

Assessing exchange rate pass-through: A new empirical approach*

Christian M. Dahl[†]

Department of Economics
Krannert School of Management
Purdue University

Melody Lo

Department of Economics
University of
Southern Mississippi

July 19, 2005

Abstract

Recent work by Devereux, Engel, and Storgaard (2004, JIE, pp. 286), suggests that one of the key channels through which monetary policy may work is by changing the degree of pass-through. Inspired by this observation, we develop a unified estimation framework within a fully specified open macroeconomic model where both pass-through and exchange rates are endogenously determined so as to empirically assess the importance of exchange rate pass-through. We are able to identify and estimate economically meaningful long-run equilibrium conditions. Further, our empirical framework allows policymakers to precisely assess the extent of pass-through and identify the origin of pass-through in terms of economically interpretable impulses. We center the policy discussion on exchange rate management opted for a more stable domestic price level. Our empirical results indicate that there are relatively strong fundamentals motivating exchange rate control in order to achieve price stability. Finally, it is noticeable that the estimated effects of changes in money stock, exchange rate, price level movements, and other types of economic impulses are fully consistent with the theoretical predictions of the "classical" open macroeconomic modelling framework.

*The authors are grateful to John Carlson and Vera Brencic for helpful comments. The scientific notation follows the standard proposed by Abadir and Magnus (2002).

[†]Corresponding author. Address: 403 West State Street, Purdue University, West Lafayette, IN 47907-2056, USA. E-mail: dahlc@mgmt.purdue.edu. Phone: +1 765-494-4503. Fax: +1 765-496-1778.

The estimation framework we propose is relatively simple and could serve as a useful tool for central banks in assessing the extent of exchange rate pass-through.

Keywords: Small-open economy; price stability; exchange rate; (open) monetary policy; intervention; cointegration.

JEL classification: F41; F31; E31; E52; C51; C52.

1 Introduction

In international economics, the degree to which exchange rate movements are reflected in the domestic price level has been studied intensively. Central banks generally view the degree, commonly referred to in the literature as the exchange rate pass-through, as having important implications for their choice of exchange rate management and design of optimal monetary policy, see, e.g., Balliu and Bouakez (2004). With the universal regime shift in pursuing stable prices as the major goal of macroeconomic policies within the past decade, a key issue is whether and to what extent exchange rates might “destabilize” the domestic price level by serving as a channel to pass-through and aggravate the impact of various economic shocks. The relevance of this question arises because central banks typically can choose to respond to exchange rate fluctuations, hereby potentially offsetting undesirable impact that shocks may have on the domestic price level. This issue is of particular interest for many small-open economies, for example, in East Asia, Latin America, and Eastern Europe, where central banks have long been observed to control exchange rate through either currency board or government interventions. The purpose of this paper is to offer a useful framework for central banks to precisely assess both the extent and the origin of domestic price fluctuations passed through exchange rates. Such a framework facilitates that decisions on policy choices opted for more stable domestic price can be based on economic fundamentals.

Abundant empirical evidence has indicated that the exchange rate pass-through to either the import price or the consumer price index (CPI) is incomplete, see for

example Engel (1993), Engel and Rogers (1996), and Parsley and Wei (2001).¹² Motivated by these empirical findings, numerous theoretical arguments have been proposed to explain why pass-through is only partial, even in the long run. While researchers generally agree that it is the firms' pricing to market strategy that causes incomplete pass-through, it is still unclear whether producer-currency-pricing or local-currency-pricing (LCP) is more prevalent empirically. In recent years, attention has shifted towards understanding the linkage between the degree of exchange rate pass-through and the effectiveness of macroeconomic policies. Most recently, it has been suggested that exchange rate pass-through should be considered as endogenous with respect to the choices of macroeconomic policies. Taylor (2000) shows that a drop in the degree of exchange rate pass-through to CPI in many industrialized countries since the 1990s is the result of a relative stable price level being pursued successfully via monetary policy. Devereux, Engel, and Storgaard (2004) develop a model of endogenous exchange rate pass-through, in a general equilibrium framework, where exchange rate itself is endogenously determined. The main finding of their study is that countries with relatively stable monetary policies will tend to have a prevalence of LCP and thereby a smaller degree of pass-through. Furthermore, the authors conclude their study with a quite intriguing statement. On pp. 286, they write: "Our findings suggest that monetary policy analysis that takes the amount of pass-through as given misses one of the key channels through which monetary policy may work by changing the degree of pass-through."

In conjecture with the above statement by Devereux et al (2004), our paper emphasizes that "precise" identification/estimation of the magnitude of exchange rate pass-through based on a fully specified general equilibrium model is a fundamental step prior to the design of any effective macroeconomic policy. Without such knowledge it is practically infeasible for a policymaker to design and conduct any operation in order to set the exchange rate pass-through to the desirable level.

In contrast to previous studies that typically attempt to estimate exchange

¹The definition of exchange rate pass-through has evolved over time to include different types of prices other than import price, mostly CPI. The analysis of this paper will focus on exchange rate pass-through to CPI.

²See Goldberg and Knetter (1997) for a comprehensive review of earlier studies along this line of research.

rate pass-through using either a single reduced form equation or a VAR system, we will employ a structured economic model to identify possible interactions among macroeconomics variables. The major drawback of any reduced form approach is that it obscures the mechanism through which the exchange rate is affected by other macroeconomic variables. Our approach, on the other hand, enables us to attribute the origin of exchange rate pass-through to economically interpretable impulses. We are therefore able to draw policy implications toward exchange rate management based on our estimation framework.

Regarding the exchange rate management, a fundamental question to policy-makers in small open economies since the 1990s has been "Whether continuous manipulation of exchange rate conflicts with the goal of price stability?", or conversely, "To what extent, if any, manipulation of exchange rates may assist the goal of price stability?" In this paper, we propose that two fundamental economic channels need to be quantified in order to determine whether manipulation of exchange rates can help the goal of price stability. First, the impact on the domestic economy of foreign shocks passing through the exchange rate must be measured. We refer to this impact as the exchange rate pass-through effect. The motivation for examining the size of this impact is to initially determine whether policy-makers have an incentive to consider exchange rate management. Policymakers would only undertake exchange rate control when foreign shocks cause sufficiently large fluctuations in the domestic economy through their impacts on exchange rates. In order to identify the exchange rate pass-through effect, the impact of economic shocks on the domestic economy passing through the exchange rate channel needs to be completely separated from the effect passing through other channels in the economy. The framework presented in this study is developed to meet this need and we view the empirical identification/estimation of the pass-through effect of exchange rate changes to domestic inflation as an important contribution of the paper. Secondly, the impact of the change in the monetary stock on exchange rates has to be measured. The gain in terms of stabilizing the price level is possible only if the intervention operation (represented by a change in the money stock) affects exchange rates.³ Although, the theoretical arguments

³It is still an open question whether sterilized interventions can affect exchange rates. The exclusive theoretical agreement is that interventions, if not sterilized fully, can have long-lasting impacts on exchange rates since they change the money supply, see, Mussa (1988). In our

for considering the magnitude of these two impacts are already well established, see, e.g., Hodgman and Wood (1989), no persuasive empirical evidence has yet been provided.

