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DEPARTMENT OF ECONOMICS

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Working Paper No. 13/10
May 2013

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Abstract

We investigate bilateral currency pressures against the U.S. dollar for three currencies: the Japanese yen, the Chinese yuan, and the U.K. pound during the period 2000:Q1 to 2009:Q4. We employ a model-based methodology to measure exchange market pressure over the period. Conversion factors required to estimate the pressure on these currencies are computed using a time-varying coefficient regression. We then use our measures of currency pressures to assess deviations of exchange rates from their market-equilibrium levels. For the yen, our measure of currency pressure suggests undervaluation during the initial part of our estimation period, a period during which the Bank of Japan sold yen in the foreign exchange market. We find persistent undervaluation of the yuan throughout the estimation period, with the undervaluation peaking at about 20 per cent in 2004 and 2007. For the pound, the results indicate low pressure - - suggesting a mainly free-floating currency - - throughout the sample period. These results appear consistent with the policies pursued by the central banks of the currencies in question.

Keywords: Exchange market pressure, Currency misalignment, Time-varying-coefficient.

JEL classifications: C22, F31, F41

* The views expressed are those of the authors and not those of their respective institutions. We are grateful to Takeo Hoshi and two referees for comments on an earlier version of this paper.
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1. Introduction

The issue of currency misalignment has long been a focus of empirical research in international finance. Empirical studies have applied a fairly-wide variety of models, ranging from fairly simple Purchasing Power Parity (PPP) approaches to more complex models, in an attempt to compute misalignment. Most studies specify misalignment as a prolonged difference between the actual real exchange rate and its "fundamental equilibrium" level (Williamson 1985, Edwards 1989, Clark and MacDonald 1998), the latter level of which is typically estimated on the basis of a particular model (e.g., the exchange rate that corresponds to PPP, the exchange rate that yields a cyclically-adjusted current account equal to "normal" capital flows). In this paper, we employ the exchange market pressure (EMP) methodology pioneered by Girton and Roper (1977) and further developed by Weymark (1998) to derive a measure of currency misalignment. The model-consistent EMP approach is based on a small macroeconomic set-up. Consequently, when it is implemented empirically it is inevitably subject to problems of oversimplification, including the problems of incorrect functional form and omitted variables. As a result, previous research has been marked by a tendency to produce implausible estimates of the underlying structural parameters of the Girton-Roper model. In contrast to previous studies, we use a time-varying-coefficient (TVC) regression to compute conversion factors, dealing with these misspecifications. As we demonstrate below, by implementing the model using TVC methodology, we are able to correct these specification errors and derive consistent estimates of the relevant elasticities, thereby providing consistent estimates of the degree of currency misalignment.

The motivation underlying the use of the EMP to compute currency misalignment is as follows. Under a pure floating regime, any departure of the exchange rate from its market-equilibrium level should be normally short-lived; it should be absorbed by the exchange rate itself, eliminating the disequilibrium.[1] Therefore, the degree of misalignment should, in principle, be close to zero. However, under fixed or managed

[1] In this paper, we follow Williamson (1985, p. 13), who defined the market equilibrium exchange rate as the nominal exchange rate "that balances demand and supply in the absence of official intervention". Consequently, nonintervention implies that the exchange rate is in market equilibrium. However, as Williamson (1985) pointed out, the market equilibrium exchange rate need not coincide with the fundamental equilibrium rate, which he defined as the *real* exchange rate based on the economic fundamentals (e.g. sustainable current-account and fiscal balances). The difficulties involved in identifying the fundamentals lead us to use the market equilibrium rate from which to gauge misalignments. Consequently, in what follows misalignment can be interpreted as the deviation from the market equilibrium rate.

exchange regimes disequilibrium may arise because of the monetary authorities' intervention in the exchange market. Consequently, if the currency deviates from its market-equilibrium rate, we would expect pressure on the exchange rate towards its equilibrium level and an offsetting actions from the authorities through foreign-exchange intervention or other measures (e.g., capital controls), which counteract this pressure; the greater the disequilibrium in the exchange market, the greater will be the pressure on the exchange rate and the greater will be the required strength of action from the authorities. As a result, at least two fundamental questions arise. (1) Is it possible to detect the currency pressure? (2) If it is possible, what is the magnitude of that pressure?

