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A Double-Edged Sword: High Interest Rates in Capital Control Regimes

Gudmundur S. Gudmundsson and Gylfi Zoega

Abstract
This paper describes the relationship between central bank interest rates and exchange rates under a capital control regime. Higher interest rates may strengthen the currency by inducing owners of local currency assets not to sell local currency off shore. There is also an effect that goes in the opposite direction: higher interest rates may also increase the flow of interest income to foreigners through the current account, making the exchange rate fall. The historical financial crisis now under way in Iceland provides excellent testing grounds for the analysis. Overall, the experience does not suggest that cutting interest rates moderately from a very high level is likely to make a currency depreciate in a capital control regime, but it highlights the importance of effective enforcement of the controls.

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Keywords Financial crises; capital controls; policy rates; exchange rates

Authors
Gudmundur S. Gudmundsson, Department of Economics and Business, Universitat Pompeu Fabra, Barcelona, Spain
Gylfi Zoega, ✉ Department of Department of Economics, University of Iceland, Reykjavik, Iceland; Department of Economics, Birkbeck College, London, UK; CESifo, Munich, Germany, gz@hi.is

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How should an economy respond to a sudden stop of capital inflows? In particular, how should it combine the use of capital controls and high interest rates when attempting to stem capital outflows? The objective of this paper is to analyze the effect of interest rates in capital control regimes and explore the relationship using data from Iceland's recent financial crisis.

In recent years many countries have experienced inflows of foreign capital driven by very low dollar and yen interest rates. Massive carry trading in US dollars has taken place in emerging economies. Many Asian economies, as well as Brazil, Turkey, and others, currently face the prospect that these capital inflow will turn into outflows when the Federal Reserve begins raising interest rates. The rising dollar may already be affecting the price of commodities, including oil, with the fall in oil prices contributing to capital flight from the Russian ruble and threatening financial stability in that country.

A common response to capital outflows is to raise domestic interest rates in order to raise the rate of return on domestic assets. However, raising the central bank interest rate to very high levels may drive foreign investors away when they sense desperation in the policy response and observe the adverse effects of the high interest rates on the solvency of local businesses and banks. In such circumstances, countries may resort to capital controls, as did Malaysia in 1998 and Iceland in 2008.[1]

Rapid unwinding of the carry trade had disastrous consequences in Iceland in the autumn of 2008, when the exchange rate collapsed, rendering most of the business sector insolvent due to foreign-denominated borrowing, while the commercial banks suffered a bank run leading to their demise.[2] One possible response to the unwinding is to impose capital controls while keeping the current account open and allowing the conversion of interest income into foreign currency.[3] This was the measure recommended by the IMF following the collapse of Iceland's financial system in October 2008. More controversially, the Fund recommended that the capital controls be supported by high central bank interest rates, which were raised to 18%. The question addressed in this paper is to what extent the policy of high interest rates really helps support the exchange rate when capital controls

[1] See Kaplan and Rodrik (2001) on the use of capital controls in Malaysia.
[2] For a recent survey of the macroeconomic consequences of financial crises, see Reinhart and Rogoff (2009). On sudden stops, see Calvo *et al*. (2006). For an account of the turmoil in Iceland, see Benediktsdottir, Danielsson, and Zoega (2011).
[3] See Ariyoshi (2000) for a review of different countries' experience with capital controls, including those in East Asia in the late 1990s.

are in place. The objective is to describe the channels through which interest rates may help stabilize exchange rates in a capital control regime and to test empirically for the effect using data from the Icelandic financial crisis.

The rationale for keeping interest rates high in the presence of capital controls rests mainly on the premise that a high rate of return on domestic-currency financial assets will discourage foreign holders of such assets from seeking to circumvent the controls, i.e. by finding local exporters willing to buy the local currency for foreign exchange in the offshore currency market. However, high interest rates will only have the intended effect if they translate into higher interest income measured in foreign currency. This can be shown not always to be the case, as high interest rates also have the effect of lowering the exchange rate by creating a flow of interest payments through the current account. As in Malaysia in 1998, foreign holders of domestic currency assets in Iceland were allowed to convert interest income and profits into foreign currency in spite of the capital controls, partly for reputational reasons in order not to affect future foreign investments adversely.

The empirical work on the effect of high interest rates on exchange rates during financial crises does not lend strong support to the argument that high interest rates defend the value of the currency. Caporale *et al*. (2005) and others find that, while tight monetary policy boosts the exchange rate during normal periods, it weakened it during the Asian crisis in the late 1990s. Goldfajn and Gupta (2003) analyze a large dataset of currency crises in eighty countries for the period 1980-1998 in order to explore whether high interest rates are successful in reversing currency undervaluation in the aftermath of a currency crisis. They find that this is so except when the economy also faces a banking crisis, in which case the results are not robust. Flood and Jeanne (2005) derive a model showing that an interest rate defense of a fixed exchange rate regime can prove ineffective if accompanied by unsound fiscal policy because the high interest rates will be perceived to have a detrimental effect on the public finances which weakens the currency.

In the following sections, we briefly review the background to the imposition of capital controls in Iceland before turning to modeling the relationship between interest rates and capital controls. The final section studies time series of interest rates and exchange rates in Iceland after capital controls were imposed in November 2008.

1. Collapse and capital controls

Iceland was hit particularly hard by the global credit crunch of 2008. In the years preceding the crash, the country experienced capital inflows and one of the world's most rapid credit expansions when the balance sheets of the country's three largest banks grew from one GDP to nine times GDP in just over four years. This expansion of the banks' balance sheets was accompanied by an expansion of the balance sheets of businesses that became increasingly leveraged over the same period, usually in foreign-denominated loans (80% of total business debt to domestic deposit institutions). Domestic asset prices reflected this development: stock prices rose ninefold over a period of four years, the currency appreciated, and house prices more than doubled.

The capital inflows turned into outflows in the spring of 2008, making the currency tank and businesses insolvent due to their high levels of foreign-denominated debt. The banks also became technically insolvent as a result but did not realize losses on their loan books, as this might have triggered a bank run. Instead, they continued to report impressive operating profits until their liquidity problems became even more severe and one of them defaulted in October 2008, which then led to a run on the remaining two. The currency market ceased to function after the currency lost half its value. The authorities eventually requested assistance from the International Monetary Fund.

In November 2008, the IMF published its analysis of the crisis, together with the only published official plan on how to respond to it.[4] The plan laid out the objectives of monetary policy, fiscal policy, and banking sector restructuring. The IMF program aimed at stabilizing the exchange rate through a combination of high interest rates and stringent capital controls that were to be gradually dismantled. Another goal was to create a new banking system, and the final objective was to organize fiscal consolidation in light of the anticipated surge in public indebtedness.

A major problem preventing the return to a floating exchange rate was the substantial amount of foreign speculative capital (carry trade) remaining in the local currency. The total volume of domestic currency assets owned by foreign investors was around 35% of GDP at the time of the collapse.[5] With free-floating capital, the expectation was that

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[4] International Monetary Fund, Iceland, *Request for Stand-By Arrangement*, 25 November 2008 (see http://www.sedlabanki.is/lisalib/getfile.aspx?itemid=6606).

[5] It is currently around 17% of GDP, following a series of foreign currency auctions conducted by the central bank.

substantial amounts would flow out of the currency, causing an even larger fall in the exchange rate, which would have further damaged balance sheets. The IMF justified its decision to impose capital controls by citing the reversal of the carry trade, and businesses mired in FX debt, and CPI indexation of household mortgages. In order to curb leakages, the policy interest rate was raised from 12% to 18%, a policy the IMF referred to as wearing both "belt and suspenders". This was perhaps the most controversial part of the program. The subsequent lowering of the policy rate constitutes a natural experiment in the role of high interest rates in defending a currency under a capital control regime.

2. Interest rates and exchange rates with no leakages

The conventional method of modeling exchange rate determination using uncovered interest parity (UIP) is problematic in the presence of capital controls. Although low interest rates may increase leakages by lowering the return from holding domestic currency assets, this is not the only effect at work, as we will show. The success of the capital controls depends on how successful they are at preventing owners of domestic currency from being able to sell the currency offshore to exporters that need to buy local currency using their foreign currency earnings. In order to analyze the effect of interest rate changes on the exchange rate, one must therefore study the effect of changing the interest rate on the decisions made by both owners of domestic currency and exporters of goods and services.

Assume that the foreign owners of domestic currency assets are concerned about their interest income measured in foreign currency, iED, where i is the rate of interest, E is the nominal exchange rate measured as the foreign currency price of one unit of local currency (so that an increase in E means appreciation), and D is the stock of foreign-owned assets measured in domestic currency. Prices at home and abroad are fixed and assumed to equal one, so that E is also the real exchange rate. Foreign investors will benefit from both higher interest rates i as well as a higher exchange rate E. They will not benefit from an interest rate rise if this is offset by a large depreciation of the domestic currency. It follows that one can derive an *iso-interest* curve that gives all combinations of i and E between which the foreign investor is indifferent. Taking the total differential of iED and setting it equal to zero gives the slope of the curve as

$$\frac{dE}{di} = -\frac{E}{i} < 0 \ . \tag{1}$$

The equation defines a downward-sloping, strictly convex iso-interest curve in the exchange rate/interest rate space.