As our interest primarily is towards small-open economies, we specify an open economy stochastic equilibrium model, which is in the tradition of the classical Mundell-Flemming model. We argue that the structure imposed by the theoretical framework and the trended nature of the variables entering the model, facilitate the use of cointegration analysis for estimation purposes. Conditional on Taiwan/US as domestic/foreign sectors, we demonstrate how one can use the proposed framework to study the size of the pass-through effects and variety of policy issues that are essential to policymakers in small-open economies. We preview two principal findings here. First, the exchange rate pass-through effect from a foreign interest rate shock to the domestic price level is of a considerable size. In particular, most of the impact on the domestic price level from a foreign interest rate shock is transmitted through exchange rates rather than through other types of economic channels. Secondly, a change in the monetary stock, representing either non-sterilized interventions or open market operations has the capacity of affecting exchange rates relative more than the domestic price level. These results suggest that the policy makers in small-open economies are motivated by strong fundamentals when managing exchange rates in pursuit of stabilization of the price level. Overall, the results from our empirical model are fully consistent with traditional monetary theory.

The paper is organized as follows. Section 2 describes the fully specified general equilibrium macroeconomic model used and presents the key equations for policy analysis. Section 3 outlines the econometric framework. Section 4 presents estimation results, and provides a discussion of the various policy issues of interest. Finally, Section 5 concludes and suggests directions for future research.

analysis, change in money stock can be interpreted as the result of government interventions in foreign exchange markets.

2 Theoretical background

2.1 A standard macroeconomic model for a small-open economy

To examine the role of exchange rates in passing through the effect of various economic impulses, we set up a standard stochastic general equilibrium model. The small-open economy consists of three markets: The goods market, the money market, and the international financial market, given as

$$\text{Goods market} \quad : \quad Y_t = -a_2 r_t - a_3 (E_t + P_t - P_t^*) + u_{21t}, \quad (1)$$

$$\text{Money market} \quad : \quad M_t - P_t = b_1 Y_t - b_2 i_t + u_{22t}, \quad (2)$$

$$\text{Int. financial market} \quad : \quad i_t - i_t^* = \theta (E_t - \bar{E}) + u_{23t}, \quad (3)$$

where all variables except interest rates are in natural logarithms and variables with asterisk represent the foreign sector. Variables with bars denotes equilibrium levels.⁴ Subscript t denotes time. The definitions of the variables are as follows: Y is the real output level; i and r are the nominal and real interest rates, respectively; E is the nominal exchange rate, which is foreign price of domestic currency; P is the price level; M is the money stock; u_{21t} , u_{22t} , u_{23t} are stochastic disturbances in domestic goods market, money market, and international financial market, respectively.⁵ Furthermore, in equations (1) to (3), all parameters are restricted to be positive.

It is assumed that the Fisher relation holds domestically as well as in the foreign economy and that agents form "some degree" of rational expectations with respect to their inflation forecasts, i.e.,

$$\pi_t^e = \omega_1 (\bar{P} - P_t), \text{ and } \pi_t^{e*} = \omega_2 (\bar{P}^* - P_t^*), \quad (4)$$

$$r_t = i_t - \pi_t^e \text{ and } r_t^* = i_t^* - \pi_t^{e*}, \quad (5)$$

for $(\omega_1, \omega_2) \in ([0; 1], [0; 1])$, where π_t^e is expected inflation rate (from period t to $t + 1$), formed in period t . With $\omega_i \in [0; 1]$, $i = 1, 2$, the forecast of next period's price is a weighted average of the current price level and the equilibrium price level. To see this, let $P_{t+1,t}^e$ denote the agents' forecast of the price level for period $t + 1$, formed in period t . Then, $P_{t+1,t}^e - P_t = \pi_t^e = \omega_1 (\bar{P} - P_t)$, and consequently

⁴In the empirical part, all equilibrium levels are allowed to be time varying.

⁵Equation (3) is an equilibrium condition wrt. the international financial market for short term bonds.

$P_{t+1,t}^e = (1 - \omega_1)P_t + \omega_1\bar{P}$. Further, if $\omega_1 = 0$, then $P_{t+1,t}^e = P_t$, implying that the current price level is expected to remain constant, because agents' expectations in this case are fully adaptive. On the other hand, if $\omega_1 = 1$, then $P_{t+1,t}^e = \bar{P}$, indicating that the long-run equilibrium price is expected to be realized in period $t + 1$, which is consistent with fully rationally formed expectations.⁶ Finally, it is assumed that the foreign price level and foreign interest rates are determined exogenously, hence $P_t^* = \bar{P}^* + u_{14t}$ and $i_t^* = \bar{i}^* + u_{15t}$, where u_{14t} and u_{15t} denote disturbances to the foreign price and foreign interest rate, respectively.

Equation (1) is an open economy IS relation where the real exchange rate ($E_t + P_t - P_t^*$) and the real interest rate jointly determine the demand for domestic output. As in McCallum (1994), we adopt the classical view assuming that prices are perfectly flexible, such that Y_t continuously reaches its full employment level, \bar{Y} . The reason for choosing the classical view is primarily for the sake of simplicity.⁷ Furthermore, the data available for our empirical analysis - involving Taiwan as the domestic country - covers only the period after the 1980s. During this sample period, supply shocks seem to be very limited (absent) in the Taiwanese domestic economy and consequently the aggregate supply schedule can be omitted from the model without affecting the empirical results.

Equation (2) is the domestic money demand equation describing the domestic monetary equilibrium condition, since money supply is considered exogenous and determined by the monetary authorities. An increasing tendency in monetary analysis has been to exclude the money stock. This is due to the common belief that actual central bank behavior is well modelled by a policy rule that sets the interest rate as a function of output, inflation, and possibly exchange rates, see, e.g., Rotemberg and Woodford (1997). Despite this argument, we include a conventional monetary aggregate (M) in the analysis for two reasons. First, Leeper and Roush (2003) empirically identify that as long as money demand is not interest inelastic, money stock and interest rate would jointly transmit monetary policy in the postwar US economy. Consequently, ignoring the money stock in

⁶It can be shown in the Muthian sense that, for a static model with independent distributed disturbances, the equilibrium price level (\bar{P}) is the rational expectation forecast when $\omega_1 = 1$: $\zeta_t(P_{t+1}) = P_{t+1,t}^e = \bar{P}$, where ζ_t is the conditional expectations operator at time t .

⁷For interested readers, all derivations in the present theoretical framework with an added aggregate supply schedule are available from the authors upon request.

the empirical analysis, may result in a downward bias of the measured effects of monetary policy on output and inflation levels. Secondly, including a monetary aggregate in the model motivates a discussion/analysis of the use of government interventions in the foreign exchange markets. This seems particularly relevant to many policy makers in small-open economies, since the most common instrument in exchange rate management after the breakdown of Bretton Woods has been interventions, see, Mussa (1988). In this study, we will interpret the change in M as the result of either a domestic open market operation, a non-sterilized intervention, or a combination of the two operations.

We note that our equation (3) is very similar to the standard uncovered interest rate parity (UIP) condition where θ is restricted to be equal to one. In the existing literature, finding evidence to support the existence of traditional UIP condition appears to be a common difficulty.⁸ Osler (1998) shows that partial adjustments in exchange rates can occur when rational short-term speculators such as commercial banks or fund managers exist in the market. This is because speculators would limit the initial impact of a one-time shock to exchange rates in the current period. To implicitly account for the possible existence of these short-term speculators in exchange markets, we avoid the restriction $\theta = 1$, and consider instead a wider range of possible values of θ by assuming that $0 < \theta \leq 1$. Notice that a disturbance term, u_{23t} , is included in equation (3), mainly to capture unsystematic sources of variation such as time varying aggregation and risk premie.

2.2 Three key equations for policy implications

Since our primary concern is on how various economic impulses move the domestic price level away from its equilibrium, we will in what follows express all variables in equilibrium level deviations, i.e., $p_t = P_t - \bar{P}$, $e_t = E_t - \bar{E}$, $m_t = M_t - \bar{M}$, etc.