In what follows, we aim to determine the extent of such pressure during the period 2000:Q1-2009:Q4. We focus on the bilateral exchange rates against the U.S. dollar of three currencies: the Japanese yen, the Chinese yuan, and the U.K. pound sterling. All three currencies are major players in the international financial arena. However, during the period under consideration they operated under different exchange-rate regimes. Japan operated a floating regime but, nonetheless, the Bank of Japan tended to occasionally intervene in the foreign exchange market; in 2003, that intervention turned "massive", as the Bank of Japan sold 177 billion yen, buying dollars, in an effort to depreciate the yen (Fatum and Hutchinson, 2010; see, also, Fatum, 2009). China operated a mainly pegged regime, which involved significant intervention in the foreign exchange market. During the 2000s, its exchange-rate regime moved from a rigid peg against the U.S. dollar to a peg with elements of flexibility, especially beginning in 2005 (Goldstein and Lardy, 2008). The large-scale intervention continued into early 2004. The Bank of England did not typically intervene in the foreign exchange market; its regime was essentially a free-floating regime.

The remainder of the paper is organized as follows. The next section describes the exchange-market-pressure model used and its time-varying conversion factors. Section 3 presents the empirical findings. Section 4 concludes.

2. Exchange Market Pressure

In their seminal paper, Girton and Roper (1977) introduced the concept 'exchange market pressure'. Their aim was to provide a measure of excess demand for domestic currency, or, alternatively, the degree of misalignment between the actual real exchange rate and the level of the exchange rate in the absence of central bank intervention, keeping all other factors unchanged.

To understand the notion of exchange market pressure (EMP), suppose that any incipient pressure on the currency is relieved by allowing the exchange rate to adjust towards its equilibrium value, leaving the foreign reserves of the central bank unaffected. This situation corresponds to the case of a floating exchange rate regime. By contrast, under a managed regime the pressure on the exchange rate to move towards its equilibrium value can be relieved through either a discrete change in the exchange rate, a change in foreign reserves, or a combination of both. In an attempt to measure the degree of EMP, Girton and Roper posited that EMP can be estimated by using two variables: the exchange rate and foreign reserves. However, changes in foreign reserves are an imperfect proxy for intervention since reserves can be influenced by interest earnings and valuation changes. Consequently, subsequent researchers utilised additional variables, including various measures of interest rates, the money supply and/or domestic credit.

The literature has basically focused on two approaches to calculate EMP.[2] The first approach is based on an underlying exchange rate model; consequently, it is known as a model-dependent approach. In this connection, Girton and Roper (1977) obtained an EMP equation using a balance-of-payments model. Their specification of EMP consisted of two components: a bilateral exchange rate (domestic currency units per US dollar) and foreign exchange reserves.[3]

$$EMP = -(-\Delta e_t + \Delta r_t) \tag{1}$$

where Δe_t is the change in the log of the exchange rate (the level of the exchange rate is denoted as ER_t) and $\Delta r_t = \dfrac{ER_t R_t - ER_{t-1} R_{t-1}}{M_{t-1}}$ is the change in reserves as a percentage of the domestic narrow money stock. Reserves (R_t) are measured in U.S. dollars; they exclude gold.[4] Under a fixed exchange-rate regime, $\Delta e_t = 0$; under freely-

[2] Li, Rajan, and Willett (2006) provide a critical review of the literature on the methods used to calculate EMP. Li, Zhang, and Willett (2012) survey the literature on macroeconomic and financial market interdependence. The difficulties encountered in calculating EMP are directly related to the difficulties in classifying exchange-rate regimes. For a critical review of the latter literature, see Willett et al. (2011).

[3] For economies of the comparable size, Girton and Roper (1977) include the foreign reserves of the second economy by specifying:

$$EMP = \Delta e_t + \Delta r_t - \Delta r_t^F \tag{17b}$$

This equation is justified on the grounds that the large economy can shift all exchange rate stabilization efforts to the smaller country (see Girton and Roper, 1977).

[4] Equation 1 differs from the original Girton and Roper definition as EMP is measured in the opposite direction and the exchange rate we use here defines a rise in the rate as depreciation. We have defined things in this way to be consistent with the rest of this paper.

floating regime, $\Delta r_t = 0$. More generally, a depreciation of the domestic currency (an increase in Δe_t) and/or a loss of international reserves will increase the EMP index.

