MEASURING THE IMPACT OF INTERVENTION ON EXCHANGE MARKET PRESSURE

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ABSTRACT

In this article, we introduce an index of ex ante exchange market pressure (EMP) that can be used as a benchmark against which to measure the effectiveness of sterilized intervention. Ex ante EMP is the change in the exchange rate that would have been observed if the policy authority had refrained from intervening and this policy decision had been correctly anticipated by rational agents. Ex post EMP measures the exchange market pressure under the policy actually implemented by the policy authority. We use a ratio of these two EMP measures to assess the effectiveness of sterilized intervention in Canada and Australia.

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1. Introduction

After the breakdown of the Bretton Woods system, and the brief experiment with floating exchange rates that followed it, most countries adopted some form of intermediate exchange rate system. The hallmark of these intermediate systems of exchange rate management is the use of sterilized intervention, in which the policy authority seeks to neutralize the impact of its foreign exchange market transactions on the domestic money supply through the purchase or sale of domestic assets.

Although the term "exchange market intervention" may be applied to any policy action that is undertaken with the objective of influencing the rate of exchange between two sovereign currencies, it is more commonly used to refer to the official purchase or sale of foreign currency by the policy authority charged with safe-guarding the international value of the domestic currency. There is general agreement that official foreign exchange transactions that are not sterilized are an effective means of exchange rate management. The same cannot be said of sterilized intervention. Although the results obtained in recent studies are somewhat more encouraging that those obtained in the past, the impact of sterilized intervention on exchange rates remains controversial.[1] In this article, we develop a new approach to assessing the impact of sterilized intervention on exchange rates. Specifically, we derive and estimate indices of exchange market pressure that provide a quantitative measure of the quarter-by-quarter effectiveness of exchange market intervention.

Empirical studies of sterilized intervention have focused primarily on determining the degree to which the signaling and portfolio balance channels, that theory suggests are the principal means by which sterilized intervention can influence exchange rates, represent empirically significant channels of transmission.[2] Until recently, central banks were disinclined to make their intervention data available to external re-

[1] Edison (1993) provides a comprehensive survey of the literature from 1982 to 1993. A survey of more recent contributions may be found in Sarno and Taylor (2001).

[2] Recently, Sarno and Taylor (2001) have suggested that the role played by sterilized intervention in remedying coordination failures in the foreign exchange market may represent a third channel of influence that merits closer study.

searchers.[3] Earlier studies therefore used changes in official foreign exchange reserves as a measure of intervention activity. The fact that reserve data is a very noisy proxy for intervention explains much of the lack of consensus among the earlier empirical studies.

The release of US daily intervention data in the early 1990s led to renewed interest in the study of sterilized intervention. Using US intervention data, Dominguez and Frankel (1993a) found support for the functioning of both a signaling and a portfolio balance channel in the 1980s at weekly and bi-weekly frequencies. Dominguez and Frankel (1993b) also found that publicly announced interventions have a significantly greater impact on the exchange rate than secret interventions do. Evidence of the operation of a signaling channel has also been provided by Lewis (1995), Kaminsky and Lewis (1996), and Bonser-Neal, Roley, and Sellon (1998), among others. Dominguez and Frankel's (1993b) conclusion regarding the importance of announcements has been challenged by Peiers (1997) and Chang and Taylor (1998). Both of these studies employ intra-day data and find that the market learns about official interventions through the foreign exchange trading associated with them, rather than through public announcements. Overall, the evidence provided by all of the more recent studies indicates that, at the very least, sterilized intervention can influence exchange rates in the short term.

Most of the empirical studies dealing with sterilized intervention use direction of causality to establish the impact of intervention on the exchange rate. Because of the speed with which the foreign exchange market responds to changing conditions, causality between intervention and observed exchange rate movements can necessarily only be detected at fairly high frequencies. However, while the results obtained using high frequency data are useful for determining the nature of the channel of transmission between sterilized intervention and exchange rate movements, they provide little information about the usefulness of sterilized intervention as a policy tool. It is

[3]Although many central banks still prefer not to give out their intervention data, a growing number of central banks in industrial countries are now making their intervention data public, though with a considerable lag.

not enough to show that sterilized intervention is capable of generating a temporary change in the exchange rate; in order to be useful as a policy tool, sterilized intervention must bring about changes in the foreign exchange market that are, to some degree, persisent.

The speed of transmission in the foreign exchange market ensures that tests of causal direction will fail at quarterly frequencies. In order to identify the longer term impact of a particular intervention, it is necessary to find some way of determining what the exchange market conditions would have been in the absence of that policy initiative. This entails using available observed data to construct a counterfactual measure of ex ante exchange market conditions. To the best of our knowledge, only two studies have employed counterfactuals to assess the impact of intervention. The first of these is by Blundell-Wignall and Masson (1985), who simulated a small macroeconomic model under the counter-factual assumption of no intervention, and then compared the results of their simulation to observed outcomes generated by the policy actually implemented. The second study, by Bonser-Neal and Tanner (1996), focuses on the impact of intervention on ex ante exchange rate volatility. They use the volatilities of currency auction prices as a measure of ex ante exchange rate volatility.

Our objective, in this article, is to determine whether the impact of sterilized intervention on the foreign exchange market is persistent enought to be discernible in quarterly data. Typically, the extant literature has assessed the effectiveness of sterilized intervention ex post. Instead, we propose a measu;re of ex ante exchange market pressure which, when combined with an indicator of ex post pressure, enables us to obtain a quantitative representation of the impact of intervention on exchange market conditions. Ex ante exchange market pressure measures the international excess demand for a currency that would have been observed in the absence of intervention. Our index of ex ante exchange market pressure therefore describes the environment that the policy authority faced and to which it responded in a given period. The concept of ex post exchange market pressure, which was introduced by Weymark (1995, 1998), measures the international excess demand for a currency under the interven-

tion policy actually implemented. The impact of sterilized intervention can then be measured in index form as the proportion of ex ante exchange market pressure removed by intervention. We refer to this index as the PICE (Policy Induced Change in Exchange market conditions) index.[4]

Neither of our exchange market pressure indices is directly observable and must, therefore, be imputed from a theoretical model. In order to obtain estimates of exchange market pressure, we apply a two-step methodology introduced by Weymark (1995, 1998). We begin by proposing a model-independent definition of each index. Next, we apply these definitions to a theoretical model, and derive model-consistent index formulae. The index formulae provide a functional relationship between exchange market pressure and economic variables that are directly observable. We then estimate our model and use the estimation results to calculate our quarterly indices of ex ante and ex post exchange market pressure.

We illustrate our approach by applying it to Canadian and Australian data. Although the methodology we have developed can be applied to any open economy, Canada and Australia have specific attributes that make them ideal subjects for our study. First, they are both economies whose central banks, during the decade or so prior to the adoption of inflation targeting, regularly intervened in the foreign exchange market. Nevertheless, the two central banks had quite different aims in pursuing their intervention policies. As we demonstrate below, these differences show up clearly in our index of the impact of sterilized interventions. Second, both economies can properly be modeled as small open economies and this simplifies the algebraic derivation of our counterfactual exchange market pressure measures.

Our findings indicate that the impact of sterilized interventions undertaken by both the Reserve Bank of Australia and the Bank of Canada had persistent effects on the value of their domestic currencies relative to the US dollar. We also conclude that the Reserve Bank of Australia intervened relatively more heavily than the Bank

[4]To the extent that the difference between ex ante and ex post measures of exchange market pressure reflects unanticipated events, and, hence, act like news, our finding that sterilized intervention has persistent exchange rate effects is consistent with the findings of Engel and West (2005).

of Canada. However, reversals in the direction of exchange rate changes are relatively more frequent for Canada, particularly after the introduction of inflation targeting. Of course, as we have not, in this article, addressed either the costs of intervention or the effects of interventions at higher moments (e.g., exchange rate volatility), we cannot comment on the advisability of sterilized interventions overall.

The rest of this article is organized as follows. The next section provides definitions for ex ante and ex post exchange market pressure. Section 3 describes our modeling strategy for Canada while Section 4 considers on the Australian case. The effectiveness of the sterilized interventions undertaken by the Bank of Canada and by the Reserve Bank of Australia is evaluated in Section 5. Section 6 concludes

2. Exchange Market Pressure: Model-Independent Definitions

In order to measure the impact of exchange market intervention on the total excess demand for a currency, we construct two indices of exchange market pressure (EMP): ex ante EMP and ex post EMP. Ex ante EMP measures the international excess demand for a currency that would have arisen if the policy authority had not intervened in the exchange market in a particular time period. Ex post EMP measures the total excess demand for a given currency that is associated with the policy actually implemented in a particular time period. The difference between the ex ante and ex post EMP indices provides a quantitative measure of the the effectiveness of the intervention undertaken by the policy authority. The formal definitions of ex ante and ex post EMP follow.

2.1 Ex Ante Exchange Market Pressure

Definition: Ex ante exchange market pressure is measured as the change in the exchange rate that would have occurred if the policy authority had refrained from exchange market intervention in a given period, under the assumption that this policy decision was correctly anticipated by economic agents.

2.2 Ex Post Exchange Market Pressure

Definition: Ex post exchange market pressure is measured as the change in the exchange rate that would have occurred if the policy authority had unexpectedly refrained from intervening in the foreign exchange market, given the exptectations generated by the exchange rate policy actually implemented.[5]

The exchange market pressure indices described above are not directly observable and must be imputed on the basis of an appropriately specified structural model. The structural model that we will use to derive model-consistent, operational indices of ex ante and ex post exchange market pressure for Canada and Australia are described in the following sections.

3. Canada: Model Specification and Exchange Market Pressure Indices

In the 1980s, the Bank of Canada frequently intervened in the foreign exchange market, ostensibly to reduce exchange rate volatility, or to prevent excessive fluctuations in the exchange rate.[6] The accumulated body of empirical literature to date tends to cast doubt on the effectiveness of this policy.[7]

In recent years, countries that have adopted inflation targeting have chosen to forego exchange market intervention in order to avoid the possibility of conflict between exchange rate and inflation targets. The Bank of Canada announced in September 1998 that foreign exchange intervention would henceforth be publicly announced.[8] Since that time, the Bank has intervened only once, as part of a coordinated inter-

[5]A detailed discussion of the theoretical foundations and the measurement of ex post exchange market pressure may be found in Weymark (1995, 1998). This article is the first to introduce two distinct concepts of exchange market pressure. Weymark's earlier articles focus only on measuring ex post EMP, and refer to this index simply "exchange market pressure."

[6]See Murray, Zelmer, and McManus (1997) for an analysis of this period.

[7]See, for example, Rogers and Siklos (2003) and Fatum and King (2005). Chiu (2003) describes the Bank of Canada's foreign exchange intervention activities over time.

[8]Foreign exchange reserves are owned by the federal government. Nominally, intervention decisions are the result of joint consultation with the Department of Finance.

vention.[9] It is not entirely clear whether the announcement refers to any form of intervention, or the non-sterilized variety only.[10] After all, even if the central bank does not formally intervene in the foreign exchange markets, it may, at the behest of the government, which retains ownership of the reserves, engage in the purchase and sale of foreign exchange for reasons of portfolio balance. In addition, trading partners may continue to intervene, possibly requiring a domestic portfolio balance adjustment. Finally, a credible signal of non-intervention can also influence expectations of the exchange rate, and, consequently, influence the degree of exchange market pressure.

3.1 A Simple Empirical Model for Canada

The quarterly model specified below was chosen with the Canadian economy in mind. Hence, it is a model of a small open economy in which foreign prices and interest rates are exogenous. Our model is rich enough to allow us to explicity incorporate varying degrees of intervention, sterilization, and asset substitutability. At the same time, our model is also simple enough to yield tractable exchange market pressure formulae. The lag structure described below reflects the outcome of the estimation phase of our procedure. Our specification choices were driven by two concerns: (1) the need to obtain model estimates with reasonable empirical properties (i.e., estimates that were broadly in agreement with those obtained for small open economies elsewhere in the literature), and (2) the need to have a model that is tractable enough to allow us to solve for the expectational variables in the model under the assumption that economic agents are fully rational. The equations described below therefore reflect a compromise between the degree of complexity that would be considered ideal for estimation purposes, and the degree of simplicity desired for reasons of analytical

[9]There was one coordinated intervention with the ECB, the Fed, and the Bank of England in September 2000.