⁸A survey paper by Froot and Thaler (1990) finds that about 75% of UIP studies cannot even support a positive coefficient of θ and that the average estimated θ is about -0.88 . Some recent studies have argued that the apparent failure of the UIP condition may be due to the lack of consideration of interactions among interest rates, exchange rates, and other economic variables, such as the price level, see, e.g., McCallum (1994), Gordon and Leeper (1994), and Juselius (1995). This argument further motivates specification of a complete general equilibrium model where such interactions among many key macro economic variables can be well accounted for.

Three equations, derived from the model (1)-(3) in Appendix A, are of particular interest and are given as

$$p_t = \frac{b_2\theta u_{21t} - (a_3 + a_2\theta)u_{22t} + a_3b_2u_{23t} + a_3b_2\theta u_{14t} + a_3b_2u_{15t}}{a_2\theta + a_3 + b_2\theta(a_3 + a_2\omega_1)} \quad (6)$$

$$+ \frac{(a_3 + a_2\theta)}{a_2\theta + a_3 + b_2\theta(a_3 + a_2\omega_1)} m_t,$$

$$e_t = \frac{u_{21t} + (a_3 + a_2\omega_1)u_{22t} - (a_2 + (a_3 + a_2\omega_1)b_2)(u_{23t} + u_{15t}) + a_3u_{14t}}{a_2\theta + a_3 + b_2\theta(a_3 + a_2\omega_1)} \quad (7)$$

$$- \frac{(a_3 + a_2\omega_1)}{a_2\theta + a_3 + b_2\theta(a_3 + a_2\omega_1)} m_t,$$

and

$$p_t = \frac{-(a_2\theta + a_3)}{a_3 + a_2\omega_1} e_t + \frac{u_{21t} + a_3u_{14t} - a_2u_{23t} - a_2u_{15t}}{a_3 + a_2\omega_1}. \quad (8)$$

We refer to equations (6) and (7) as the price deviation and exchange-rate deviation equations. They determine to what extent changes in the monetary stock as well as a wide range of unanticipated impulses can cause the domestic price and the exchange rate to deviate from equilibrium levels. Combining (6) and (7) results in (8), which is termed the trade-off equation, as it implies that a decrease in the exchange rate (below its equilibrium level) is associated with an increase in the domestic price level (above its equilibrium level). Equation (8) is important, as it can be used to distinguish impacts on the domestic price level transmitted through the exchange rate from those transmitted through other channels. In particular,

$$\frac{\partial p_t}{\partial s_t} = \frac{-(a_2\theta + a_3)}{a_3 + a_2\omega_1} \frac{\partial e_t}{\partial s_t} + \frac{1}{a_3 + a_2\omega_1} \left(\frac{\partial(u_{21t} + a_3u_{14t} - a_2u_{23t} - a_2u_{15t})}{\partial s_t} \right), \quad (9)$$

where s_t denotes a given impulse. The first term on the right hand side of equation (9) identifies the size of the exchange rate pass through effect, while the second term quantifies the impact that is transmitted through other channels.

3 The econometric modelling framework

In order to measure and compare the impact of various impulses on domestic price and exchange rate we need to obtain consistent estimates of the unknown

parameters which enter the model given by the model (1)-(3). For this purpose it is of great importance to first identify and characterize the stochastic properties of the model and the underlying variables. As will be discussed later, evidence indicates that all the variables entering the model contain unit roots and exhibit strong short and long run serial (inter-) dependencies. Therefore the cointegration methodology appears appropriate. The first part of this section is aimed at deriving and identifying an empirical estimable representation of the equations (6) and (7) in the presence of non-stationary and possible cointegrated time series. The second part discusses and presents some estimation procedures that can easily be implemented in standard statistical/econometric software packages.

3.1 Empirical representation of the trade-off equations

First, we consider re-writing the structured model (1)-(3) so it becomes suitable for estimation. Let $\mathbf{u}_{2t} = (u_{21t}, u_{22t}, u_{23t})'$ denote the vector of residuals. Define $\mathbf{x}_t = (\mathbf{x}'_{1t}, \mathbf{x}'_{2t})'$, where $\mathbf{x}_{1t} = (r_t, E_t, P_t, P_t^*, i_t^*)'$ and $\mathbf{x}_{2t} = (Y_t, M_t, i_t)'$. Assuming that all the variables entering \mathbf{x}_t individually have unit roots, equations (1)-(3) can be characterized as long run equilibrium conditions if and only if $\beta \mathbf{x}_t$ is stationary, for the cointegrating vectors $\beta = [\beta_1 : \beta_2]$, where

$$\beta = \left[\begin{array}{c} \left[\begin{array}{ccccc} a_2 & a_3 & a_3 & -a_3 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & -\theta & 0 & 0 & -1 \end{array} \right] : \left[\begin{array}{ccc} 1 & 0 & 0 \\ -b_1 & 1 & b_2 \\ 0 & 0 & 1 \end{array} \right] \end{array} \right]. \quad (10)$$

If the inverse of β_2 exists, the cointegrating vectors can be obtained as $\beta_2^{-1} \beta = [\beta_2^{-1} \beta_1 : \mathbf{I}_{n_2}] = [-\Gamma : \mathbf{I}_{n_2}]$ where

$$-\beta_2^{-1} \beta_1 = \Gamma = \begin{bmatrix} -a_2 & -a_3 & -a_3 & a_3 & 0 \\ -b_1 a_2 & -b_1 a_3 - b_2 \theta + b_2 \theta & -b_1 a_3 + 1 & b_1 a_3 & -b_2 \\ 0 & \theta & 0 & 0 & 1 \end{bmatrix}.$$

By using this particular normalization we can write model (1)-(3) in Phillips' (1991) triangular form as

$$\mathbf{x}_{1t} = \mathbf{d}_{1t} + \mathbf{x}_{1t-1} + \mathbf{u}_{1t}, \quad (11)$$

$$\mathbf{x}_{2t} = \mathbf{d}_{2t} + \Gamma \mathbf{x}_{1t} + \beta_2^{-1} \mathbf{u}_{2t}, \quad (12)$$

where \mathbf{d}_{1t} and \mathbf{d}_{2t} are vectors that include deterministic terms.⁹ To maintain full flexibility, let $\mathbf{\Omega} = \mathbf{f}_{uu}(0)$ be a full rank spectral density for $\mathbf{u}_t = (\mathbf{u}'_{1t}, (\beta_2^{-1}\mathbf{u}_{2t})')'$, such that $\mathbf{u}_t = \text{w.d.}(\mathbf{0}, \mathbf{\Omega})$, where $\mathbf{\Omega}$ can be interpreted as an unconstrained long run covariance matrix with possible non-zero off-diagonal entries.¹⁰ This degree of generality implies that cross correlation between \mathbf{u}_{1t} and \mathbf{u}_{2t} cannot be ruled out a priori and $\mathbf{\Gamma}$ therefore cannot be estimated properly simply using OLS on equation (12). Furthermore, the possible correlation between \mathbf{u}_{1t} and \mathbf{u}_{2t} makes it impossible to interpret, say, u_{22t} as a direct (or orthogonal) shock to the domestic money market. It might be a direct/orthogonal shock, say, to foreign interest rate u_{15t} that affects the money market through u_{22t} . We would like to be able to make such a distinction. Following Saikkonen (1991), and Phillips and Loretan (1991) we define \mathbf{u}_{2t}^\diamond to be the residual of a projection of \mathbf{u}_{2t} on $B(L)\mathbf{u}_{1t}$, where $B(L)$ is a two-sided polynomial lag-operator such that