As mentioned above, some researchers (e.g. Calvo and Reinhart, 2002) use the interest rate as a separate, third component of the EMP. The idea here is that, since interest-rate hikes have been part of central banks' responses to speculative attacks, interest rates are one way of capturing pressures in the foreign-exchange market. However, as pointed out by Willett, Kim, and Bunyasini (2012), inclusion of the interest rate in an evaluation of responses to currency crises would imply that all interest-rate changes are intended to defend the currency, which is a highly questionable assumption.[5] Consequently, in what follows we focus on two components of the EMP -- the bilateral nominal exchange rate and foreign exchange reserves.

It is, of course, unrealistic to expect these two components to have equal weights. Therefore, in subsequent research, Roper and Turnovsky (1980), motivated by an optimal intervention policy for domestic income stabilization, generalized the above model to have different weights. Moreover, Weymark (1998) pointed out that the reserve component should be converted into corresponding exchange rate units. Utilizing a standard monetary model, that author derived a conversion factor for reserves. Using that conversion factor, the EMP can be determined as:

$$EMP = \Delta e_t + \eta \times \Delta r_t \tag{2}$$

where η is a conversion coefficient (or factor), which is assumed to be constant and negative.[6]

Although there is a general agreement that the '*ideal*' measure of EMP should be derived from an exchange rate determination model (see, *e.g.*, Eichengreen, Rose and Wyplosz, 1997), empirical studies show that all such models do not fully explain exchange rate behaviour. As a result, the conversion coefficient leads to an inconsistent index of the currency pressure. Therefore, a second approach to estimating EMP - - known as a model-independent approach - - incorporates weights to standardize the variances of each component instead of using conversion coefficients; see for example Sachs, Tornel and Velasco (1996); Eichengreen, Rose and Wyplosz (1997); and Kaminsky, Lizondo and Reinhart (1998). Nonetheless, the model-based approach

[5] We are grateful to one of the referees for bringing this argument to our attention.

[6] Willett, Kim, and Bunyasini (2012) provide a critical assessment of Weymark's index. In this connection, those authors show that the meaning of values of the index above unity is unclear. As will be shown below, all the estimates reported in this paper for the EMP are below unity.

remains the most widely-used method, reflecting its potential ability to capture specific factors affecting currency pressure.

The EMP methodology has been applied to a wide range of countries, with most studies focusing on the bilateral exchange rate misalignment against the U.S. dollar. For example, Girton and Roper (1977), Burdekin and Burkett (1990), and Hallwood, MacDonald and Marsh (1996) applied the EMP to assess the degree of misalignment of the Canadian dollar against the U.S. dollar. Connoly and DaSilvera (1979) and Kim (1985) used Girton and Roper's model to examine the pressure on the Brazilian cruzeiro and Korean won, respectively. More recent papers include applications of the EMP index to the currencies of African countries (de Macedo, Pereira and Reis, 2009), Australia (Jeisman, 2004), East Asian and Latin American countries (Tanner, 2001, and Pontines and Siregar, 2006), East European countries (Hegerty, 2009), EU countries (Pentecost, Van Hooydonk, and Van Poeck, 2001; Klaasen and Jager, 2008), Finland (Spolander and Poso, 1997), and of Japan (Chen and Taketa, 2006). Although the foregoing studies have yielded a variety of results, a basic finding that permeates empirical work is that empirical estimates of the underlying structural parameters used to determine the degree of EMP are often incorrectly signed, reflecting misspecification errors - - see, for example, Hallwood, MacDonald and Marsh, 1996. Consequently, empirical work has increasingly avoided direct estimation of the underlying structural parameters, relying instead on such methods as the imposition of structural coefficients or VAR estimation. In what follows, we focus on direct estimates of the structural parameters using a technique that removes specification biases.

2.1. *Modelling exchange market pressure*

Although the structural model we use is a model for a relatively-small economy[7], it nevertheless captures important elements of the Japanese, U.K., and Chinese economies. It is assumed that exogenously determined foreign prices and domestic output, along with the exchange rate, affect the domestic price level. Additionally, the financial market is a constituent part of this economy, and domestic and foreign assets are assumed to be perfect substitutes. Domestic residents can employ both domestic and foreign currencies. The local currency is used as a unit of transaction while the foreign currency is used for speculative purposes. A central bank supplies foreign currency

[7] The small open economy assumption is needed so that changes in the monetary stance of the domestic economy, say, Japan or China, does not affect the general level of the U.S. dollar on global markets. While Japan and China are not small economies in terms of the size of their GDPs, this does seem to be a realistic assumption in terms of the effects of their policies on the overall level of the U.S. dollar.

from international reserves in response to high market demand. The set of equations representing this economy is presented below.