[10]The BIS (2005) refers to the purchase or sale of foreign currency by a central bank as the "narrow" form of intervention. Many emerging markets prefer to use a broader definition of intervention, which includes any purchase or sale of foreign currency regardless of whether or not the central bank is an active participant.

tractability. Formally, we characterize the Canadian economy as follows.

$$\pi_t \;=\; \alpha_0 \;+\; \alpha_1\pi_{t-1} \;+\; \alpha_2 \mathrm{E}_t\pi_{t+3} \;+\; \alpha_3 y_{t-1} \;+\; \alpha_4[\pi_t - \Delta q_t - \pi_t^*] \;+\; \epsilon_t \qquad (1)$$

$$y_t \;= \beta_0 + \beta_1 y_{t-1} \;-\; \beta_2[i_{t-2} - \pi_{t-3}] \;-\; \beta_3[\pi_t - \Delta q_t - \pi_t^*] \;+\; \eta_t \qquad (2)$$

$$i_t \;=\; \bar{c} \;+\; i_t^* \;+\; \mathrm{E}_t\Delta q_{t+1} \;+\; \mu\Delta d_t \;+\; \sigma_t \qquad (3)$$

$$\Delta m_t \;= h_0 \;+\; h_1\Delta m_{t-1} \;+\; h_2\pi_{t-1} \;+\; h_3\Delta i_{t-1} \;-\; h_4\Delta m_{t-2} \;-\; h_5\pi_{t-2} \;+\; \chi_t \qquad (4)$$

$$\Delta m_t \;= \Delta d_t \;+ \Delta r_t \qquad (5)$$

$$\Delta d_t \;=\; \Delta d_t^a \;+\; \Delta d_t^f \qquad (6)$$

$$\Delta d_t^a \;=\; \bar{m} \;+\; \gamma_\pi\pi_t \;+\; \gamma_y y_t \;+\; \delta_t \qquad (7)$$

$$\Delta d_t^f \;=\; -\lambda\Delta r_t \qquad (8)$$

$$\Delta r_t \;=\; -\rho_t\Delta q_t. \qquad (9)$$

Equations (1) and (2) describe the determinants of the Canadian inflation rate π_t and the output gap y_t. According to (1) the inflation rate in period t depends on the rate of inflation and the output gap in period $t-1$, the percentage change in the real exchange rate in period t, given by $[\pi_t + \Delta q_t - \pi_t^*]$, the three-period-ahead expectation of inflation $\mathrm{E}_t\pi_{t+3}$, and the shock ϵ_t. The variables π_t^* and q_t denote the US inflation rate and the log of the nominal Can$/US$ exchange rate, respectively. In common with several papers in the Phillips curve literature, inflation is determined by forward and backward-looking elements.[11] The Canadian output gap in period t depends on the magnitude of the gap in period $t-1$, the lagged domestic interest rate i_{t-2}, the lagged domestic inflation rate π_{t-3}, and the percentage change in the real exchange rate.

In (3) we modify the usual uncovered interest parity (UIP) condition to allow for the possibility that US and Canadian financial instruments may not be perfect substitutes. The term $\mu\Delta d_t$, represents a risk premium that the market may impose when there is an increase in the relative availability of Canadian financial instruments.

[11] Kichian (2001) is a recent paper that estimates comparable Phillips curves for Canada.

The variables i_t^* and d_t represent the US interest rate and the log of domestic credit component of the Canadian money supply, respectively.[12] It is well-known that UIP generally fails to hold empirically. Lothian and Wu (2003) arfue that this is due to the uniqueness of the 1980s, combined with noisy departures from UIP. By using the risk premium $\mu\Delta d_t$ to modify the UIP condition, we allow for deviations from UIP in a way that proves to be statistically significant.

Equation (4) is a parsimonious empirical money demand equation that is derived from a simple error-correction specification of Canadian money demand. The variable m_t denotes the log of the Canadian money supply and χ_t is an exogenous money demand disturbance. All other variables are as previously defined.[13].

Equations (5)–(9) describe the determinants of the Canadian money supply. In (5), the changes in the money supply Δm_t are identified as originating from one of two sources, changes in domestic credit Δd_t or changes in foreign exchange reserves Δr_t, with m_t, d_t, and r_t measured in logarithms. According to (6)–(8), changes in domestic credit occur either as a policy response to observed inflation or output gap levels as described in (7), or in the course of sterilizing foreign exchange market intervention as described in (8).

The policy authority's intervention policy is characterized by (9). Changes in foreign exchange reserves are described as occurring as a result of the policy authority's response to contemporaneous exchange rate changes. The time-varying intervention parameter ρ_t characterizes the degree of exchange market intervention in each period. A value of $\rho_t = 0$ indicates that the policy authority refrained from intervention and

[12]Increases in d_t increase the reserves of the Canadian banking system, leading banks to expand their holdings of high quality private and government bonds, reducing the relative availablility of such bonds for private portfolios. Where substitutability between US and Canadian assets is not perfect, the relative scarcity of high quality private and government bonds would result in a reduction in the risk premium on Canadian bonds. Thus i_t and Δd_t would be negatively related in (3).

[13]The actual estimates of the vector error correction model upon which (4) is based are provided in the Appendix. Equation (4) is obtained from the estimated equation by expressing the short-term adjustment components in log-levels, combining coefficients, as appropriate, with those of the error-correction component, and then expressing the resulting relationship in terms of log-differences

allowed the exchange rate to float freely in period t. The decision to hold the exchange rate fixed in period t, on the other hand, is characterized by $\rho_t = \infty$. Values of ρ_t between 0 and ∞ are characteristic of intermediate exchange rate systems. Negative values of ρ_t occur when intervention by the policy authority causes an exchange rate change of greater absolute magnitude than, or of opposite sign to, the change that would have occurred in the absence of intervention.

In the 1980s central banks switched from using monetary aggregates to using short-term interest rate as intermediate targets for monetary policy. It has therefore become accepted practice to characterize the determinants of systematic monetary policy in terms of an interest rate response function. However, our focus in this article is on the intervention and sterilization activities, both of which affect the components of the monetary base directly, and affect interest rates only indirectly. For this reason, the central bank's response to changes in inflation and economic activity is represented, in (4), in terms of changes in the domestic credit rather than changes in the short-term interest rate. Note however, that (4)–(9) imply an interest rate response function of the form:

$$\begin{aligned} i_t &= v_0 + \hat{\gamma}_\pi \mathrm{E}_t \pi_{t+1} + \hat{\gamma}_y \mathrm{E}_t y_{t+1} + \rho_{t+1} \hat{\lambda} \mathrm{E}_t \Delta q_{t+1} \\ &\quad + \bar{\gamma}_{pi} \pi_t + \bar{\gamma}_y y_t + \rho_t \bar{\lambda} \Delta q_t + \tilde{\gamma}_\pi \pi_{t-1} + \tilde{\gamma}_y y_{t-1} + \rho_{t-1} \tilde{\lambda} \Delta q_{t-1} \end{aligned} \tag{10}$$

where: $\hat{\gamma}_\pi = \gamma_\pi / h_3$, $\hat{\gamma}_y = \gamma_y / h_3$, $\hat{\lambda} = \lambda / h_3$, $\bar{\gamma}_{pi} = -(h_1 \gamma_{pi} + h_2)/h_3$, $\bar{\gamma}_y = (-h_1 \gamma_y)/h_3$, $\bar{\lambda} = (-h_1 \lambda)/h_3$, $\tilde{\gamma}_{pi} = -(h_4 \gamma_{pi} + h_5)/h_3$, $\tilde{\gamma}_y = (-h_4 \gamma_y)/h_3$, and $\tilde{\lambda} = (1 h_4 \lambda)/h_3$.

3.2 Model Estimates

In order to compute the values of the exchange market pressure indices defined in Section 2, our model must be estimated. In particular, we require estimates of the parameters in (1)–(4) and (7), as well as the degree of intervention λ in (8). We chose to estimate the equations separately using either OLS or GMM, depending upon whether the specification is backward or forward-looking. In every case we chose the most parsimonious specification that satisfied appropriate diagnostic test criteria as well as the test of parameter plausibility. Our estimation results are summarized in

Table 1. Our estimation results and data sources are relegated to Appendix 1.

In estimating the forward-looking Phillips curve (1), inflation, measured as the annual rate of change in the CPI, was regressed on the lagged output gap, lagged inflation, the three-quarters-ahead inflation rate, and the rate of change in the real exchange rate. The output gap was obtained using an HP filter with a standard smoothing parameter of 1600.[14] The real exchange rate variable is evaluated in terms of relative consumer prices. Our estimates reveal that the Canadian Phillips curve has significant forward and backward-looking elements, and also exhibits considerable inflation persistence. These results are in accord with estimates obtained in other studies.[15]

Because of the current interest in New Keynesian specifications, our quarterly IS curve for Canada initially contained forward-looking output gap and inflation elements. However, we were unable to specify a forward-looking IS curve that yielded plausible parameters. This problem, which has been encountered in the empirical literature more generally, led us to instead adopt a backward-looking specification. In the specification we employ, the lagged real interest rate is significant and negative, as theory predicts, and there is a high degree of persistence in the output gap.

Prior to April 1995, the Bank of Canada intervened to influence exchange rate movements outside an unobserved non-intervention band. Thereafter, the Bank of Canada reduced the frequency of interventions, but increased the intensity when it did intervene. In September 1998, the Bank of Canada abandoned its mechanistic approach to intervention altogether, engaging only in a G-7 coordinated intervention to support the euro on September 22, 2000. In view of the changes in Canadian intervention policy that took place over the sample period, we estimated several versions of an equation describing international trade in assets. The variable Δd_t

[14]Estimation of similar specifications using the Bank of Canada's own output gap estimates yielded very similar outcomes as those obtained using the HP filtered output gap. This is not an entirely surprising result given that an important element in the Bank's estimates is reliance on an HP filter. See, for example, Rennison (2003).

[15]See, for example, Guay, Luger, and Zhu (2004).

is proxied by the log difference (or annual rates) in d_t, which is measured as the difference between Gross M1 and official foreign exchange reserves. When (3) is estimated without taking into account the change in intervention policy, the coefficient μ is negative, as expected, but statistically insignificant. However, if the change in reserves is set to zero after 1998Q3, given that the Bank of Canada has not officially intervened since that time, then the dummy variable is negative and statistically significant. Hence the combined coefficients are negative and statistically significant, as confirmed by a Wald test.

The fourth set of parameter estimates belong to the Canadian money demand equation (4). Following Adam and Hendry (1999), we estimated an error correction model using the (Gross) M1 measure of the money supply. Like Adam and Hendry, we conclude that M1, CPI, real GDP, and a short-term interest rate are cointegrated. All long-term elasticities, with the exception of the one for real income, are statistically significant. Overall, our estimates are not dissimilar to those reported by Adam and Hendry.

In order to estimate the parameters γ_π, γ_y, and λ, we combined (6)–(8) to obtain the equation

$$\Delta d_t \;=\; \bar{m} \;+\; \gamma_\pi \pi_t \;+\; \gamma_y y_t \;-\; \lambda \Delta r_t. \tag{11}$$

In the theoretical model, Δr_t represents the changes in reserves that occur as a result of the central bank's intervention activities. However, reserve changes are, in practice, often a very noisy proxy for official intervention. Although actual intervention data is generally thought to be superior to reserve change data for use in studies of intervention activity, Canadian intervention data contains a rather puzzling ommission. In particular, although an announcement of the Bank of Canada's participation in the coordinated G-7 intervention of September 22, 2000 was made on the Bank of Canada's web site, the actual intervention data provided to us by the Bank of Canada records that no intervention took place on that day.[16]. We therefore estimated (11)

[16]Actual intervention data are confidential, but were provided to us the the Bank of Canada. We are not the first to have access to this data. See also Fatum (2005) and Fatum and King (2005)

twice, once using intervention data and a second time using reserve data.[17]

Except for the output gap coefficient, the parameter estimates remain unchanged regardless of whether or not reserve changes are set to zero after 1998Q3. Note that the degree of sterilization λ is almost complete regardless of whether or not the official foreign exchange reserves variable is set to zero after 1998Q3. The null hypostheis of full sterilization (i.e., $\lambda = 1$) is rejected at conventional significance levels, although not at the 1% level when the absence of intervention after 1998Q3 is ignored.

It is perhaps worth reiterating that our aim is not to estimate the best model from a purely econometric perspective, but to specify a model that yields reasonal estimates and is, at the same time, tractable from an analytical perspective. As model complexity greatly solving the model under rational expectations, our model is necessarily more parismonious than it would be if only econometric considerations were taken into account. In Appendix 1 we provide a series of diagnostic tests, including structural break tests, to attest to the robustness of our specification. The estimated equations pass the majority of the diagnostic tests with no evidence of structural breaks.

3.3 Ex Ante Exchange Market Pressure Indices

In this section we outline the derivation of ex ante EMP indices. We assume that economic agents are rational. Under the rational expectations hypothesis, changes in government policy may have a significant impact on the expected future path of economic variables.

Expectations about the future path of economic variables appear in (1) and (3) of our model. By definition, ex ante EMP for period t is the change in the exchange rate that would have occurred in period t if economic agents had anticipated the policy authority's decision to refrain from intervention in that period. In order to calculate our counterfactual EMP measure, we therefore need to be able to determine what would have happened to inflation and exchange rate expectations in this case.

[17]Reserve changes are measured using closing balances in the Exchange Fund Account (denominated in US dollars) which includes the effects of other foreign exchange operations.

Consequently, the first step in deriving model-consistent measures of ex ante exchange market pressure, is to obtain the rational expectations solution for our model.

Even though our model is a relatively simple one, it is nevertheless too complex to allow closed-form rational expectations solutions to be obtained analytically; numerical methods must therefore be employed. However, before we can implement algorithms to obtain numerical rational expectations solutions, the parameters of our model must be estimated. The estimation procedures employed are described in Appendix 1. Details of the numerical methods used to compute the rational expectations solutions based on these parameter estimates are given in Appendix 2.

The reduced-form rational expectations solutions we obtain for the endogenous variables in our model are functions of the lagged values of all of the domestic and foreign variables (except the nominal exchange rate). This means that $E_t\pi_{t+3}$ will depend on current and future variables. According to our EMP definitions, EMP is measured quarter by quarter which means that the calculation of ex ante EMP for period t requires ρ to be set equal to 0 only in period t; in all other periods ρ should be set equal to the value associated with the policy actually implemented in that period. In order to derive counter-factual expectations which take into account this hypothetical, one-period deviation from the policy actually implemented, we compute a numerical RE solution for our model with ρ set equal to the sample average value.[18] The solutions obtained using the average observed value of ρ are then used to express the expected inflation and exchange rate terms as functions of ρ_t and variables dated period t or earlier. The impact of the counterfactual policy on expectations may then be captured by setting $\rho_t = 0$.[19] Details of these derivations are provided in Appendix

[18]In reality, ρ is time-varying. However, the numerical procedure we employ requires that ρ take on a constant value over time. Rather than calculate separate RE solutions for each quarter, we have chosen to use an average value for all quarters.