$$\mathbf{u}_{2t} = B(L)\mathbf{u}_{1t} + \mathbf{u}_{2t}^\diamond. \quad (13)$$

By definition, (13) implies that $E(\mathbf{u}_{1it}\mathbf{u}_{2jt}^\diamond) = 0$, for all $t = 1, 2, \dots, T$, $i = 1, 2, \dots, 5$, and $j = 1, 2, 3$. Typically, \mathbf{u}_{2t}^\diamond will be serially correlated and accordingly we will assume that $\beta_2^{-1}\mathbf{u}_{2t}^\diamond = \text{w.d.}(\mathbf{0}, \mathbf{\Omega}_2^\diamond)$, where $\mathbf{\Omega}_2^\diamond$ is the long-run variance-covariance matrix. In particular, if $\boldsymbol{\eta}_{2t} \sim \text{i.i.d.}(\mathbf{0}, \mathbf{A}_2)$, we can write

$$\begin{aligned} \beta_2^{-1}\mathbf{u}_{2t}^\diamond &= \boldsymbol{\Psi}_2(L)\boldsymbol{\eta}_{2t} \\ &= \boldsymbol{\Psi}_2(L)\mathbf{A}_2^{\frac{1}{2}}\boldsymbol{\varepsilon}_{2t}, \end{aligned} \quad (14)$$

for $\boldsymbol{\varepsilon}_{2t} \sim \text{i.i.d.}(\mathbf{0}_3, \mathbf{I}_3)$ and interpret ε_{21t} , ε_{22t} , and ε_{23t} as orthogonal shocks to the goods market, the money market, and the international financial market, respectively. Consequently, $\mathbf{\Omega}_2^\diamond = \boldsymbol{\Psi}_2(1)\mathbf{A}_2\boldsymbol{\Psi}_2(1)'$, and by defining $\mathbf{A}\mathbf{A}' = \mathbf{\Omega}_2^\diamond$, the asymptotic relationship between \mathbf{u}_{2t}^\diamond and $\boldsymbol{\varepsilon}_{2t}$ can be obtained empirically using a HAC estimator of $\mathbf{\Omega}_2^\diamond$, see, e.g., Newey and West (1987) or Andrews and Monahan (1992).¹¹ Similarly, we let $\mathbf{u}_{1t} = \text{w.d.}(\mathbf{0}, \mathbf{\Omega}_1)$ and write $\mathbf{u}_{1t} = \boldsymbol{\Psi}_1(L)\boldsymbol{\eta}_{1t} = \boldsymbol{\Psi}_1(L)\mathbf{A}_1^{\frac{1}{2}}\boldsymbol{\varepsilon}_{1t}$, for $\boldsymbol{\eta}_{1t} \sim \text{i.i.d.}(\mathbf{0}, \mathbf{A}_1)$, and $\boldsymbol{\varepsilon}_{1t} \sim \text{i.i.d.}(\mathbf{0}_5, \mathbf{I}_5)$. The long run variance-covariance matrix $\mathbf{\Omega}_1$ can then be defined as $\mathbf{\Omega}_1 = \boldsymbol{\Psi}_1(1)\mathbf{A}_1\boldsymbol{\Psi}_1(1)'$ with $\mathbf{P}'\mathbf{P} = \mathbf{\Omega}_1$. Again, estimates of \mathbf{P} can be obtained from a HAC estimator of

⁹Note, that the equilibrium levels of the variables, i.e., $\bar{\mathbf{x}}$, enter the deterministic terms.

¹⁰Weak dependence is abbreviated as w.d.

¹¹HAC: Heteroskedasticity and Autocorrelation Consistent.

Ω_1 . According to the definition of \mathbf{x}_{1t} we will interpret $\epsilon_{11t}, \epsilon_{12t}, \epsilon_{13t}, \epsilon_{14t}$, and ϵ_{15t} as orthogonal shocks to real interest rate, exchange rate, domestic price, foreign price, and foreign short term interest rate, respectively. It should be noted, that since \mathbf{A} and \mathbf{P} are Choleski decompositions of Ω_2° and Ω_1 respectively, hence lower/upper triangular matrices, the ordering of the variables in \mathbf{x}_{2t} and \mathbf{x}_{1t} matters. We performed the empirical analysis using alternative orderings. However, this did not alter the main conclusions in any economically significant way.¹²

Following the procedure outlined above, it is now possible to obtain a decomposition of \mathbf{u}_{2t} into the 8 different types of orthogonal impulses/shocks summarized by $\boldsymbol{\varepsilon}_{1t}$ and $\boldsymbol{\varepsilon}_{2t}$. Pre-multiplying equation (13) by β_2^{-1} gives

$$\beta_2^{-1}\mathbf{u}_{2t} = \beta_2^{-1}\mathbf{B}(L)\mathbf{u}_{1t} + \beta_2^{-1}\mathbf{u}_{2t}^\circ, \quad (15)$$

and by defining $\tilde{\mathbf{B}}(L) = \beta_2^{-1}\mathbf{B}(L)$, $\tilde{\mathbf{u}}_{2t}^\circ = \beta_2^{-1}\mathbf{u}_{2t}^\circ$, and $\tilde{\mathbf{d}}_{2t} = \beta_2^{-1}(\mathbf{d}_{2t} - \mathbf{B}(1)\mathbf{d}_{1t})$, \mathbf{u}_{2t} can be written as

$$\mathbf{u}_{2t} = \beta_2\tilde{\mathbf{B}}(1)\mathbf{P}\boldsymbol{\varepsilon}_{1t} + \beta_2\mathbf{A}\boldsymbol{\varepsilon}_{2t}. \quad (16)$$

From expanding the first and second term in (16) we get

$$\begin{aligned} \beta_2\tilde{\mathbf{B}}(1)\mathbf{P}\boldsymbol{\varepsilon}_{1t} &= \begin{bmatrix} \sum_{i=1}^5 \sum_{j=i}^5 \tilde{b}_{1i}p_{ij}\epsilon_{1jt} \\ \sum_{i=1}^5 \sum_{j=i}^5 \left(-b_1\tilde{b}_{1i} + \tilde{b}_{2i} + b_2\tilde{b}_{3i}\right)p_{ij}\epsilon_{1jt} \\ \sum_{i=1}^5 \sum_{j=i}^5 \tilde{b}_{3i}p_{ij}\epsilon_{1jt} \end{bmatrix}, \\ \beta_2\mathbf{A}\boldsymbol{\varepsilon}_{2t} &= \begin{bmatrix} a_{11}\epsilon_{21t} \\ (-b_1a_{11} + a_{21} + b_2a_{31})\epsilon_{21t} + (a_{22} + b_2a_{32})\epsilon_{22t} + b_2a_{33}\epsilon_{23t} \\ a_{31}\epsilon_{21t} + a_{32}\epsilon_{22t} + a_{33}\epsilon_{23t} \end{bmatrix}, \end{aligned}$$

¹²Notice, that \mathbf{A} is a lower triangular matrix whereas \mathbf{P} is an upper triangular matrix. The reason is that orthogonal domestic shocks should not have any contemporaneous effect on P_t^* and i_t^* .

and consequently

$$\begin{bmatrix} u_{21t} \\ u_{22t} \\ u_{23t} \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^5 \sum_{j=i}^5 \tilde{b}_{1i} p_{ij} \epsilon_{1jt} + a_{11} \epsilon_{21t} \\ \sum_{i=1}^5 \sum_{j=i}^5 \left(-b_1 \tilde{b}_{1i} + \tilde{b}_{2i} + b_2 \tilde{b}_{3i} \right) p_{ij} \epsilon_{1jt} \\ \quad + (-b_1 a_{11} + a_{21} + b_2 a_{31}) \epsilon_{21t} \\ \quad + (a_{22} + b_2 a_{32}) \epsilon_{22t} + b_2 a_{33} \epsilon_{23t} \\ \sum_{i=1}^5 \sum_{j=i}^5 \tilde{b}_{3i} p_{ij} \epsilon_{1jt} + \sum_{i=1}^3 a_{3i} \epsilon_{2it} \end{bmatrix}. \quad (17)$$