Since the standard model is only a simplified approximation to the true model and omits several important variables (*e.g.*, special restrictions to incoming or outgoing capital), estimation of this simplified model using fixed coefficient methods that do not account for misspecifications, including omitted variables and incorrect functional forms, yields biased results. To deal with this circumstance, we use a time-varying coefficient (TVC) approach that allows coefficients to change while also allowing the model to perfectly approximate the true unknown model (Swamy and Tavlas, 2001 and Swamy, Tavlas, Hall and Hondroyiannis, 2010).

Under the TVC set-up used in this paper, the coefficients represent total effects of the regressors on the dependent variables, including the omitted-variable and measurement-error biases. Consistent estimates of the partial derivatives of the dependent variable with respect to the regressors in a structural model can be found by removing these biases from the total effects. The decomposition of the total effects into bias-free and bias components is provided in section 2.4.

Our basic model is the following. (All variables are in log form, unless specified otherwise.)

The demand for money in this economy is given by

$$m_t^d = b_{0t} + p_t + b_{1t} y_t + b_{2t} i_t \tag{3}$$

where m_t^d is the log of money demand at time *t*, p_t is the log of the domestic price level, y_t is the log of real domestic output and i_t is the domestic nominal interest rate.

The domestic price level is represented by

$$p_t = a_{0t} + fp_t + a_{1t} e_t \tag{4}$$

where fp_t is the log of the foreign price level and e_t is the log of the exchange rate, defined as a domestic price of one unit of foreign currency (so that an increase in e_t is a depreciation of the domestic currency); thus, both changes in the foreign prices and changes in the exchange rate affect the domestic price level.

The nominal interest rate is given by

$$i_t = fi_t + E(e_{t+1} \mid t) - e_t \tag{5}$$

This equation represents the uncovered interest rate parity. The variable fi_t is the foreign nominal interest rate and $E(e_{t+1} | t)$ is the expectation of the exchange rate in *t+1* formed at time *t.*

The money supply is given by

$$m_t^s = m_{t-1}^s + \Delta d_t + \Delta r_t \tag{6}$$

Where m_t^s is the supply of the money at time *t*, Δd_t is a change in the log of the stock of domestic credit, and Δr_t is proxy variable representing a change in the foreign exchange reserves. Eq. (6) states that changes in the domestic credit and reserves, together with the inherited money-supply, have a direct impact on the present level of the money supply. This specification is a growth rate approximation to the usual definition of the determination of foreign exchange reserves. It is assumed that the money multiplier is constant.

The final equation is

$$\Delta r_t = -\rho_t \Delta e_t \tag{7}$$

where ρ_t is the parameter denoting the time-varying response of policy by the central bank to a change in the exchange rate. Eq. (7) captures the impact of the central bank's exchange rate policy on the foreign reserves. While the policy response is not the central concern of this paper, it is an interesting aspect of the model and is obviously related to the measure of exchange market pressure we develop. If there is no pressure on the exchange rate this implies a free float and, hence $\rho = 0$; if pressure is high then this implies that the exchange rate is manipulated and so $\rho > 0$ and large in magnitude. We present the time-varying evolution of this coefficient for the three countries considered in Appendix A.

A central bank can refrain from intervention in the foreign exchange market and allow the exchange rate to float freely. In this case, the response function in Eq. (7) is zero. However, if the central bank follows a managed exchange regime, the response coefficient can take any value between zero and infinity, implying that the central bank is not committed to a free float, but also avoids the total control over the exchange rate. The fixed rate policy can be seen as a special case of the managed regime with the response coefficient going to infinity as we approach a fixed rate regime.

Market participants can observe only the current exchange rate and interest rates. International reserves increase when the central bank purchases foreign currency in response to the local currency appreciation (i.e., a decrease in e_t) and decrease when the central bank supplies foreign currency in response to a depreciation of the domestic currency.