[19]In our model, economic agents are assumed to be rational and fully informed. As a consequence, the RE coefficients that would be obtained under the counterfactual assumption $\rho_t = 0$ can be expected differ from those obtained under the policy rule that was actually implemented. A precise representation of the impact of such a deviation from the policy rule on expectations requires a closed-form RE solution. Because the model we employ is too complex to admit a tractable closed-

2 (section A2.3).

Using the RE solutions reported in Appendix 2, we obtain the following expressions for $\mathrm{E}_t\pi_{t+3}$ and $\mathrm{E}_t\Delta q_{t+1}$

$$\begin{aligned}\mathrm{E}_t\pi_{t+3} &= 0.0203 + 1.1568\pi_t + 0.6718y_t - 0.0264i_t + 0.0267\pi_{t-1} \\ &\quad - 0.0374\pi_{t-2} - 0.0374i_{t-1} - 0.0787\pi_t^* - 0.0103i_t^* \end{aligned} \tag{12}$$

$$\begin{aligned}\mathrm{E}_t\Delta q_{t+1} &= -9.6427 - 2.8082\pi_t - 1.7702y_t + 0.1199i_t - 0.0213\pi_{t-1} \\ &\quad +0.1011i_{t-1} - 0.1011\pi_{t-2} + 0.0655\pi_t^* + 0.1285i_t^* \end{aligned} \tag{13}$$

Substituting (12) into (1), (13) and (6)–(9) into (3), (5)–(9) into (4), and setting $\rho_t = 0$ in (9), yields the following estimated economic structure under the counterfactual assumption $\rho_t = 0$:

$$\begin{bmatrix} 0.9278 & -0.0564 & 0.0250 & 0.0022 \\ -0.0222 & 1 & 0.0222 & 0 \\ 2.2722 & 1.3491 & 0 & 1 \\ 1.7300 & 1.2400 & 0 & 0 \end{bmatrix} \begin{bmatrix} \pi_t^0 \\ y_t^0 \\ \Delta q_t^0 \\ i_t^0 \end{bmatrix} = \begin{bmatrix} X^\pi \\ X^y \\ X^q \\ X^m \end{bmatrix} \tag{14}$$

where

$$\begin{aligned} X^\pi &= -0.0623 + 0.9082\pi_{t-1} + 0.1370y_{t-1} - 0.0031i_{t-1} + 0.0031\pi_{t-2} \\ &\quad + 0.0184\pi_t^* - 0.0009i_t^* + \epsilon_t \\ X^y &= 0.2510 + 0.9290y_{t-1} - 0.0697i_{t-2} + 0.0697\pi_{t-3} - 0.0222\pi_t^* + \eta_t \\ X^q &= -6.2139 - 0.0242\pi_{t-1} + 1.2511i_{t-1} - 0.1149\pi_{t-2} + 0.0744\pi_t^* \\ &\quad + 1.2822i_t^* - 0.5340\delta_t + 1.1362\sigma_t \\ X^m &= 9.9196 - 1.2470\Delta m_{t-1} + 0.2280\Delta m_{t-2} - 0.6623\pi_{t-1} + 0.6430\pi_{t-2} \\ &\quad + 0.0020\Delta i_{t-1} - \chi_t + \delta_t \end{aligned}$$

form solution, we approximate the solution by employing the RE coefficients computed under the observed policy rule. Given that we are only failing to adjust the coefficients for a one-period deviation from the estimated policy rule, this approximation should not have any significant impact on the quantitative results obtained.

The ex ante EMP formula may then be obtained by solving (27) for Δq_t^0. Our procedure yields the following model-consistent ex ante EMP formula:

$$\begin{aligned}\Delta q_t^0 \;=\; & -\,125.1262 \;+\; 30.8090\pi_{t-1} \;+\; 19.5367y_{t-1} \;-\; 0.1699i_{t-1} \\ & +\,16.0444\Delta m_{t-1} \;-\; 8.1908\pi_{t-2} \;-\; 1.1878i_{t-2} \;+\; 1.2136\pi_{t-3} \\ & -\,2.9335\Delta m_{t-2} + \;0.0609\pi_t^* \;-\; 0.0918i_t^* \;+\; 24.5389\epsilon_t \\ & +\,17.4111\eta_t \;-\; 12.8374\delta_t \;-\; 0.0618\sigma_t \;+\; 12.8664\chi_t \qquad (15)\end{aligned}$$

The ex ante EMP indices that we calculated using (28) are given in Tables 1A and 1B.

3.4 Ex Post Exchange Market Pressure

Ex post exchange market pressure is the excess demand for a currency that remains after the intervention policy has been implemented. When a policy authority intervenes in the exchange market, some portion of this excess demand for currency is alleviated by the intervention. Consequently, exchange rate changes alone will reflect the total excess demand for currency only in the absence of intervention. Whenever this is not the case and $\rho_t \neq 0$, the magnitude of ex post EMP will have to be imputed from observed changes in the exchange rate as well as changes in those variables which, through the intervention activities of the policy authority, relieved the excess demand. Under intermediate exchange rate systems, ex post EMP, as we have defined it, will generally have to be imputed from observed changes in the exchange rate and changes in foreign exchange reserves associated with intervention activities.[20] The computation of ex post EMP therefore involves a measurement experiment in which observed changes in foreign exchange reserves (and possibly also domestic credit changes) are converted into exchange rate equivalent units and then combined with observed exchange rate changes to yield a composite summary statistic. In this section we describe the method by which model-consistent indices of ex post EMP can be obtained.

[20]When the policy authority is known to use domestic credit changes to influence the external value of its currency, changes in this variable must also be included in the aggregate measure.

TABLE 1A

CANADA
Exchange Market Pressure 1978:4 – 1995:4

	observed Δq_t	ex ante Δq_t^0	ex post Δq_t^w		observed Δq_t	ex ante Δq_t^0	ex post Δq_t^w
1978:1				1987:1	−3.67	−30.74	−3.67
2				2	−0.25	44.57	−0.25
3				3	−0.50	39.65	−0.50
4	2.87	107.05	2.87	4	−1.01	−15.14	−1.01
1979:1	0.85	105.25	0.85	1988:1	−3.36	−11.76	−3.36
2	−2.27	60.10	−2.27	2	−2.93	10.36	−2.93
3	0.57	138.65	0.57	3	−1.09	30.66	−1.09
4	0.85	130.84	0.85	4	−0.82	25.65	−0.82
1980:1	−1.14	81.65	−1.14	1989:1	−1.39	32.58	−1.39
2	0.57	108.49	0.57	2	0.00	28.96	0.00
3	−1.15	110.17	−1.15	3	−0.84	41.69	−0.84
4	2.56	183.819	2.56	4	−1.42	56.89	−1.42
1981:1	0.56	226.06	0.56	1990:1	1.42	53.92	1.42
2	0.28	152.36	0.28	2	−1.42	13.06	−1.42
3	1.11	226.42	1.11	3	−1.15	−41.40	−1.15
4	−1.39	158.03	−1.39	4	0.58	−53.14	0.58
1982:1	1.11	40.25	1.11	1991:1	−0.29	14.30	−0.29
2	2.99	89.82	2.99	2	−0.87	9.61	−0.87
3	0.53	41.50	0.53	3	−0.29	5.77	−0.29
4	−1.34	−22.71	−1.34	4	−0.58	59.22	−0.58
1983:1	−0.27	14.90	−0.27	1992:1	3.46	−115.81	3.46
2	0.00	14.67	0.00	2	1.68	−131.29	1.68
3	0.00	−39.24	0.00	3	0.28	−131.46	0.28
4	0.81	−36.87	0.81	4	5.14	−88.15	5.14
1984:1	1.34	−21.16	1.34	1993:1	0.00	−89.94	0.00
2	2.62	−27.84	2.62	2	0.53	−128.30	0.53
3	1.53	−45.78	1.53	3	2.59	−63.54	2.59
4	0.76	−47.257	0.76	4	1.77	−53.48	1.78
1985:1	2.25	−41.19	2.25	1994:1	1.00	−75.46	1.00
2	1.47	−28.05	1.47	2	2.94	−77.61	2.94
3	−0.73	2.16	−0.73	3	−0.73	−99.71	−0.73
4	1.46	−0.36	1.46	4	−0.24	−113.13	−0.24
1986:1	1.68	−0.10	1.68	1995:1	2.88	−70.21	2.88
2	−1.19	−41.44	−1.19	2	−2.40	−15.12	−2.40
3	0.00	−16.71	0.00	3	−1.47	−36.72	−1.47
4	0.00	−47.88	0.00	4	0.25	−54.21	0.25

TABLE 1B

CANADA
Exchange Market Pressure 1996:1 – 2003:4

	observed Δq_t	ex ante Δq_t^0	ex post Δq_t^w		observed Δq_t	ex ante Δq_t^0	ex post Δq_t^w
1996:1	1.22	−74.62	1.22	2000:1	−1.37	3.81	−1.37
2	−0.49	−103.43	−0.49	2	2.04	38.51	2.04
3	0.24	−53.36	0.24	3	0.00	35.36	0.00
4	−1.47	−58.07	−1.47	4	2.66	−0.28	2.66
1997:1	0.74	−23.34	0.74	2001:1	0.22	−17.12	0.22
2	1.70	−39.09	1.70	2	0.87	3.55	0.87
3	0.24	−50.44	0.24	3	0.43	−41.52	0.43
4	1.67	−66.10	1.67	4	2.13	−100.72	2.13
1998:1	1.41	−72.96	1.41	2002:1	1.05	−35.44	1.05
2	1.39	−99.68	1.39	2	−2.75	−64.08	−2.75
3	4.50	−98.44	4.50	3	0.85	−56.98	0.85
4	1.74	−94.41	1.74	4	0.00	−0.76	0.00
1999:1	−1.96	−99.63	−1.96	2003:1	−3.68	15.34	−3.68
2	−2.68	−58.25	−2.68	2	−7.80	−56.86	−7.80
3	0.90	−35.06	0.90	3	−1.20	−75.43	−1.20
4	−0.90	−32.52	−0.90	4	−4.95	−44.47	−4.95

As a first step, we substitute (6)–(9) into (3) to eliminate Δd_t and (5)–(9) into (4) to eliminate Δm_t. The structure of the small open economy can then be described, in matrix form, as:

$$\begin{bmatrix} (1-\alpha_4) & 0 & \alpha_4 & 0 \\ \beta_3 & 1 & -\beta_3 & 0 \\ -\mu\gamma_\pi & -\mu\gamma_y & -\mu\lambda\rho_t & 1 \\ \gamma_\pi & \gamma_y & -(1-\lambda)\rho_t & 0 \end{bmatrix} \begin{bmatrix} \pi_t \\ y_t \\ \Delta q_t \\ i_t \end{bmatrix} = \begin{bmatrix} Z^\pi \\ Z^y \\ Z^q \\ Z^m \end{bmatrix} \tag{16}$$

where

$$\begin{aligned} Z^\pi &= \alpha_0 + \alpha_1\pi_{t-1} + \alpha_2 \mathrm{E}_t\pi_{t+3} + \alpha_3 y_{t-1} - \alpha_4\pi_t^* + \epsilon_t \\ Z^y &= \beta_0 + \beta_1 y_{t-1} - \beta_2[i_{t-2} - \pi_{t-3}] + \beta_3\pi_t^* + \eta_t \\ Z^q &= -\mu\bar{m} + i_t^* + \mathrm{E}_t\Delta q_{t+1} + \sigma_t \\ Z^m &= [h_0 - \bar{m}] + h_1\Delta m_{t-1} + h_2\pi_{t-1} + h_3\Delta i_{t-1} - h_4\Delta m_{t-2} - h_5\pi_{t-2} + \chi_t - \delta_t. \end{aligned}$$

The semi-reduced form for the observed change in the exchange rate, which is obtained by solving (16) for Δq_t, is given by

$$\Delta q_t = H^{-1}\{(1-\alpha_4)[\gamma_y Z^y - Z^m] + (\gamma_\pi - \beta_3\gamma_y)Z^\pi\} \tag{17}$$

where $H = (1-\alpha_4)(1-\lambda)\rho_t - \beta_3\gamma_y + \alpha_4\gamma_\pi$.

In order to compute our measure of ex post EMP, we use the procedure developed by Weymark (1995, 1998). In particular, we conduct a measurement experiment in which we set ρ_t equal to zero in (16) but do not allow this hypothetical change in intervention activity to have any impact on expectations. Solving the resulting system for Δq_t, we obtain the following expression for ex post EMP

$$\Delta q_t^\omega = H_\omega^{-1}\{(1-\alpha_4)[\gamma_y Z^y - Z^m] + (\gamma_\pi - \beta_3\gamma_y)Z^\pi\} \tag{18}$$

where $H_\omega = -\beta_3\gamma_y + \alpha_4\gamma_\pi$.