The long run decomposition of \mathbf{u}_{1t} into orthogonal shock is given by

$$u_{1it} = \sum_{j=i}^5 p_{ij} \epsilon_{1jt}, \quad (18)$$

for $i = 1, 2, \dots, 5$. By inserting (17) and (18) in (7), the exchange rate relation can be expressed in terms of the orthogonal shocks as

$$e_t = \sum_{i=1}^5 \left(\frac{S_i}{D} \right) \epsilon_{1it} + \sum_{j=1}^3 \left(\frac{\rho_j}{D} \right) \epsilon_{2jt} - \left(\frac{S_1}{D} \right) m_t,$$

where $S_1 = (a_3 + a_2 \omega_1)$, $D = a_2 \theta + a_3 + b_2 \theta S_1$, $n_j = (-b_1 \tilde{b}_{1j} + \tilde{b}_{2j} + b_2 \tilde{b}_{3j})$, $l_j^e = (\tilde{b}_{1j} + n_j - (a_2 + S_1 b_2) \tilde{b}_{3j})$, $\varsigma_i = \sum_{j=1}^i l_j^e p_{j3}$, for $i=1, 2, 3$, $\varsigma_4 = \sum_{j=1}^4 l_j^e p_{j4} + a_3 p_{44}$, $\varsigma_5 = \sum_{j=1}^5 l_j^e p_{j5} + a_3 p_{45} - (a_2 + S_1 b_2) p_{55}$, $\rho_1 = a_{11}(1 - b_1 S_1) + a_{21} S_1 - a_{31} a_2$, $\rho_2 = a_{22} S_1 - a_{32} a_2$ and $\rho_3 = -a_{33} a_2$. Similarly, the domestic price level relation becomes

$$p_t = \sum_{i=1}^5 \left(\frac{\zeta_i}{D} \right) \epsilon_{1it} + \sum_{j=1}^3 \left(\frac{\vartheta_j}{D} \right) \epsilon_{2jt} + \left(\frac{S_2}{D} \right) m_t,$$

where $S_2 = (a_3 + a_2 \theta)$, $l_j^p = (b_2 (\tilde{\theta} \tilde{b}_{1j} + a_3 \tilde{b}_{3j}) - S_2 n_j)$, $\zeta_i = \sum_{j=1}^i l_j^p p_{j3}$, for $i=1, 2, 3$, $\zeta_4 = \sum_{j=1}^4 l_j^p p_{j4} + a_3 b_2 \theta p_{44}$, $\zeta_5 = \sum_{j=1}^5 l_j^p p_{j5} + a_3 b_2 (\theta p_{45} + p_{55})$, $\vartheta_1 = (b_2 \theta + S_2 b_1) a_{11} - a_{21} S_2 - b_2 a_{31} \theta a_2$, $\vartheta_2 = -(a_{22} S_2 + b_2 a_{32} \theta a_2)$, and $\vartheta_3 = -b_2 a_{33} \theta a_2$.

3.2 Estimation

In order to obtain estimates of the unknown parameters that enter the right hand side of (17) and (18) we propose a simple two-step estimation procedure. First, the restricted estimate of β (denoted $\hat{\beta}^c$) in equation (10) is obtained using

the likelihood procedures described by Doornik (1995) and Boswijk and Doornik (2003).¹³ Secondly, after having obtained $\widehat{\Gamma}^c$ as described in Section 3.1, (11)-(12) can be represented as

$$\mathbf{x}_{2t} - \widehat{\Gamma}^c \mathbf{x}_{1t} = \widetilde{\mathbf{d}}_{2t} + \widetilde{\mathbf{B}}(L) \Delta \mathbf{x}_{1t} + \widetilde{\mathbf{u}}_{2t}^\circ, \quad (19)$$

using (15). From (19) it is possible to obtain the least squares estimates of $\widetilde{\mathbf{B}}(L)$ and $\widetilde{\mathbf{u}}_{2t}^\circ$ and subsequently estimates of $\widetilde{\mathbf{B}}(1)$ and \mathbf{A} . Finally, notice that an estimate of \mathbf{u}_{1t} can be obtained as

$$\widehat{\mathbf{u}}_{1t} = \Delta \mathbf{x}_{1t} - \widehat{\mathbf{d}}_{1t},$$

where $\widehat{\mathbf{d}}_{1t}$ is computed by equation-by-equation (SUR) least squares. From $\widehat{\mathbf{u}}_{1t}$ the estimate of \mathbf{P} is produced using a HAC estimate of $\boldsymbol{\Omega}_1$.¹⁴ To obtain an estimate of ω_1 let ν_t denote an i.i.d. expectation error and substitute π_t^e with $\pi_t + \nu_t$ in the expectation formation expression and notice that

$$(\pi_t + \nu_t) - (\pi_{t-1} + \nu_{t-1}) = \omega_1(p_t - p_{t-1}). \quad (20)$$

From (20) a consistent estimate of ω_1 can be obtained from a least squares regression of $\pi_t - \pi_{t-1}$ on π_{t-1} where a sufficient number of lags of $\pi_t - \pi_{t-1}$ are included to eliminate serial dependencies in the residuals.¹⁵

4 Empirical results and policy implications

Taiwan is used as an illustrative case study and serves as the small-open domestic economy. We use the United States to represent the foreign sector and to serve the role as the foreign sector relative to Taiwan. Using Taiwan/US as domestic/foreign sectors seems a natural choice for a number of reasons. First, Taiwan is an economy that strictly pursues price stability through monetary operations. The evidence of this claim comes from Taiwanese central bank itself. The Taiwanese central bank management regulations clearly state that “*Among*

¹³The procedures used by Doornik (1995) and Boswijk and Doornik (2003) are implemented in Ox/Pcgive and very easy accessible. Alternatively, the method proposed by Elliott (2000) could be applied.

¹⁴In particular, we used the Newey-West (1987) HAC estimator of $\boldsymbol{\Omega}_2^\circ$ and $\boldsymbol{\Omega}_1$, based on the Bartlett kernel truncated at $q = 4$, see, e.g., equation [10.5.15] pp. 281 in Hamilton (1994).

¹⁵All the software developed for this paper is available from the authors upon request.

all economic targets, maintaining domestic price stability is the Taiwanese central bank's priority economic target." Secondly, Taiwan also is a very open economy. The ratio of Taiwan's exports plus imports to GDP has been in the range from 72 to 93 percent from 1985 to 2000. A major portion of that trade has been with the U.S. This explains why Taiwanese monetary authorities regularly claim that they intervene in response to external shocks mainly from the U.S. to keep the US\$/NT\$ exchange rate within its desirable range. Because Taiwan is relatively small and open to the U.S. and the Taiwanese external policy are used to respond to mostly U.S. shocks, it is reasonable to regard U.S. as an exclusive foreign sector.

