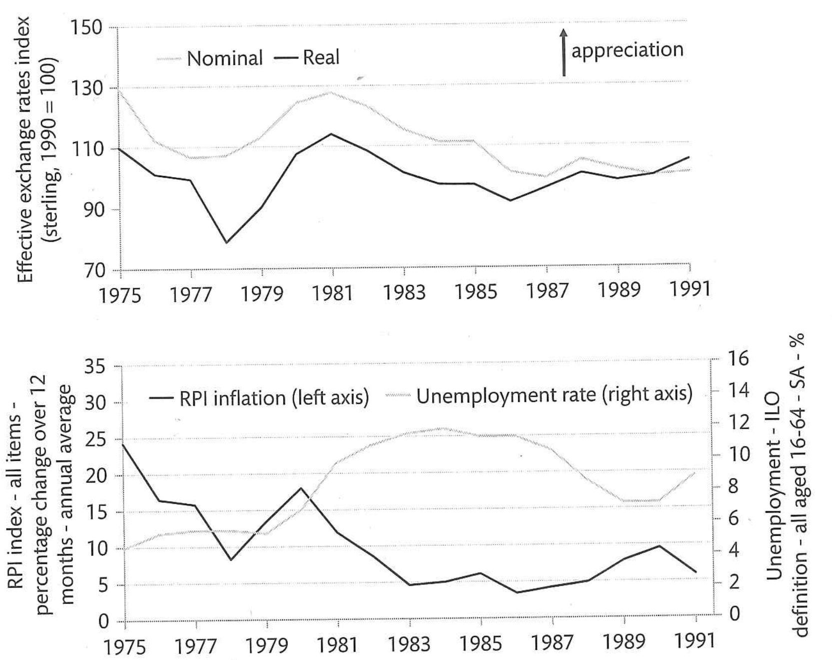

Figure 9.12 UK nominal and real effective exchange rate indices (1990 = 100): 1975–1991 (upper panel) and UK unemployment and inflation: 1975–1991 (lower panel).

Note: An increase in the effective exchange rate indices represents an appreciation.

Source: Bank of England; IMF International Financial Statistics; UK Office of National Statistics (data accessed October 2011).

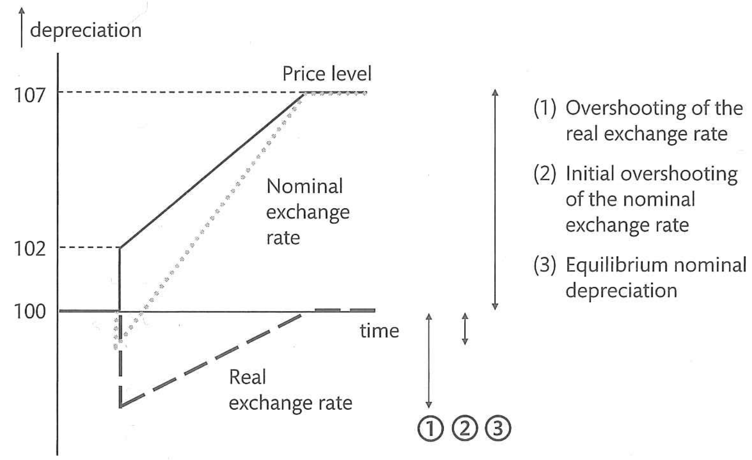

Figure 9.13 Real and nominal exchange rate paths following an inflation shock.

What determines the behaviour of the nominal exchange rate?

Our discussion of the 3-equation model to this point has been in terms of the real exchange rate—after all, it is the real exchange rate that affects aggregate demand and output, so that is the focus of attention of the central bank and the foreign exchange market in making their calculations. This is exactly the same logic as the focus on the choice of the real interest rate in the closed economy. However, it is interesting to know how the behaviour of the nominal exchange rate fits into the picture.

In Section 9.2.1, we used the *UIP* condition to see how the nominal exchange rate moved in response to a change in the home or world nominal interest rate, and in response to a change in the expected exchange rate. In the 3-equation model, the same logic is at work. However, we now have a full model of what determines the expected real exchange rate and what determines any gap between home and world real interest rates. This means that rational expectations in the foreign exchange market are oriented to producing the jump in the nominal exchange rate that is implied by solving the model.

It is useful to look at a particular example to understand the evolution of the nominal exchange rate. We take the case of an inflation shock. Looking back at Fig. 9.8b, we can see that the behaviour of domestic inflation is determined entirely by the Phillips curve and monetary rule mechanisms (in the middle panel). Since the model pins down how the real exchange rate (in conjunction with the central bank's monetary policy rule) must respond to the inflation shock, the behaviour of the *nominal* exchange rate is a residual. This follows from the definition of the real exchange rate: $Q \equiv \frac{P^*e}{P}$. Since we know that P^* is exogenous to the small open economy because it is set in the rest of the world, and P and Q are pinned down by the inflation shock and the best response policy rule, it follows that the nominal exchange rate e is just the residual.