It follows immediately from (17) and (18) that the magnitude of ex post EMP can be expressed as

$$\Delta q_t^\omega = \Delta q_t + \frac{(1-\alpha_4)(1-\lambda)\rho_t}{-\beta_3\gamma_y + \alpha_4\gamma_\pi}\Delta q_t. \tag{19}$$

Making the substitution $\Delta r_t = -\rho_t \Delta q_t$ in (19) we obtain the following operational, model-consistent ex post EMP formula

$$\Delta q_t^{\omega} \;=\; \Delta q_t \;-\; \frac{(1-\alpha_4)(1-\lambda)}{-\beta_3\gamma_y \;+\; \alpha_4\gamma_\pi}\Delta r_t. \tag{20}$$

Using the parameter estimates $\alpha_4 = 0.025$, $\lambda = 0.9$, $\beta_3 = 0.0222$, $\gamma_y = -1.24$, and $\gamma_\pi = -1.73$, as reported in Appendix 1, our ex post EMP formula becomes

$$\Delta q_t^{\omega} \;=\; \Delta q_t \;-\; 1.3771\Delta r_t. \tag{21}$$

The ex post exchange market pressure estimates that we obtain for Canada using (21) are reported in Tables 1A and 1B.

4. Exchange Market Pressure in Australia

Australia, like Canada, can be characterized as a small open economy with a well-developed financial sector. Hence, the model that we use to describe the Australian economy is very similar to the one previously employed for Canada, differing only in the details of the Phillips curves and IS equations that we estimated for the two countries. The sample also differs from the Canadian case since Australia effectively floatted beginning 1983, although the gradual movement to liberalize financial markets began a few years earlier. Our sample therefore spans the 1983-2004 period. In the Australian case, (1) and (2) are replaced, respectively, by (22) and (23)

$$\pi_t \;=\; \alpha_0 \;+\; \alpha_1\pi_{t-1} \;+\; \alpha_2 \mathrm{E}_t\pi_{t+4} \;+\; \alpha_3 y_{t-1} \;+\; \alpha_4[\pi_t - \Delta q_t - \pi_t^*] \;+\; \epsilon_t \tag{22}$$

$$y_t \;= \beta_0 \;+\; \beta_1 y_{t-1} \;-\; \beta_2[i_t \;-\; \mathrm{E}_t\pi_{t+1}] \;-\; \beta_3[\pi_t - \Delta q_t - \pi_t^*] \;+\; \eta_t \tag{23}$$

Rankin (1998), Kim and Sheen (2202), and Rogers and Siklos (2003) describe the various phases of intervention activity in Australia. Other dexcritions can be found in Becker and Sinclair ()2004), and Edison, Cashin and Laing (2003). Broadly speaking, the RBA's intervention policies evolved from fegular daily interventions, until the late 1980s, to larger but less frequent interventions during the 1990s. As a result, there have been periods when the RBA eschewed interventions altogether. Rankin (1998) provides an explanation of the factors motivating foreign exchange intervention by

the RBA. With the possible exception of the sterilization equation, diagnostic tests on the estimated specifications suggest no serious econometric problems or evidence of structural breaks. We estimated several versions of (**??**) and the estimates obtained appear reasonable. The coefficient estimates obtained for Australia are reported in Appendix 1.

4.1 Ex Ante Exchange Market Pressure

In order to compute ex ante exchange market pressure for Australia, we need to obtain the expressions for expectational variables $\mathrm{E}_t\pi_{t+1}$, $\mathrm{E}_t\pi_{t+4}$ and $\mathrm{E}_t\Delta q_{t+1}$ under the counterfactual assumption that $\rho_t = 0$. Using the methodology described in Section 3.1 and the RE solutions reported in Appendix 2, we obtain for Australia

$$\mathrm{E}_t\pi_{t+1} = 1.3539 + 0.8548\pi_t + 0.3677y_t - 0.0009i_t + 0.0547\pi_t^* - 0.0081i_t^* \quad (24)$$

$$\mathrm{E}_t\pi_{t+4} = 5.6247 + 0.4600\pi_t + 0.9166y_t - 0.0014i_t + 0.2070\pi_t^* - 0.0438i_t^* \quad (25)$$

$$\mathrm{E}_t\Delta q_{t+1} = 26.8543 - 0.8120\pi_t + 2.4812y_t + 0.0284i_t - 0.0741\pi_t^* - 0.0637i_t^* \quad (26)$$

Substituting (25) into (22), (24) into (23), (26) and (6)–(9) into (3), (5)–(9) into (4), and setting $\rho_t = 0$ in (9), yields for Australia under the counterfactual assumption $\rho_t = 0$:

$$\begin{bmatrix} 0.9738 & -0.1081 & -0.0280 & -0.0002 \\ -0.0529 & 0.9946 & 0.0403 & 0.0148 \\ 0.8730 & -2.4336 & 0 & 1 \\ 0.8077 & 2.6058 & 0 & 0 \end{bmatrix} \begin{bmatrix} \pi_t^0 \\ y_t^0 \\ \Delta q_t^0 \\ i_t^0 \end{bmatrix} = \begin{bmatrix} X_a^\pi \\ X_a^y \\ X_a^q \\ X_a^m \end{bmatrix} \quad (27)$$

where

$$X_a^\pi = -0.4860 + 0.8600\pi_{t-1} + 0.1950y_{t-1} + 0.0524\pi_t^* - 0.0052i_t^* + \epsilon_t$$

$$X_a^y = 0.0667 + 0.7951y_{t-1} - 0.0395\pi_t^* - 0.0001i_t^* + \eta_t$$

$$X_a^q = -27.8024 + 0.0763\pi_{t-1} - 0.0656i_t^* - 0.0461\delta_t + 1.0292\sigma_t$$

$$X_a^m = -8.0505 - 1.1625\Delta m_{t-1} - 0.2847\Delta m_{t-2} - 0.2810\pi_{t-1} + 0.4098\pi_{t-2} + 0.0001\Delta i_{t-1} - 0.0001i_{t-2} + \chi_t + \delta_t.$$

The ex ante EMP formula may then be obtained by solving (27) for Δq_t^0. Our procedure yields the following model-consistent ex ante EMP formula:

$$\begin{aligned}\Delta q_t^0 \;=\; & -\,53.2283 \;+\; 7.9949\pi_{t-1} \;+\; 14.5980y_{t-1} \;-\; 0.0007i_{t-1} \\ & -\,8.0989\Delta m_{t-1} \;-\; 2.8550\pi_{t-2} \;+\; 0.0007i_{t-2} \\ & -\,1.9834\Delta m_{t-2} - \;0.3782\pi_t^* \;-\; 0.0204i_t^* \;+\; 7.0200\epsilon_t \\ & +\,18.3600\eta_t \;+\; 0.0126\delta_t \;-\; 0.2807\sigma_t \;-\; 6.9668\chi_t \qquad (28)\end{aligned}$$

The ex ante EMP indices that we calculated using (28) are given in Table 2.

4.2 Ex Post Exchange Market Pressure

Using the procedure described in Section 3.2 to obtain the semi-reduced form for the observed change in the value of the Australian dollar relative to the US dollar Δq_t, we obtain

$$\Delta q_t \;=\; H^{-1}\left\{(1-\alpha_4)\left[\gamma_y Z_a^y \;-(1+\beta_2\mu\gamma_y)Z_a^m - \beta_2\gamma_y Z_a^q\right] \;+\; (\gamma_\pi \;+\; \beta_3\gamma_y)Z_a^\pi\right\} \quad (29)$$

where

$$\begin{aligned}H &= (1-\alpha_4)[(1-\lambda)+\beta_2\mu\gamma_y]\rho_t + (1-2\alpha_4)\beta_3\gamma_y - \alpha_4\gamma_\pi \\ Z_a^\pi &\;=\; \alpha_0 \;+\; \alpha_1\pi_{t-1} \;+\alpha_2\mathrm{E}_t\pi_{t+3} + \;\alpha_3 y_{t-1} \;+\; \alpha_4\pi_t^* \;+\; \epsilon_t \\ Z_a^y &\;=\; \beta_0 \;+\; \beta_1 y_{t-1} \;+\; \beta_2\mathrm{E}_t\pi_{t+1} \;+\; \beta_3\pi_t^* \;+\; \eta_t \\ Z_a^q &\;=\; -\;[\bar{c}+\mu\bar{m}] \;+\; i_t^* \;+\; \mathrm{E}_t\Delta q_{t+1} \;+\; \sigma_t \\ Z_a^m &\;=\; -\bar{m} \;+\; h_1\Delta m_{t-1} \;+\; h_2 y_{t-1} \;+\; +h_3\pi_{t-1} \;+\; h_4\Delta i_{t-1} \;-\; h_5\Delta m_{t-2} \;-\; h_6\pi_{t-2} \;+\; \chi_t \;-\delta_t.\end{aligned}$$

Setting $\rho_t = 0$ in (29) and using the resulting expression, together with (29) to solve for ex post EMP in terms of observed exchange rate changes yields

$$\Delta q_t^\omega \;=\; \Delta q_t \;+\; \frac{(1-\alpha_4)(1-\lambda+\beta_2\mu\gamma_\pi)}{(1-2\alpha_4)\beta_3\gamma_y \;+\; \alpha_4\gamma_\pi}\rho_t\Delta q_t. \qquad (30)$$

Making the substitution $\Delta r_t = -\rho_t\Delta q_t$ in (30) we obtain the following operational, model-consistent ex post EMP formula for Australia

$$\Delta q_t^\omega \;=\; \Delta q_t \;-\; \frac{(1-\alpha_4)(1-\lambda+\beta_2\mu\gamma_\pi)}{(1-2\alpha_4)\beta_3\gamma_y \;+\; \alpha_4\gamma_\pi}\Delta r_t. \qquad (31)$$

Using the parameter estimates $\alpha_4 = 0.028$, $\beta_2 = 0.0148$, $\beta_3 = 0.0403$, $\mu = -0.0448$, $\lambda = 0.1464$, $\gamma_y = 2.6058$, and $\gamma_\pi = 0.8077$, as reported in Appendix 1, our ex post EMP formula becomes

$$\Delta q_t^{\omega} \;=\; \Delta q_t \;-\; 10.8235\Delta r_t. \tag{32}$$

Comparing (21) with (32) indicates that intervention by the Reserve Bank of Australia had an impact on the AUD/USD exchange rate that was almost ten times the size of the impact of the Bank of Canada's intervention on the CAD/USD dollar exchange rate. However, it is important to note that our estimates for Australia are relative to a broad money aggregate while a narrow monetary aggregate was employed for the Canadian estimations. Our estimate for the degree of sterilization by the Reserve Bank is $\lambda = 0.1464$, whereas our estimate for the Bank of Canada is $\lambda = 0.9$.

5. Evaluating EMP in Canada and Australia

The results reported in Tables 1A, 1B, and 2 clearly indicate that the effects of sterilized interventions can perisist at quarterly frequencies. Moreover, it is often the case that the differences between ex post EMP and actual exchange rate changes are very small. This is a reflection of the fact that the magnitude of interventions, in absolute terms, is small relative to the volume of foreign exchange transactions that take place on a daily basis. In contrast, there are noticeable differences between ex ante and ex post EMP. These are discussed in greater detail below. The overall implication of our results is that intervention affects expectations about inflation and exchange rates and, consequenctly, exchange rate movements.

In order to assess the effectiveness of sterilized interventions we compute an index that measures the policy induced change in exchange market conditions (PICE). The PICE index measures the differnce between ex ante and ex post EMP over a chosen time period. More formally,

$$\text{PICE}_t \;=\; 1 \;-\; \frac{\Delta q_t^{w}}{\Delta q_t^{0}} \tag{33}$$

where, as before, Δq_t^w is ex post EMP and Δq_t^0 is ex ante EMP in period t.

For purposes of interpretation, the PICE index values we obtain from (33) can be divided into three distinct ranges. When ex post EMP is smaller than ex ante EMP, and both EMP measures are of the same sign so that $\Delta q_t^w/\Delta q_t^0 < 1$, then

TABLE 2

AUSTRALIA
Exchange Market Pressure 1985:1 – 2003:3

	observed Δq_t	ex ante Δq_t^0	ex post Δq_t^w		observed Δq_t	ex ante Δq_t^0	ex post Δq_t^w
1985:1	22.19	65.49	22.11	1995:1	−5.81	51.03	−5.83
2	30.93	115.60	30.99	2	−0.48	59.49	−0.48
3	18.32	130.43	18.32	3	0.00	74.22	0.01
4	20.78	118.47	20.80	4	1.00	72.61	1.00
1986:1	6.03	123.82	6.02	1996:1	−1.00	72.56	−0.99
2	−6.65	82.69	−6.67	2	−8.61	56.63	−8.65
3	11.42	85.02	11.42	3	−6.36	55.76	−6.33
4	6.00	100.57	5.98	4	−6.17	49.28	−6.18
1987:1	4.80	100.40	4.72	1997:1	−3.07	42.57	−3.07
2	−0.48	103.88	−0.51	2	3.12	53.95	3.12
3	−13.76	109.41	−13.80	3	6.85	37.90	6.84
4	−8.31	115.64	−8.25	4	14.08	49.32	14.07
1988:1	−7.17	107.77	−7.20	1998:1	15.82	58.10	15.84
2	−8.44	110.75	−8.47	2	20.14	68.14	20.13
3	−11.33	108.50	−11.33	3	20.53	87.05	20.54
4	−17.62	125.42	−17.60	4	10.49	101.04	10.48
1989:1	−16.10	124.14	−16.12	1999:1	4.97	89.73	4.98
2	−0.26	144.96	−0.27	2	−3.85	86.87	−3.85
3	4.69	160.93	4.69	3	−8.32	81.88	−8.34
4	7.01	141.90	7.00	4	−3.59	86.96	−3.59
1990:1	9.91	154.67	9.93	2000:1	0.21	86.14	0.22
2	1.29	142.22	1.27	2	10.14	95.76	10.14
3	−5.76	101.42	−5.78	3	12.62	97.64	12.60
4	0.00	101.44	0.00	4	19.30	77.01	19.30
1991:1	−1.54	81.64	−1.54	2001:1	17.35	70.67	17.34
2	−0.26	45.04	−0.26	2	14.11	74.34	14.11
3	3.44	35.24	3.44	3	11.20	57.56	11.20
4	−0.52	13.62	−0.52	4	3.83	60.72	3.83
1992:1	3.31	12.20	3.33	2002:1	2.62	65.30	2.62
2	1.53	2.89	1.52	2	−7.08	66.99	−7.09
3	6.55	4.30	6.60	3	−6.72	68.94	−6.71
4	11.84	14.68	11.84	4	−8.55	53.18	−8.54
1993:1	8.87	32.73	8.87	2003:1	−13.65	56.42	−13.65
2	8.72	32.89	8.71	2	−14.80	41.79	−14.82
3	8.86	16.39	8.86	3	−18.20	41.79	−14.82
4	4.32	34.89	8.86				
1994:1	−2.56	44.12	−2.56				
2	−4.02	48.34	−4.02				
3	−9.84	57.34	−9.84				
4	−12.31	46.94	−12.31				