The feasible combinations of exchange rates and interest rates under a capital control regime are given by the current account balance,

$$iED = EX\left(E\right) - M\left(E\right). \tag{2}$$

The interest payments measured in foreign currency must equal the excess of foreign currency export earnings and the cost of imports. An appreciation of the currency gives lower export volumes, $X_E(E) < 0$, and higher import volumes, $M_E(E) > 0$.[6]

Assume that imports become more sensitive to changes in exchange rates as their volumes increase – that is, as the exchange rate rises, $M_{EE}(E)>0$ – while the sensitivity of exports with respect to exchange rates in a resource-based economy does not depend on the volume of exports, $X_{EE}(E)=0$. Conversely, when the currency depreciates, imports fall, but consecutive depreciations have a smaller effect on imports because consumers initially reduce their consumption of the more price-elastic imports – cars, consumer durables, and so forth – making their remaining consumption basket gradually more price-inelastic. Even a very large depreciation will not dissuade consumers from using some imported food, oil, and medication; therefore, the elasticity of imports with respect to exchange rates becomes very small.

Taking the total differential of equation (2) and setting it equal to zero gives a *current account constraint* that reflects all the combinations of E and i that make the current account balanced. The slope of the curve in the E-i space is equal to the marginal rate of transformation between E and i;

$$\frac{dE}{di} = \frac{ED}{X + EX_E - M_E - iD} \ , \tag{3}$$

which is negative as long as:

[6] Note that leakages do not occur, by assumption, so that the appreciation does not have the effect of increasing leakages by making it more tempting for exporters to sell their foreign currency at the lower offshore rate, nor does it reduce leaks by making it less tempting for the foreign investors (trapped behind capital controls) to find these exporters in the offshore market.

$$e_X + e_M > 1\ , \tag{4}$$

where $e_X = -EX_E(E)/X(E)$ and $e_M = E\left(M_E(E) + iD\right)/\left(M(E) + iED\right)$ are the elasticities of exports and imports (plus interest payments on domestic currency assets to foreigners) with respect to the exchange rate. The Marshall-Lerner condition is thus necessary and sufficient for $dE/di<0$. A depreciation will raise exports and lower imports to enable the transfer of resources to pay the interest on the debt, but it will also reduce the foreign currency income from exports, therefore requiring the elasticities to be large enough to offset this effect.[7]

The current account constraint is concave in the E-i space, so that a given interest rate rise requires a larger depreciation of the currency the higher the interest rate. The concavity is increasing in the level of debt – because a given increase in interest rates generates a larger outflow of interest expenditures as the level of debt rises – and it is increasing in M_{EE} – which measures the degree to which a depreciation of the currency becomes less effective at reducing imports the more depreciated the currency is and the lower the level of imports.[8]

The tangency between the iso-interest curve and the current account constraint – given by the equality of the slopes of the two as shown in equations (1) and (3) – gives $X+EX_E-M_E=0$. Dividing by X yields

$$-EX_E(E)/X(E) + EM_E(E)/\left(M(E) + iED\right) = 1, \tag{5}$$

which is the condition:

$$e_X + e_M - \frac{iD}{M(E) + iED} = 1 \tag{6}$$

Equation (6) defines a maximum if, as assumed, $X_{EE}=0$ and $M_{EE}>0$, since the second-order condition is: $2X_E - M_{EE} < 0$.

[7] There is also an effect of depreciation on the foreign currency value of interest payments: the interest burden falls when the exchange rate E falls, and this effect is increasing in the stock of debt.

[8] From equation (3), it follows that the current account constraint is concave if:

$$\left[X + EX_E - M_E - iD\right] - 2EX_E + EM_{EE} + ED > 0$$

where the terms in the square bracket sum to a negative number according to (4) and the three terms outside the bracket are all positive. It follows that concavity depends on the level of debt D being high and the effect of exchange rates on imports, M_E, being very small in absolute value at low exchange rates, $M_{EE} > 0$.

The maximization of the interest income of foreign investors is not desirable from the viewpoint of the home country, which wants to maximize the foreign currency value of domestic output net of interest payments to foreigners: $EY - iED$. This gives upward-sloping *iso-income* curves; higher interest payments must be met by a higher exchange rate to make the local economy indifferent to the change:

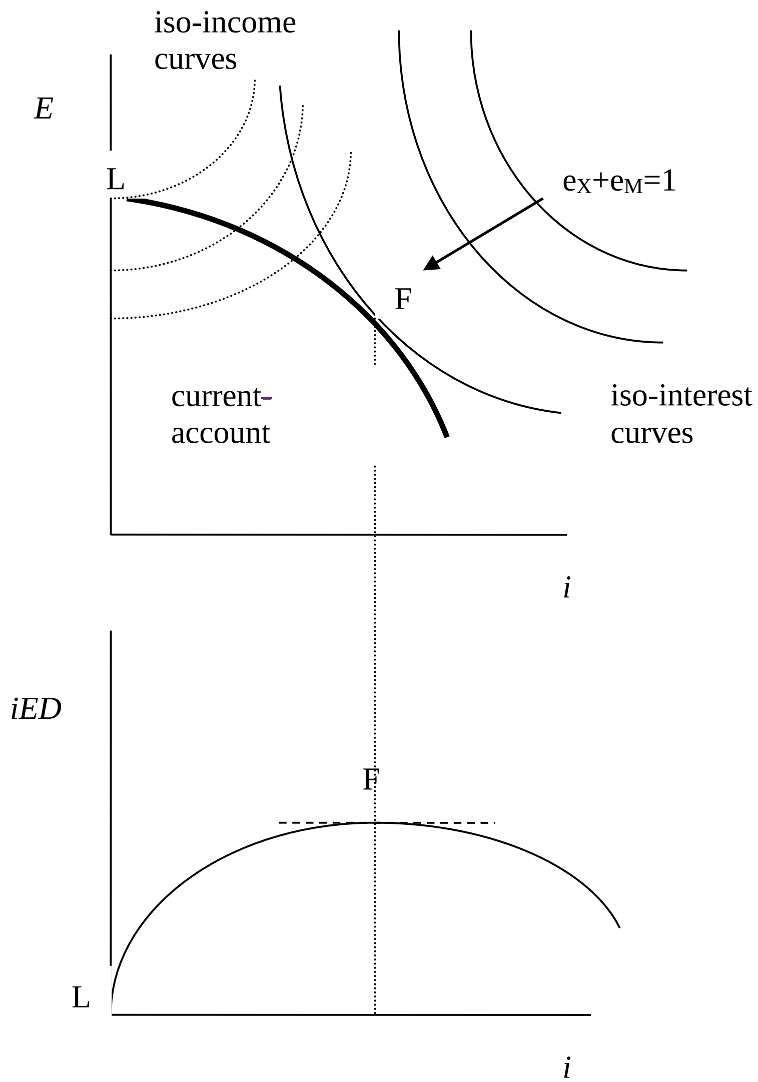
$$\frac{dE}{di} = \frac{ED}{Y - iD} > 0 \tag{7}$$

The home country prefers not to pay any interest to foreign holders of domestic currency assets because there is no reason for them to offer positive interest rates in the absence of leakages.[9]

The bold current account constraint in Figure 1 shows all the combinations of *i* and *E* that give a balance on the current account. The iso-interest curves give all combinations of *i* and *E* that leave the foreign investor indifferent – give the same flow of interest income measured in foreign currency – and the iso-income curves give all combinations of *i* and *E* that leave the home country as well off in terms of national income net of interest payments measured in foreign currency. At *F*, the interest income of foreign investors, measured in foreign currency, is maximized, while the home country is best off at point *L*, where the interest rate is equal to zero and the currency is appreciated to generate a current account balance. Local authorities would never decide to pay interest to foreigners in the absence of leakages – to move from point *L* toward *F* – except perhaps out of concern for maintaining credibility in international financial markets. We now turn to studying the effect of leakages on this decision.

[9] The iso-income curves are convex because $\frac{d^2E}{di^2} = \frac{ED^2}{(Y - iD)^2} > 0$.

Figure 1. The interest income of foreign investors, without leakages



The bold current account constraint shows all of the combinations of *i* and *E* that give a balance on the current account. The iso-interest curves give all combinations of *i* and *E* that leave the foreign investor indifferent – give the same flow of interest income measured in foreign currency – and the iso-income curves give all combinations of *i* and *E* that leave the home country as well off in terms of national income net of interest payments measured in foreign currency.

3. Leakages introduced

In this section, we describe the behavior of exporters that must decide whether to buy domestic currency onshore or offshore – in the latter case, risking detection and penalties. We then turn to the decision of the owners of domestic currency assets, who must decide whether to invest in domestic currency assets or buy foreign currency from the exporters offshore, then invest in foreign bonds and subsequently return to the domestic currency using the onshore currency market.