Let us look at an example. Figure 9.13 shows the stylized paths of the domestic price level and the nominal and real exchange rates following an inflation shock using index numbers for each variable set initially at 100. For simplicity, we assume the inflation target and world inflation are both zero. With a target of zero inflation, the price *level* is therefore constant in medium-run equilibrium.

Following the inflation shock (say of 2%), the price level jumps from 100 to 102, and since home's inflation is higher than world inflation on the path back to target inflation, home's price level continues to rise until the medium-run equilibrium is reached (e.g. at a level of 107). The real exchange rate appreciates immediately and depreciates back to its initial level along the path to the medium-run equilibrium.

The nominal exchange rate depreciates more rapidly than the real exchange rate along the path to the medium-run equilibrium. At medium-run equilibrium, the price level has risen by 7% and the nominal exchange rate has depreciated by 7% relative to their starting levels: the real exchange rate is therefore back at its initial level. This reflects the fact that an inflation shock does not change the medium-run real exchange rate.

Two features of the response of the nominal exchange rate are worth pointing out. The first is that the initial nominal appreciation in period 0 is less than the real appreciation because part of the required real appreciation takes place through the initial inflation shock (and foreign exchange operators can work this out).[14] The second relates to the path back to equilibrium (from point *B* to *Z* in Fig. 9.8). In this phase, it is clear that home's inflation (although falling) is above world inflation, which would by itself imply an appreciating real exchange rate. However, the real exchange rate must be depreciating for two reasons:

1. in order to push the *IS* curve back to equilibrium (i.e. to the right); and
2. because home's real interest rate is above the world's, i.e. $r > r^*$. The gains from holding home bonds must be offset by the expected real exchange rate loss.

This accounts for the extent of the nominal depreciation, which outstrips the real depreciation, along the path back to equilibrium.

9.3.3 Exchange rate volatility

In this chapter, we have used the open economy $AD - ERU$ model to show that adjustment to demand and supply shocks requires changes in the real exchange rate. Under flexible exchange rates, the 3-equation model tells us that real and nominal exchange rate overshooting are an integral part of the adjustment process. Stabilization of shocks is successful under inflation targeting, but it is necessarily accompanied by exchange rate overshooting.

To this point, we have ignored an important characteristic of the foreign exchange market: its ability to generate shocks. Like other financial markets (see Chapters 1, 4 and 6), the foreign exchange market is subject to panics, waves of optimism and pessimism, and to herd and bandwagon effects. This means that the exchange rate can move—not in response to the mechanisms discussed in this chapter arising from shocks that shift the equilibrium real exchange rate and the overshooting that accompanies the adjustment to shocks—but because of changes in sentiment in the market.

14 It can be useful here to rearrange the definition of the real exchange rate to $\overset{\downarrow}{e} = \frac{\overset{\downarrow}{Q}\overset{\uparrow}{P}}{P^*}$ to think about how changes in *Q* and *P* affect the nominal exchange rate.

An example occurred in 2011 as the Eurozone crisis took hold and growth prospects in the USA weakened. The Swiss franc became a 'safe haven' currency. The Swiss National Bank (SNB) was alarmed at the extent of the inflow of foreign currency and the appreciation of the franc, which was making its manufacturing sector uncompetitive. On September 6th 2011, the SNB took the extremely unusual step of announcing it would buy unlimited quantities of euros to weaken the franc. This amounted to the attempt to fix or peg the exchange rate to the euro. The threat was credible in the market and the pressure shifted to other currencies, creating potential distortions elsewhere in the world.

In Sections 9.3.2 and 9.3.3, we highlighted two features of flexible exchange rate regimes in highly integrated financial markets that complicate efficient resource allocation decisions by households and firms:

1. the presence of exchange rate overshooting due to sluggish adjustment of wages and prices; and
2. the noise arising from unpredictable and uncontrollable features of forex market.

In Chapter 12, we return to the discussion of the merits of different exchange rate regimes when we analyse the Eurozone.

9.4 Conclusions

This chapter has set out the basic framework for analysing economic shocks in the open economy. The framework has two key components; the $AD - ERU$ model, which determines medium-run equilibrium and the dynamic open economy 3-equation model, which shows how the central bank stabilizes the economy after an economic shock. The latter model extends the core closed economy 3-equation model of Chapter 3 by opening up the economy to international trade and capital flows. This requires the introduction of the foreign exchange market. In particular, we focus on the the behaviour of investors engaged in arbitrage between the bonds issued by different governments.

