International Evidence on the Role of Monetary Policy in the Uncovered Interest Rate Parity Puzzle

By

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Abstract:

CPI inflation targeting necessitates a flexible exchange rate regime. This paper embeds an endogenous target rule into a simple open economy macro model to explain the UIP puzzle. The model predicts that the change in the exchange rate is inversely related to the lagged interest rate differential. Foreign inflation and the foreign interest rate also affect exchange rate changes. This hypothesis is tested on data from three small open economies, Canada, Norway, and Switzerland, all of which target CPI inflation and maintain extensive trade and finance links with a larger neighboring country. Supportive evidence is strongest for Switzerland during a clean float period before the outbreak of the Global Financial Crisis.

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Uncovered interest rate parity (UIP) is a non-arbitrage condition which is founded upon the idea that yields on comparable domestic and foreign financial assets should be equal in the absence of a risk premium. The standard test of the joint hypothesis of UIP and rational expectations consists of a regression of the change in the nominal exchange rate on the lagged interest rate differential. Employing this test regression, scores of empirical papers reject the UIP hypothesis for a large number of countries over different sample periods because the estimated coefficient on the interest rate differential turns out to be statistically insignificant or statistically significant but *negative*. The observed violation of the UIP condition has been labeled the "UIP Puzzle".[1] The "Carry Trade" phenomenon whereby high interest rate countries see their currencies appreciate is symptomatic of the failure of the UIP condition.

This paper examines the UIP puzzle from the angle of an optimizing inflation-targeting central bank. It offers a fresh perspective on the determinants of exchange rate behavior under CPI inflation targeting and looks at the experience of three-inflation targeting countries to assess the empirical plausibility of a model-based exchange rate equation.

The theory section of the paper presents a simple open economy model where uncovered interest rate parity is presumed to hold. The central bank's optimizing behavior gives rise to an endogenous target rule. Combining the target rule with the building blocks of the model determines the behavior of the nominal exchange rate. In sharp contrast to the standard test specification of the UIP hypothesis, the model implies that actual changes in the nominal exchange rate do not respond merely to the lagged interest rate differential but also to two additional *observable* factors - the foreign inflation rate, and the level of the foreign interest rate. A key finding is that the UIP puzzle is not a figment of the data but a direct consequence of the central bank's monetary policy strategy. The change in the nominal exchange rate is negatively related to the lagged interest rate differential. Two parameters affect the sensitivity of nominal exchange rate changes to movements in the lagged interest rate differential. They are: the relative weight the central bank places on the variability of CPI inflation in its objective function and the degree of openness of the economy. Greater emphasis on stable inflation and greater openness weaken the link between movements in the nominal exchange rate and lagged interest rate differentials.

[1] See, for instance, Fama (1984), Froot and Thaler (1990), Lewis (1995), Engel (1996), Chinn and Meredith (2004), Brunnermeier et al (2009), and Burnside et al (2011).

The empirical section of the paper examines whether actual experience supports the theoretical framework. It looks at the behavior of the spot exchange rate in three countries – Canada, Norway, and Switzerland - to ascertain whether exchange rate changes are systematically related to the three key drivers identified by the model. These countries practice CPI inflation targeting, maintain no capital controls, and have allowed their exchange rate to float for extended periods of time. Carrying out the econometric investigation requires defining the "foreign country" in respect of the spot exchange rate, the foreign rate of inflation, and the foreign interest rate. The choice of the "foreign country" is exceedingly simple. A larger next-door neighbor with whom the country maintains extensive trade relations and financial linkages represents the foreign country. For Canada, the larger next-door neighbor is the United States, for Switzerland it is Germany, and for Norway it is Sweden.

Fitting the model-based exchange rate equation to data from the countries in question over a 30-year plus period produces mixed results. In each case there is partial support for the estimated specification of the exchange rate equation underlying the model. Support is limited because the specification estimated can explain actual exchange rate behavior to varying extents only during certain episodes. But that should not be surprising given the occurrence of monetary policy regime shifts in Canada, Norway, and Switzerland at particular points in time. Switzerland provides a case in point. Over the whole sample period or during the recent Crisis period, the model-based equation receives virtually no support from the data. However, once periods of massive intervention in the foreign exchange market and outright exchange rate targeting are eliminated from the sample the picture changes dramatically. From the early 1980s to the Crisis period, when the Swiss Franc floated freely, the estimated specification provides an adequate fit of the data. In Canada, US inflation appears to be an important driver of changes in the Canadian-US Dollar exchange rate since the introduction of inflation targeting in the early 1990s. In Norway, the Krone-Krona exchange rate has been susceptible to movements in the Swedish rate of inflation and particularly the Swedish short-term interest rate since the switch to CPI inflation targeting in 2001. Taken altogether, episodes of CPI inflation targeting combined with a freely floating exchange rate in the three countries provide substantial but not conclusive empirical support for the specification implied by the model.

The remainder of the paper is structured as follows. Section II briefly reviews the literature and introduces the model. Section III determines the optimal policy setting under a target rule and derives the key equation of the model which identifies the factors that drive changes in the nominal exchange rate. Section IV presents the empirical findings of the test of exchange rate behavior in Canada, Norway, and Switzerland. Section V concludes.

II. Related Literature and the Model

McCallum (1994) is an early contribution that relates the UIP puzzle to the conduct of monetary policy. He presents a two-equation framework consisting of the standard non-arbitrage UIP condition and an *ad hoc* instrument rule. The central bank engages in interest smoothing and leans against changes in the nominal exchange rate. Combining the two equations yields the negative relationship between the change in the nominal exchange rate and the lagged interest rate differential.[2] Employing an optimizing two-country framework, Backus et al (2010) show the negative link between the interest rate differential and the change in the nominal exchange rate to be the result of the domestic central bank ignoring exchange rate movements in setting the policy instrument. The central bank follows a simple *ad hoc* instrument rule to control domestic inflation. Paradoxically, the foreign central bank must tighten monetary policy in response to its currency appreciating for the negative association of the interest rate differential with the change in the nominal exchange rate to hold.

Using a small open economy model, Guender (2013) shows that simple *ad hoc* instrument rules - such as variants of Taylor rules that respond to CPI inflation - are inferior to optimal target rules as specifications of monetary policy rules. In general, *endogenous* target rules that are derived from an explicit optimizing framework dominate simple *ad hoc* instrument rules because the former draw on superior information relative to the latter. Target rules rely on an implied reaction function which permits the central bank to respond *directly* to *all* shocks of the model while a simple instrument rule responds only to deviations of target variables from their target levels. Evidently, there is an informational advantage to being able to optimally react to the shocks of the model rather than to the target variables proper.[3]

This section uses the model by Guender (2013, 2014) as the frame of reference for examining the UIP puzzle. The linear model consists of four equations and a policy rule whose characteristics are discussed at greater length in the next section. Variables marked by an asterisk denote the foreign counterpart of the domestic variable. Foreign variables are

[2] See also Anker (1999) who extends McCallum's approach.
[3] Froyen and Guender (2007, 2012) provide an analysis of instrument versus target rules.

treated as exogenous random variables. The first equation is the definition of the policy instrument (x_t).The policy instrument is defined as the difference between the domestic nominal interest rate (i_t) and its foreign counterpart (i_t^*) . Adopting this convention simplifies the analysis and allows us to compare our results directly with those reported by McCallum (1994). The second equation is the UIP condition in nominal terms. It allows for the existence of a risk premium (ρ_t). The two remaining equations describe the behavior of inflation. Equation (3) is a condensed equation of the rate of domestic inflation. It is obtained by combining three different elements: an open economy IS equation, UIP in real terms, and a Phillips curve.[4] The rate of domestic inflation is inversely related to the difference between the expected real rate of interest at home and abroad. The sensitivity of inflation to the expected real interest rate differential (α) depends on demand-side (a_1, a_2) and supply-side (κ) parameters as well as the degree of openness (γ). The composite stochastic disturbance (u_t) captures the effect of demand-side and cost-push shocks on domestic inflation. Equation (4) is the definition of CPI inflation.