We start by describing exporting firms' decision about where to buy domestic currency, thereby describing the demand for the domestic currency in the offshore market as well. Allowing for leakages, the flow of export revenues into the onshore foreign exchange market depends on the difference between the onshore and the offshore exchange rates, E and e. The typical exporting firm maximizes its domestic currency profits, defined as the sum of domestic currency revenue onshore and offshore net of the expected cost of being caught evading the capital controls. The expected costs of evasion depend on the volume of offshore trading, $t_0\left(X-X^L\right)+t_1\left(X-X^L\right)^2$, where X^L is the volume of exports appearing in the onshore export market and $t_0 > 0$ and $t_1 > 0$. The expected profits in units of output are given by equation (8),

$$\pi=\frac{e}{E}X^L+\left(X-X^L\right)-\left[t_0\left(X-X^L\right)+t_1\left(X-X^L\right)^2\right], \tag{8}$$

where e is the offshore exchange rate and E the onshore exchange rate, as before. The volume X^L that shows up in the onshore market generates less revenue – in terms of domestic currency – than that which shows up in the offshore market. Each unit of exports generates e units of foreign currency in the offshore market – this is the market exchange rate – but when this is bought back in using the onshore market at a higher exchange rate, the revenue coming from exports through the onshore market measured in domestic currency is lower per unit of output sold than that coming from the offshore market because $e<E$. It follows that exporting firms will lose from buying the domestic currency onshore, where it is more expensive. However, buying onshore will reduce the expected cost of detection.

The first-order condition with respect to X^L gives exports traded in the offshore market as a positive function of the difference between the onshore and offshore exchange rates and a negative function of the intensity of capital controls monitoring, t_0:[10]

$$X - X^L = \frac{1}{2t_1}\left(\frac{E-e}{E}\right) - \frac{t_0}{2t_1} \ . \tag{9}$$

The onshore exchange rate is determined so as to generate a balanced current account, taking only into account the part of exports that show up onshore X^L, which, from equations (2) and (9), gives:

$$iED = EX^L\left(E, e, t_0, t_1\right) - M\left(E\right), \tag{10}$$

or, using (9):

$$iED = E\left(X - \frac{1}{2t_1}\log\left(E\right) + \frac{1}{2t_1}\log\left(e\right) + \frac{t_0}{2t_1}\right) - M\left(E\right). \tag{11}$$

A larger exchange rate differential – making the currency relatively more expensive onshore – will increase leakages and lower X^L, while an increase in monitoring t_0 and t_1 will raise X^L by increasing the likelihood that violations of the capital controls will be detected. Greater enforcement of the controls will strengthen the currency, while an offshore depreciation will weaken it by encouraging local exporters to buy domestic currency offshore.

We turn next to the decision faced by holders of domestic currency: whether to buy bonds denominated in the domestic currency or, alternatively, to leave the domestic currency through the offshore market, invest in foreign bonds, and then return to the domestic currency through the onshore market (where the value of the domestic currency is higher). This describes the supply of domestic currency in the offshore market. In equilibrium, the expected return from remaining in the domestic currency is equal to the expected return from leaving through the offshore market. The equilibrium condition gives a relationship between domestic interest rates, foreign interest rates, the expected onshore exchange rate, and the offshore exchange rate. The following equation states the equilibrium condition by setting the returns on remaining in the domestic currency asset

[10] The effect is also negative with respect to t_1 as long as $(E\text{-}e)/E > t_0$.

earning an interest rate *i* equal to the returns on exiting the currency offshore and investing in foreign assets that yield an interest rate of *i** plus a risk premium on domestic currency assets *p*:

$$i_t = i_t^* - \log\left(E_{t+1}^e\right) + \log\left(e_t\right) + p_t \ . \tag{12}$$

This interest parity condition determines the offshore exchange rate given the domestic and foreign interest rate and the risk premium. An increase in domestic interest rates will raise the expected return from holding domestic currency assets, and this will make the offshore exchange rate increase – because of a smaller supply of domestic currency in the offshore market – until the expected return from exiting the currency offshore is raised to equal the higher domestic currency interest rates; an increase in the foreign interest rate *i** will have the opposite effect of making the offshore exchange rate fall – by increasing the supply of domestic currency in the offshore market in order to reducing the returns on exiting the currency back to the previous level; an increase in the risk premium *p* will lower the offshore exchange rate for the same reason; and finally, the higher the expected future onshore exchange rate E_{t+1}^e, the higher the offshore exchange rate.

Together, equations (9), (11), and (12) determine the onshore exchange rate *E*, the offshore rate *e*, and the volume of exports that show up in the onshore market X^L. The equations reveal that cutting interest rates has both a *flow effect* – captured by equation (11) – and a *stock effect* – captured by equation (12). Lower interest rates strengthen the currency by reducing the required trade balance. This is the flow effect, which is essentially the transfer problem discussed by Keynes (1929). But they also lower the expected return from holding domestic currency assets, which makes the offshore exchange rate fall when leakages increase, which then lowers the volume of exports that go to the onshore market X^L, thereby making the onshore exchange rate fall. This is the stock effect.

Substituting equation (12) into equation (11) gives

$$iE_t D = E_t\left[X\left(E_t\right) - \frac{1}{2t_1}\log\left(E_t\right) + \frac{1}{2t_1}\left(i_t - i_t^* + \log\left(E_{t+1}^e\right) - p\right) + \frac{t_0}{2t_1}\right] - M\left(E_t\right) \ . \tag{13}$$

Taking the total differential of the equation gives the effect of changing domestic interest rates on the onshore exchange rate:

$$\frac{dE}{di}=\frac{E\left(D-\frac{1}{2t_1}\right)}{\Omega}<0 \text{ iff } D>\frac{1}{2t_1}\ , \tag{14}$$

where $\Omega = X^L + EX_E - \frac{1}{2t_1} - M_E - i\left(D-\frac{1}{2t_1}\right) < 0$ according to equation (4). The effect of changing the domestic interest rate therefore depends on the level of debt. Once debt exceeds a threshold, the flow effect of higher interest rates dominates the stock effect and higher interest rates will only make the currency depreciate because of an increase in the trade surplus required to finance the interest payments. The threshold is given by the term $1/(2t_1)$, so that the lower the value of t_1 in equation (8), the higher the level of the threshold. This implies that with a low level of t_1, when the capital controls are not rigorously enforced so that buying domestic currency offshore is not as costly in terms of penalties, a higher interest rate is more likely to help boost the exchange rate. In contrast, high interest rates are most likely to lower the exchange rate when the level of debt D is high and the capital controls are enforced with vigor; i.e., t_1 is high. Coming back to Figure 1 above, with low levels of debt the current account constraint may be upward-sloping, but with high levels of debt it remains downward-sloping and the optimal rate of interest for the home country remains equal to zero.

In contrast to the effect of raising domestic interest rates, the effects of higher foreign interest rates, a higher expected onshore exchange rate, a higher country risk premium, and a higher cost t_0 of evading capital controls do not depend on the level of debt. Again, taking the total differential of equation (13) above shows that an increase in the foreign interest rate i^* makes the onshore exchange rate fall, as does an increase in the country risk premium p. In both cases, there is an incentive for owners of domestic currency assets to leave the domestic currency offshore, invest in foreign bonds, and then re-enter onshore. The effect is to make the offshore exchange rate fall, making exporters buy local currency offshore and therefore lowering the onshore exchange rate.. In contrast, an increase in the expected onshore exchange rate and the penalty from evading controls t_0 will raise the onshore exchange rate by increasing the cost to exporters of using the offshore market and reducing the expected profits to investors of leaving the currency for foreign bonds.