Substituting Eq. (4) and (5) into Eq. (3), the demand for money can be specified as

$$m_t^d = b_{0t} + a_{0t} + fp_t + (a_{1t} - b_{2t})e_t + b_{1t}y_t + b_{2t}fi_t + b_{2t}E(e_{t+1} \mid t) \tag{8}$$

Assuming that the money market clears continuously, we can write $m_t^d = m_t^s = m_t$, and $\Delta m_t = m_t - m_{t-1}$. Under this assumption, Eqs. (6) - (8) can be written as

$$\begin{aligned} \Delta d_t - \rho_t \Delta e_t = \Delta m_t = &\left\{(b_{0t} + a_{0t}) - (b_{0t-1} + a_{0t-1})\right\} + \left\{ fp_t - fp_{t-1}\right\} + \\ &+ \left\{(a_{1t} - b_{2t})e_t - (a_{1t-1} - b_{2t-1})e_{t-1}\right\} + \left\{b_{1t}y_t - b_{1t-1}y_{t-1}\right\} + \\ &+ \left\{b_{2t}fi_t - b_{2t-1}fi_{t-1}\right\} + \left\{b_{2t}E(e_{t+1} \mid t) - b_{2t-1}E(e_t \mid t-1)\right\} \end{aligned} \tag{9}$$

It is possible to combine the difference between current and past values of the products of variables and their coefficients on the right hand side of Eq. (9) to identify their impact on a change in the money supply.[8]

$$\begin{aligned} \Delta d_t - \rho_t \Delta e_t = \Delta m_t = &\alpha_{0t} + \Delta fp_t + (\Delta a_{1t} - \Delta b_{2t})e_{t-1} + (a_{1t} - b_{2t})\Delta e_t \\ &+ \Delta b_{1t}y_{t-1} + b_{1t}\Delta y_t + \Delta b_{2t}fi_{t-1} + b_{2t}\Delta fi_t + \Delta b_{2t}E(e_t \mid t-1) + b_{2t}\Delta E(e_{t+1} \mid t) \end{aligned} \tag{10}$$

where $\alpha_{0t} = (b_{0t} + a_{0t}) - (b_{0t-1} + a_{0t-1})$

After rearranging Eq. (10), the exchange rate change can be specified as

$$\Delta e_t = \frac{1}{\beta_t} \times X_t \tag{11}$$

where $\beta_t = -\left[\rho_t + a_{1t} - b_{2t}\right]$

and

$$\begin{aligned} X_t = &\left\{\alpha_{0t} + \Delta fp_t + [\Delta(a_{1t} - b_{2t})]e_{t-1} + (a_{1t} - b_{2t})\Delta e_t + \Delta b_{1t}y_{t-1} + b_{1t}\Delta y_t \right. \\ &\left. + \Delta b_{2t}fi_{t-1} + b_{2t}\Delta fi_t + \Delta b_{2t}E(e_t \mid t-1) + b_{2t}\Delta E(e_{t+1} \mid t) - \Delta d_t\right\} \end{aligned}$$

The central bank's policy is confined to the change in the exchange rate through the response coefficient ρ_t.

[8] For a proof, see Hall, Swamy, Tavlas and Hondroyiannis (2009, p. 4); Swamy, Tavlas, Hall and Hondroyiannis (2010, p. 14).

2.2. *Exchange market pressure index*

In what follows, we employ the following general definition of the EMP, given by Weymark (1998, p. 278): "exchange market pressure measures the total excess demand for a currency in international markets as the exchange rate changes that would have been required to remove this excess demand in the absence of exchange market intervention [both unilateral and coordinated], given the expectations generated by the exchange rate policy actually implemented."

As shown in Eq. (2) above, the pressure on this currency can be specified as follows:

$$EMP_t = \Delta e_t + \eta_t \Delta r_t \tag{2}$$

The parameter η_t (the conversion coefficient) is required to transform Δr_t into comparable exchange rate units. Eq. (2) can be obtained from Eq. (11) under the assumption that the response of the domestic central bank to the changes in the exchange rate is $\Delta r_t = -\rho_t \Delta e_t$.

$$\Delta e_t = -\frac{1}{(a_{1t} - b_{2t} + \rho_t)} \times X_t \tag{12}$$

This can be transformed into

$$\Delta e_t = -\frac{1}{(a_{1t} - b_{2t})} \times \left[X_t - \Delta r_t \right] \tag{13}$$

Two channels through which reserves can affect the exchange rate are given in Eq. (14) as follows.

$$\frac{d\Delta e_t}{d\Delta r_t} = \frac{\partial \Delta e_t}{\partial X_t} \times \frac{dX_t}{d\Delta r_t} + \frac{\partial \Delta e_t}{\partial \Delta r_t} \times \frac{d\Delta r_t}{d\Delta r_t} \tag{14}$$