$$x_t = i_t - i_t^* \qquad (1)$$

$$x_t = Es_{t+1} - s_t + \rho_t \qquad (2)$$

$$\pi_t = -\alpha(x_t - (E_t\pi_{t+1} - E_t\pi_{t+1}^*)) + u_t \qquad (3)$$

$$u_t = \kappa(v_t - a_1(i_t^* - E_t\pi_{t+1}^*) + (a_2 - a_1\gamma)\rho_t) + w_t$$

$$\alpha = \kappa((1-\gamma)a_1 + a_2)$$

$$\pi_t^{CPI} = (1-\gamma)\pi_t + \gamma(\Delta s_t + \pi_t^*) \qquad (4)$$

$$0 \le \gamma \le 1$$

III. Optimal Policy Based on a Target Rule

III.1 The Central Bank's Objective and the Specification of Monetary Policy

The aim of the central bank is to minimize the variability of the CPI inflation rate and the policy instrument:

$$V(x_t) + \mu V(\pi_t^{CPI}) \qquad (5)$$

[4] For further details on the derivation of equation (3), the reader is referred to part C of the appendix.

$\mu =$ aversion to inflation variability relative to variability of policy instrument.

Associated with the quadratic objective function is a linear target rule. This rule embodies a systematic relationship between the variables that appear in the objective function. The specific form that the target rule takes depends in part on the way monetary policy is implemented. For the case at hand, the linear target rule is a simplified version of the one that underlies optimal policy from a timeless perspective.[5] Employing this particular target rule has two important advantages. First, it permits the derivation of closed form solutions of the endogenous variables of the model and, second, it identifies the key parameters in the UIP puzzle.

The specification of the target rule takes the following form:

$$\theta_1 x_t + \theta_2 x_{t-1} + \pi_t^{CPI} = 0 \tag{6}$$

θ_1 and θ_2 are relative weights that the central bank treats as policy parameters. They represent the importance that the central bank attaches in the target rule to the policy instrument in the current and previous period, respectively, compared to the current rate of CPI inflation. Being endogenous and of "higher order" in the sense that it is only one step below the objective function, the target rule locks x_t, x_{t-1} and π_t^{CPI} into a systematic relationship which guarantees that the central bank implements monetary policy optimally.[6] The target rule is enforced by the implicit reaction function which illustrates the optimal response of the policy instrument to the shocks of the model and current as well as past feedback variables:

$$x_t = \frac{1}{(1-\gamma)\alpha}\left(\theta_2 x_{t-1} + (1-\gamma)(\alpha(E_t\pi_{t+1} - E_t\pi_{t+1}^*) + u_t) + \gamma(\Delta s_t + \pi_t^*)\right) \tag{7}$$

where $u_t = \kappa\left[v_t - a_1(i_t^* - E_t\pi_{t+1}^* + (a_2 - a_1\gamma)\rho_t)\right] + w_t$.

III.2 Model Solution and Optimal Policy

To solve the model for the endogenous variables, substitute first the definition of the CPI inflation rate, equation (4), into the target rule. Next, eliminate the current-period rate of

[5] Woodford (2003) and Froyen and Guender (2007) describe policy from a timeless perspective.

[6] Part A of the appendix shows how the target rule is determined from an intertemporal perspective.

domestic inflation by substituting equation (3) into the target rule. The policy instrument can be eliminated by the amended UIP condition where the expected change in the exchange rate next period has been disposed of with the help of the putative solution for the exchange rate. Finally, solve for the change in the nominal exchange rate. Using the solution for the change in the nominal exchange rate, we can solve for the remaining endogenous variables of the model. The solutions appear in equations (8) – (11).

$$x_t = \frac{\gamma}{\gamma+\theta_2}\rho_t \tag{8}$$

$$\pi_t = -\left(\frac{\kappa\big(((1-\gamma)a_1+a_2)\gamma-(a_2-a_1\gamma)(\gamma+\theta_2)\big)}{\gamma+\theta_2}\right)\rho_t + \kappa(v_t - a_1 i_t^*) + w_t \tag{9}$$

$$\pi_t^{CPI} = -\theta_2 x_{t-1} - \frac{\theta_1}{\gamma+\theta_2}\rho_t \tag{10}$$

$$\Delta s_t = -\frac{\theta_2}{\gamma}x_{t-1} - [\left(\frac{\theta_1+(1-\gamma)(-\alpha)}{\gamma}\right)\frac{\gamma}{\gamma+\theta_2} + \frac{(1-\gamma)}{\gamma}\kappa(a_2 - a_1\gamma)]\rho_t - \frac{(1-\gamma)}{\gamma}(\kappa(v_t - a_1 i_t^*) + w_t) - \pi_t^* \tag{11}$$

The variances of the CPI inflation rate and the policy instrument are then substituted into the objective function. The policymaker's objective is to minimize the expected loss function by choosing the optimal values of θ_1 and θ_2:

$$\min_{\theta_1,\theta_2} E[L_t] = V(x_t) + \mu V(\pi_t^{CPI}) \tag{12}$$

Minimizing expected losses with respect to the two policy parameters yields their respective optimal value:

$$\theta_1^* = 0 \qquad \theta_2^* = \frac{1}{\mu\gamma} \tag{13}$$

Substituting the optimal policy coefficients into equation (11) yields the solution for the change in the nominal exchange rate:

$$\Delta s_t = -\frac{1}{\mu\gamma^2}x_{t-1} - \pi_t^* + \frac{(1-\gamma)\kappa\, a_1}{\gamma} i_t^* - \left[\left(\frac{(1-\gamma)(-\alpha)}{\gamma}\right)\frac{\mu\gamma^2}{\mu\gamma^2+1} + \frac{(1-\gamma)}{\gamma}\kappa(a_2 - a_1\gamma)\right]\rho_t + \frac{(1-\gamma)}{\gamma}(\kappa v_t + w_t) \tag{11'}$$

The target rule approach offers a solution to the UIP puzzle: the coefficient on x_{t-1}in equation (11') equals $-\frac{1}{\mu\gamma^2}$. The above result is thus consistent with the widely reported empirical observation that high-interest rate countries see their currencies rise in value. Two deep parameters determine the strength of the relation between an observed movement in the nominal exchange rate and the lag of the policy instrument: the central bank's relative aversion to CPI inflation variability and the degree of openness of the domestic economy. The greater the aversion to inflation variability, the weaker the negative association between the lagged interest rate differential and the change in the nominal exchange rate. Indeed, in countries where strict CPI inflation targeting is the norm ($\mu \rightarrow \infty$), there should be no evidence for a robust link between the two variables.[7] Greater openness also weakens the relation between exchange rate movements and lagged interest rate differentials. According to the target rule, the central bank trades off deviations of CPI inflation from target against deviations of the interest rate differential. Greater openness increases the relative weight on CPI inflation in the target rule and, by implication, the relative weight on the change of current exchange rate which is a component of CPI inflation. This effect materializes in equation (11') by the coefficient on the lagged interest rate differential becoming smaller as γ increases.[8]

Apart from the lagged policy instrument, two other observable variables affect the change in the nominal exchange rate. According to equation (11'), the foreign rate of inflation and the current level of the foreign interest rate affect the nominal exchange rate change. In fact, a one percent increase of the foreign inflation rate should lead to a decrease of the nominal exchange rate by the same magnitude. An increase in the foreign interest rate should cause the domestic currency to depreciate.