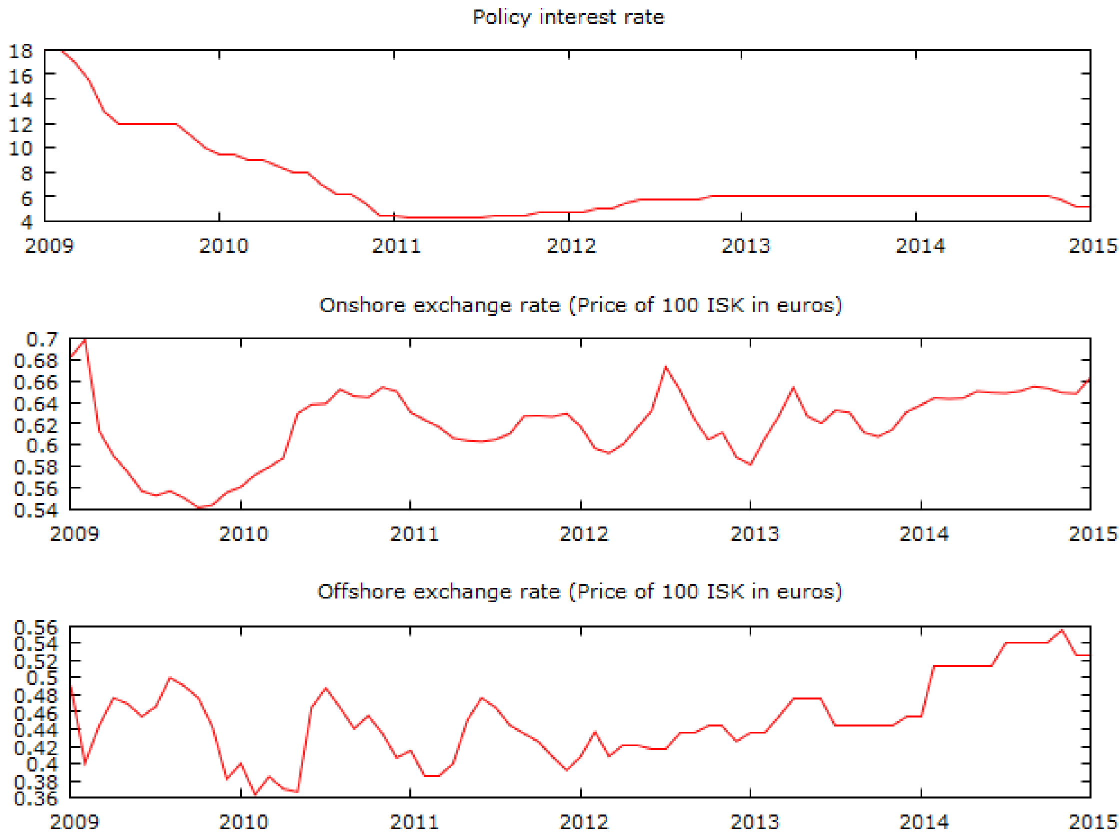
We have found that raising domestic interest rates may or may not have the effect of raising the exchange rate, all depending on the level of debt in the form of domestic assets held by foreign investors. When the level of domestic assets owned by foreign investors is high, an increase of the domestic interest rates will make the exchange rate fall because of the greater outflows of interest payments to foreign investors that require a larger trade surplus. In contrast, a fall in foreign interest rates does help the home country because it reduces leakages so that the offshore exchange rate rises, making it less tempting for exporters to sell their foreign currency offshore. Similarly, a fall in the risk premium on domestic currency assets would have the effect of raising the onshore exchange rate through reduced leakages, and the same applies to expectations of a higher future onshore exchange rate.

4. Empirical study

The Central Bank of Iceland began monetary easing in March 2009, which was justified by rapidly declining inflation. It reduced its policy rate by 1% (from 18% to 17%) in March, then by 1.5% (to 15.5%) in April, and finally, to 13% in May. Three more cuts followed in 2009, lowering the rate to 10% by the end of the year. Further cuts followed in 2010, lowering the policy rate to 4.25% by the beginning of 2011. Figure 2 shows the policy rate, the onshore exchange rate, and the offshore exchange rate between January 2009 and March 2015. Note that the EURISK exchange rate is fairly stable at around 0.62 euros per 100 ISK, while the offshore rate fluctuates around 0.46 euros per 100 ISK.

One pattern that is visible in Figure 2 is the lax monitoring of the capital controls in 2009, which makes the onshore rate fall and the offshore rate rise. In November 2009, enforcement of the capital controls was tightened, subsequently making the onshore rate rise and the offshore rate fall. Increased leakages appear also to have occurred in 2011.

Figure 2. Interest rates and exchange rates



The pattern of changes in the policy rate, the onshore exchange rate, and the offshore exchange rate can be used to discriminate between the different channels from interest rates to exchange rates, discussed in Section 3 above. We employ a simple VECM based on the interest parity condition in equation (12). For our experiment, we use the policy rates of the Central Bank of Iceland and the ECB for i and i^* respectively, after subtracting the corresponding CDS spread to correct for risk premia. For the estimation of the model, we use monthly data from January 2009 to February 2015.

Interest parity conditions such as equation (12) are often rejected empirically, especially in the short run, as they normally state that expected returns in different currencies should be the same. In the presence of, for example, transaction costs or risk, this is not a realistic assumption. We have already corrected for the risk premium, but the issue of transaction costs remains.[11] Regardless, the condition can serve as an equilibrium benchmark in the VECM, from which the economy deviates in the short run.

Rewriting equation (12) and making the strong assumption of rational expectations yields:

$$\log(E_{t+1}) - \log(e_t) = i_t^* - i_t + \varepsilon_t \tag{15}$$

where ε_t is a white noise term. A pth-order VECM in the variables in (15), taking the eurozone interest rate to be exogenous, is:

$$\Delta \boldsymbol{y}_t = \boldsymbol{\beta}_0 + \boldsymbol{\Pi} \boldsymbol{x}_{t-1} + \sum_{i=1}^{p} \boldsymbol{\beta}_i \, \Delta \boldsymbol{y}_{t-i} + \boldsymbol{\nu}_t \tag{16}$$

where $\boldsymbol{y}_t' = (\log(E_t), \log(e_t), i_t)$, $\boldsymbol{x}_t' = (\log(E_t), \log(e_t), i_t, i_t^*)$, $\boldsymbol{\Pi}$ is a parameter matrix with rank equal to the number of cointegrating relations, $\boldsymbol{\beta}_0$,..., $\boldsymbol{\beta}_p$ are matrices of parameters, and $\boldsymbol{\nu}_t$ a vector of error terms.

Performing unit-root tests on the four variables suggests that all of them are non-stationary, although the Augmented Dickey-Fuller and Kwiatkowski–Phillips–Schmidt–Shin tests do not agree in the case of $\log(E)$. The differences of all variables are stationary, so we conclude that that they are I(1). Allowing a maximum of 12 lags, the Akaike and Hannan-Quinn Information Criteria suggest 12 lags, while the Bayesian Information Criterion suggests 1. As the suggestions of the criteria differ significantly, we resort to residual diagnostics. In both cases, the null of normality is rejected, but there is less evidence of autocorrelation in the residuals with 12 lags, so we opt for a VECM(11). A Johansen cointegration test suggests that there exist two cointegrating relations between the variables. The estimation and test results can be found in Appendix 1.

[11] A possible way to account for transaction costs would be to allow for a constant in the interest parity relation, as in Lacerda *et al.* (2010), which would account for systematic deviations in the short run.

Most of the estimated coefficients in the three equations are statistically insignificant, with a few exceptions. Some lags in the policy rate equation and one in the onshore rate equation are significant in the policy rate and offshore exchange rate equations. In the onshore exchange rate equation, the constant and some lags of both the onshore and the offshore exchange rates are significant, but none of the policy rate lags are. Both error correction terms are significant in the offshore equation, neither in the policy rate equation, and the second error correction term is significant in the onshore equation. As an example, consider the second cointegrating vector, which was estimated as $\log(e_t) - 5.024\log(E_t) - 0.181\, i_t^*$. If this equation takes a positive value, the offshore rate must fall, the onshore rate rise or the foreign interest rate rise to balance it. The signs of the second error correction term in the three VECM equations reflect this equilibrium reversion.

Our Cholesky ordering identification strategy is to order the policy instrument first, so that it responds to the two exchange rates with a lag. The second term is the offshore exchange rate, which responds to the onshore rate with a lag.[12] The impulse response functions are shown in Figures 3 and 4 below, in response to a one standard deviation shock with 90% boot strap confidence intervals.