The open economy framework can be utilized to answer pertinent questions about economic policy and macroeconomic fluctuations in small open economies with flexible exchange rates:

1. What are the key features of the foreign exchange market? How do exchange rates respond to changes in interest rates? In an economy open to international capital flows, households have the option of holding both home and foreign bonds. Assuming there is no difference in default risk between the bonds issued by different governments, the only difference between these bonds is their expected return, which depends on the interest rate and any expected movements in the exchange rate. Households use sophisticated agents (e.g. pension funds) to allocate their investments between home and foreign bonds. These agents buy and sell foreign exchange and are assumed to be both forward looking and rational. Investors see that they can profit from arbitrage opportunities when there is an interest rate differential between home and foreign bonds. Arbitrage means that a movement into home bonds (e.g. as a result of a positive interest differential) causes home's currency to immediately appreciate, so that it can depreciate over the period of the differential. This

exchange rate response wipes out any potential gain from holding home bonds over foreign bonds. The relationship between the interest rate differential and the expected change in exchange rates is captured by the *UIP* condition.

2. How does the central bank's response to economic shocks compare in the closed and open economies? In the closed economy, the central bank responds to economic shocks by adjusting the interest rate. In the open economy, the central bank must also take into account the reaction of the forex market to any change in interest rates. The central bank and bond investors using the foreign exchange market are rational forward-looking agents who act simultaneously to solve the model after an economic shock. For example, if the central bank raises the home interest rate to squeeze an inflation shock out of the system, then the foreign exchange market will buy home bonds causing the currency to appreciate. This will dampen demand by reducing net exports. We can see from this example that the central bank does not have to change interest rates as much in response to shocks in the open economy, as some adjustment will occur through the real exchange rate channel.

3. How can the open economy model developed in this chapter shed light on the phenomenon of exchange rate overshooting? The overshooting of the exchange rate occurs when the initial jump in the exchange rate as the result of an economic shock is larger than the equilibrium change. This takes place in the model due to our assumption that there are rational expectations in the foreign exchange market, but that wages and prices are sluggish to adjust. The persistence of inflation in our model requires interest rates to diverge from world interest rates for a number of periods after a shock. The rational forex market responds to the interest differential and the exchange rate jumps. The exchange rate then slowly adjusts to equilibrium whilst the differential remains. Overshooting can have long term effects. For example, the over-appreciation of the exchange rate that accompanied the Thatcher disinflation in the UK in the 1980s is said to have done permanent damage to the UK manufacturing sector.

The next chapter looks more closely at the demand and supply sides in the open economy, providing the counterpart to the closed economy discussed in Chapters 1 and 2. Chapter 11 analyses the impact of oil price shocks and show how imbalances can occur between open economies even when inflation is low and stable. We end our analysis of the open economy by looking at the economics of the Eurozone in Chapter 12.

9.5 Appendix

9.5.1 Deriving the real *UIP* condition

The first step is to add $-\pi^E_{t+1} + \pi^{*E}_{t+1}$ onto both sides of the nominal *UIP* condition, which gives:

$$i_t - i^* - \pi^E_{t+1} + \pi^{*E}_{t+1} = \log e^E_{t+1} - \log e_t - \pi^E_{t+1} + \pi^{*E}_{t+1}. \tag{9.1}$$

If we now use the Fisher equation (i.e. $i = r + \pi^E$), then the left hand side of the equation becomes $r_t - r^*$.

In addition, if we recall that $Q = \frac{P^*e}{P}$ and that $\log Q = q$, then using the properties of logs we can express the log of the real exchange rate (q) as:

$$q = \log P^* + \log e - \log P. \tag{9.2}$$

We also know that the difference between a log variable at time $t+1$ and time t is approximately equal to the growth rate of the underlying variable between those two periods, which means that:

$$\pi^E_{t+1} = \log P^E_{t+1} - \log P_t. \tag{9.3}$$

This is because inflation is defined as the growth rate of the price level. If we substitute back into Equation 9.1 then this gives us the real *UIP* condition,

$$\begin{aligned} i_t - i^* - \pi^E_{t+1} + \pi^{*E}_{t+1} &= \log e^E_{t+1} - \log e_t - (\log P^E_{t+1} - \log P_t) + (\log P^{*E}_{t+1} - \log P^*_t) && (9.4)\\ r_t - r^* &= (\log P^{*E}_{t+1} + \log e^E_{t+1} - \log P^E_{t+1}) - (\log P^*_t + \log e_t - \log P_t)\\ r_t - r^* &= q^E_{t+1} - q_t. && \text{(real } UIP \text{ condition)} \end{aligned}$$

9.5.2 The 3-equation model in more detail

In Section 9.2.4, we showed graphically how the openness of the economy affects the policy of an inflation-targeting central bank. In this Appendix, we set out more carefully how the model works. In particular, we show how rational expectations and arbitrage (captured by the *UIP* condition) in the foreign exchange market allow us to pin down precisely the interest and exchange rate responses to different shocks.[15]

It is convenient to repeat the equations for the structure of the economy, because it helps to clarify the origins of the parameters that will be used to derive the *RX* curve.