$0 < \text{PICE} < 1$. Under these circumstances, EMP following intervention is smaller, in absolute terms, than EMP conditional on no intervention taking place. This could be viewed as a successful intervention. When ex post and ex ante EMP are of the same sign, but ex post EMP exceeds ex ante EMP, then $\Delta q_t^w / \Delta q_t^0 > 1$ and PICE < 0. Negative values of the PICE index are indicative of periods of unsuccessful intervention because the intervention activity was unsuccessful in reducing exchange market pressure. Lastly, there is the possibility that ex post and ex ante EMP are of opposite signs so that $\Delta q_t^w < 0$ when $\Delta q_t^0 > 0$, and vice versa. In this case it is not entirely clear how one should interpret the outcome of the intervention. For example, $\Delta q_t^0 > 0$ indicates that the exchange rate would have depreciated in the absence of intervention by the policy authority. If, in this case, intervention resulted in $\Delta q_t^w < 0$, then the policy authority's intervention activities prevented the currency from depreciating but, instead, caused a currency appreciation. Such a situation could easily come about if the policy authority underestimated the impact of its intervention activities on expectations. Even though the intervention caused the exchange rate to overshoot the zero EMP mark, we view it as having been successful because the course of the exchange rate was reversed.

Figures 1A and 1B plot the PICE indices for Canada and Australia, respectively, alongside the relevant nominal short-term interest rate for each country.[21] Beginning with the Canadian results, we note that the PICE index is always positive and fluctuates around the value of 1 most of the time. Nevertheless, the index behaves asymmetrically, with PICE > 1 almost two-thirds of the time. Evidently, the Bank of Canada often underestimated the impact of its intervention activity on expectations, causing frequent overshooting of the zero EMP mark.

Figure 1A highlights several events that can be used to demonstrate the usefulness of the ex ante EMP concept introduced in this article. In the early 1980s, the Bank of Canada placed greater emphasis on exchange rate developments than on meeting

[21] Plotting instead the Canada-US or Australia-US interest rate differentials does not alter the interpretation of the Figures.

targets for monetary growth (Howitt (1986), p. 155). Nevertheless, as Howitt goes on to describe in some detail, while the Bank clearly resisted the ongoing exchange rate depreciation at the time, there was no clearly announced target. The behavior of the PICE index around this time indicates that ex ante and ex post EMP were in sharp contradiction to each other.[22] It is well known that the Canadian dollar came under speculative attack numerous times during the first half of the 1980s. The frequent overshooting of the zero EMP mark in this period is consistent with Weymark's (1995) analysis of the Bank of Canada's policy response to the speculative pressures that were present at that time.

During the mid-1980s, the Bank of Canada's policy changed course as the central bank came to realize that its policy of accommodating Treasury objectives resulted in excessive inflation (Courchene (1981)). As a result, particularly between 1984 and 1985, the Bank of Canada's monetary policy became far less expansionary (Howitt (1986), p.77). The impact of this change in policy is captured in Figure 1 as a sharp drop in the PICE index in 1986. This period in Canada's recent monetary history has been described by Bernanke and Mishkin (1992), among others, as having been turbulent.

The next sharp fluctuations in Canada's PICE index are associated with several notable events. During the years 1987-88, a new Governor, John Crow, was appointed to the Bank of Canada. Immediately after taking office, Crow publicly announced (at the Hanson Lecture) that there would henceforth be a more concerted effort to control inflation in Canada (see Crow (2002) and Laidler and Robson (1993)). Shortly thereafter, the Bank became involved in the Paris Louvre Accord, the purpose of which was to support the value of the US dollar. While the agreement was considered to be largely unsuccessful, it caused the foreign exchange market to exhibit considerable turbulence for several months (Crow (2002), p.96ff). Finally, there was the stock market crash of October 1987 which led to a softening in the stance of monetary policy,

[22]Figure 1A omits the PICE values for 1985Q4 and 1986Q1 which are, respectively, 5.09 and 17.99. In the preceding two quarters the Canadian dollar ceased to depreciate and began a sharp and rapid appreciation against the US dollar.

albeit temporarily. The confluence of these events is clearly seen in the behavior of the PICE index during this period which initially fell in response to Crow's announcement regarding inflation control, and then rose sharply when the Louvre Accord and the stock market crash undermined the credibility of the announcement. A similar reaction shows up in the PICE index later in the sample in the aftermath of the bursting of the tech bubble in 1999-2000 that would eventually result in historically low interest rates.[23]

Two other events are noteworthy. First, our PICE index reveals that in the months leading up to the Quebec referendum of October 1995, large, and successful, interventions were undertaken by the Bank of Canada.[24] Second, the coordinated intervention in support of the euro in September 2000 also shows up clearly in Figure 1A.[25] The behavior of the PICE index after July 1998 may also have been influenced by the Bank's explicit abandonment of intervention. The Bank's relatively brief use of a monetary conditions index, which linked interest rates and exchange rates, as a means of communicating its monetary policy stance to the public may also have had some impact on the PICE index (see Siklos (2000) and Laidler and Robson (2004)).[26] There are also two events that are notable because of their failure to have any significant impact on the PICE index. Neither the adoption of inflation targets

[23]The behavior of the PICE index at this time may also have been affected by the events surrounding the appointment of David Dodge as Governor of the Bank of Canada (see Laidler and Robson 2004)).

[24]The values of the PICE index during 1995 suggest that the referendum did not have as large an affect on perceptions of the exchange rate as did the other events described here. This seems consistent with the space, or lack thereof, devoted to the overall impact of the Quebec referendum in the most widely read narratives of monetary policy in Canada (e.g., Crow (2002), Laidler and Robson (2004)).

[25]Laidler and Robson (2004, p.125) state that the Bank of Canada did intervene in the foreign exchange market though actual intervention data supplied to us by the Bank suggests that no such intervention took place.

[26]the Bank of Canada began using the monetary conditions index the mid 1990s. The Bank's reliance on this measure and its communication to financial markets gradually faded away entirely by the end of the sample considered here.

in 1991 nor the Asian financial crisis of 1997-98 generate any discernible movement in the PICE index.

We now turn to the evidence for Australia. The Australian PICE index is plotted in Fiugure 1B. As can be seen from the highlighted range of valued for the index, interventions by the Reserve Bank of Australia have been largely successful. Unlike the Bank of Canada, the Reserve Bank of Australia has actively intervened in foreign exchange markets even after the adoption of inflation targeting in 1993 (see, for example, Pitchford (1993) and Rogers and Siklos (2003)). The absence of outlier values for the PICE index is an indication that sharp divergences between ex ante and ex post EMP are not apparent in the Australian data. Nor is there evidence of any asymmetry in the behavior of the PICE index; only slightly under one half of the reported values for the index either exceed one or are negative. Indeed, the only negative value for the PICE index occurs shortly before the inflation targeting policy was announced by the Reserve Bank of Australia (RBA).[27] Note, however, that the introduction of these targets followed a period of rapidly falling nominal interest rates.[28] Once interest rates ceased falling quickly, in the two quarters preceding the introduction of the new policy regime, there was a sharp adjustment in the PICE index. Hence, unlike the Canadian experience, the introduction of inflation targeting in Australia temporarily undermined the effectiveness of the RBA's intervention activities causing exchange market pressure to be considerably larger than it would have been in the absence of intervention. As in the Canadian case, there is nothing out of the ordinary about the behavior of the Australian PICE index around the time of the Asian financial crisis. This is consistent with the view that monetary policy in

[27]Inflation targets were announced by the RBA in 1993 but were only jointly agreed to by the government in 1996 (see Siklos (2002) and Bell(2004)). Moreover, the targets were medium range objectives for inflation rather than the short-term inflation target ranges introduced in Canada.

[28]Bell (2004, chapter 4) argues that the RBA had little credibility, let alone meaningful autonomy prior to the 1990s. The Australian dollar began floating in December 1983. During the 1984-86 period, the trade-weighted exchange rate fell by approximately one third. The impact of this change in exchange rate regime appears to show up primarily in interest rate volatility.

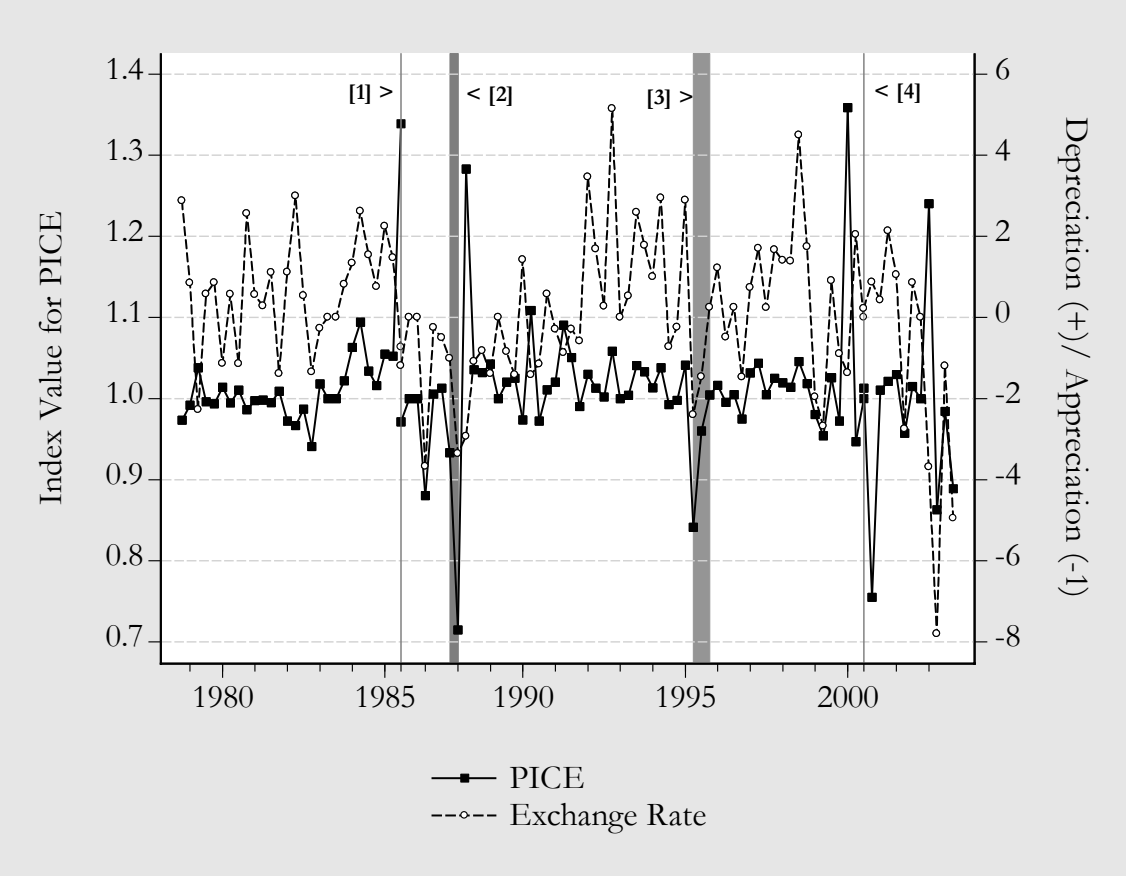
Australia was "at peace" during this period, a circumstance which Bell (2004, chapter 4) attributes to the RBA's pragmatic approach to inflation targeting which avoided displaying, at least in public, undue emphasis on inflation control.

6. Conclusion

In this article we introduce a new method of evaluating the effectiveness of sterilized interventions in foreign exchange markets. Because actual interventions by central banks occur at high frequencies, it is difficult for standard macroeconomic models, which are usually estimated using quarterly data, to capture the impact and signficance of intervention activity. We propose the concept of ex ante exchange market pressure as a benchmark against which to measure the longer term effectiveness of exchange market intervention. Ex ante EMP is our estimate of the change in the exchange rate under the counterfactual experiment that the central bank did not intervene and that this policy was rationally anticipated by economic agents. The difference between ex ante and ex post EMP measures, expressed in the form of an index, represents the proportion of EMP removed through intervention. We refer to the resulting indicator as the policy induced change in expectations (PICE). Using this approach we find that the effects of sterilized interventions persist at quarterly frequencies. We also find that the differential between ex post EMP and actual exchange rate movements dissipates almost completely within a quarter. From this we conclude that interventions primarily impact expectations.