[7] Under strict inflation targeting ($\mu \rightarrow \infty$), the coefficient on ρ_t in eqn. (8) approaches unity. This suggests that the policy instrument completely offsets the effect of the stochastic risk premium. With $x_t = \rho_t$ this implies further from eqn. (2) that $E_t \Delta s_{t+1}$must be zero for UIP to hold. This is indeed the case. Update eqn. (11') by one period, take conditional expectations dated t and let $\mu \rightarrow \infty$. $E_t \Delta s_{t+1} = 0$ results. The UIP condition is also satisfied for $0 \leq \mu < \infty$ as in this case x_t and $E_t \Delta s_{t+1}$ share the burden of adjusting to the stochastic risk premium.

[8] Updating the target rule and taking conditional expectations yields: $E_t \pi_{t+1}^{CPI} = -\frac{1}{\mu\gamma} x_t$. The effect on expected CPI inflation of an expected change in the nominal exchange rate is given by $\gamma E_t \Delta s_{t+1}$. Hence $\gamma E_t \Delta s_{t+1} = -\frac{1}{\mu\gamma} x_t$ or $E_t \Delta s_{t+1} = -\frac{1}{\mu\gamma^2} x_t$ which results by updating equation (11') by one period and taking conditional expectations.

IV. International Evidence on Exchange Rate Behavior

The model discussed in the previous section describes a setting where the domestic economy is a small open economy where the policy focus rests on targeting CPI inflation. The model is consistent with the notion that there exists a larger next-door neighbor with whom the domestic economy maintains extensive trade and financial linkages. There are no barriers to the free flow of capital and goods in the model. Developments in the larger neighboring country affect the domestic economy. But the latter is too small to have an impact on the economy or policy in the larger adjoining country. This scenario is a fairly realistic description of the position of Canada, Norway, and Switzerland, the three countries included in this study, vis-à-vis their next-door neighbors. In the case of Canada, the large neighbor is the United States while for Switzerland and Norway the larger neighbor is Germany and Sweden, respectively.[9] The central banks in Canada, Switzerland, and Norway are considered by many to fall into the rubric of flexible inflation targeters, all of which operate in an environment where the exchange rate is a key factor in the transmission process of monetary policy.

This section begins with a short overview of recent and current monetary arrangements in the three-small open economies. Following the descriptive analysis and a brief statistical review of the behavior of key variables, we next examine whether the prediction of exchange rate behavior underlying the model of the previous section is consistent with the data.

1.1 Monetary Arrangements in Switzerland (1975-2013)

The focus of monetary policy in Switzerland had been on price stability long before it was categorized as a flexible inflation targeter in 1999.[10] From an operational perspective, price stability in Switzerland is defined as CPI inflation of less than 2 percent. This objective is to be achieved via steering an intermediate target, the 90-day Swiss Franc LIBOR rate. The

[9] Measuring size can be a tricky affair, depending on the yardstick used. In 2012, according to World Bank statistics, the ratio of Canada's GDP (in US Dollars) to the GDP of the United States was 0.11. The Switzerland-Germany ratio was 0.18 while the ratio for Norway and Sweden was 0.95. Switzerland's and Norway's economies are heavily influenced by events in special sectors. The share of the Swiss financial sector in total value added amounted to about 11 percent in 2011 (Swiss Bankers Association). About 25 percent of Norway's income is generated by oil and gas (Olsen, (2014)). If size is measured instead by population (estimates for 2014) then the respective ratio is 0.11 (CA/US), 0.09 (SW/GE), and 0.52 (NO/SV). Source: www.geoba.se.

[10] Mishkin (2002), Ball and Sheridan (2005). For a recent survey see Walsh (2009). They all consider Switzerland to be an inflation targeter, a view not necessarily shared inside the Swiss National Bank (Baltensperger, Hildebrand and Jordan (2007)). Jordan (2014) argues that price stability is *a*, if not, *the* key mandate of the Swiss National Bank. He emphasizes that conditional inflation forecasts play an important role in charting out the future path of the policy rate (3-month Swiss Franc LIBOR).

Swiss Franc has been floating since the collapse of the fixed exchange regime in 1973 although the late 1970s was fraught with frequent and massive interventions in the foreign exchange market. In the post-Bretton Woods era, for some 25 years, the Swiss National Bank relied on monetary targeting to achieve price stability. In late 1999 the bank began to move towards targeting inflation forecasts.[11]

The Swiss Franc floated freely from 1982 until the outbreak of the Global Financial Crisis in 2009. Being a safe haven currency, the Swiss currency came under heavy pressure to appreciate during the Global Financial Crisis. The second quarter of 2009 marked the beginning of a period of sustained intervention by the Swiss National Bank in the foreign exchange market to stabilize the Swiss Franc.[12] Indeed, the pressure intensified in late 2011 and early 2012 to such an extent that the Bank announced a minimum exchange rate (*1.20* Swiss Franc per Euro), motivated in part by the danger posed by the deflationary pressure of an appreciating Swiss Franc on import prices.[13] In 2012 the IMF changed the classification of the Swiss Franc from "free floating" to "other managed".[14]

1.2 Summary Measures of Inflation, Interest, and Exchange Rates in Switzerland

Table 1 shows the mean and standard deviation of annualized quarterly CPI inflation, the 3-month Eurocurrency deposit rates, and changes in the spot exchange rate for Switzerland and Germany. The whole sample period (1975q1-2013q1) is broken down into individual sub-periods. The first sub-period begins with the free float of the Swiss Franc in the first quarter of 1982 and goes to the end of the sample period. As the Swiss Franc-Euro exchange rate ceased being a free float during the Crisis period, we distinguish between three additional sub-periods.[15] The second sub-period ranges from the beginning of the free float period to 2011q2, the quarter before the Swiss National Bank announced the minimum exchange rate

[11] Rich (2003).

[12] As the crisis unfolded, the Swiss National Bank also had to resort to unconventional monetary measures to provide much needed liquidity to the financial sector and give emergency loans to the most important trading banks. By late 2008 conventional monetary policy had run out of room as the LIBOR had reached its effective lower bound, dropping below 0.5 percent.

[13] The Swiss Monetary Authorities stabilized primarily the Swiss Franc/Euro exchange rate because of the close trade links between Switzerland and the European Union (EU). In 2011, 78 percent of the country's imports came from and 57 percent of its exports went to the EU. Chetwin and Munro ((2013), p. 48).

[14] Chetwin and Munro (2013). In general, what constitutes an exchange rate regime is hard to measure in practice. See Rose (2011) for an overview of the difficulties and problems encountered in classifying exchange rate regimes.

[15] 1999 saw the introduction of the Euro within the EMU and a new monetary policy strategy by the Swiss National Bank and could therefore be considered perhaps as the beginning of a sub-period in its own right. But neither event had any serious ramifications for the behavior of the Swiss Franc/German Mark (Euro) exchange rate. For more details, see Fischer (2003).

in the maelstrom caused by the European Debt Crisis.[16] The third sub-period captures essentially the free float period of the Swiss Franc. The Swiss National Bank began to intervene in the foreign exchange market in the second quarter of 2009 as the Swiss Franc appeared to settle below the 1.50 Franc/Euro mark in the wake of the Global Financial Crisis. The last sub-period considers the Crisis period in isolation. Following others, we date the beginning of the Crisis period to the third quarter of 2007.[17]

Inspection of the entries in the table reveal a few interesting findings:

- In all sample periods inflation in Switzerland was lower but more variable than in Germany.
- The same result can be reported for the mean but not necessarily for the standard deviation of short-term interest rates. The mean interest rate differential $i_t^{SW} - i_t^{GE}$ was always negative.
- Changes in the spot exchange rate were very volatile throughout with the peak (12.52%) occurring in the Crisis period. The Swiss Franc gained against the Euro (German Mark) over the whole period and in every sub-period. The mean rate at which the Swiss Franc appreciated was also highest at -5.33% per quarter in the Crisis Period.
- The average change in the nominal exchange rate during the free float period (1982q1-2009q1) was fairly low though not necessarily very stable.