The quarterly data used (all except interest rates and expected inflation rates are in logarithms) are as follows: Taiwan consumer price index (P_t), U.S. consumer price index (P_t^*), exchange rate of US\$/NT\$ (E_t), Taiwan 6-month interest rates on loans (i_t), U.S. 6-month Treasury bill rate (i_t^*), Taiwan M2 (M_t), and Taiwan real GDP (Y_t). U.S. data is taken from the International Financial Statistics (IMF) while the data on Taiwan is obtained from the Taiwanese central bank. The available period of data is from the first quarter of 1982 to (and including) the fourth quarter of 2000. This sample period covers Taiwan's floating exchange-rate system. Within the sample period, there was a shift in the monetary policy. At the beginning of 1990, the Taiwanese monetary authorities dramatically tightened the monetary conditions to depress the asset bubbles in the financial markets. We account for this regime shift by including a shift dummy $I_{\{t \geq 1989.4\}}$ which equals one if $t \geq 1989.4$, and is zero otherwise.

We specify a VAR(2) model for \mathbf{x}_t , treating $(P_t^*, i_t^*)'$ as weakly exogenous variables, with unrestricted deterministic variables $(1, I_{\{t \geq 1989.4\}})'$ and a restricted trend (t). Based on Augmented Dickey-Fuller (ADF) tests on each component of \mathbf{x}_t , it is not possible to reject $H_0 : \mathbf{x}_t \sim I(1)$.¹⁶ We assume that the cointegrating rank is given by $r_{CI} = 3$, although the evidence reported in Table 1 is somewhat mixed.

The restricted maximum likelihood estimates (standard errors in parenthesis) and the likelihood ratio test statistic (p-value in brackets) for overidentifying

¹⁶The results on the ADF tests are not reported, but can be obtained from the authors upon request

Table 1: Test statistics and associated p-values for cointegrating rank in the Johansen (1988) framework. The listed p-values is based on Doornik (1998). Testing commences at $r_{CI} = 0$ and stops at the first insignificant statistics.

λ_i	Null	Alt.	$\lambda_{(max)}$	Null	Alt.	Trace
0.484	$r_{CI} = 0$	$r_{CI} = 1$	46.39 [0.026]	$r_{CI} = 0$	$r_{CI} \geq 1$	156.22 [0.000]
0.385	$r_{CI} = 1$	$r_{CI} = 2$	34.04 [0.146]	$r_{CI} \leq 1$	$r_{CI} \geq 2$	109.83 [0.000]
0.319	$r_{CI} = 2$	$r_{CI} = 3$	26.93 [0.194]	$r_{CI} \leq 2$	$r_{CI} \geq 3$	75.79 [0.003]
0.305	$r_{CI} = 3$	$r_{CI} = 4$	25.51 [0.052]	$r_{CI} \leq 3$	$r_{CI} \geq 4$	48.86 [0.010]
0.224	$r_{CI} = 4$	$r_{CI} = 5$	17.83 [0.082]	$r_{CI} \leq 4$	$r_{CI} \geq 5$	23.35 [0.099]
0.075	$r_{CI} = 5$	$r_{CI} = 6$	5.51 [0.535]	$r_{CI} \leq 5$	$r_{CI} = 6$	5.51 [0.534]

restrictions are obtained as

$$\hat{\beta}^c = \left[\begin{array}{ccccc} 12.590 & 0.822 & 0.822 & -0.822 & 0 \\ (2.442) & (0.487) & (0.487) & (0.487) & \\ 0 & 0 & -1 & 0 & 0 \\ 0 & -0.037 & 0 & 0 & -1 \\ (0.027) & & & & \end{array} \right] : \left[\begin{array}{ccc} 1 & 0 & 0 \\ -4.367 & 1 & 6.044 \\ (0.550) & & (1.023) \\ 0 & 0 & 1 \end{array} \right],$$

$$LR = 17.489 [0.09].$$

All the signs of the entries in $\hat{\beta}^c$ are as predicted by the theoretical model and given a p-value of 0.09. Thus, the restrictions imposed on the VAR(2) representation by our economic model cannot be rejected at a 5% significance level. This result indicates that entire structured model is consistent with the data and is appropriate for further policy implications. Conditional on $\hat{\beta}^c$, $\hat{\omega}_1 = 0.510$, assuming that $B(L) = \sum_{s=-4}^4 B_s$, $\tilde{\mathbf{d}}_{1t} = (\tilde{d}_{11}, \tilde{d}_{12}I_{\{t \geq 1989.4\}}, \tilde{d}_{13t})'$, and $\tilde{\mathbf{d}}_{2t} = (\tilde{d}_{21}, \tilde{d}_{22}I_{\{t \geq 1989.4\}}, \tilde{d}_{23t})'$ we obtain the following estimates of equation (6) and (7)

$$p_t = 0.4518m_t + \begin{bmatrix} 0.0579 \\ -0.0351 \\ 0.0208 \\ -0.0069 \\ 0.0648 \end{bmatrix}' \begin{bmatrix} \epsilon_{11t} \\ \epsilon_{12t} \\ \epsilon_{13t} \\ \epsilon_{14t} \\ \epsilon_{15t} \end{bmatrix} + \begin{bmatrix} 0.0157 \\ -0.0589 \\ -0.0073 \end{bmatrix}' \begin{bmatrix} \epsilon_{21t} \\ \epsilon_{22t} \\ \epsilon_{23t} \end{bmatrix}, \quad (21)$$

$$e_t = -2.5213m_t + \begin{bmatrix} -0.0763 \\ 0.3071 \\ -0.4123 \\ 0.2071 \\ -0.2282 \end{bmatrix}' \begin{bmatrix} \epsilon_{11t} \\ \epsilon_{12t} \\ \epsilon_{13t} \\ \epsilon_{14t} \\ \epsilon_{15t} \end{bmatrix} + \begin{bmatrix} 0.0768 \\ 0.3919 \\ -0.0335 \end{bmatrix}' \begin{bmatrix} \epsilon_{21t} \\ \epsilon_{22t} \\ \epsilon_{23t} \end{bmatrix}, \quad (22)$$

where $\epsilon_{11t}, \dots, \epsilon_{15t}$ and $\epsilon_{21t}, \dots, \epsilon_{23t}$ are as described in Section 3.1 and summarized in Table 2. The two estimated relations give a complete set of quantitative implications regarding how domestic price and exchange rate respond to changes in the money stock as well as a large variety of stochastic impulses that may potentially affect the economy. It should be emphasized that all estimated coefficients in equations (21) and (22) have the signs predicted by the theoretical model.¹⁷ We can now turn to a discussion of the policy implications of the empirical findings.

First notice from (22), that a U.S. price shock (ϵ_{14t}) and a U.S. interest rate shock (ϵ_{15t}) move exchange rate by a comparable magnitude. A one percent unexpected increase (decrease) in the U.S. price level (interest rate) will appreciate the domestic currency by approximately 0.20% (0.23%). However, in contrast to the negligible effect that the U.S. price shock has on domestic prices, the U.S. interest rate seems more capable of affecting prices. In particular, a one percent unexpected increase in the U.S. interest rate adds about 0.07% to domestic inflation. Furthermore, comparing the size of all coefficients in equation (21), it can be seen that U.S. interest rate impulse and domestic money demand impulse (ϵ_{22t}) can move the price level to a larger extent compared to other types of impulses. The policy implication from this result is that policymakers must act more vigorously to restore price stability when these two types of impulses/shocks appear.