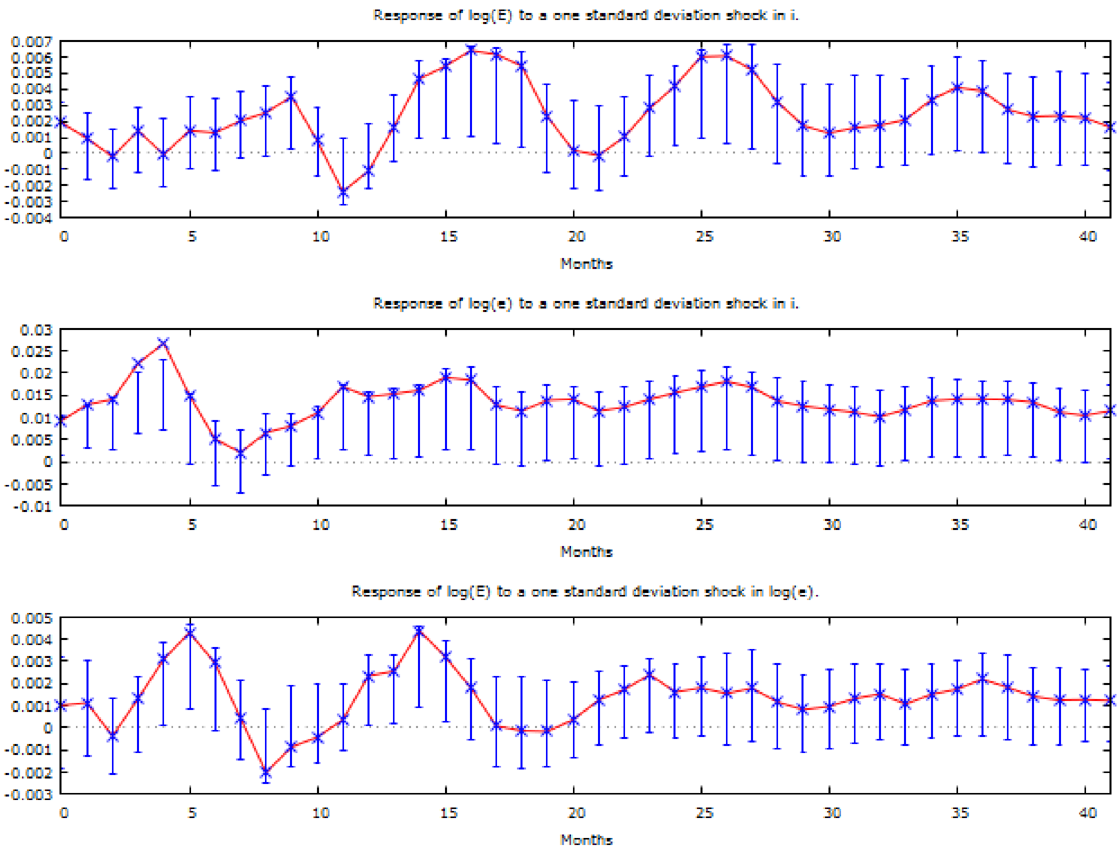
The impulse response function of the onshore exchange rate in response to a shock in domestic interest rates is shown in the top panel of Figure 3. Note that the effect is not statistically significant from zero for most of the periods following the shock. The impact response at time zero can be compared to the one for the period before capital controls, as shown in Appendix 2, when the response appears to have been stronger in the very short run. We conclude that changes in the interest rate have a very weak effect on the onshore exchange rate in a capital control regime.

The impulse response function for the offshore exchange rate in response to a shock to domestic interest rates is shown in the middle panel. The offshore rate appreciates initially, which in terms of our model is due to a reduced supply of the domestic currency in the offshore market. The effect is significant the first four months following the shock, as indicated by the confidence intervals. The bottom panel shows the response of the onshore exchange rate to a shock to the offshore exchange rate. A rise in the offshore rate yields a rise in the onshore rate, although the effect is only positively significant at the four

[12] We tried different orderings, and the results were not significantly altered except for the obvious time zero effect.

and five month mark and then between 12 and 15 months. This occurs in our model when it becomes more profitable to convert export earnings into the local currency onshore.

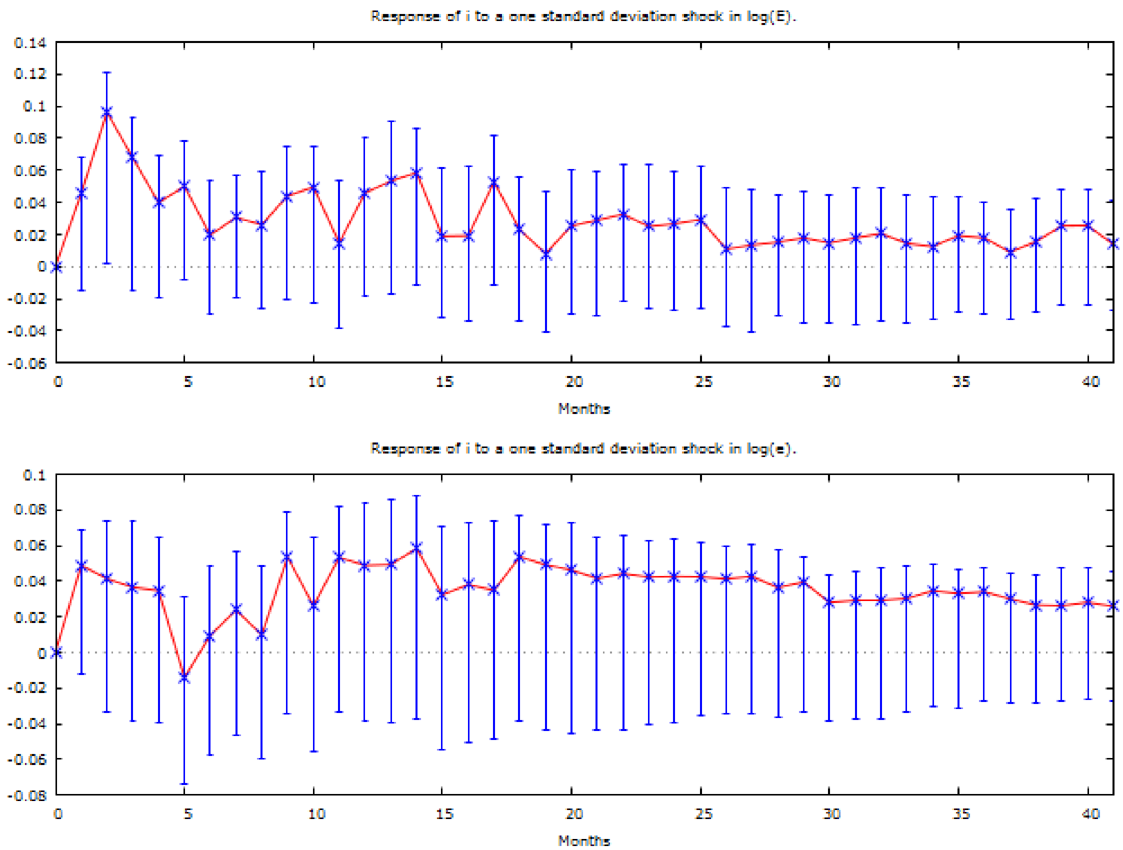
Figure 3. Impulse responses



The top panel of Figure 4 below shows the impulse response function of the domestic interest rate when there is a shock to the onshore exchange rate. The effect of a shock to the onshore rate on the policy rate is mostly statistically insignificant from zero. In contrast, the impulse response functions for the period of free capital mobility shown in Appendix 2 indicate that interest rates were raised following a depreciation of the exchange rates. Thus in that period, monetary policy responded to exchange rate movements and interest rate increases had the short-term effect of raising the exchange rate while in the capital control period the central bank did not respond in the same way to exchange rate movements nor did interest rate changes have as strong an effect on the exchange rate.

The bottom panel of the figure has the effect of a shock in the offshore rate on the interest rate, but the effect is not statistically significant from zero.

Figure 4. Impulse responses.



In Appendix 3, we present the variance decomposition forecast of all three variables. The variance of the policy instrument is initially fully explained by monetary policy shocks due to the Cholesky ordering, but shocks to the exchange rates account for close to 20 percent in three years' time. Shocks to the offshore exchange rate initially explain the majority of the variance in the offshore exchange rate, but at around the two-year mark the interest rate explains roughly 60 percent and the onshore rate 10 percent. Shocks to the onshore exchange rate explain around 95 percent of the variance in the onshore rate initially, but in three years interest rates explain around 50 percent and the offshore rate 20 percent.

5. Conclusion

This paper has derived a relationship between central bank interest rates and exchange rates under a capital control regime. The onshore and offshore exchange rates are determined by the requirement of a balance on the current account and an interest parity condition.

Higher interest rates onshore may raise both onshore and offshore exchange rates by inducing owners of local currency assets not to sell local currency offshore. This will make the offshore exchange rate rise, thereby discouraging exporters from buying local currency offshore and increasing the supply of foreign currency onshore. The onshore exchange rate will increase as a result. There is also an effect that goes in the opposite direction: Higher interest rates increase the flow of interest income to foreigners through the current account, making the onshore exchange rate fall, which then makes exporters turn to the onshore market, lowering the offshore rate. The former effect is likely to dominate when the level of debt held by foreigners is low and the enforcement of capital controls weak while the latter effect dominates when the level of debt is high and capital controls are strongly enforced.

The historical financial crisis in Iceland provides excellent testing grounds for the effect of high interest rates accompanied by capital controls. Starting from a policy rate of 18% in February 2009, a sequence of interest rate reductions brought interest rates down to 4.25% at the end of 2011. The estimation of a VECM in interest and exchange rates shows that an interest rate increase makes the currency appreciate, although this effect is weak and barely statistically significant due to the weakness of the coefficient estimates in the VECM. This stands in contrast to the years of free capital movements when the short term impact of higher interest rates on the exchange rate were stronger. Also, with capital controls, higher interest rates make the offshore exchange rate increase, which can be explained by a fall in leakages. An offshore rise in the exchange rate causes the onshore exchange rate to rise, which in our model occurs when exporters turn to the onshore market because of the offshore appreciation, although this effect is weak.

While the effects of changes in interest rates are statistically weak, the paths of exchange rates indicate a strong effect of the enforcement of the capital controls. Better enforcement increased the difference between the onshore and the offshore exchange rate in late 2009 and 2010, raising the onshore rate and weakening the offshore rate.