The first term on the right hand side shows how reserves may affect other variables in the economy and how these other variables, in turn, may affect the exchange rate. The second term shows the direct effect of reserves on the exchange rate. Since the second term in Eq. (14) is assumed to convert the reserve changes into equivalent changes in the exchange rate (see Spolander and Poso 1997),

$$\frac{\partial \Delta e_t}{\partial \Delta r_t} = \frac{1}{a_{1t} - b_{2t}} \tag{15}$$

Eq. (15) is the coefficient of intervention of the model-consistent parameter of the exchange market pressure (*i.e.*, a conversion factor). Using Eq. (15) gives

$$EMP_t = \Delta e_t - \left(\frac{1}{a_{1t} - b_{2t}} \right) \Delta r_t \qquad (16)$$

Therefore, the coefficient of Δr_t is $\eta_t = -(a_{1t} - b_{2t})^{-1}$. (As noted in the discussion following the presentation of equation (2) above, η is a conversion factor that is negative. This assumption underlies the negative coefficient of Δr_t). Negative values of EMP are associated with appreciation pressure and vice versa for positive values, since the exchange rate is given as the domestic price of a unit of foreign currency.

2.3. *Derivation of Conversion Factor*

Most previous studies that utilized a model-dependent approach to evaluate EMP employed two-stage least squares (2SLS) to compute the conversion factor, reflecting the simultaneity in the structural form of the model.[9] In a recent paper, Swamy, Hall and Tavlas (2009) give plausible reasons why the instrumental variable estimators are inconsistent. In particular, in this case if the model equations have an incorrect functional form, or if there are missing variables in the model (both of which are almost certainly true), then 2SLS is not a consistent estimator. Another possible source of inconsistency of the conversion factor arises due to the limitation of macroeconomic models in explaining the exchange rate. For example, Hall (1987) reports, that exchange rate models do not perform well in predicting the exchange rate movement compared to more complex models (a similar conclusion was by Goodhart, Hall, Henry and Pesaran, 1993). However, it is difficult -- perhaps not even possible -- to construct a full economic model to accurately predict exchange rate behaviour.

To obtain a consistent estimator of the conversion factor we need to remove the specification biases from the coefficients of Eqs. (3)-(7). The next section provides a method that aims to remove such biases using a time-varying-coefficient model.[10] The appealing feature of the TVC model is that it can be used in the case of unknown functional form, omitted variables, and measurement errors. Therefore, it helps to overcome the problems caused by omitted variables and mis-specified functional forms, described in Hall (1987), and, at the same time, acts as a reliable alternative to the 2SLS technique.

[9] See for example Spolander (1999, p. 60).
[10] This model grew from a random coefficient regression model pioneered by Swamy (1970).

2.4. *The Time-Varying-Coefficient (TVC) model*

In this section we provide a largely intuitive account of the novel estimation strategy used. A more formal exposition is provided in Appendix B.

TVC estimation proceeds from an important theorem that was first established by Swamy and Mehta (1975), which has subsequently been confirmed by Granger (2008). This theorem states that any nonlinear functional form can be exactly represented by a model that is linear in variables but which has TVCs. The implication of this result is that, even if we do not know the correct functional form of a relationship, we can always represent this relationship as a time-varying-coefficients relationship and, hence, estimate it.

The implication of this theorem is that if we have the complete set of relevant variables with no measurement error, then, by estimating a TVC model, we will get consistent estimates of the true partial derivatives of the dependent variable with respect to each of the independent variables given the unknown, non-linear functional form. If we then allow for the fact that we do not know the full set of independent variables and that some, or all, of them may be measured with error, then the TVC estimates become biased (for the usual reasons). What we would now like is to have some way to decompose the full, biased, time-varying coefficients into two parts: the biased component and the remaining part which would (with the biases having been removed) be a consistent estimate of the true coefficient. Of course, this is asking a great deal of an estimation technique. However, that is precisely what TVC estimation aims to provide (Swamy, Tavlas, Hall and Hondroyianis, 2010). This technique builds on the Swamy and Mehta (1975) theorem, mentioned above, to produce such decomposition.