Secondly, in terms of monetary policy variables, a change in the money stock (M_t) appears to have larger impact on exchange rates than on the domestic inflation. A one percent drop in the money stock, which might be the result of an intervention of selling foreign assets, appreciates the domestic currency by 2.5% while reducing inflation by about 0.5%. This considerably large impact on exchange rate from change in the money stock indicates that the Taiwanese mon-

¹⁷We can ignore coefficients of ϵ_{14t} (-0.0069) and ϵ_{23t} (-0.0073) in equation (21), as their sizes are very close to zero and extremely small compared to others.

etary authorities are capable of manipulating \$US/\$NT rate if they wish to do so. However, as we argued earlier, this ability does not constitute the appropriate use of monetary policy to control exchange rate when price stability is the major concern. A strong incentive to control exchange rates is present when various economic shocks can cause domestic price to fluctuate a lot through their impact on exchange rate. To establish whether there exists such incentive, we need to decompose the overall impact of each individual shock on the deviation of domestic price level, indicated by equation (21), into 2 categories: **a.** impacts through the exchange rate (exchange rate pass-through effect); and **b.** impacts passing through other channels. The estimated relations of equations (21) and (22) imply that the following trade-off relation between price deviation and exchange-rate deviation must hold

$$p_t = -0.1792e_t + \begin{bmatrix} 0.0442 \\ 0.0199 \\ -0.0531 \\ 0.0302 \\ 0.0239 \end{bmatrix}' \begin{bmatrix} \epsilon_{11t} \\ \epsilon_{12t} \\ \epsilon_{13t} \\ \epsilon_{14t} \\ \epsilon_{15t} \end{bmatrix} + \begin{bmatrix} 0.0295 \\ 0.0113 \\ -0.0133 \end{bmatrix}' \begin{bmatrix} \epsilon_{21t} \\ \epsilon_{22t} \\ \epsilon_{23t} \end{bmatrix}. \quad (23)$$

This relation indicates that any economic impulse which leads to a one percent depreciation in exchange rate must at the same time add 0.2% of inflation to the domestic economy. Recall, that the second and third terms on the right hand side of (23) identify those impacts on equilibrium price deviation that are not associated with exchange rate effects. Table 2 summarizes the overall impact (the second column) of a one percent unexpected increase in various impulses on the domestic inflation level along with the impact passing through the exchange rate (the third column) and the effect passing through all other channels (the fourth column). We can consider the equilibrium price deviation given by the fourth column as results of the various impulses if there were no exchange rate channel in the economy. The equilibrium price deviations reported in the second column are the outcomes if there is an exchange rate channel. For ϵ_{11t} , ϵ_{12t} , ϵ_{15t} , and ϵ_{22t} , the absolute size of overall impact on equilibrium price deviation is estimated to be larger than the impact passing through other channels. This result indicates that in these cases, if there is no exchange rate channel, the domestic economy will end up with less price instability. Thus, the exchange

Table 2: Decomposition of the impact of a one percent shock on the domestic equilibrium price deviation. In the "Exch. rate" column the estimated exchange rate pass-through effects are reported while the pass-through effects from other factors are reported in the column labeled "Other".

Type of shock	Overall	Exch. rate	Other
ϵ_{11t} (Real interest rate)	0.0579	0.0137	0.0442
ϵ_{12t} (Exchange rate)	-0.0351	-0.0550	0.0199
ϵ_{13t} (Domestic price)	0.0208	0.0739	-0.0531
ϵ_{14t} (Foreign price)	-0.0069	-0.0371	0.0302
ϵ_{15t} (Foreign interest rate)	0.0648	0.0409	0.0239
ϵ_{21t} (Demand)	0.0157	-0.0138	0.0295
ϵ_{22t} (Money)	-0.0589	-0.0702	0.0113
ϵ_{23t} (Financial markets)	-0.0073	0.0060	-0.0133

rate serves as a channel to aggravate the impact of shocks on the domestic price level in these cases. In particular, if a domestic money demand shock (ϵ_{22t}) hits the economy, the absolute size of the impact passing through the exchange rate is about 6.2 ($= 0.070/0.011$) times of the effect of the shock passing through all other channels. This result, along with our earlier finding that a change in money stock is capable of moving the exchange rate, constitute fundamentals that should strongly motivate policymakers to control the exchange rate by managing the money supply.

It appears that if policymakers in any way can manage to block exchange rate from passing through the effect of shocks to the domestic price level, the domestic economy will suffer less price instability. An even more aggressive policy is to manipulate exchange rate to fully offset the effect of any impulse that may potentially be affecting the domestic price level. It was earlier shown, see equation (22), that any event that moves money stock can affect the exchange rates. Two policies may in practice be used to control exchange rates. One is a standard monetary policy, such as an open market operation, and the other is an (non-sterilized) intervention operation. Although both policies change the money stock, they affect exchange rate in different ways. The former moves exchange rate indirectly through the (modified) UIP relation, see, Taylor (2001), while the latter moves exchange rate directly since this policy changes the outstanding

share of domestic currency to foreign currency. This explains why an intervention operation is particularly favored in open economies, since it is believed to affect exchange rates faster than a standard monetary policy, see, e.g., Mussa (1988).

In reality, insufficient foreign reserves constrains the central banks ability to adopt intervention. Thus, it seems interesting to investigate further whether an intervention policy based on our estimates is a feasible policy choice in the Taiwanese case. For illustrative purposes, we discuss the case of an unanticipated one percent increase in the U.S. interest rate (i.e., changing ϵ_{15t}), which was shown to have the most profound effect on domestic price level from (21). When the U.S. interest rate jumps by 1%, it depreciates the domestic currency by 0.2%, see equation (22). To prevent this depreciation of the domestic currency from adding inflationary pressure, the monetary authority needs to impose an intervention that would reduce the outstanding money supply by 0.1% ($\approx 0.2\%/2.5\%$). Using Taiwan's M2 for the fourth quarter of 2000, this share accounts for 17003 millions NT\$. The intervention operation will then amount to a sale of 510 millions U.S.\$, assuming that the exchange rate is 0.03 US\$/NT\$.¹⁸ This intervention, however, will still leave the domestic economy with an inflation rate level of about 0.02%. If the monetary authority wishes to fully offset the inflationary pressure resulting from a one percent (positive) U.S. interest rate shock, 760 millions U.S.\$ must be sold. Given that the Taiwanese central bank has a foreign reserve equivalent to 111,374 millions U.S.\$ such intervention certainly seems feasible.¹⁹

5 Conclusion

Since Sims's (1980) influential work, macroeconometricians have been studying interactions among macroeconomic variables with minimal economic structure imposed on data. Following this trend, most time series studies have avoided modelling behavioral relations and have ended up with performing estimations on reduced form equations. This approach, however, has generated numerous results that very clearly contradict common knowledge and economic theory based predictions. Well-known examples of such puzzling results are the liquidity and

¹⁸The official figure reported by the Taiwanese central bank for 2000q4 is 0.03 US\$/NT\$.

¹⁹Taiwan's foreign assets consist primarily of US\$, Deutsche marks (DM), and yen. US\$ assets often account for more than 85% of Taiwan's total foreign assets.

price puzzles in monetary response studies, and the failure to find support for UIP relation.

In this paper we propose a structured economic model that takes thorough consideration of interactions among macroeconomic variables in an open economy setting. In contrast to a reduced form estimation, we are able to attribute the response of specific variables to an economically interpretable shock through cointegration analysis. The purpose of this paper is to provide some fresh insight on whether exchange rates should be considered/controlled in small-open economies when price stability is being set as the primary goal by the monetary authorities. Regarding the Taiwanese economy, the answer is affirmative. Specifically, we find that a U.S. interest rate shock affects the Taiwanese price level mostly through its impact on exchange rates. Furthermore, a change in the money stock is capable of having a considerable impact on the US\$/NT\$ rate. Last, we find that intervention is a feasible/effective policy option for the Taiwanese monetary authorities. All together, these results provide a strong motivation for the adoption of intervention in Taiwanese economy to achieve a better outcome in terms of stabilizing the overall economy.