2.1 Monetary Arrangements in Canada (1975-2013)

In the mid-1970s Canada had to grapple with double-digit inflation. Following a timely trend, the Bank of Canada attempted to curb inflation by targeting the growth rate of a monetary aggregate (M1). By 1982 it was clear that the monetarist experiment had failed and monetary targeting was abandoned. A policy target vacuum ensued. Commentators argue that the Bank of Canada adopted an implicit exchange rate target vis-à-vis the US Dollar to curb inflation in the 1980s[18]. This arrangement lasted until February 1991 when Canada officially adopted inflation targeting. A two-percent CPI inflation target has been in place since the end

[16] The minimum exchange rate was announced on September 6th, 2011.
[17] Bullard (2010) and Mishkin (2011) regard August 7th, 2007 as the beginning of the Global Financial Crisis. On this day, BNP Paribas closed one of its money market funds.
[18] Bordo and Redish (2005, p. 11). The United States is Canada's most important trading partner, accounting for 73.2 percent of its exports and 50.6 percent of its imports. Source: CIA World Factbook, 2012.

of 1995. During the recent financial crisis, the Bank of Canada did not have to rescue failing banks or resort to quantitative or credit easing.[19]

Except as noted above, Canada has maintained a flexible exchange rate regime over the past 40 years. Periodic interventions in the foreign exchange market have occurred, particularly during the 1995-1998 period. Since 1999 the Bank of Canada has not intervened in the foreign exchange market even though the Canadian Dollar appreciated substantially over the 2002-2008 period on the heels of a boom in commodity prices.

2.2 Summary Measures of Inflation, Interest, and Exchange Rates in Canada and the United States

The right-most column of Table *3* contains arguably the most striking result. Over the whole sample period and in every sub-period, fluctuations in the change of the CAN$-US$ spot rate were quite dramatic, particularly during the Crisis period and the somewhat longer Clean Float period. In the latter period, the Canadian Dollar appreciated approximately 2.5 percent on average vis-à-vis the US Dollar due to the boom in commodity prices from 2002 to 2008. The 3-month Eurocurrency deposit rate on the Canadian Dollar was on average higher than the rate for the American Dollar but it became less variable relative to its American counterpart with the adoption of inflation targeting in the first quarter of 1999. The inflation record in both countries is similar over the whole sample period. Since the introduction of an official inflation target average inflation in Canada has been somewhat lower – roughly speaking half a percentage point- but not necessarily more stable compared to the United States.

3.1 Monetary Arrangements in Norway (1987-2013)

For a long time the focus of monetary policy in Norway rested squarely on the exchange rate. After the collapse of the Bretton Woods System in 1971, Norway operated a medley of different exchange rate arrangements that sought to keep the Krone exchange rate stable, especially against the currencies of its major European trading partners. From 1986 to 1992 a fixed exchange rate system whereby the value of the Krone could narrowly fluctuate against a basket of currencies was in place.[20] Turmoil in international currency markets and the ensuing speculation against the Nordic currencies led to the eventual float of the Norwegian

[19] The asset-backed commercial paper market though seized up at the beginning of the Global Financial Crisis in August 2007 and became completely dysfunctional. See Melino (2012) for an account of how the Bank of Canada dealt with the Global Financial Crisis.

[20] In 1990 the Krone was pegged to the ECU (European Currency Unit).

Krone in December 1992. This marked the beginning of a period during which Norges Bank, Norway's central bank, managed the exchange rate with a view towards keeping inflation in Norway close to inflation in its main European trading partners.[21] Foreign exchange market intervention was an instrument of monetary policy, though not heavily used, until Norges Bank switched to inflation targeting in 2001.[22] Since then its mandate has been to keep inflation close to 2.5 percent *over time* on the understanding that the Bank takes account of the state of the real economy in making monetary policy decisions. Along with the Reserve Bank of New Zealand, Norges Bank pioneered the use of forward-guidance as a communications strategy with financial markets. Forward guidance has been an extensively used tool of monetary policy since 2004.[23]

3.2 Summary Measures of Inflation, Interest, and Exchange Rates in Norway and Sweden

Average CPI inflation in Norway was remarkably close to its current target of 2.5 percent over a 35-year period even though formal inflation targeting did not begin until 2001. Sweden has a similar mean inflation record but its inflation rate was more variable than Norway's. On average, the nominal interest rate (90-day interbank borrowing rate) in Norway lay above Sweden's, particularly during the inflation targeting period when the difference exceeded a full percentage point. Somewhat higher inflation in Norway can only partly account for the difference in borrowing cost in the two countries. Over the whole sample period, the Norwegian Krone appreciated slightly against the Swedish Krona. As in the previous two cross-country comparisons, fluctuations in the change of the nominal spot rate dwarf fluctuations in inflation rates. The most pronounced swings in the change of the exchange rate occurred during the 1993q1-2013q1 period when the Krone was subject to a managed float until the switch to inflation targeting midway through the period. It must be borne in mind that this period includes the Asian Financial Crisis and the Russian Default in 1998. The turbulence in international money markets at the time put enormous downward pressure on the Norwegian currency. During the Crisis period, fluctuations in the change of the bilateral exchange rate were by comparison fairly modest with the standard deviation of changes hovering around the 9 percent mark.

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[21] Norway's main import partners are Sweden (13.6 percent) and Germany (12.4 percent). Main export destinations are the United Kingdom (25.6%) and Germany (12.6%). Sweden ranks sixth with an export share of 6.3 percent. This is largely because Norway's exports are dominated by sales of oil and gas. Source: CIA World Factbook, 2012.

[22] Gjedrem (1999, p. 4) writes that "[i]n Norges Bank's experience, extensive exchange-market interventions have yielded poor results."

[23] Olsen (2014) explains the rationale for forward guidance in the conduct of monetary policy in Norway.

4. Econometric Analysis

The starting point of the econometric analysis of exchange rate behavior is equation (11'). To examine the fit of the model-based exchange rate equation, we propose the following regression equation (updated by one period):

$$s_{t+1} - s_t = \alpha + \beta_i(i_t^{3mo} - i_t^{3mo*}) + \beta_{\pi^*}\pi_{t+1}^* + \beta_{i^*}i_{t+1}^* + \epsilon_{t+1} \qquad (11'')$$

Data frequency is quarterly. The estimation method is ordinary least squares. Three identifiable variables appear on the right-hand side of the regression equation. They are: the lagged interest rate differential (difference between the domestic and foreign 90-day (3-month) interest rates in period *t*), the foreign rate of inflation, and the foreign 90-day (3-month) interest rate.

4.1 Evidence on the Swiss Franc Euro (German Mark) Exchange Rate

Table 4 presents the coefficient estimates of equation (11'') along with standard regression diagnostics. The specification is estimated over the whole sample period and a number of sub-periods during which the Swiss National Bank either abstained from or staged extensive interventions in the foreign exchange market. The specification is also estimated separately on data from the Crisis period.

Over the 1975-2013 period, there is not much evidence in favor of the specification suggested by the model. Although the three estimated β coefficients bear the correct sign only one of them is statistically significant at the one percent level. The explanatory variables are rather poor predictors of actual changes in the exchange rate over the whole period as the adjusted R^2 is rather low at *0.05*.