Swamy, Tavlas, Hall and Hondroyianis (2010) show exactly what happens to the TVCs as other forms of misspecification are added to the model. If we allow for some variables to be omitted from the model, then the true, TVCs get contaminated by a term that involves the relationship between the omitted and included variables. Also, if we allow for measurement error, then the TVCs get further contaminated by a term that allows for the relationship between the exogenous variables and the error terms. Thus, as one might expect, the estimated TVC is no longer a consistent estimate of the true partial derivatives of the non-linear function; instead, it is now biased due to the effects of omitted variables and measurement error. There are exact mathematical proofs provided for our statements up to this point (see the Appendix).

Some parametric assumptions are needed to make TVC estimation fully operational. We make two key assumptions. First, we assume that the TVCs themselves are determined by a set of stochastic linear equations, making the TVCs functions of a set of variables that we call driver (or coefficient-driver) variables. This is a relatively uncontroversial assumption. Second, we assume that some of these drivers are correlated with the misspecification in the model and some are correlated with the time-variation emanating from the non-linear (true) functional form. With this assumption, we can then simply remove the bias from the TVCs by removing the effect of the set of coefficient drivers that are correlated with the misspecification. This procedure, then, yields a consistent set of estimates of the true partial derivatives of the unknown nonlinear function, which may then be tested by constructing 't' tests in the usual way. An important difference between coefficient drivers and instrumental variables is that a valid instrument requires a variable that is uncorrelated with the misspecification, which often proves difficult to find. For a valid driver we need variables that are correlated with the misspecification, and we would expect that the latter objective is much easier to achieve.

3. Data and Estimation Results

As mentioned, we utilize quarterly data spanning 1999:Q1 to 2009:Q4 on the three currencies: the Chinese yuan, the Japanese yen, and the British pound. [11] As also mentioned, this sample period contains episodes of a mainly fixed exchange rate regime in China, a flexible regime for the pound, and, occasional but significant, intervention activity by the Bank of Japan. Most of the data are extracted from the International Monetary Fund's (IMF's) International Financial Statistics; however, some series are obtained from Datastream, the OECD databank, the Bank of Japan and the Bank of England. See the Appendix for a detailed description of the data.

3.1. *Time-varying conversion factors*

Recall that b_{2t} denotes the interest elasticity of money demand and a_{1t} denotes the exchange rate elasticity of price given by Eqs. (3) and (4), respectively. The time-varying conversion factors are estimated using the (bias-free) estimates of b_{2t} and a_{1t}. Table 1 presents the results. Panel A of the table shows the time-varying *averages* of both the total effects, from which specification biases have not been removed, and bias-

[11] The effective period runs from 2000:Q1 to 2009:Q4

free estimates of b_{2t} and a_{1t}.[12] We also computed the fixed coefficients of the money demand function and price equation using ordinary least squares in levels and in first differences (Panels B and C of Table 1, respectively). Turning first to Panel A, the TVC estimates of the total coefficient of the interest rate in the money demand equation are -0.793 for China, -0.01 for Japan, and 0.001 for the U.K. The TVC estimates of the total coefficient of the exchange rate in the price equation are -0.232, -0.043, and 0.034 for China, Japan, and U.K., respectively.

After removing specification biases, all the estimates of the bias-free components have the right sign. For China, the estimates of these components of the coefficients of the interest rate and the exchange rate are -0.071 and 0.359, respectively. The corresponding coefficients for Japan are -0.011 for the interest rate and –0.364 for the exchange rate. For the U.K., the bias-free coefficients are -0.109 for the interest rate and 0.045 for the exchange rate. We then use these bias-free coefficients to compute the time-varying conversion factors; the results are reported in Panel A, Column 6, of Table 1.

Panels B and C of Table 1 present the estimates obtained by OLS regression using levels of the variables and first differences, respectively. We focus our discussion of the results on the estimates of the money demand and price equations. For the estimates in levels, the money demand function and the price equation for Japan have positive coefficients for both the interest rate (0.018) and the exchange rate (0.455). For China, the coefficients on the interest rates and the exchange rate are -0.452 and 0.002, respectively; for the U.K., both coefficients are negative (-0.072 and -0.025, respectively). Consequently, two of the coefficients - - those on the interest rate for Japan and the exchange rate for the U.K. - - are of the wrong sign. This finding of wrong-signed coefficient is consistent with previous empirical work.