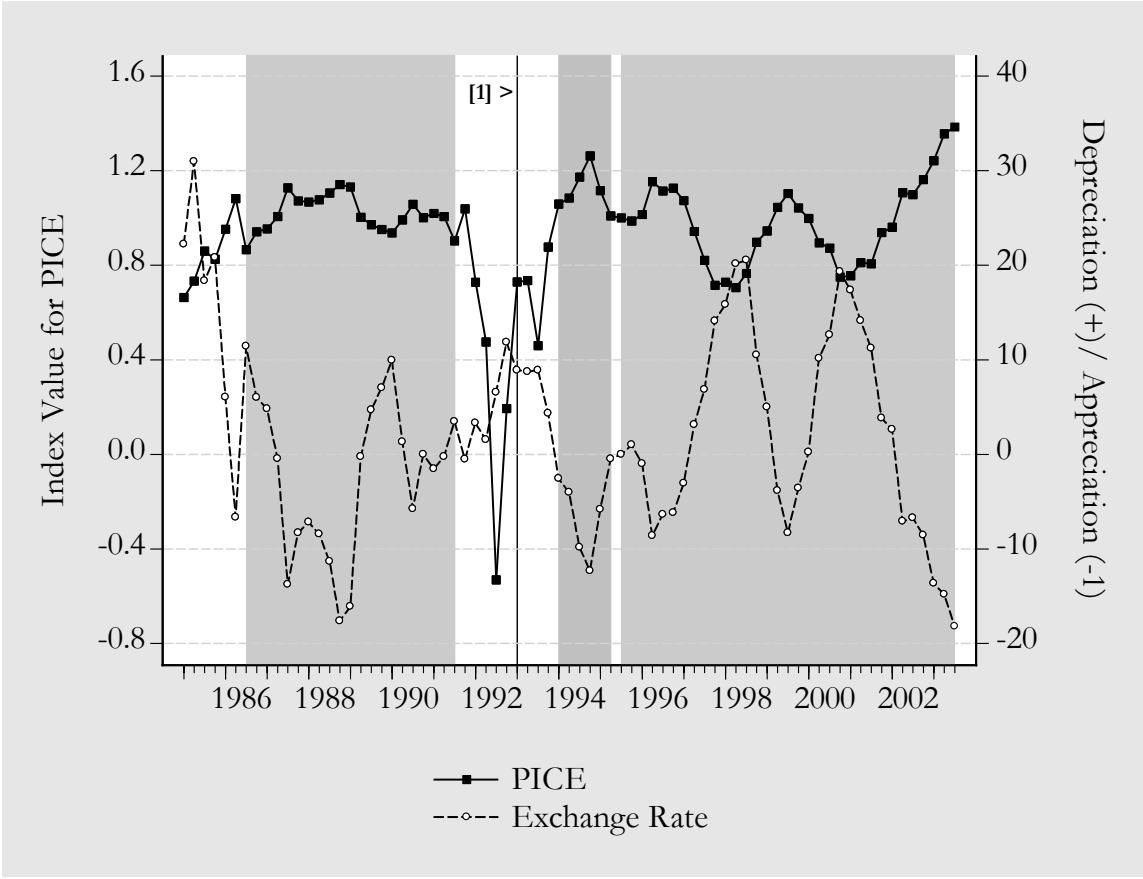
We apply our methodology to data from Canada and Australia, two archetypical small open economies with notably different foreign exchange market intervention practices and histories. Our results highlight how meaningful our index of intervention effectiveness is in that we are able t o explain notable changes in the PICE index on the basis of actual events that would have had a significant impact on exchange rate expectations. An obvious next step is to apply the procedures developed here to economies with emerging markets or other economies where explicit exchange rate management is in place and sterilized intervention is routinely undertaken. These extensions are left for future research.

Figure 1A Policy Induced Changes in Exchange Market Conditions: Canada



Note: See text for details of the construction of the index. The exchange rate is the first log difference of the CAD/USD nominal exchange rate. [1] = BoC switches to an exchange rate objective; [2] = Hanson lecture by John Crow, BoC Governor, Louvre Accord, and October 1987 crash; [3] = inflation targeting introduced; [4] = ECB coordinated intervention. PICE estimates for 198Q4, 1986Q1, and 2000Q4 are omitted because these would distort the figure. See n.23 for the estimates for these dates.

Figure 1B Policy Induced Changes in Exchange Market Conditions: Australia



Note: See text for details of the construction of the index. The exchange rate is the first log difference of the AUD/USD nominal exchange rate. [1] = Adoption of inflation targets. The shaded areas are the various phases of intervention activity documented by Rankin (1998). The shaded areas to the left and right were periods of intensive intervention. The middle area represents a period of zero intervention.

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Appendix 1
Data Sources and Estimation Equations

A1.1 Data Sources for Canada and the US

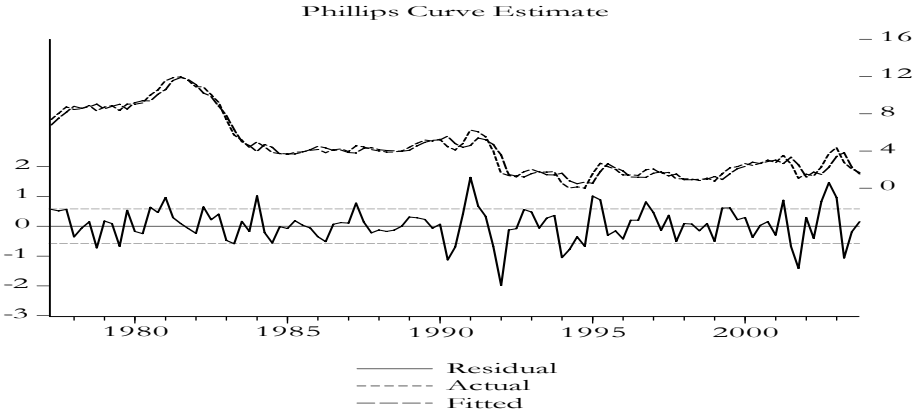
Definition	Source
Price level, CPI (2000 = 100)	IFS, line 64
Exchange rate, nominal	IFS, line RF
Interest rate, overnight market rate	IFS, line 60b
Interest rate, US fed funds rate	IFS, line 61a
Real exchange rate, unit labor costs (2000 = 100)	IFS, line 65 UMC
Real exchange rate, relative prices (2000 = 100)	IFS, line rec
Commodity prices, total	CANSIM, v36382
Monetary aggregates, Gross M1	CANSIM, v37141
Monetary aggregates, M3	CANSIM, v37125
Official international reserves	CANSIM, v122396
Bank of Canada, holdings of government bonds	CANSIM, v37369
Total outstanding government debt	CANSIM, v37312
Price level, US CPI	IFS, line 64
Forward premium, US dollar	CANSIM, v122505
Bank of Canada, output gap	www.bankofcanada.ca/en/indinf/fproduct_data_en.html
GDP, real (2000 = 100)	IFS, line 99b

A1.2 Canadian Coefficient Estimates: Quarterly Data, 1978–2004

1. Phillips Curve (GMM)

$$\pi_t = -0.064 + 0.906\pi_{t-1} + 0.084\ \mathrm{E}_t\pi_{t+3} + 0.137\,y_{t-1} - 0.025[\pi_t - \Delta q_t - \pi_t^*] + \varepsilon_t$$
$$(0.069)\quad (0.043)^*\quad (0.045)^*\quad (0.049)^*\quad (0.009)^*$$

J-Stat = 8.35(0.68); Q(1)=1.16 (.28), Q(2)= 1.17 (.56).
GMM=629.95 (1.00)

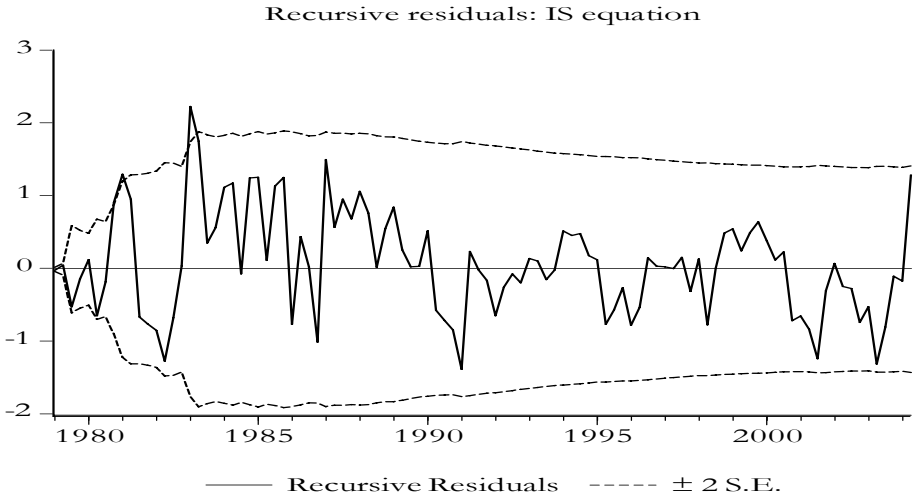


2. IS Curve (OLS)

$$y_t = 0.251 + 0.929\,y_{t-1} - 0.0697[i_{t-2} - \pi_{t-3}] - 0.022[\pi_t - \Delta q_t - \pi_t^*] + \eta_t$$

$$(0.124)\quad (0.034)^{*}\qquad (0.028)^{*}\qquad\qquad (0.013)^{***}\quad \bar{R}^2 = 0.893$$

Q(1)= 18.94 (.00), Q(2)=28.49 (.00); ARCH-LM=18.84 (.00), F=0.73 (.58).

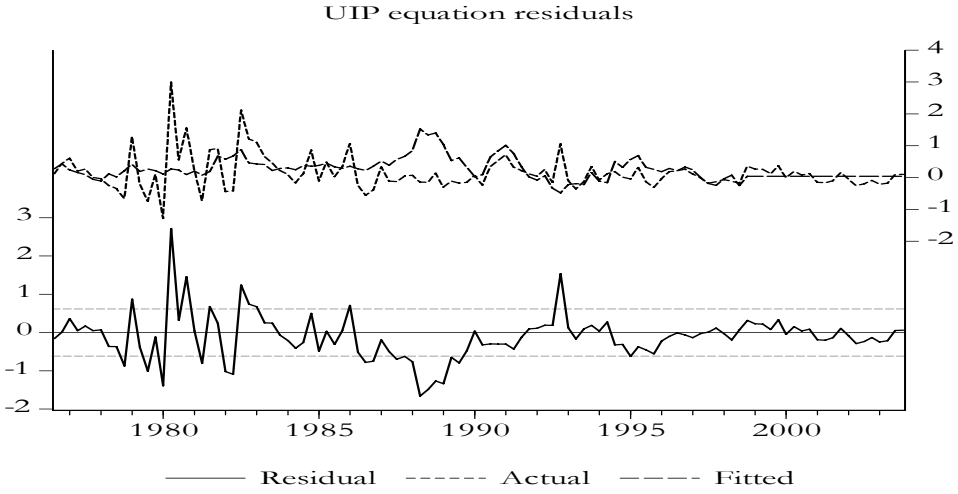


3. International Trade in Assets (OLS)

$$i_t - (i_t^* + [\mathrm{E}_t q_{t+1} - q_t]) = 0.4887 - 0.47\ \Delta d_t + \sigma_t$$

$$(0.048)\quad (0.080)^{*}\qquad\qquad \bar{R}^2 = 0.004$$

GMM=5049 (1.00); Q(1)=8.52 (.00), Q(2)=17.34 (.00)

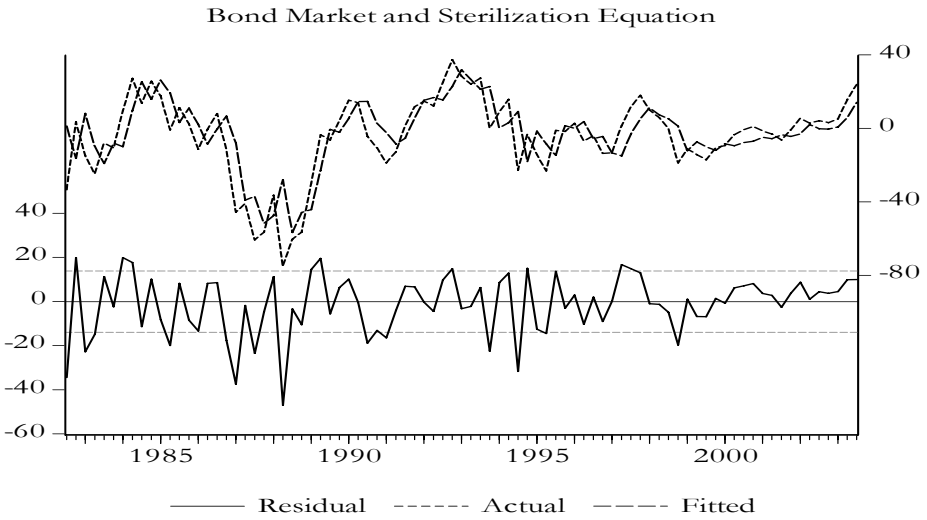


4. Bond Market and Sterilization (GMM)

$$\Delta d_t = 9.92 - 1.73\pi_t - 1.24\,y_t - 0.90\Delta r_t + \delta_t$$

$$(0.97)^{*}\ (0.27)^{*}\quad (0.26)^{*}\quad (0.03)^{*}\qquad\qquad J - Stat = 5.70\,(0.31)$$

GMM= 2384 (1.00); Q(1)= 0.03 (.85), Q(2)= 0.28 (.87).