The proposed specification receives far more support from the data if it estimated over the *1982-2013* period which excludes the years during which the Swiss National Bank intervened heavily in the foreign exchange market to prevent the Swiss Franc form appreciating as a result of the inflow of petro-dollars in the wake of the oil crises.[24] All estimated β coefficients are statistically significant at the one percent level and economically relevant. Two of the three estimated coefficients bear the expected sign. The estimated coefficient on the interest rate differential suggests that, ceteris paribus, a one percentage

[24] The IMF considered the Swiss Franc to be a freely floating currency again by 1982(IMF Official Exchange Rate Classification published in the online data appendix of Reinhart and Rogoff (2008)). Fischer (2002) argues that the interventions by the Swiss National Bank in the foreign exchange market were confined to the 1978/79 period.

point difference between the Swiss and German interest rate led to a *2.84* percent decrease in the Swiss Franc-German Mark exchange rate, i.e. an appreciation of the Swiss currency. The level of German interest rates also impacted on changes in the nominal exchange rate as suggested by the model. A *100* basis point increase in the German interest rate is, ceteris paribus, associated with a *5.37* percent depreciation of the Swiss currency. The fit of the regression equation also improves markedly with the adjusted R^2 rising to *0.12*. The fit of the regression equation improves further if episodes of major interventions in the foreign exchange market during the Crisis period are dropped from the analysis. The clean float of the Swiss Franc was interrupted as early as March 2009 (Intervention I) when the Swiss National Bank began to selling domestic currency in the foreign exchange market and yet again in September 2011 (Intervention II) when it announced the minimum exchange rate vis-à-vis the Euro. Inspection of the two estimated regressions reveals that the adjusted R^2 rises to *0.13* and *0.14*, respectively, while the estimated coefficients remain statistically and economically significant.

A completely different picture emerges if the specification is tested only on data from the Crisis period. The predictive power of the model equation disappears completely. None of the estimated coefficients is statistically significant and the adjusted R^2 turns negative. Interestingly, the coefficient on the interest rate differential turns positive and is fairly close to one, which is of course what the UIP hypothesis suggests. Indeed, the UIP hypothesis is nested within the specification of equation (11'') and can be tested by imposing the following restrictions on the coefficients in the test equation: $\beta_i = 1$, $\beta_{\pi^{GE}} = 0$, $\beta_{i^{GE}} = 0$. Carrying out a Wald-test of these restrictions on the three coefficients, we cannot reject the null hypothesis of the UIP condition holding during the Crisis period; however, we can safely reject the null hypothesis over the whole sample period and the other sub-sample periods. The χ^2 test statistics appear in the center of Table 1.

4.2 Evidence on the Canadian-US Dollar Exchange Rate

According to Table 5, the estimated regression provides a rather poor fit for the Canadian-US Dollar exchange rate over the whole sample period. The adjusted R^2 is close to zero. Only the US interest rate had a significant positive effect on the change in the spot exchange rate. A much better fit is obtained if the sample period is shortened to coincide with the start of the inflation targeting period in Canada. For the 1991q2-2013q1 period the adjusted R^2 rises to *0.14.* The qualitative effect of US inflation on the spot exchange rate is consistent with the prediction of the model: a rise in US inflation puts upward pressure on CPI inflation in Canada which is counteracted by a tightening of monetary policy. The rise in the Canadian interest rate in turn causes the Canadian Dollar to appreciate. While the negative effect of US inflation on the change in the spot exchange rate is statistically significant at the one percent level, its quantitative effect exceeds the size predicted by the model: a 95 percent confidence interval around the estimated coefficient *-2.7774* does not include *-1*. Restricting the sample size further to the Clean Float period yields similar results. The fit of the regression improves slightly to *0.17*. The lagged interest rate differential does not appear to be a driver of changes in the spot exchange rate. This remains true for the Crisis period even though the coefficient is now positive and rather large. Again, only the US inflation rate is systematically related to changes in the spot exchange rate during this interval. A 95 percent confidence interval around the estimated coefficient includes *-1*. Notice that the fit of the regression model during the Crisis period is better than the fit in other (sub)-periods.

Testing the coefficient restrictions implied by UIP results in a clear rejection of the null hypothesis in all periods considered.

4.3 Evidence on the Norwegian Krone-Swedish Krona Exchange Rate

Table 6 reports the coefficient estimates of the regression for the case of Norway and its neighbor Sweden. Compared to the other two cases, the results for the pair of Nordic countries are somewhat different in one important respect. There are no dramatic differences in the reported results across sample periods. The empirical relationship between the change in the exchange rate and its presumed key drivers observed over the whole sample period holds also in the shorter sub-periods.

Over a period spanning 25 years the Swedish interest rate and to a lesser extent Swedish inflation affected the behavior of the spot exchange rate in the way suggested by the model. In marked contrast, the lagged interest rate differential had no bearing on changes in the Krone-Krona exchange rate over the whole sample period. The estimated regression model explains about 10 percent of the variation in nominal exchange rate changes. Beginning with the introduction of inflation targeting in 2001, the latter half of the sample period provides the strongest evidence in favor of the estimated specification. Inflation and the interest rate in Sweden exercised a statistically and economically significant effect on the change in the spot exchange rate.

- A 95 percent confidence interval around the estimated coefficient on Swedish inflation includes *-1*.
- A one percentage point increase in the Swedish interest rate is associated with a depreciation of the Krone-Krona exchange rate of over seven percent.

Two noteworthy findings apply to the Crisis period. First, the fit of the model improves with the adjusted R^2 rising to *0.17* and, second, the coefficient on the lagged interest rate differential increases markedly in size.

Once again the restrictions on the coefficients of the estimated regression specification implied by the UIP condition are rejected at the one percent level.

4.4. Summary of Cross-Country Evidence

Inspection of the results for Switzerland, Canada, and Norway reveals that

- the relationship between cross-country interest rates and exchange rate changes underwent a fundamental shift during the Crisis period. The estimated coefficient turns positive -as in the case of Switzerland, turns positive and large in Canada, or becomes much larger as in Norway. It remains to be seen, however, whether the Crisis period spells the end of the UIP puzzle and marks the beginning of a new era of increasingly sensitive responses of exchange rate movements to cross-country interest rate differentials.
- the fit of the regression is best for Canada and Norway but worst for Switzerland during the Crisis period. Repeated interventions in the foreign exchange market followed by the announcement of an explicit exchange rate floor by the Swiss National Bank go a long way towards explaining this result.
- Periods of CPI Inflation targeting (implicit as in Switzerland or explicit as in Canada and in Norway) coupled with a clean float provides the strongest support for the model-based specification of exchange rate behavior.
    - ♦ Lagged interest differential matters only in Switzerland
    - ♦ Inflation and interest rate abroad matter in Norway and Switzerland
    - ♦ US inflation matters in Canada.

V. Conclusion

This paper has shown that mere reliance of standard UIP tests to examine observed exchange rate behavior presents a fundamental problem, both from a theoretical and an empirical perspective. The problem arises because the effect of monetary policy on the exchange rate, or more generally, the action taken by a central bank to attain its objectives, is left out of the picture. To make this point, the paper presents a simple model of an optimizing central to show how the nominal exchange rate acts as a shock absorber under CPI inflation targeting. The optimizing approach provides a rationale for why CPI inflation and the lag of the policy instrument – the interest rate differential - appear in the endogenous target rule. When the target rule is combined with the building blocks of the open economy model – one of which is the assumption of uncovered interest rate parity plus the existence of an exogenous risk premium – the current change in the nominal exchange rate responds

- negatively to an increase in the lagged interest rate differential
- negatively to a rise in the foreign rate of inflation and
- positively to a rise in the level of the foreign interest rate.