Overall, the experience suggests a very weak effect of interest rates on the onshore exchange rate. It follows that cutting interest rates from a very high level is not likely to make a currency depreciate in an effective capital control regime, highlighting the importance of the effective enforcement of the controls.

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Appendix 1

The results of the ADF tests, where the null hypothesis is that the process contains a unit root:

Table A1.1. Augmented Dickey-Fuller Test Results

	$\log(E)$	$\log(e)$	i	i^*
Optimal lags (max 12)	1	0	12	0
Test statistic	-3.066	-2.390	-2.741	-2.782
Asymptotic p-value	0.029	0.148	0.067	0.066

The results of the KPSS tests with lag truncation parameter equal to 3, where the null hypothesis is of stationarity:

Table A1.2. Kwiatkowski–Phillips–Schmidt–Shin Test Results

	$\log(E)$	$\log(e)$	i	i^*
Test statistic	0.691	0.841	0.500	1.614
Interpolated p-value	0.016	< 0.01	0.044	< 0.01

The critical values for the KPSS test are: 10% - 0.350, 5% - 0.462 and 1% - 0.731.

The VAR lag selection results with a maximum of 12 lags:

Table A1.3. VAR lag selection criteria

Lags	Log-likelihood	AIC	BIC	HQC
1	212.717	-6.378	-5.863	-6.176
2	226.042	-6.517	-5.694	-6.194
3	226.966	-6.257	-5.125	-5.812
4	235.935	-6.256	-4.815	-5.690
5	253.141	-6.521	-4.771	-5.834
6	266.529	-6.662	-4.604	-5.854
7	273.986	-6.612	-4.245	-5.683
8	289.202	-6.813	-4.137	-5.762
9	301.461	-6.918	-3.933	-5.746
10	315.985	-7.096	-3.803	-5.803
11	330.396	-7.271	-3.668	-5.856
12	360.720	-7.959	-4.048	-6.423

Estimating VECM(0) and VECM(11) with an appropriate number of cointegrating vectors, we test normality and 12^{th}-order autocorrelation of residuals using the Doornik-Hansen and Ljung-Box tests.

Table A1.4. Residual diagnostics

	Doornik-Hansen		Ljung-Box					
			Eq. 1 (Δi_t)		Eq. 2 (Δ log(e_t))		Eq. 3 (Δ log(E_t))	
Lags	Statistic	p-value	Statistic	p-value	Statistic	p-value	Statistic	p-value
1	81.295	0.000	29.254	0.004	19.407	0.079	8.337	0.758
12	16.429	0.012	14.825	0.251	15.840	0.199	16.417	0.173

The null of the DH test is one of multivariate normality. The null of the LB test is that there is no autocorrelation up to the 12th order.

The Johansen cointegration tests results:

Table A1.5. Johansen Trace and Max Test Results

Rank, r	Eigenvalue	Trace test	p-value	Max test	p-value
0	0.646	97.534	0.000	64.305	0.000
1	0.407	33.229	0.000	32.398	0.000
2	0.013	0.831	0.362	0.831	0.362

The null of the trace test is that there are r or fewer cointegrating vectors. The null hypothesis of the max test is that the number of cointegrating vectors is equal to r.

Finally, the results of estimating the VECM:

Table A1.6. Estimation results for VECM(11) for the period 2009-2015

	Equation 1: Δi_t	Equation 2: $\Delta\log(e_t)$	Equation 3: $\Delta\log(E_t)$
Constant	22.890 (17.872)	2.845 (1.762)	-3.625 *** (0.792)
Δi_{t-1}	0.171 (0.136)	0.002 (0.013)	0.001 (0.006)
Δi_{t-2}	0.072 (0.127)	-0.010 (0.126)	0.001 (0.006)
Δi_{t-3}	-0.095 (0.133)	0.039 *** (0.013)	0.004 (0.006)
Δi_{t-4}	-0.042 (0.135)	0.036 ** (0.013)	-0.011 (0.006)
Δi_{t-5}	0.147 (0.153)	-0.035 ** (0.015)	0.000 (0.007)
Δi_{t-6}	0.001 (0.168)	-0.022 (0.017)	-0.008 (0.007)
Δi_{t-7}	0.368 ** (0.171)	-0.003 (0.017)	-0.006 (0.008)
Δi_{t-8}	0.303** (0.146)	0.007 (0.014)	-0.004 (0.006)
Δi_{t-9}	0.110 (0.145)	-0.019 (0.014)	0.002 (0.006)
Δi_{t-10}	-0.057 (0.144)	-0.031 ** (0.014)	-0.000 (0.006)
Δi_{t-11}	0.330 ** (0.137)	-0.009 (0.013)	0.004 (0.006)

$\Delta\log(e_{t-1})$	2.295 (1.605)	-0.080 (0.158)	-0.157 ** (0.071)
$\Delta\log(e_{t-2})$	0.088 (1.711)	0.033 (0.169)	-0.207 ** (0.076)
$\Delta\log(e_{t-3})$	0.309 (1.840)	-0.040 (0.181)	-0.122 (0.082)
$\Delta\log(e_{t-4})$	1.093 (1.571)	-0.272 (0.155)	-0.064 (0.070)
$\Delta\log(e_{t-5})$	-2.155 (1.434)	-0.166 (0.141)	0.071 (0.636)
$\Delta\log(e_{t-6})$	-0.684 (1.495)	-0.007 (0.147)	0.003 (0.066)
$\Delta\log(e_{t-7})$	0.179 (1.421)	-0.015 (0.140)	-0.070 (0.063)
$\Delta\log(e_{t-8})$	-2.093 (1.337)	-0.033 (0.132)	-0.185 *** (0.059)
$\Delta\log(e_{t-9})$	1.972 (1.426)	0.174 (0.141)	-0.151 ** (0.063)
$\Delta\log(e_{t-10})$	0.198 (1.418)	-0.050 (0.140)	-0.115 (0.063)
$\Delta\log(e_{t-11})$	1.346 (1.131)	0.147 (0.112)	-0.008 (0.050)
$\Delta\log(E_{t-1})$	0.240 (4.171)	-0.222 (0.411)	0.353 (0.185)
$\Delta\log(E_{t-2})$	1.965 (3.745)	0.058 (0.369)	0.078 (0.166)
$\Delta\log(E_{t-3})$	-1.953 (3.657)	-0.897 ** (0.361)	0.404 ** (0.162)
$\Delta\log(E_{t-4})$	-0.024 (4.156)	-0.405 (0.410)	0.421 ** (0.184)
$\Delta\log(E_{t-5})$	-1.435 (4.209)	-0.371 (0.415)	0.225 (0.187)
$\Delta\log(E_{t-6})$	-3.336 (3.464)	-0.464 (0.342)	-0.002 (0.154)
$\Delta\log(E_{t-7})$	4.207 (2.952)	-0.012 (0.291)	-0.087 (0.131)
$\Delta\log(E_{t-8})$	-2.024 (2.964)	-0.212 (0.292)	0.052 (0.131)
$\Delta\log(E_{t-9})$	1.169 (2.929)	-0.411 (0.289)	0.438 *** (0.130)
$\Delta\log(E_{t-10})$	-0.218 (3.147)	-0.269 (0.310)	0.378 ** (0.139)
$\Delta\log(E_{t-11})$	-8.043 ** (3.268)	0.085 (0.322)	0.255 (0.145)
Error Correction 1	-0.168 (0.087)	0.024 ** (0.009)	-0.002 (0.004)
Error Correction 2	-0.084 (1.281)	-0.290 ** (0.126)	0.191 *** (0.057)
R^2	0.831	0.819	0.801

Maximum likelihood estimates, observations 2010:01-2015:02 (T = 62).
Cointegrating vectors (std. errors):
i_t: 1.000 (0.000), $\log(e_t)$: 0.000 (0.000), $\log(E_t)$: -24.283 (12.325), i_t^*: -1.820 (0.949).
i_t: 0.000 (0.000), $\log(e_t)$: 1.000 (0.000), $\log(E_t)$: -5.024 (0.821), i_t^*: -0.181 (0.063).
*** denotes significance at the 1% level, ** at the 5% level.