5. Money Demand (VECM)

$$\Delta M_t = 0.010 + 0.019EC_{t-1} + 0.228\Delta M_{t-1} - 0.014\Delta M_{t-2} + 0.643\Delta\pi_{t-1}$$
$$(0.005)^{*} \quad (0.007)^{*} \quad (0.103)^{*} \quad (0.102) \quad (0.310)^{*}$$
$$+0.074\pi_{t-2} + 0.165\Delta\tilde{y}_{t-1} - 0.343\Delta\tilde{y}_{t-2} + 0.0008\Delta i_{t-1} + 0.002\Delta i_{t-2}$$
$$(0.324) \quad (0.231) \quad (0.239) \quad (0.001) \quad (0.001)^{*}$$
$$EC_t = M_t + 1.015P_t + 0.985\tilde{y}_t - 0.107i_t + 0.019\tau + 9.253$$
$$(0.361)^{*} \quad (1.081) \quad (0.019)^{*} \quad (0.010)^{**}$$

$\bar{R}^2 = 0.234$; J-B= 7.97 (.44).

The cointegrating equation that is used to generate the error correction term is:

$$LM_t = \underset{(.361)}{1.015LP_t} + \underset{(1.082)}{0.985\tilde{y}_t} - \underset{(.019)}{-0.107} + \underset{(.010)}{0.019} + 9.253$$

Maximum Eigenvalue Cointegration test

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	**0.41**	**60.52**	**32.12**	**0.00**
At most 1	0.17	21.69	25.82	0.16
At most 2	0.10	12.24	19.39	0.39
At most 3	0.06	7.11	12.52	0.33

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level

* denotes rejection of the hypothesis at the 0.05 level

**MacKinnon-Haug-Michelis (1999) p-values

Notes: For each equation, the method of estimation is given in parentheses to the right of the equation name. Standard errors are given in parentheses below the relevant

parameter estimates. * indicates statistically significant at the 1% (** 5%; *** 10%) level of significance. *J*-Stat is Hansen's test for over-identifying restrictions. The χ^2 test statistic is shown with the p-value in parenthesis. Q(k) is the Q-statistic for the squared residuals with p-value in parenthesis. GMM is the Hodrick-Srivastava (1984) test statistic, distributed as a χ^2 (p-value), for stability. The break point shown is assumed to be 1991Q1, that is, when inflation targeting is introduced. Neighboring break-points did not change the conclusions. ARCH-LM is the test for first order ARCH effects with the p-value in parenthesis. F is the Chow test for structural stability. The break point shown is assumed to be 1991Q1, that is, when inflation targeting is introduced. Neighboring break-points did not change the conclusions. J-B is the test statistics for Normality in the residuals with the p-value in parenthesis.

Variable definitions: π_t = inflation; y_t = output gap; $\tilde{y}_t$ = log real GDP; $\Delta\tilde{y}_t$ = real GDP growth; M_t = money supply (Gross M1); i_t = nominal short-term interest rate; P_t = log CPI; q_t = nominal exchange rate; EC_t = error correction; τ = linear time trend.

A1.3 Data Sources for Australia

Consumer Price Index (CPI, 2000=100)	IFS, line 64
Real GDP (2000=100)	IFS, line 99b
Exchange Rate (nominal; AUD per USD)	IFS, line rf
Average money market rate	IFS, line 60b
Real exchange rate, relative prices (2000=100)	IFS, line rec
Terms of trade (G0PITT)	RBA, G04HIST.xls
M3, monetary aggregate, billions, seasonally adjusted	RBA, D03HIST.xls
M1 monetary aggregate, billions, seasonally adjusted	RBA, D03HIST.xls
Monetary Base, billions, seasonally adjusted	RBA, D03HIST.xls
Reserve Bank holdings on government securities, millions (ECGSCRBT)	RBA, E03HIST.xls
Total government debt, millions (ECGSCTHT)	RBA, E03HIST.xls
Official reserve assets, millions AUD (ORA)	RBA, A04HIST.xls

Note: RBA is Reserve Bank of Australia, *.xls refers to the Excel spreadsheets that were downloaded from the RBA's website.

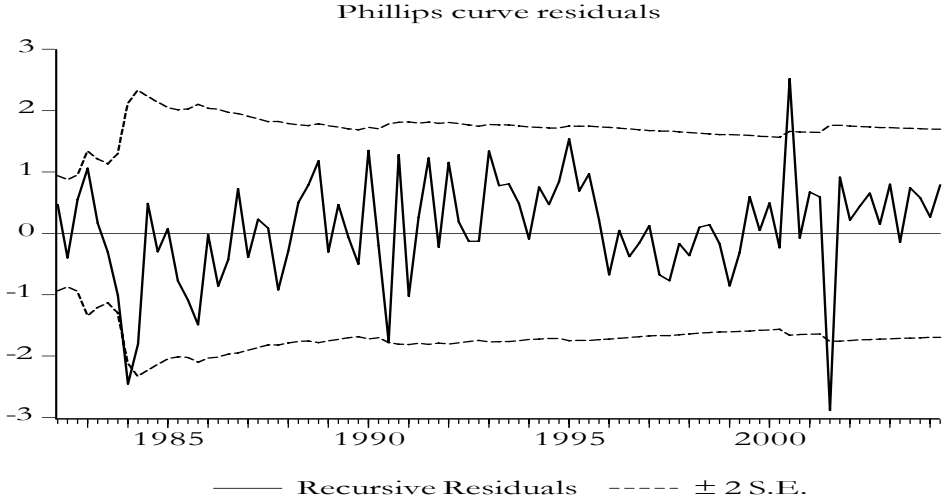
A1.4 Australian Coefficient Estimates: Quarterly Data, 1983–2004

1. Phillips Curve (OLS)

$$\pi_t = -0.177 + 0.906\pi_{t-1} + 0.118\ \mathrm{E}_t\pi_{t+4} + 0.195y_{t-1} - 0.028[\pi_t - \Delta q_t - \pi_t^*] + \varepsilon_t$$
$$(0.249)\quad (0.052)\quad (0.062)\quad (0.065)\quad (0.010)$$

$\bar{R}^2 = 0.929$

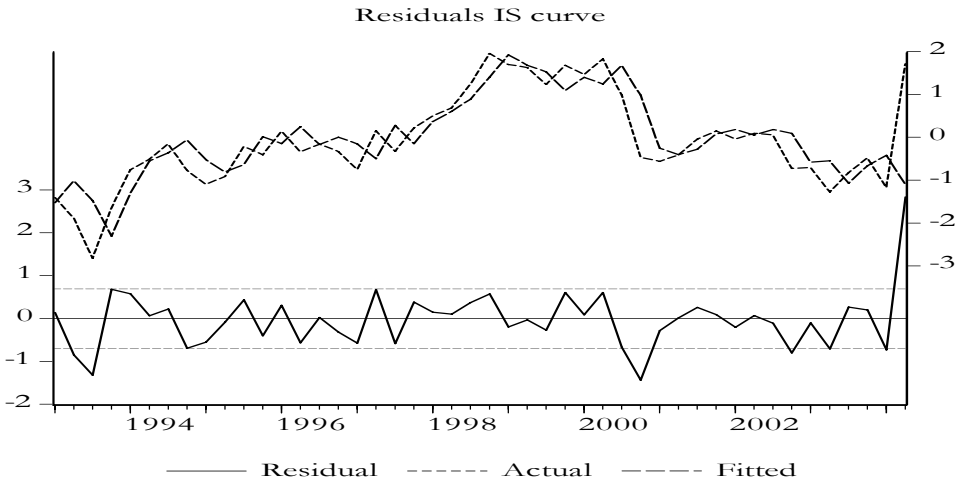
F (1993.1) = 1.46 (.21); ARCH-LM = 0.0001 (.99); Q(1) = 0.35 (.56), Q(2) = 2.29 (.32)



2. IS Curve (GMM)

$$y_t = 0.047 + 0.795y_{t-1} - 0.015[i_{t-2} - \pi_{t-3}] + 0.040[\pi_t - \Delta q_t - \pi_t^*] + \eta_t$$
$$(0.154)\quad (0.046)\quad (0.051)\quad (0.019)$$

J-stat = 7.38 (0.61); GMM = 3203 (1.00)

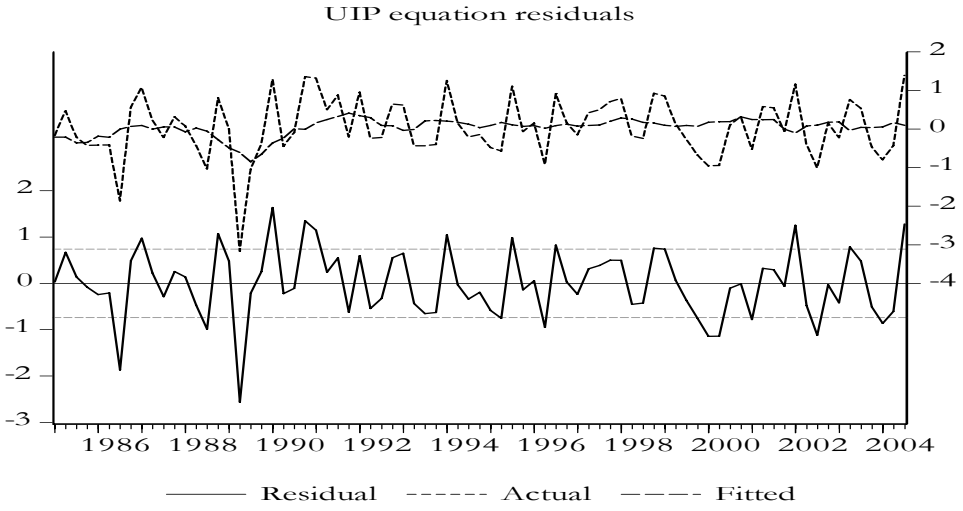


3. International Trade in Assets (OLS)

$i_t - (i_t^* + [\mathrm{E}_t q_{t+1} - q_t]) = 0.519 - 0.045\ \Delta d_t + \sigma_t$

(0.193) (0.016)

$\bar{R}^2 = 0.075$; ARCH-LM = 0.72 (.40); F = 1.16 (.32); Q(1) = 0.22 (.64), Q(2) = 5.32 (.07)

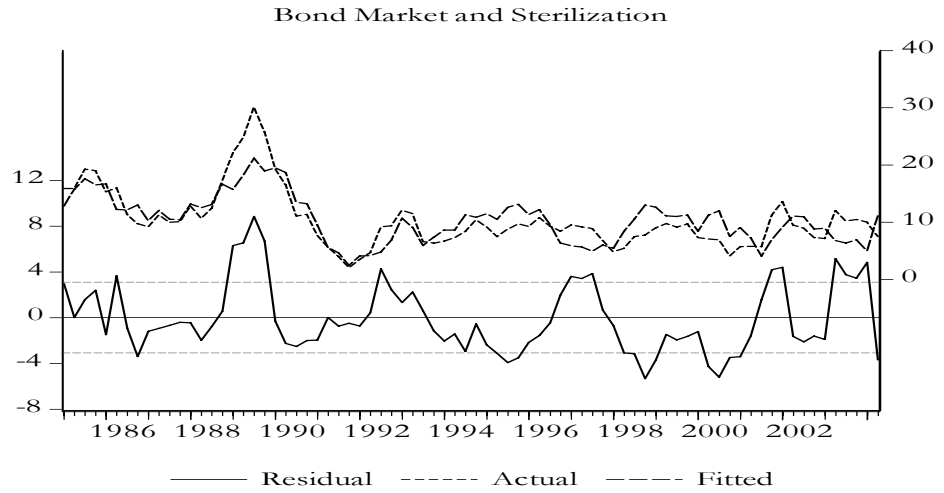


4. Bond Market and Sterilization (OLS)

$\Delta d_t = 8.050 + 0.808\pi_t + 2.606 y_t - 0.146\Delta r_t + \delta_t$

(0.653) (0.138) (0.338) (0.032)

$\bar{R}^2 = 0.633$; F = 18.10 (.00); ARCH-LM= 36.50 (.00); Q(1)= 34.22, Q(2) = 45.65.



5. Money Demand (VECM)

$$\Delta M_t = 0.025 - 0.122EC_{t-1} + 0.285\Delta M_{t-1} - 0.002\Delta M_{t-2} - 0.410\Delta\pi_{t-1}$$
$$(0.005)\quad (0.031)\quad (0.106)\quad (0.110)\quad (0.218)$$
$$-0.073\pi_{t-2} + 0.180\Delta\tilde{y}_{t-1} - 0.308\Delta\tilde{y}_{t-2} + 0.002\Delta i_{t-1} + 0.001\Delta t_{t-2}$$
$$(0.208)\quad (0.190)\quad (0.192)\quad (0.001)\quad (0.001)$$

$$EC_t = M_t - 1.054P_t - 1.608\tilde{y}_t - 0.008i_t + 6.322$$
$$(0.119)\quad (0.143)\quad (0.004)$$

$\bar{R}^2 = 0.378$

Cointegrating equation

$$LM3_t = \underset{(0.119)}{1.054LP_t} + \underset{(0.143)}{1.608\tilde{y}} + \underset{(0.004)}{0.008} - 6.322$$

Maximum Eigenvalue Cointegration Test

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	**0.37**	**39.57**	**27.58**	**0.00**
At most 1	0.16	15.44	21.13	0.26
At most 2	0.08	7.18	14.26	0.47
At most 3	0.00	0.15	3.84	0.70

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level

* denotes rejection of the hypothesis at the 0.05 level

**MacKinnon-Haug-Michelis (1999) p-values

Appendix 2

Rational Expectations Computation

A2.1 Computational Formulae

In this section, we use the model of the Canadian economy and the coefficient estimates obtained on the basis of that model to illustrate the procedures we used to compute the RE solution. The same procedures were employed to obtain the RE solution for the Australian model.