This hypothesized reaction of the exchange rate is a clear alternative to the one underlying the standard test of UIP. The empirical part of the paper presents the results of a test of exchange rate behavior under CPI inflation targeting in three small open economies and contrasts them with those that accord with the conventional test underlying the UIP hypothesis. The restrictions implied by the UIP hypothesis are overwhelmingly rejected for Canada, Switzerland, and Norway. The model-based specification of exchange rate behavior fares much better, particularly in Switzerland during a 25-year interval of a freely floating Swiss Franc and some form of monetary/inflation targeting. There is also some support for the model-based specification of the exchange rate in Norway and Canada though the lagged interest rate differential seems to have played no role at all in either country. Instead the rate of inflation and/or the level of interest rates in the adjoining large neighbor lay behind changes in the respective nominal exchange rate, particularly since the introduction of formal CPI inflation targeting in both countries.

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Table 1: Summary Measures for Switzerland (SW) and Germany (GE) (%).

	π^{SW}	π^{GE}	i^{SW}	i^{GE}	Δs^{1}
1975q1-2013q1	1.95	2.39	3.19	4.81	-1.37
Whole Period	*2.73*	*2.41*	*2.59*	*2.71*	*11.55*
1982q1-2013q1	1.67	1.91	3.09	4.43	-0.79
Floating Period	*2.66*	*2.10*	*2.52*	*2.46*	*9.73*
1982q1-2011q2	1.83	1.90	3.27	4.65	-0.87
Intervention I	*2.62*	*2.11*	*2.48*	*2.36*	*10.00*
1982q2-2009q1	1.89	1.94	3.52	4.95	-0.11
Intervention II	*2.62*	*2.16*	*2.41*	*2.19*	*9.13*
2007q3-2013q1	0.25	1.69	0.80	1.91	-5.33
Crisis Period	*2.99*	*1.79*	*1.11*	*1.71*	*12.52*

Note:

In each row, the top entry is the mean of the respective variable. The standard deviation appears in italics below the mean.

[1] First difference of the log of the bilateral spot exchange rate (units of Swiss Franc per Euro or German Mark), annualized and multiplied by 100.The rate of inflation is calculated as the annualized first difference of the log of the quarterly CPI index (not seasonally adjusted) multiplied by 100. The nominal interest rate is the respective 3-month Eurocurrency deposit rate.

Data Source: DATASTREAM.

Table 2: Summary Measures for Canada (CA) and the United States (US) (%).

	π^{CA}	π^{US}	i^{CA}	i^{US}	Δs[1]
1975q2-2013q1	3.89	3.88	6.76	6.02	0.15
Whole Period	*3.51*	*3.09*	*4.26*	*4.04*	*12.60*
1982q1-2013q1	1.81	2.44	3.80	3.50	-0.42
Inflation Targeting	*2.13*	*1.91*	*1.99*	*2.13*	*14.85*
1999q1-2013q1	2.03	2.39	2.88	2.72	-2.59
Clean Float	*2.42*	*2.31*	*1.57*	*2.15*	*17.04*
2007q3-2013q1	1.56	1.94	1.72	1.30	-0.14
Crisis Period	*2.62*	*3.09*	*1.31*	*1.52*	*20.55*

Note:

In each row, the top entry is the mean of the respective variable. The standard deviation appears in italics below the mean.

[1] First difference of the log of the bilateral spot exchange rate (units of Canadian Dollar per US Dollar), annualized and multiplied by 100.The rate of inflation is calculated as the annualized first difference of the log of the quarterly CPI index (not seasonally adjusted) multiplied by 100. The nominal interest rate is the respective 3-month Eurocurrency deposit rate.

Data Source: DATASTREAM.

Table 3: Summary Measures for Norway (NO) and Sweden (SV) (%).

	π^{NO}	π^{SV}	i^{NO}	i^{SV}	Δs^{1}
1987q1-2013q1	2.52	2.50	6.39	5.80	-0.84
Whole Period	*2.81*	*4.15*	*3.74*	*3.93*	*11.87*
1993q1-2013q1	1.96	1.40	4.66	4.05	-1.16
Floating Krone	*2.65*	*3.45*	*2.04*	*2.37*	*13.26*
2001q1-2013q1	1.80	1.41	3.88	2.76	-0.75
Inflation Targeting	*3.18*	*3.64*	*1.96*	*1.31*	*11.53*
2007q3-2013q1	2.03	1.28	3.42	2.38	-0.46
Crisis Period	*2.77*	*3.95*	*1.66*	*1.56*	*9.08*

Note:
In each row, the top entry is the mean of the respective variable. The standard deviation appears in italics below the mean.

[1] First difference of the log of the bilateral spot exchange rate (units of Norwegian Krone per Swedish Krona), annualized and multiplied by 100.The rate of inflation is calculated as the annualized first difference of the log of the quarterly CPI index (not seasonally adjusted) multiplied by 100. The nominal interest rate is the respective 90-day interbank borrowing rate.

Data Sources: DATASTREAM, Norges Bank, Sveriges Riksbank.

Table 4: An Empirical Assessment of the Swiss Franc – German Mark (Euro) Spot Exchange Rate.

Sample Period	α	β_i	$\beta_{\pi^{GE}}$	$\beta_{i^{GE}}$	$\chi^2(3)$-Statistic for UIP Test $H_0: \beta_i = 1, \beta_{\pi^{GE}} = 0, \beta_{i^{GE}} = 0$	*Adj* R^2	*DW*	*N*
1975q1 – 2013q1	-0.0104**	-1.0679	0.5448	2.8573***	19.50***	0.05	2.12	153
Whole Period	(0.0045)	(1.0059)	(0.3519)	(1.1297)				
1982q1 – 2013q1	-0.0139***	-2.8403***	0.8452***	5.3673***	31.30***	0.12	2.08	125
Floating Exch. Rate	(0.0045)	(1.1052)	(0.3005)	(1.3020)				
1982q1 - 2011q2	-0.0159***	-3.2417***	0.8719***	5.6192***	34.65***	0.13	2.10	118
Intervention I	(0.0048)	(1.1309)	(0.3193)	(1.296)				
1982q1 – 2009q1	-0.0116***	-2.6219***	0.7300***	5.7227***	28.22***	0.14	2.00	109
Intervention II	(0.0040)	(1.1071)	(0.3070)	(1.3398)				
2007q3 –2013q1	-0.0164	1.7191	1.8208	-0.8675	2.54	-0.07	2.58	23
Crisis Period	(0.0142)	(3.0978)	(1.2305)	(4.7489)				

Notes:

1. Newey-West standard errors in parentheses. * (**) [***] indicates significance at the 10 (5) [1] percent level. In each cell, the asterisk denotes rejection at the respective significance level of the hypothesis that the estimated coefficient equals zero.
2. Augmented Dickey-Fuller (ADF) tests for non-stationarity were carried out prior to estimation. Over the whole sample period the change in the bilateral exchange rate, the nominal interest rate differential, and the German rate of inflation were found to be stationary. The null hypothesis that the respective series contained a unit root could be rejected at the 1 percent level. In sharp contrast, ADF tests for the German 3-month interest rate could not reject the null-hypothesis of a unit root in the series. As a result, the German interest rate (yield) series enters the estimated regression in first differences.
3. The calculation of the spot exchange rate is as follows: 1975q1 – 1998q4, Swiss Franc-German Mark exchange rate. For the period since the introduction of the Euro the Buba fixing of the Swiss Franc–German Mark exchange rate is used.
4. The equation estimated is: $s_{t+1} - s_t = \alpha + \beta_i(i_t^{SW} - i_t^{GE}) + \beta_{\pi^{GE}}\pi_{t+1}^{GE} + \beta_{i^{GE}} i_{t+1}^{GE} + \epsilon_{t+1}$

$s_{t+1} - s_t$ = change in the quarterly exchange rate of the Swiss Franc per Euro (German Mark) in period *t+1*

$i_t^{SW} - i_t^{GE}$ = difference between the 3-month Eurocurrency deposit rate on Swiss Francs and Euros (German Marks) in period *t*

π_{t+1}^{GE} = level of quarterly CPI inflation rate in Germany in period *t+1*

i_{t+1}^{GE}= first difference of the 3-month Eurocurrency deposit rate on Euros (German Marks) in period *t+1*

The quarterly interest rate is computed as $i^j = \log(1 + x^j/4)$ where *x* represents the annual interest rate in decimal form (*j*=SW, GE).