We begin with the Phillips curve and the monetary rule equations, which under the assumption of domestic inflation targeting, are the same as in the closed economy. This means the same methodology as Chapter 3 is used here to derive the *MR* curve.

Persistence in the inflation process is reflected in the Phillips curve, which is:

$$\pi_t = \pi_{t-1} + \alpha(y_t - y_e). \qquad \text{(Phillips curve, } PC\text{)}$$

As in Chapter 3, the central bank is modelled as operating under discretion. Each period it minimizes a loss function:

$$L = (y_t - y_e)^2 + \beta(\pi_t - \pi^T)^2, \qquad \text{(central bank loss function)}$$

where $\beta > 1$ characterizes a central bank that places less weight on output fluctuations than on deviations in inflation, and vice versa. The central bank optimizes by minimizing its loss function subject to the Phillips curve. This produces the monetary rule equation (the *MR* curve), which is the same as in the closed economy:

$$(y_t - y_e) = -\alpha\beta(\pi_t - \pi^T). \qquad \text{(monetary rule, } MR\text{)}$$

[15] This section uses the formula for the sum of an infinite series, which is set out in full in Chapter 1.

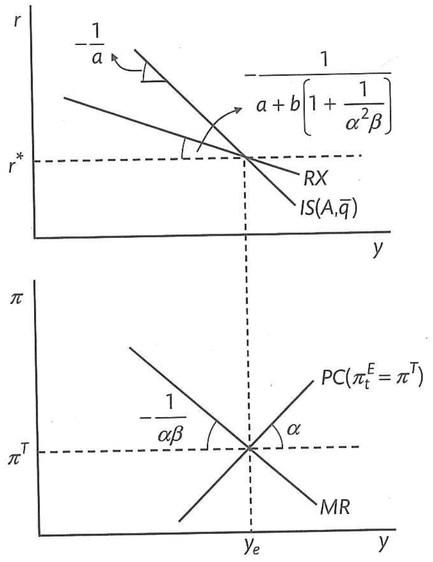

Figure 9.14 The 3-equation open economy model.

The demand side of the economy is represented by the open economy *IS* curve, which captures the fact that demand responds negatively to the real interest rate and positively to a depreciation in the real exchange rate, q:

$$y_t = A - ar_{t-1} + bq_{t-1}. \qquad \text{(open economy } IS \text{ curve)}$$

The dynamics of the adjustment of the economy to a shock depend on the same aspects of the economy as in the closed economy. The additional open economy factors are the responsiveness of aggregate demand to the real exchange rate, b and the real *UIP* condition:

$$r_t - r^* = q^E_{t+1} - q_t. \qquad \text{(real } UIP \text{ condition)}$$

The real *UIP* condition says that any positive (negative) real interest differential will be matched by an expected depreciation (appreciation) in the real exchange rate.

Figure 9.14 shows where the different structural parameters fit into the open economy model. In Chapter 3, we showed how the different parameters affect the curves underlying the core closed economy 3-equation model. In Fig. 9.14, we can see where the open economy elements fit in: the lower panel is exactly the same as in the closed economy. In the *IS* panel, the *IS* will shift by more in response to a given change in the real exchange rate if b is larger: this flattens the *RX* curve and implies that a smaller rise in the interest rate is necessary to achieve a given output level on the *MR* curve.

Deriving the *RX* curve

In order to pin down the interest rate that the central bank needs to set once a shock has been observed, we make the following assumptions about the agents in the model:

- forward looking with rational expectations: central bank, which targets domestic inflation, and foreign exchange market;
- backward looking: private sector as represented by *IS* and *PC* curves.

We break the problem into the following steps:

1. From these assumptions, we know we can use the same $PC - MR$ diagram as for the closed economy. But to translate the chosen output gap from the *MR* line into the central bank's interest rate decision in the *IS* diagram, we must derive the *RX* line, which will incorporate the real *UIP* condition.