In order to derive the ex ante exchange market pressure formula (28) we need reduced-form expressions for the two expectational variables $E_t\pi_{t+3}$ and $E_t\Delta q_{t+1}$. We have chosen to measure exchange market pressure as a one-period deviation from the policy rule actually implemented. Because expectations about future inflation are formed three periods ahead, we need to express this expectation in such a way as to capture the impact of a change in policy in period t alone. In order to do this, we need to compute two rational expectatations solutions: one that pertains to the policy rule actually implemented and another that pertains to the imposition of the counterfactual assumption $\rho_t = 0$.

The computational program we employ was developed by Sims (2001). The application of Sims' program requires that we express our RE model in the following form:

$$\bar{\Gamma}_0 x_t \;=\; \bar{\Gamma}_1 x_{t-1} \;+\; C \;+\; \Psi z_t \;+\; \Pi w_t \tag{A.1}$$

One configuration of vectors that allows the quarterly model given by (1)–(9) to be expressed in a manner that is consistent with (A.1) is:

$$x_t = \begin{bmatrix} \pi_t \\ y_t \\ \Delta q_t \\ i_t \\ \Delta m_t \\ \pi_{t-1} \\ \pi_{t-2} \\ i_{t-1} \\ \pi_t^* \\ i_t^* \\ \hat{q}_{t+1} \\ \hat{\pi}_{t+1} \\ \tilde{\pi}_{t+2} \\ \bar{\pi}_{t+3} \end{bmatrix} \qquad x_{t-1} = \begin{bmatrix} \pi_{t-1} \\ y_{t-1} \\ \Delta q_{t-1} \\ \imath_{t-1} \\ \Delta m_{t-1} \\ \pi_{t-2} \\ \pi_{t-3} \\ i_{t-2} \\ \pi_{t-1}^* \\ i_{t-1}^* \\ \hat{q}_t \\ \hat{\pi}_t \\ \tilde{\pi}_{t+1} \\ \bar{\pi}_{t+2} \end{bmatrix} \qquad z_t = \begin{bmatrix} \eta_t \\ \epsilon_t \\ \sigma_t \\ \chi_t \\ \delta_t \\ e_t \\ g_t \end{bmatrix}$$

$$w_t = \begin{bmatrix} u_t \\ v_t \\ \phi_{t+1} \\ \theta_{t+1} \end{bmatrix}$$

The definitional equations that are associated with these vectors and which must be added to the system are

$$\Delta q_t = \hat{q}_t + u_t \tag{A.2}$$

$$\pi_t = \hat{\pi}_t + v_t \tag{A.3}$$

$$\tilde{\pi}_{t+1} = \hat{\pi}_{t+1} + \phi_{t+1} \tag{A.4}$$

$$\bar{\pi}_{t+2} = \tilde{\pi}_{t+2} + \theta_{t+1} \tag{A.5}$$

$$i_{t-1} = i_{t-1} \tag{A.6}$$

$$\pi_{t-1} = \pi_{t-1} \tag{A.7}$$

$$\pi_{t-2} = \pi_{t-2} \tag{A.8}$$

Two more equations are needed to close the model. We therefore make the assumption that foreign inflation and the foreign interest rate level Follow AR(1) processes such that:

$$\pi_t^* = s_\pi \pi_{t-1}^* + e_t \tag{A.9}$$

$$i_t^* \;=\; s_i i_{t-1}^* \;+\; g_t. \tag{A.10}$$

To complete the model specification, the matrices Γ_0, Γ_1, C, Ψ, and Π are then given by:

$$\Gamma_0 \;=\; \begin{bmatrix}
(1-\alpha_4) & 0 & \alpha_4 & 0 & 0 & 0 & 0 & 0 & \alpha_4 & 0 & 0 & 0 & 0 & -\alpha_2 \\
\beta_3 & 1 & -\beta_3 & 0 & 0 & 0 & 0 & 0 & -\beta_3 & 0 & 0 & 0 & 0 & 0 \\
-\mu\gamma_\pi & -\mu\gamma_y & -\mu\lambda\rho_t & 1 & 0 & 0 & 0 & 0 & 0 & -1 & -1 & 0 & 0 & 0 \\
-1.015 & 0 & 0 & 0.107 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-\gamma_\pi & -\gamma_y & (1-\lambda)\rho_t & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

Note that only the long-run component of the money demand function was used in computing the RE solution. The complete error-correction specification could not be used as estimated because the computational program could not identify a valid solution when the short-term dynamics were included in the money demand specification. This only affects the calculation of the counter-factual expectations; the remainder of the analysis uses the money demand function as estimated.

$$\Gamma_1 = \begin{bmatrix} \alpha_1 & 0 & \alpha_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \beta_1 & 0 & 0 & 0 & 0 & \beta_2 & -\beta_2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -0.107 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & s_\pi & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & s_i & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\Psi = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \qquad \Pi = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \qquad C = \begin{bmatrix} \alpha_0 \\ \beta_0 \\ \bar{c} + \mu\bar{m} \\ \text{- } 0.019 \\ \bar{m} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

A slightly different formulation was required for Australia in order to accommodate the differences between the Phillips curves and the IS equations that were estimated for the two countries. In order to conserve space, the formulation used for Australia is not included here, but may be obtained from the authors upon request.

A2.2 Estimated Coefficients used in Computation of RE Solutions

CANADA

1. Phillips Curve:

$$\pi_t = -0.064 + 0.906\pi_{t-1} + 0.084\,\mathrm{E}_t\pi_{t+3} + 0.137y_{t-1} + 0.025[\pi_t - \Delta q_t - \pi_t^*] + \epsilon_t$$

2. IS Curve:

$$y_t = 0.251 + 0.929y_{t-1} - 0.0697[i_{t-2} - \pi_{t-3}] - 0.022[\pi_t - \Delta q_t - \pi_t^*] + \eta_t$$

3. UIP Equation:

$$i_t = 0.4887 + i_t^* + \mathrm{E}_t\Delta q_{t+1} - 0.47\Delta d_t + \sigma_t$$

4. Δd_t Equation:

$$\Delta d_t = 9.92 - 1.73\pi_t - 1.24y_t - 0.90\Delta r_t + \delta_t$$

5. Long-Run Money Demand Equation:

$$\Delta m_t = \text{- } 0.019 + 1.015\pi_t - 0.1075\Delta i_t + \chi_t$$

6. AR(1) Processes:

$$\pi_t^* = 0.9\pi_{t-1}^* + e_t$$

$$i_t^* = 0.9i_{t-1}^* + g_t$$

AUSTRALIA

1. Phillips Curve:

$$\pi_t = -0.177 + 0.860\pi_{t-1} + 0.118\,\mathrm{E}_t\pi_{t+4} + 0.195y_{t-1} - 0.028[\pi_t - \Delta q_t - \pi_t^*] + \epsilon_t$$

2. IS Curve:

$$y_t = 0.047 + 0.795y_{t-1} - 0.015[i_t - \mathrm{E}_t\pi_{t+1}] + 0.040[\pi_t - \Delta q_t - \pi_t^*] + \eta_t$$

3. UIP Equation:

$$i_t = 0.519 + i_t^* + \mathrm{E}_t\Delta q_{t+1} - 0.045\Delta d_t + \sigma_t$$

4. Δd_t Equation:

$$\Delta d_t = 8.05 + 0.8077\pi_t + 2.6058y_t - 0.1464\Delta r_t + \delta_t$$

5. Long-Run Money Demand Equation:

$$\Delta m_t \;=\; 1.0539\pi_t \;+\; 1.6082y_t \;+\; 0.0078\Delta i_t \;+\; \chi_t$$

6. AR(1) Processes:

$$\pi_t^* \;=\; 0.9\pi_{t-1}^* \;+\; e_t$$

$$i_t^* \;=\; 0.9i_{t-1}^* \;+\; g_t$$

A2.3 Estimated RE Solutions

Our estimated RE solutions for Canada and Australia are reported in Tables A2.1 and A2.2, respectively. The sample average ρ_t value was approximated as the average value of $-\Delta r_t/\Delta q_t$.

A2.3 Derivation of Counterfactual Expectations

The counterfactual expression for $\mathrm{E}_t\pi_{t+3}$ given in (12) was obtained in the follwing manner. Using the results given in Table A2.1, $\mathrm{E}_t\pi_{t+3}$ may be expressed as

$$\begin{aligned}\mathrm{E}_t\pi_{t+3} \;=\; & -0.2306 \;+\; 1.0710\mathrm{E}_t\pi_{t+2} \;+\; 0.2375\mathrm{E}_t y_{t+2} \;-\; \mathrm{E}_t i_{t+2} \\ & -\; 0.0058\mathrm{E}_t i_{t+1} \;+\; 0.0033\mathrm{E}_t\Delta m_{t+2} \;+\; 0.0035\mathrm{E}_t\pi_{t+1} \\ & +\; 0.0058\pi_t \;-\; 0.0313\mathrm{E}_t\pi_{t+2}^* \;-\; 0.0044\mathrm{E}_t i_{t+2}^* \qquad \text{(A.11)}\end{aligned}$$

Using the results of the RE computations in Table A2.1 to substitute, successively, for the two-period-ahead expectations, and then, following that, the one-period-ahead expectations in (A.11) yields

$$\begin{aligned}\mathrm{E}_t\pi_{t+3} \;=\; & 0.0599 \;+\; 1.0710\pi_t \;+\; 0.6084y_t \;+\; 0.0166i_t \;-\; 0.0058\Delta m_t \\ & +\; 0.0256\pi_{t-1} \;+\; 0.0334\pi_{t-2} \;-\; 0.0334i_{t-1} \;-\; 0.3468\pi_t^* \;-\; 0.0216i_t^*. \qquad \text{(A.12)}\end{aligned}$$

Note that the estimated AR(1) processes for foreign inflation and foreign interest rates from Appendix 1 were used to solve for $\mathrm{E}_t\pi_{t+2}^*$ and $\mathrm{E}_t i_{t+2}^*$.The counterfactual three-period-ahead inflation expectation (12) is then obtained by replacing π_t, y_t, i_t, and Δm_t with the relevant counterfactual RE solutions given in Table A2.1.

An analogous procedure was used to obtain the counterfactual expression for $\mathrm{E}_t\Delta q_{t+1}$. First, the results in Table A2.1 were used to express $\mathrm{E}_t\Delta q_{t+1}$ in terms

TABLE A2.1

CANADA

Estimated Rational Expectations Solutions

average $\rho_t = 7.3351$

	π_t	y_t	Δq_t	i_t	Δm_t
const	−0.2545	0.4707	9.6427	−27.8360	2.7011
π_{t-1}	1.0867	−0.0865	−2.8082	7.5230	0.2980
y_{t-1}	0.2492	0.8842	−1.7702	4.4814	−0.2266
i_{t-1}	−0.0059	0.0028	0.1199	−0.2979	−0.0812
π_{t-2}	0.0041	−0.0006	−0.0213	−0.0481	0.0093
π_{t-3}	0.0064	0.0673	−0.1011	0.2509	−0.0204
i_{t-2}	−0.0064	−0.0673	0.1011	−0.2509	0.0204
π^*_{t-1}	−0.0323	0.0222	0.0655	−0.12030	−0.0199
i^*_{t-1}	−0.0079	0.0030	0.1285	0.7148	−0.0845
ϵ_t	1.1963	−0.0951	−3.0890	8.2997	0.3262
η_t	0.0918	0.9658	−1.4500	3.5999	−0.2920
σ_t	-0.0049	0.0028	0.1192	0.7235	-0.0824
χ_t	0.0173	−0.0208	−0.9207	3.2345	0.6714
δ_t	−0.0173	0.0208	0.9207	−3.2345	0.3286
e_t	−0.0359	0.0246	0.0728	−0.1337	−0.0221
g_t	−0.0087	0.0034	0.1428	0.7942	−0.0939

TABLE A2.2

AUSTRALIA

Estimated Rational Expectations Solutions

average $\rho_t = 0.3574$

	π_t	y_t	Δq_t	i_t	Δm_t
const	1.3539	0.6975	26.8543	28.2518	2.7689
π_{t-1}	0.8548	−0.0440	−0.8120	−0.8512	0.8234
y_{t-1}	0.3677	0.8634	2.4812	1.7740	1.7899
i_{t-1}	0.0009	0.0011	0.0284	0.0018	−0.0050
π^*_{t-1}	0.0547	0.0370	0.0741	0.1108	0.1181
i^*_{t-1}	−0.0081	−0.0149	−0.0637	0.8382	−0.0260
ϵ_t	0.9939	−0.0512	−0.9441	−0.9898	0.9575
η_t	0.2187	1.0984	3.3521	2.4739	2.0163
σ_t	-0.0041	−0.0179	−0.0804	0.9895	−0.0253
χ_t	−0.1201	−0.1405	−3.6346	−0.2284	0.6546
δ_t	0.1201	0.1405	3.6346	0.2284	0.3544
e_t	0.0608	0.0412	0.0823	0.1231	0.1312
g_t	−0.0090	−0.0166	−0.0708	0.9313	−0.0289

of current and lagged variables. Following this, the variables with period t dates were replaced with the appropriate counterfactual RE solutions reported in Table A2.1 resulting in the counterfactual one-period-ahead exchange rate expectation for Canada, given in (13). The same procedures, together with the results reported in Table A2.2, were used to compute the counterfactual expectations in (22), (23), (13) of the Australian model.