Appendix 2

The model is estimated for the period 2000-2008, before the capital controls were implemented. For this period, there is little to no difference between onshore and offshore exchange rates, so the model is instead based on the UIP relation. After taking logs and assuming rational expectations, we have:

$$\Delta \log(E_{t+1}) = i_t^* - i_t + \varepsilon_t \qquad \text{(A2.1)}$$

Unit root tests suggest that all variables are no greater than I(1). A Johansen test suggests one cointegrating vector. The HQC and BIC suggest 2 and 1 lags respectively, while the AIC suggests 11. Residual diagnostics favour the more parsimonious specifications. The results of estimating a VECM(2) are as follows:

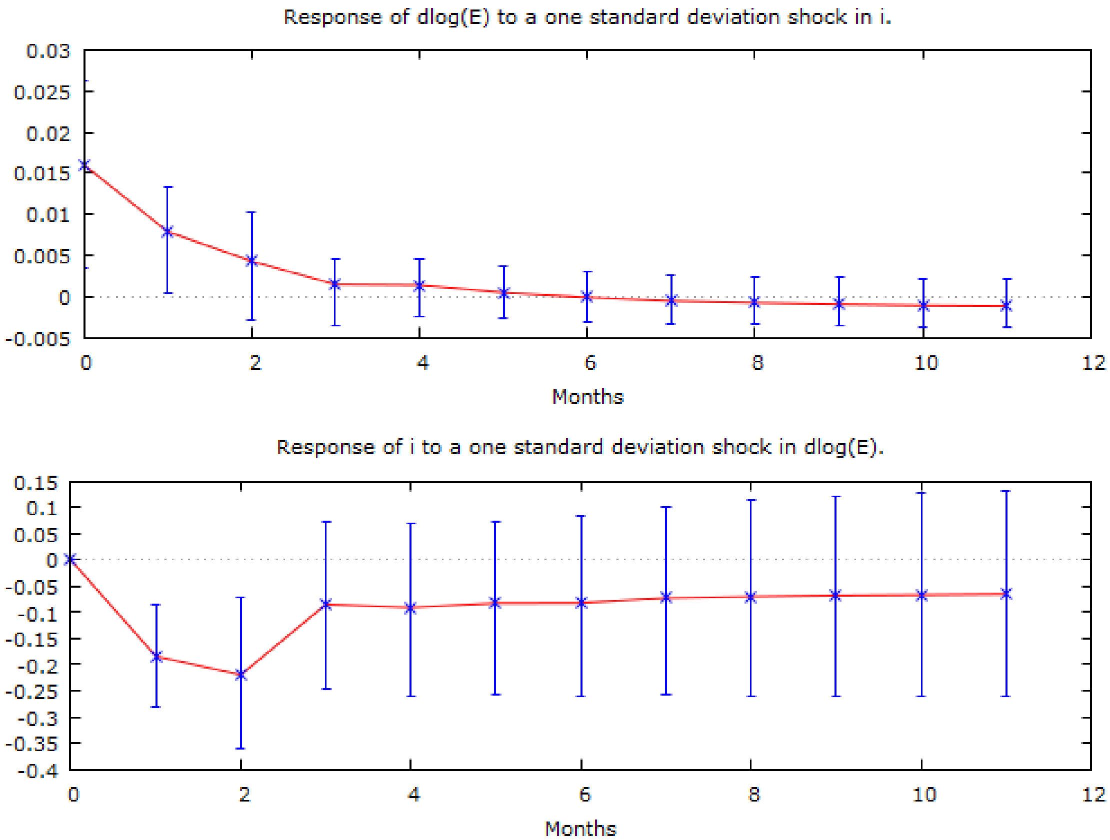
Table A2.1. Estimation results for VECM(2) for the period 2000-2008

	Equation 1: Δi_t	Equation 2: $\Delta^2 \log(E_{t+1})$
Constant	-0.003 (0.072)	0.014 *** (0.005)
Δi_{t-1}	0.242 ** (0.119)	0.021 ** (0.009)
Δi_{t-2}	-0.010 (0.123)	0.003 (0.009)
$\Delta^2 \log(E_t)$	-3.993 (2.334)	-0.363 ** (0.168)
$\Delta^2 \log(E_{t-1})$	-4.644 *** (1.643)	-0.128 (0.118)
Error Correction Term	-0.002 (0.005)	-0.002 *** (0.000)
R^2	0.145	0.539

Maximum likelihood estimates, observations 2000:05-2008:12 (T =104).
Cointegrating vector (std. errors): i_t: 1.000 (0.000), $\Delta\, log(E_t)$: : 496.64 (96.050), i_t^*: 1.272 (2.564).
*** denotes significance at the 1% level, ** at the 5% level.

For impulse responses and variance decomposition, we order interest rates first. All impulse responses are in response to a shock of one standard deviation and are shown with 90% boot strap confidence intervals. The impulse response functions are as follows:

Figure A2.1. Impulse responses.



The top panel of Figure A2.1 shows the impulse response of the difference in the exchange rate to a shock in policy rates. The difference is positive and statistically significant for the first period, but insignificant from zero thereafter. The lower panel of Figure A2.1 shows that an increase in the exchange rate is met with a statistically significant decline in the policy rate for the first two periods, but insignificant after the second period.

Figures A2.2 and A2.3 show the variance decomposition of the two variables. Interest rates are explained primarily by monetary policy shocks, whereas exchange rate shocks explain roughly 80 percent of the variation in exchange rates.

Figure A2.2. Variance decomposition for the policy interest rate.

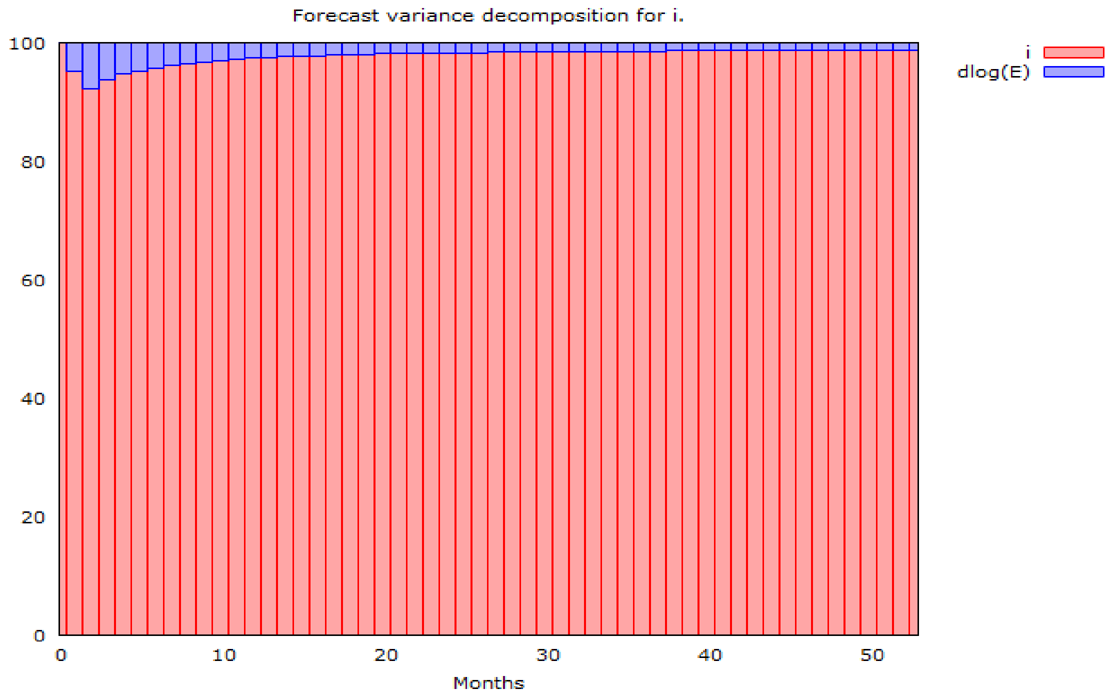
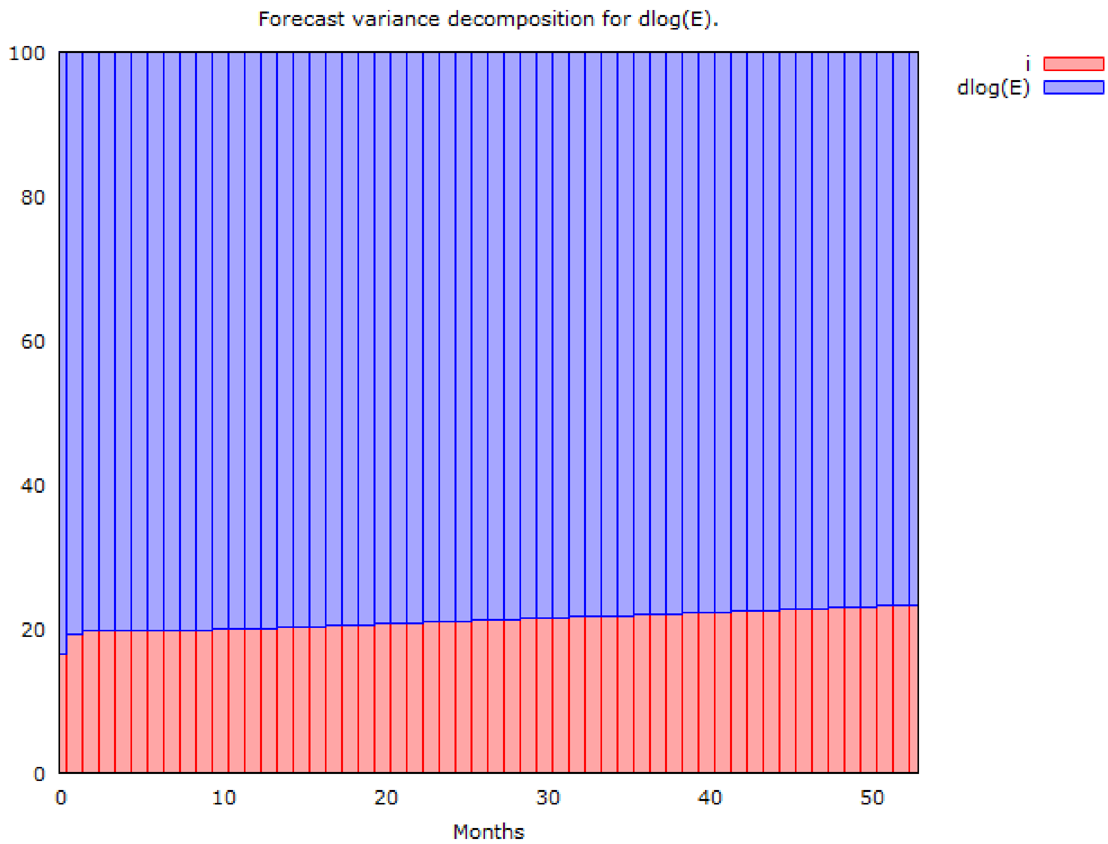