2. The key to understanding how the central bank and foreign exchange market solve the model is encapsulated in the *RX* line. For a period during which the economy moves down the *MR* back to equilibrium $r > r^*$, and we know from the real *UIP* condition that it must be the case that the real exchange rate is expected to depreciate. Hence, the forex market and the central bank work out that there must be an initial jump appreciation of the real exchange rate so that it can depreciate *in every period* as the economy moves down the *MR* during which $r > r^*$. This jump appreciation in q causes an initial shift in the *IS* curve to the left. Hence the central bank's desired output gap in the first period after the shock is achieved by a combination of a shift of the *IS* ($\downarrow q$; i.e. appreciation) and the usual closed economy mechanism of a shift to the left along the *IS* ($\uparrow r$).

3. If we assume that $\sum_{t=0}^{\infty}(r_t - r^*) > 0$ then q needs to immediately appreciate to q_0 such that $\sum_{t=0}^{\infty}(r_t - r^*) = \overline{q} - q_0$ so that the expected depreciation from holding £ bonds over the whole adjustment period to the new equilibrium exactly balances the interest rate gain. $\overline{q} - q_0$ is referred to as 'overshooting'. If the initial equilibrium exchange rate (and the initial actual exchange rate before the jump to q_0) is $\overline{q}'$ then it is still true that $\sum_{t=0}^{\infty}(r_t - r^*) = \overline{q} - q_0$. But we can see the size of the initial jump by expanding the RHS:

$$\sum_{t=0}^{\infty}(r_t - r^*) = \overline{q} - q_0 = (\overline{q} - \overline{q}') + (\overline{q}' - q_0) = eqm\ \Delta\ in\ q + initial\ jump. \tag{9.5}$$

If the equilibrium q appreciates (as in a positive permanent demand shock), then $\overline{q}' - q_0 = (\overline{q} - q_0) - (\overline{q} - \overline{q}') > (\overline{q} - q_0)$ so the initial appreciation is greater than the subsequent depreciation.

4. The deviations in the rate of interest from its equilibrium value will decline at a constant rate and at the same rate at which the output gap declines on the path down the *MR*. Call this rate $(1 - \lambda)$. It reflects the CB preferences (β) and the constraint it faces, i.e. the slope of the Phillips curve, α.[16] The rate of decline is $(1 - \lambda) = 1 - \frac{1}{1+\alpha^2\beta}$ and is lower, the lower are α or β and hence, the steeper is the *MR*. Therefore, $(r_{t+1} - r^*) = \lambda(r_t - r^*)$ and we can write the left hand side of Equation 9.5 as:

[16] To see how $(1 - \lambda)$ is derived and why it must be the case that the rate of interest will decline at the same rate as the output gap declines then refer to Section 9.5.3 of the Appendix.

$$\sum_{t=0}^{\infty}(r_t - r^*) = (r_0 - r^*)\left[1 + \lambda + \lambda^2 + \lambda^3 + \ldots\right] = \frac{(r_0 - r^*)}{(1-\lambda)}. \tag{9.6}$$

If we now substitute Equation 9.6 into Equation 9.5,

$$\frac{(r_0 - r^*)}{(1-\lambda)} = \bar{q} - q_0, \tag{9.7}$$

we know the relationship between the initial rise in r and in q.[17]

5. We can now work out the initial r_0 set by the central bank, once we know its chosen output gap: $(y_1 - y_e)$, which is found by using the Phillips curve and the *MR*, exactly as it was in the closed economy. The way to think about how the desired output gap in the open economy is achieved by the policy response is that it consists of two parts: one due to the appreciation of q and the other due to the rise in r. We can write this as:

$$y_1 - y_e = -a(r_0 - r^*) + b(q_0 - \bar{q}). \tag{9.8}$$

Now, we just substitute 9.7 into 9.8 to get an expression for r_0 once the desired output gap for period 1 is known: this is the interest rate the central bank sets in period 0:

$$\begin{aligned} y_1 - y_e &= -a(r_0 - r^*) + b(q_0 - \bar{q}) && (9.9)\\ &= -a(r_0 - r^*) - b\left(\frac{(r_0 - r^*)}{(1-\lambda)}\right) \\ &= -\left(a + \frac{b}{1-\lambda}\right)(r_0 - r^*). && (RX \text{ equation}) \end{aligned}$$

Since a, b and λ are all parameters and r^* is a constant, once y_1 is known, the central bank can calculate r_0. This is the *RX* equation. It is clear immediately from this equation that the *RX* is flatter than the *IS* line: if we think of an increase in r above r^*, the *RX* equation tells us that the fall in y below y_e will be greater (since we multiply by $(a + \frac{b}{1-\lambda})$) than is the case on the *IS*, when we multiply by a.