The consistency between the estimated responses and the theoretical predictions, gives support to the monetary theory framework applied. Furthermore, the results indicate that the empirical methodology proposed might be useful for other empirical studies using a long-run macroeconomic modelling framework.

References

- Abadir, K. M. & Magnus, J. R. (2002), 'Notation in econometrics: a proposal for a standard', *The Econometrics Journal* **5**, 76–90.
- Andrews, D. W. K. & Monahan, J. C. (1992), 'An improved heteroskedastic and autocorrelation consistent covariance matrix estimator', *Econometrica* **60**, 953–966.
- Balliu, J. & Bouakez, H. (2004), 'Exchange rate pass-through in industrialized countries', *Bank of Canada Review* pp. 19–28.

- Boswijk, P. & Doornik, J. A. (2003), ‘Identifying, estimating and testing restricted cointegrated systems: An overview’, *Unpublished Manuscript, Universiteit van Amsterdam* .
- Devereux, M. B., Engel, C. & Storgaard, P. E. (2004), ‘Endogenous exchange rate pass-through when nominal prices are set in advance’, *Journal of International Economics* **63**, 263–291.
- Doornik, J. A. (1995), ‘Testing general restrictions on the cointegrating space’, *Discussion paper, Nuffield College, Oxford University* .
- Doornik, J. A. (1998), ‘Approximations to the asymptotic distribution of cointegration tests’, *Journal of Economic Surveys* **12**, 573–593.
- Elliott, G. (2000), ‘Estimating restricted cointegrating vectors’, *Journal of Business and Economic Statistics* **18**, 91–99.
- Engel, C. (1993), ‘Real exchange rates and relative prices: An empirical investigation’, *Journal of Monetary Economics* **32**, 35–50.
- Engel, C. & Rogers, J. H. (1996), ‘How wide is the border?’, *American Economic Review* **86**, 1112–1125.
- Froot, K. & Thaler, R. (1990), ‘Foreign exchange’, *Journal of Economic Perspectives* **4**, 179–192.
- Goldberg, P. K. & Knetter, M. M. (1997), ‘Goods prices and exchange rates: What have we learned?’, *Journal of Economic Literature* **35**, 1243–1272.
- Gordon, D. & Leeper, E. (1994), ‘The dynamic impacts of monetary policy: an exercise in tentative identification’, *Journal of Political Economy* **102**, 1228–1247.
- Hamilton, J. D. (1994), *Time Series Analysis*, Princeton University Press, Princeton, NJ.
- Hodgman, D. R. & Wood, G. E. (1989), *Macroeconomic policy and economic interdependence*, New York: St. Martin’s Press.

- Johansen, S. (1988), ‘Statistical analysis of cointegrated vectors’, *Journal of Economic Dynamics and Control* **12**, 231–254.
- Juselius, K. (1995), ‘Do purchasing power parity and uncovered interest rate parity hold in the long run? an example of likelihood inference in a multivariate time-series model’, *Journal of Econometrics* **53**, 211–240.
- Leeper, E. & Roush, J. (2003), ‘Putting m back in monetary policy’, *Journal of Money, Credit, and Banking, Part 2* **35**, 1217–1256.
- McCallum, B. (1994), ‘A reconsideration of the uncovered interest parity relationship’, *Journal of Monetary Economics* **33**, 105–132.
- Mussa, M. (1988), The role of official intervention, in L. Melamed, ed., ‘The merits of flexible exchange rates: an anthology’, Fairfax, Va.: George Mason University Press; Lanham, Md. and London, pp. 331–359.
- Newey, W. K. & West, K. (1987), ‘A simple, positive semidefinite, heteroskedasticity and autocorrelation consistent covariance matrix’, *Econometrica* **55**, 703–708.
- Osler, C. L. (1998), ‘Short-term speculators and the puzzling behavior of exchange rates’, *Journal of International Economics* **45**, 37–57.
- Parsley, D. C. & Wei, S. J. (2001), ‘Explaining the border effect: The role of exchange rate variability, shipping costs, and geography’, *Journal of International Economics* **55**, 87–105.
- Phillips, P. C. B. (1991), ‘Optimal inference in cointegrated systems’, *Econometrica* **59**, 283–306.
- Phillips, P. C. B. & Loretan, M. (1991), ‘Estimating long-run economic equilibria’, *Review of Economic Studies* **59**, 406–436.
- Rotemberg, J. J. & Woodford, M. (1997), An optimization-based econometric framework for the evaluation of monetary policy, in B. S. Bernanke & J. J. Rotemberg, eds, ‘NBER macroeconomics annual’, Cambridge and London: MIT Press, pp. 297–346.

- Saikkonen, P. (1991), ‘Asymptotically efficient estimation of cointegration regressions’, *Econometric Theory* **7**, 1–21.
- Sims, C. (1980), ‘Macroeconomics and reality’, *Econometrica* **48**, 1–48.
- Taylor, J. B. (2000), ‘Low inflation, pass-through, and the pricing power of firms’, *European Economic Review* **44**, 1389–1408.
- Taylor, J. B. (2001), ‘The role of exchange rate in monetary-policy rule’, *American Economic Review* **91**, 263–267.

Appendix

In this appendix the equations (6) and (7) will be derived. First, the current values of price and exchange rates are transformed and measured in deviations from their steady state values. The real interest can then be written as

$$r_t = \bar{i}^* + \omega_1(P_t - \bar{P}) + \theta(E_t - \bar{E}) + u_{23t} + u_{15t}. \quad (24)$$

Next, using (24) an expression for the domestic price level can be derived from (1) as

$$P_t = \frac{1}{a_3}[-Y_t - a_2(\bar{i}^* + \omega_1(P_t - \bar{P}) + \theta(E_t - \bar{E}) + u_{23t} + u_{15t}) - a_3(E_t - \bar{P}^* - u_{14t}) + u_{21t}]. \quad (25)$$

Similarly, the expression for the money stock M_t can be written as

$$M_t = b_1 Y_t - b_2(\bar{i}^* + u_{15t} + \theta(E_t - \bar{E}) + u_{23t}) + u_{22t} + P_t. \quad (26)$$

The steady-state is defined by setting all disturbances equal to zero and assuming that expectations are realized. Consequently, the steady-state conditions for (25) and (26) becomes

$$\bar{P} = \frac{1}{a_3}[-\bar{Y} - a_2\bar{i}^* - a_3(\bar{E} - \bar{P}^*)], \quad (27)$$

$$\bar{M} = b_1\bar{Y} - b_2\bar{i}^* + \bar{P}. \quad (28)$$

Subtracting (27) from (25) gives

$$P_t - \bar{P} = \frac{1}{a_3 + a_2\omega_1}[-(Y_t - \bar{Y}) - (a_2\theta + a_3)(E_t - \bar{E}) + u_{21t} - a_2u_{23t} + a_3u_{14t} - a_2u_{15t}]. \quad (29)$$

From adopting a classical viewpoint it must hold that $Y_t - \bar{Y} = 0$. Equation (29) then writes

$$p_t = \frac{1}{a_3 + a_2\omega_1}[-(a_2\theta + a_3)e_t + u_{21t} - a_2u_{23t} + a_3u_{14t} - a_2u_{15t}]. \quad (30)$$

Using similar techniques on (28) we get

$$m_t = p_t - b_2\theta e_t + u_{22t} - b_2u_{23t} - b_2u_{15t}. \quad (31)$$

Finally, substituting the expression of e_t from equation (31) into equation (30) the expression of p_t given by equation (6) emerges as claimed. Similarly, substituting the expression of p_t given by (30) into (31) gives the expression of e_t as described by equation (7), which completes the proof.