Figure A2.3. Variance decomposition for the exchange rate.



Appendix 3

The following three figures show the variance decomposition forecast of the three variables in the VECM(11):

Figure A3.1. Variance decomposition for the policy interest rate.

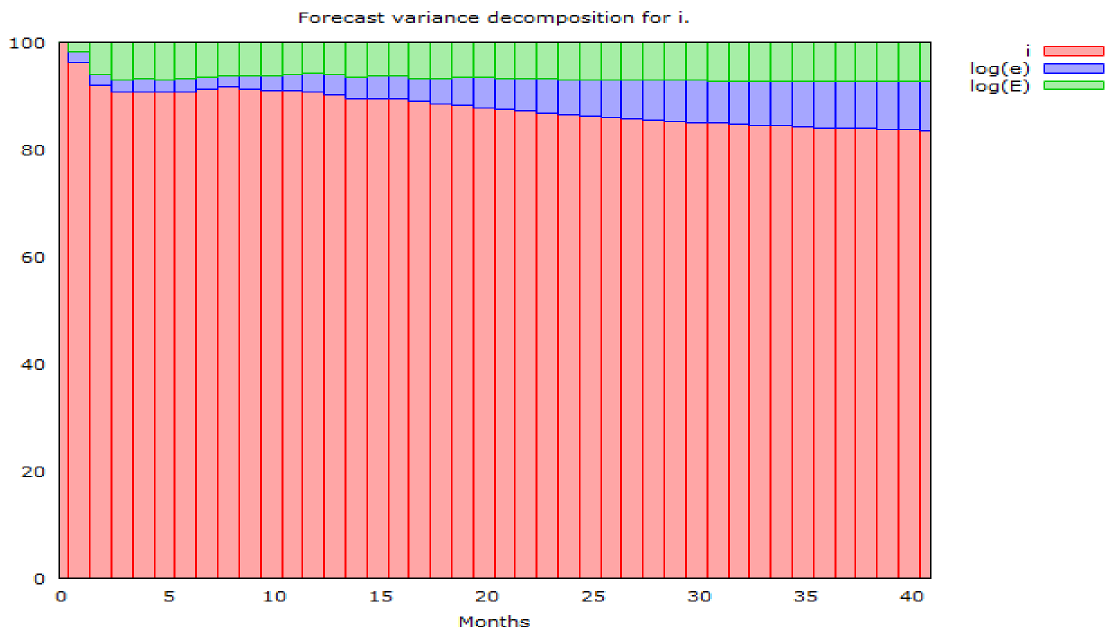


Figure A3.2. Variance decomposition for the offshore exchange rate.

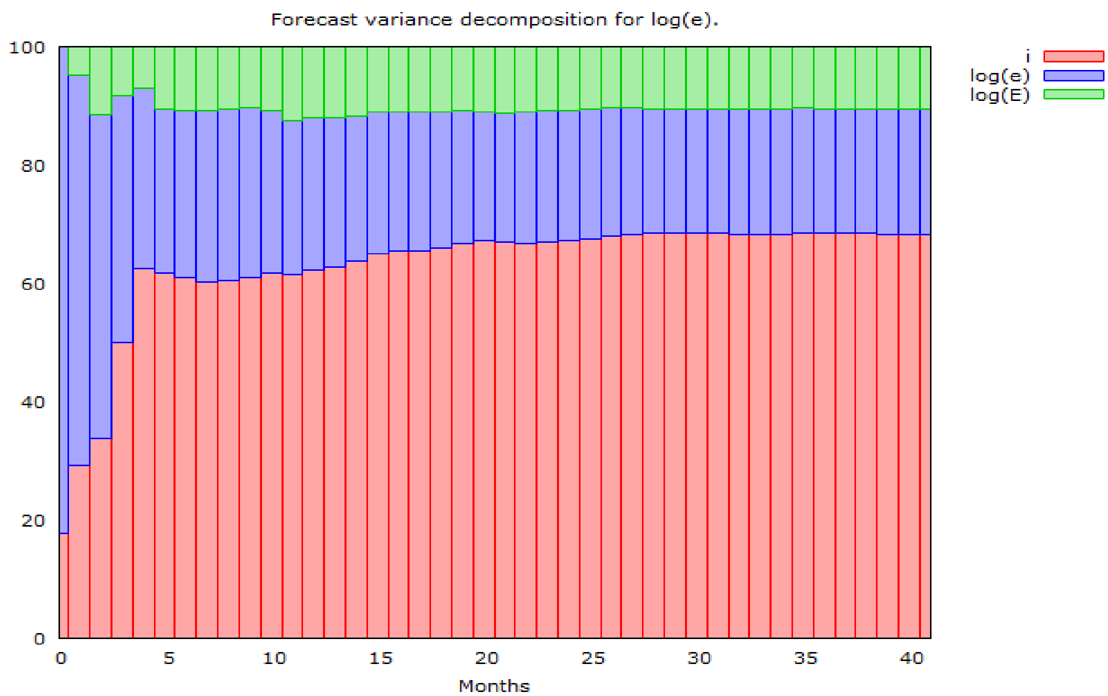
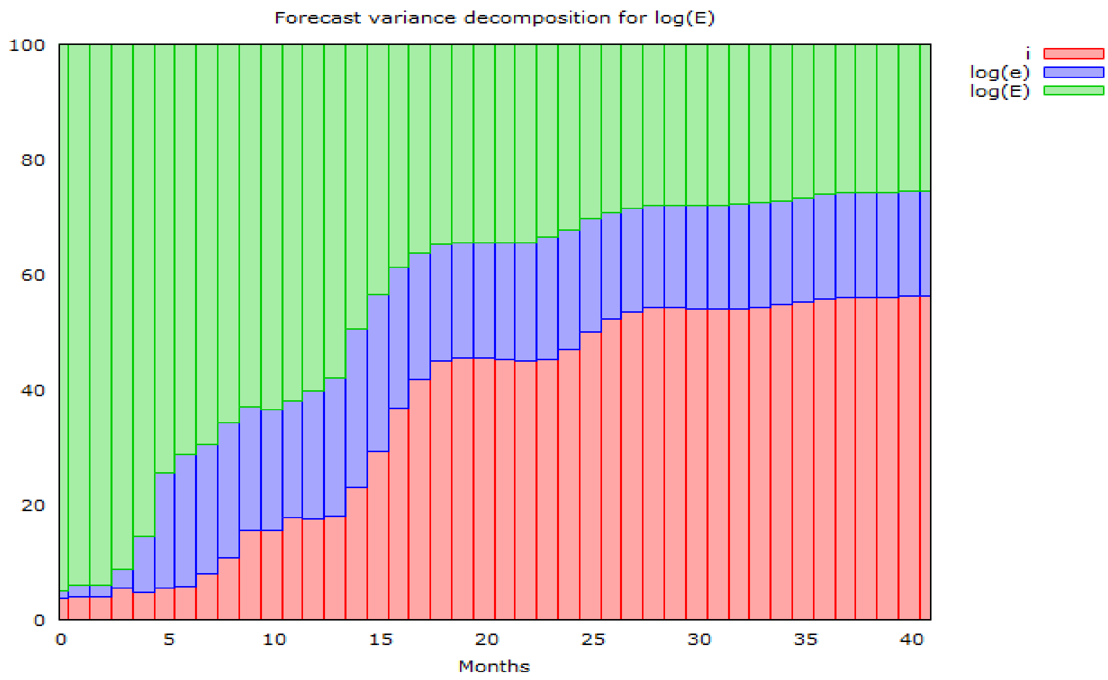


Figure A3.3. Variance decomposition for the onshore exchange rate.



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