Ordinary Least Squares is used to estimate the coefficients. The German rate of inflation and interest rate are considered to be exogenous regressors in the following sense. Both variables are viewed as affecting the Swiss Franc – Euro (German Mark) spot exchange rate. But the bilateral exchange rate has no bearing on the German rate of inflation and the German short-term interest rate because of the small size of Switzerland relative to Germany.

5. The German rate of inflation is calculated as the log difference in the quarterly German CPI index.

Data Source: DATASTREAM

Table 5: An Empirical Assessment of the Canadian Dollar – US Dollar Spot Exchange Rate.

Sample Period	α	β_i	$\beta_{\pi^{US}}$	$\beta_{i^{US}}$	$\chi^2(3)$-Statistic for UIP Test $H_0: \beta_i = 1, \beta_{\pi^{US}} = 0, \beta_{i^{US}} = 0$	*Adj* R^2	*DW*	*N*
1975q1 – 2013q1	0.0060	-0.1284	-0.5525	1.1346**	17.33***	0.01	1.61	153
Whole Period	(0.0066)	(0.5864)	(0.5198)	(0.5408)				
1991q2 – 2013q1	0.0155***	0.1198	-2.7774***	-2.8006	21.55***	0.14	1.61	88
Inflation Targeting	(0.0063)	(1.2167)	(0.8172)	(2.1778)				
1999q1 - 2013q1	0.0101	-1.3665	-2.7856***	-3.6082	33.32***	0.17	1.65	57
Clean Float	(0.0068)	(2.5408)	(0.8427)	(2.5113)				
2007q3 –2013q1	0.0065	8.2695	-3.0751**	-4.5968	14.05***	0.21	1.54	23
Crisis Period	(0.0195)	(10.237)	(1.2758)	(5.6556)				

Notes:

1. Interest rate is the 3-month Eurocurrency deposit rate for the respective country. The rate of inflation is calculated as the log difference in the US CPI.
2. Augmented Dickey-Fuller (ADF) tests for non-stationarity were carried out prior to estimation. Over the whole sample period the change in the bilateral exchange rate, the nominal interest rate differential, and the US rate of inflation were found to be stationary. The null hypothesis that the respective series contained a unit root could be rejected at the 1 percent level. In sharp contrast, ADF tests for the US 3-month interest rate could not reject the null-hypothesis of a unit root in the series. As a result, the US interest rate (yield) enters the estimated regression in first differences.

3. The equation estimated is: $s_{t+1} - s_t = \alpha + \beta_i(i_t^{CA} - i_t^{US}) + \beta_{\pi^{US}}\pi_{t+1}^{US} + \beta_{US} i_{t+1}^{US} + \epsilon_{t+1}$

   $s_{t+1} - s_t$ = change in the quarterly exchange rate of the Canadian Dollar per US Dollar in period *t+1*

   $i_t^{CA} - i_t^{US}$ = difference between the 3-month Eurocurrency deposit rate on Canadian Dollars and US Dollars in period *t*

   $\pi_{t+1}^{US} =$ level of quarterly CPI inflation rate in the United States in period *t+1*

   i_{t+1}^{US}= first difference of the 3-month Eurocurrency deposit rate on US Dollars in period *t+1*

The quarterly interest rate is computed as $i^j = \log(1 + x^j/4)$ where *x* represents the annual interest rate in decimal form (*j*=CA, US).

Data Source: DATASTREAM.

Table 6: An Empirical Assessment of the Norwegian Krone – Swedish Krona Spot Exchange Rate.

Sample Period	α	β_i	$\beta_{\pi^{SV}}$	$\beta_{i^{SV}}$	$\chi^2(3)$-Statistic for UIP Test $H_0: \beta_i = 1, \beta_{\pi^{SV}} = 0, \beta_{i^{SV}} = 0$	*Adj* R^2	*DW*	*N*
1987q1 – 2013q1 Whole Period	0.0038 (0.0031)	-0.6033 (0.5814)	-0.6317* (0.3786)	4.4354** (1.8858)	25.25***	0.10	1.71	105
1993q1 – 2013q1 Floating Exch. Rate	0.0046 (0.0035)	-0.9737 (0.8576)	-0.8230*** (0.3351)	4.421* (2.4910)	11.60***	0.04	1.82	81
2001q1 - 2013q1 Inflation Targeting	0.0029 (0.0055)	0.5999 (1.9216)	-1.1270*** (0.3777)	7.3563*** (2.7102)	10.07***	0.07	1.56	49
2007q3 –2013q1 Crisis Period	-0.0010 (0.0082)	3.2395 (2.1783)	-1.0225* (0.5904)	8.4433*** (2.9296)	12.43***	0.17	1.97	23

Notes:

1. Newey-West standard errors in parentheses. * (**) [***] indicates significance at the 10 (5) [1] percent level. In each cell, the asterisk denotes rejection at the respective significance level of the hypothesis that the estimated coefficient equals zero.
2. Augmented Dickey-Fuller (ADF) tests for non-stationarity were carried out prior to estimation. Over the whole sample period the change in the bilateral exchange rate, the nominal interest rate differential, and the Swedish rate of inflation were found to be stationary. The null hypothesis that the respective series contained a unit root could be rejected at the 1 percent level. In sharp contrast, ADF tests for the Swedish 90-day interbank borrowing rate could not reject the null-hypothesis of a unit root in the series. As a result, the Swedish interest rate series enters the estimated regression in first differences.
3. The equation estimated is: $s_{t+1} - s_t = \alpha + \beta_i(i_t^{NO} - i_t^{SV}) + \beta_{\pi^{SV}}\pi_{t+1}^{SV} + \beta_{i^{SV}} i_{t+1}^{SV} + \epsilon_{t+1}$
   $s_{t+1} - s_t$ = change in the quarterly exchange rate of the Norwegian Krone per Swedish Krona in period *t+1*

   $i_t^{NO} - i_t^{SV}$ = difference between the 90-day interbank borrowing rate in Norway and Sweden in period *t*

   π_{t+1}^{SV} = level of quarterly CPI inflation rate in Sweden in period *t+1*

   i_{t+1}^{SV}= first difference of quarterly 90-day interbank borrowing rate in Sweden in period *t+1*

The quarterly interest rate is computed as $i^j = \log(1 + x^j/4)$ where *x* represents the annual interest rate in decimal form (*j*=NO, SV).

Ordinary Least Squares is used to estimate the coefficients. The Swedish rate of inflation and interest rate are considered to be exogenous regressors in the following sense. Both variables are viewed as affecting the Norwegian Krone - Swedish Krone spot exchange rate. But the bilateral exchange rate has no bearing on the Swedish rate of inflation and the Swedish short-term interest rate because of the small size of Norway relative to Sweden.

Data Sources: Swedish Rijksbank and Norges Bank .