To find the interest rate r_0 graphically, as shown in Fig. 9.15, we mark the desired output gap, $(y_1 - y_e)$ and then note that this can be broken into the two parts as shown in Equation 9.8. Once we find the length of $b(q_0 - \bar{q})$, we know the horizontal shift of the *IS*, since this shift is caused by the appreciation. To find the length of $b(q_0 - \bar{q})$, we note from the *RX* equation that this is equal to $-\left(\frac{b}{1-\lambda}\right)(r_0 - r^*)$,

$$b(q_0 - \bar{q}) = -\left(\frac{b}{1-\lambda}\right)(r_0 - r^*).$$

Rearranging gives $(r_0 - r^*) = -\left(\dfrac{1-\lambda}{b}\right)\cdot b(q_0 - \bar{q})$.

Hence, if we draw a line from the point B with a slope of $\left(\frac{1-\lambda}{b}\right)$ to intersect the *IS* curve, this will define a triangle with its base equal to $b(q_0 - \bar{q})$ and its height equal to $(r_0 - r^*)$. This pins

[17] This relationship can be plotted in the r-q space. It is flatter than the -45° of the real *UIP* condition because a larger initial jump in q is necessary when r varies from r^* for more than one period.

1. *AB* is given by the central bank's choice of y_1
2. Draw line *BC* with slope $(1-\lambda)/b$
3. Point *C* shows the r_0 chosen by the central bank
4. This fixes the shift in the *IS* curve, *DC*, and in the interest rate chosen by the central bank, *BD*
5. The *RX* curve goes through *D* and *A*

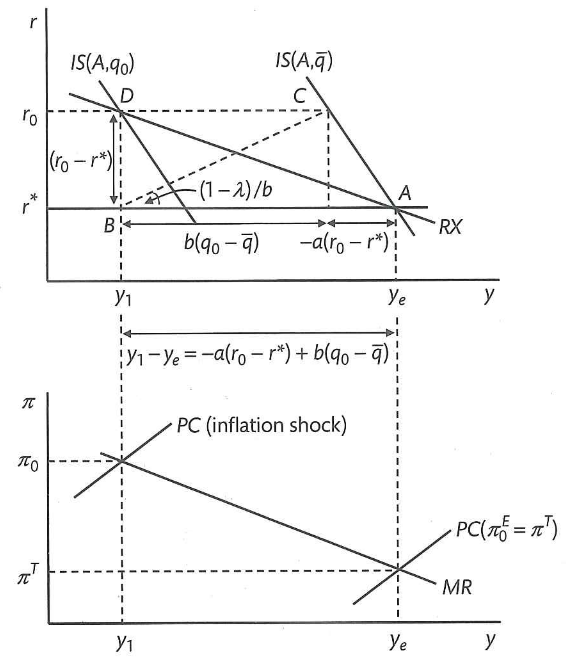

Figure 9.15 The geometry of the *RX* curve-example of a positive inflation shock.

down the shift in the *IS* and the interest rate the central bank sets. By drawing a line through the period 0 interest rate at the central bank's desired output gap and the initial equilibrium (i.e. between point *D* and *A*), we have the path along which the interest rate will be adjusted on the return to equilibrium. This is the *RX* curve. Section 9.5.4 provides more discussion of the geometry of parameter changes in the *RX* diagram.

9.5.3 **Derivation of $(1-\lambda)$ and its properties**

$(1-\lambda)$ represents the rate of decline of deviations of inflation from target and output from equilibrium. It is derived from the equations for the Phillips curve and the monetary rule as follows:

$$(\pi_t - \pi^T) = (\pi_{t-1} - \pi^T) - \alpha^2\beta(\pi_t - \pi^T)$$

$$\rightarrow \frac{(\pi_t - \pi^T)}{(\pi_{t-1} - \pi^T)} = \frac{1}{1+\alpha^2\beta} \equiv \lambda = \frac{y_t - y_e}{y_{t-1} - y_e}.$$

In the previous section of the Appendix, we stated that it must be the case that the rate of interest will decline at a constant rate and at the same rate at which the output gap declines on the path down the *MR*. If you want to see why this is true, you can go through the argument here. Let y, r and q be in deviation form (i.e. the deviation from y_e, r^* and $\bar{q}$ respectively. Let $r_t = \rho r_{t-1}$ and $y_t = \lambda y_{t-1}$ along the best response adjustment path. We show that $\rho = \lambda$.

From the *IS* equation, $y_{t+1} = -ar_t + bq_t$.

From the *UIP* condition, $-q_t = \sum_{i=0}^{\infty} r_{t+i} = r_t\left[1+\rho+\rho^2+\ldots\right] = \frac{r_t}{1-\rho}$

$$\rightarrow y_{t+1} = -\left(a+\frac{b}{1-\rho}\right)r_t$$

$$\rightarrow y_t = -\left(a+\frac{b}{1-\rho}\right)r_{t-1}$$

$$\rightarrow \frac{y_{t+1}}{y_t} = \frac{r_t}{r_{t-1}}$$

$$\therefore \rho = \lambda.$$

9.5.4 Geometry of the *RX* curve: varying the parameters

The *RX* equation is

$$y_1 - y_e = -\left(a+\frac{b}{1-\lambda}\right)(r_0 - r^*), \qquad (RX \text{ equation})$$

where

$$\lambda = \frac{1}{1+\alpha^2\beta}.$$

One way of developing an intuitive understanding of the effect of parameter changes on the central bank's best response to shocks in the open economy is to conduct experiments of varying the parameters. Variations in a and b, the coefficients in the *IS* curve, have simple graphical representations: an increase in a means that interest-sensitive expenditure responds more to changes in the interest rate, and the *IS* curve is flatter. This has the effect of reducing the interest and exchange rate responses, and a larger share of the output gap is accounted for by the interest rate component (which increases from $(r_0 - r^*)$ to $-a(r_0 - r^*)$). The *RX* curve is flatter.

If b increases, aggregate demand is more sensitive to changes in the real exchange rate. Geometrically, the line with slope $\left(\frac{1-\lambda}{b}\right)$ becomes flatter. This lowers the initial interest rate chosen by the central bank and the associated exchange rate appreciation, and increases the share of the output gap accounted for by the exchange rate component. The *RX* curve is flatter.

If α or β decrease, then the *MR* curve is steeper. This means a lower $(1-\lambda)$ and a slower rate of decline of the output gaps on the path back to equilibrium. For example, the central bank's preferences are weighted less strongly toward reducing inflation—it is a 'wetter' central bank. In the *RX* equation, a slower rate of decline of the output gap has the same effect on the slope of the *RX* as a rise in b: i.e. it makes the *RX* flatter. If we compare two economies identical in every way except that the first has a less hard-nosed central bank (lower β), then in the face of the same inflation shock, the first will be observed to have a smaller output gap and a lower interest rate.

9.6 Questions

9.6.1 Checklist questions

1. Use a *UIP* diagram to illustrate the following cases. Discuss the adjustment process in each case and show how it relates to the *UIP* equation.
   (a) Home's interest rate falls below the world interest rate for one period.
   (b) The world interest rate increases for one period and the home economy raises their interest rate in line.
   (c) The foreign exchange market changes their expectation of the exchange rate in a year's time to a more depreciated exchange rate.
2. Answer the following questions about the supply and demand sides in the medium-run model:
   (a) What does the *ERU* curve represent? What would happen to the *ERU* curve if unemployment benefits were raised? What would you expect to happen to inflation?
   (b) What does the *AD* curve represent? Derive the *AD* curve graphically from the *IS* curve. [Hint: draw the *IS* diagram below the *AD* diagram and think about how changes in the real exchange rate affect the *IS* curve. To derive the *AD*, map the combinations of q and y on each *IS* curve at $r = r^*$.]
   (c) How does a rise in the world real interest rate affect the *AD* curve? What is the effect on the medium-run real exchange rate?
3. What conditions need to hold for a small open economy to be in medium-run equilibrium?
4. In a small open economy, is a negative supply shock or a negative demand shock more damaging for medium-run output? Explain in words and use *AD* − *ERU* diagrams to back up your argument. Describe the effects on the real wage, unemployment and the real exchange rate in medium-run equilibrium of an increase in unemployment benefits.
5. Use the 3-equation open economy model to answer the following questions:
   (a) Explain what the following statement means: 'after a demand shock in a small open economy, the exchange rate often overshoots'. Use an *AD* − *ERU* diagram to help explain your answer.
   (b) What causes exchange rate overshooting?
   (c) What problems, if any, would you expect exchange rate overshooting to cause?
   (d) How could you modify the 3-equation open economy model so that exchange rate overshooting does not occur? Explain in words.
6. Is the following statement true or false? Explain your answer. 'Central banks have to be more aggressive when making interest rate changes in the open economy because the *IS* curve is steeper than in the closed economy.'
7. Consider a large negative demand shock that hits two small economies. The economies are identical except that one is closed and the other is open. Answer the following:
   (a) Briefly explain how a large negative demand shock can lead to a deflation trap.
   (b) Which of the economies is more likely to fall into a deflation trap following the shock? Justify your answer.