Appendix: A. The Intertemporal Optimization Problem

The policymaker seeks to minimize an intertemporal loss function that consists of squared deviations of the CPI inflation rate and the policy instrument. After manipulating equation (3), we can express the constraint in terms of the CPI inflation rate and the policy instrument.[25] The policy problem that the central bank faces can then be stated as:

$$\min_{\pi_t^{CPI}\ x_t} \quad E_0 \sum_{t=0}^{\infty} \beta^t (x_t^2 + \mu \pi_t^{CPI^2})$$

subject to

$$\pi_t^{CPI} = \alpha E_t \pi_{t+1}^{CPI} - \alpha x_t - \alpha E_t \pi_{t+1}^* + \gamma(\Delta s_t + \pi_t^*) + \alpha\gamma\rho_t + (1-\gamma) u_t \qquad (14)$$

The policymaker implements monetary policy from a timeless perspective, a form of optimal policy under commitment.

The Lagrangean takes the following form:

$$\mathcal{L} = E_0\{x_0^2 + \mu\pi_0^{CPI^2} + \delta_0\big(\gamma(\pi_0^* + \Delta s_0) + \alpha\pi_1^{CPI} - \alpha(x_0 + \pi_1^*) + \alpha\gamma\rho_0 + (1-\gamma)u_0 - \pi_0^{CPI}\big)$$

$$+\beta[x_1^2 + \mu\pi_1^{CPI^2} + \delta_1\big(\gamma(\pi_1^* + x_0 - \rho_0) + \alpha\pi_2^{CPI} - \alpha(x_1 + \pi_2^*) + \alpha\gamma\rho_1 + (1-\gamma)u_1 - \pi_1^{CPI}\big)]$$

$$+ \cdots\} \qquad (15)$$

Policy from a timeless perspective imposes special conditions on the initial period. The constraint in period *-1* is not binding for policy choice in period *0.* In addition, there is no effect of x_{-1}on Δs_0. Suppose the policymakers sets policy for period *t*. The optimizing condition for the rate of CPI inflation in period *t* is given by

$$2\mu\pi_t^{CPI} - \delta_t + \delta_{t-1}\alpha = 0 \quad \text{for } t\text{=0,1,2…} \qquad (16)$$

and δ_{-1}=0 for the initial period.

The optimizing condition for the policy instrument for period *t* is:

$$2x_t - \delta_t\alpha + \beta\delta_{t+1}\gamma = 0 \quad \text{for } t\text{=0,1,2…} \qquad (17)$$

δ_t denotes the Lagrange multiplier in period *t*.

Combining the two optimizing conditions yields the target rule:

$$\mu \sum_{j=0}^{\infty} \alpha^j \pi_{t-j}^{CPI} = -\sum_{j=0}^{\infty} \frac{\alpha^j}{(\beta\gamma)^{j+1}} x_{t-j-1} \qquad (18)$$

[25] The derivation of the constraint appears in part B of the appendix.

A parsimonious representation of the above target rule is obtained by restricting the number of terms of the sequence to one on both sides of eqn. (18) and setting $\beta = 1$:

$$\pi_t^{CPI} = -\ \frac{1}{\mu\gamma} x_{t-1} \qquad (19)$$

Eqn. (19) is the same target rule that appears in Section III which discusses the implementation of monetary policy via the target rule approach from a more heuristic angle. The loss function in Section III (eqn. (5)) results if, first, one multiplies the intertemporal loss function (first term of eqn. (14)) by (1-β) and, second, takes the limit as $\beta \rightarrow 1$.

A numerical optimization procedure (DYNARE) can be used to determine the variances of the endogenous variables and the policy instrument under the globally optimal rule, i.e. under policy from a timeless perspective. Guender (2014) shows that the results (loss scores, variances) based on policy from the timeless perspective and the simplified target rule (eqn. (19)) are virtually the same.

B. Derivation of Budget Constraint

Multiply the domestic inflation equation by $(1-\gamma)$:

$$(1-\gamma)\pi_t = (1-\gamma)(-\alpha x_t + \alpha(E_t\pi_{t+1} - E_t\pi_{t+1}^*) + u_t) \qquad (20)$$

Add and subtract $\gamma(\Delta s_t + \pi_t^*)$on the left-hand side of above equation and restate resulting expression as:

$$\pi_t^{CPI} = \gamma(\Delta s_t + \pi_t^*) + \alpha(1-\gamma)E_t\pi_{t+1} + \alpha\gamma(E_t\Delta s_{t+1} + E_t\pi_{t+1}^*) - \alpha(E_t\Delta s_{t+1} + E_t\pi_{t+1}^*) + (1-\gamma)(u_t - \alpha\rho_t) \qquad (21)$$

Making use of the definition of the CPI inflation rate and the UIP condition on the right-hand side allows us to express eqn. (21) as the policymaker's constraint:

$$\pi_t^{CPI} = \alpha E_t\pi_{t+1}^{CPI} - \alpha x_t - \alpha E_t\pi_{t+1}^* + \gamma(\Delta s_t + \pi_t^*) + \alpha\gamma\rho_t + (1-\gamma)u_t \qquad (22)$$

C. Derivation of Domestic Inflation Equation

We begin with a simple specification of the Phillips curve and an open-economy IS relation:[26]

$$\pi_t = \kappa y_t + u_t \qquad (23)$$

$$y_t = -a_1\left(i_t - E_t\pi_{t+1}^{CPI}\right) + a_2(q_t - E_t q_{t+1}) + v_t \qquad (24)$$

q_t = real exchange rate

Assume perfect exchange rate pass-through. This allows us to replace the CPI inflation rate with

[26] Typically, forward-looking expectations of inflation appear in the Phillips curve. But they are not necessary to generate an expectations channel through which monetary policy works in the present model. As shown below, the forward-looking expectation of inflation eventually enters the domestic inflation equation via the IS relation. Adding $\beta E_t\pi_{t+1}$ to eqn. (23) would merely enhance the potency of the expectations channel. The omission of $E_t y_{t+1}$ from eqn. (24) is of greater consequence. An analytic solution of the UIP puzzle exists only if this term does not appear in eqn. (24).

$$\pi_t^{CPI} = \pi_t + \gamma \Delta q_t. \tag{25}$$

Using eqn. (25) and imposing real UIP allows us to eliminate $E_t \Delta q_{t+1}$ from IS:

$$y_t = -a_1\left(i_t - E_t\pi_{t+1}\right) - (a_2 - a_1\gamma)\left(i_t - i_t^* - (E_t\pi_{t+1} - E_t\pi_{t+1}^*) - \rho_t\right) + v_t \tag{26}$$

Next, add to and subtract $a_1(i_t^* - E_t\pi_{t+1}^*)$ from eqn. (26). After making use of the definition of the policy instrument and substituting the IS relation into the Phillips curve, we can restate the rate of domestic inflation as:

$$\pi_t = -\alpha x_t + \alpha\left[E_t\pi_{t+1} - E_t\pi_{t+1}^*\right] + \kappa\left[v_t - a_1(i_t^* - E_t\pi_{t+1}^*) + (a_2 - a_1\gamma)\rho_t\right] + w_t \tag{27}$$

$$\alpha = \kappa[a_1(1-\gamma) + a_2] > 0$$

The presence of the forward-looking expectation of inflation in this equation implies that monetary policy works partly through the expectations channel.

The above equation can be simplified to read:

$$\pi_t = -\alpha x_t + \alpha\left[E_t\pi_{t+1} - E_t\pi_{t+1}^*\right] + u_t \tag{28}$$

where[27]

$$u_t = \kappa\left[v_t - a_1(i_t^* - E_t\pi_{t+1}^* + (a_2 - a_1\gamma)\rho_t)\right] + w_t\,.$$

[27] Here we see that if the Phillips curve included $\beta E_t \pi_{t+1}$ then the coefficient on $E_t \pi_{t+1}$ in eqn. (28) would change to $(\alpha + \beta)$. The constraint facing the policymaker would change slightly. However, the target rule (eqn. (19)) would remain unaffected. This alternative derivation is available upon request from the author.