(c) What initial conditions would make it likely that both economies would fall into a deflation trap?

8. Compare the decision making process taken by the central bank (and forex market in the open economy) in a closed and open economy after a permanent positive supply shock. Create a table similar to Table 9.2. How does the real interest rate in the new medium-run equilibrium compare in the two cases?
9. Explain what is meant by this statement: 'The behaviour of the nominal exchange rate in the model is a residual'.
10. This question uses material from Sections 9.5.2 and 9.5.4 of the Appendix. For a benchmark case, draw the *PC* – *MR* and the *IS* – *RX* diagrams after an inflation shock. Now increase the interest sensitivity of aggregate demand (i.e. *a*) and redraw the graphs. What has happened to r_0 and q_0? Explain your results.

9.6.2 **Problems and questions for discussion**

1. 'Following an announcement from the Riksbank (the Swedish central bank) of an interest rate increase, an immediate depreciation of the Krona was observed'. How can you explain this outcome? In your answer explain the economics of the *UIP* condition. Summarize your findings highlighting the role played by expectations and communication by the central bank. You are advised to take the following steps and in each case to draw a *UIP* diagram:
   (a) Show the 'normal case' in which the central bank announcement is followed by an immediate appreciation of the Krona.
   (b) Suppose the rise in the interest rate had been widely expected in financial markets. Show in the *UIP* diagram that there would be no immediate change in the exchange rate when the Riksbank made its announcement.
   (c) Finally, show how an immediate depreciation in the Krona can be explained.
2. The Bank of England keeps a directory of the minutes from the monthly meetings of their Monetary Policy Committee online:
   (http://www.bankofengland.co.uk/monetarypolicy/pages/decisions/decisions.apx)
   (a) Pick a period following a shock such as after September 11th 2001 or following the 2008–09 financial crisis, and see how the Bank of England comments on the interaction between the interest rates they set and the UK pound exchange rate. Are interest rate differentials thought to be causing movements in the exchange rate? If not, then does the movement of exchange rates invalidate the *UIP* condition?
   (b) Find some news articles from the same period that talk about the reactions of the foreign exchange market (useful sources for market news include the Financial Times, Reuters and Bloomberg). Did the forex market anticipate changes in interest rates before they happened? If so, were their predictions proved correct?
3. Assume you are in a small open economy with flexible exchange rates. The economy experiences a permanent positive demand shock.
   (a) Draw the *PC* – *MR*, the *IS* – *RX* and the *AD* – *ERU* diagrams to help you explain the path back to medium-run equilibrium.
   (b) Draw a graph of the real exchange rate over time and give a brief explanation of its path.

   (c) How does the medium-run equilibrium vary from that which would occur in a closed economy subjected to the same shock?
4. This question uses the Macroeconomic Simulator available from the Carlin and Soskice website http://www.oup.com/uk/orc/carlin_soskice to model supply-side reform in the open economy. Start by opening the simulator and choosing the open economy (flexible exchange rate) version. Then reset all shocks by clicking the appropriate button on the left hand side of the main page. Use the simulator and the content of this chapter to work through the following questions:
   (a) Decide on a supply-side reform and describe briefly how it is modelled–i.e. does it affect the *WS* or *PS*? What effect does this have on the *ERU* curve?
   (b) Apply a permanent 2% positive supply shock. (Note that a positive supply shock is one that reduces equilibrium unemployment; raises equilibrium employment.)
   (c) Use the impulse response functions from the simulator or from your sketches to help explain the path of the economy following the above shock.
   (d) Draw the *IS* – *RX* and *PC* – *MR* diagrams for this scenario. Draw the *AD* – *ERU* diagram for this scenario. [Hint: the path of the key variables (output, inflation, real interest rate, real exchange rate) will have to match the impulse response functions from the simulator. Remember that whenever the central bank sets the interest rate different from r^* to get the economy on to the *MR* curve, the economy will be *off* the *AD* curve. Once the economy is back at a MRE, then $r = r^*$ and the economy is, once again, *on* the *AD* curve.]
   (e) Briefly discuss one aspect of this way of modelling the adjustment of the economy to a supply-side reform that seems to you to be unrealistic. Express your concern in terms of the assumptions of the model.
5. This question uses material from Sections 9.5.2 and 9.5.4 of the Appendix. The parameters that underlie the economy are $a = b = \alpha = \beta = 1$, which implies that $\lambda = 0.5$. The economy is initially in equilibrium and experiences a positive inflation shock. Use the steps set out in Section 9.5.2 to graphically derive the *RX* curve. [Hint: you will need pick the initial equilibrium r^* and use a grid to ensure accurate measurements.] What is the new r_0?