Turning to Panel C, we find that for OLS estimates in first differences, the signs of the coefficients are reversed compared with OLS in levels. This finding with regard to levels and first differences is consistent with the forward premium bias (see, *inter alia*, Fama, 1984, and Engel, 1995), where OLS often gives a positive coefficient when the spot rate is regressed on the forward rate, but a negative coefficient when the changes in the spot rate are regressed on the forward rate premium. In our case, the dependent variables are the money supply and price differentials; nonetheless, the

[12] The estimates of time-varying coefficients and time-varying conversion factors are available from the authors upon request.

results are somewhat similar to the forward premium puzzle. Therefore, we could conjecture that anomalies analogous to the forward premium bias can occur as a result of the specific feature of the mechanism generating the spot exchange and interest rates series.

3.2. *Exchange market pressure*

Using the TVC estimates of the coefficients in Eq. (16), we constructed two measures of exchange market pressure for each of the currencies under consideration. One measure is based on the quarter-to-quarter values of the coefficients of the variables appearing in Eq. (16). The second measure was computed using the average values over the entire sample period of the (quarterly) TVC coefficients of these variables. That is, for the second measure we used the average of the sum of the TVC coefficients, so that there is only a single coefficient for exchange market pressure; the latter (average) measure produces a smoother pattern of EMP than the former measure.[13]

Table 2 reports the main results. Columns (1) through (4) of the table contain data on the average bilateral exchange rate of each currency against the dollar over the sample period, the change in that rate, the log of that rate, and the change in the log of that rate, respectively. Columns (5) and (6) report the two measures of EMP using quarter-to-quarter TVC estimates and average TVC estimates over the entire sample, respectively. Columns (7) through (12) contain information on the number of quarters in which (i) the exchange rates in question depreciated and (ii) the depreciation pressure was predicted by each of the two EMP measures.

From Column 4 it can be observed that, for both the yen and the yuan, the average changes in the respective currencies were negative for the period from 2000 to 2009, implying some appreciation against the dollar. For the pound, there was no change in the bilateral rate against the dollar. However, the table also reveals that all three currencies, on average, experienced negative pressure (i.e., appreciation pressure), although for the pound sterling the values are very small. This latter result is expected, since, *on average*, in the free floating regime, which is used by the Bank of England, any pressure on the currency should be absorbed by the exchange rate itself. In case of the managed and fixed exchange regimes, however, the pressure on the currency should increase with the level of the intervention in the exchange market. Therefore, because

[13] In reporting TVC results, it is our practice to focus on the average values of the TVC coefficients.

the People's Bank of China resisted appreciation of its currency against the dollar, and aggressively intervened in the foreign exchange market, we can observe substantial pressure on the yuan. Such pressure is also present for the yen but, as expected, much less than in the case of the yuan.

Figures 1, 2 and 3 show the quarterly exchange market pressure for yuan, yen, and the pound, respectively. The interpretation of the Figures is as follows. The line dLg (ER) shows the change in log of the actual exchange rate of the currency concerned against the U.S. dollar; a decline in dLg (ER) means that the actual exchange rate appreciated against the dollar. The bars in the top part of the Figures show what the EMP measure predicts should have occurred on the basis of the quarter-to-quarter TVC estimates. The bars at the bottom of the figures show what the EMP measure predicts should have occurred to the (log of the) exchange rate on the basis of the average TVC estimates over the sample period.

Consider, first, the case of the Chinese yuan. As the bars in both the upper and lower parts of Figure 1 show, throughout the sample period there was pressure on the yuan to appreciate against the U.S. dollar. This implies that the actual exchange rate was above the exchange rate predicted by the EMP measure, suggesting that the yuan was undervalued for most of the sample period. In turn, the undervaluation likely reflected the intervention activity of China's central bank. Beginning in 2005, China stopped publishing data on intervention activity.[14] Nevertheless, it is highly likely that the People's Bank of China intervened in the exchange market to stop further appreciation of the currency in 2005:Q2 and 2005:Q3.[15] We believe that it is possible to surmise that, in these quarters, the extreme deprecation pressures on the yuan reflected the intervention by the People's Bank of China. The level of undervaluation over the whole period averages out at just under 8 per cent, using the average coefficient results. However, the TVC results in Figures 1 to 3 show that the undervaluation is less at the beginning of the period. It reaches its peak in 2004 and 2007 when the level of undervaluation reaches approximately 20 per cent. For most of the period from 2004 to 2008 undervaluation was around 10-12 per cent.[16]

[14] After June 2005, People's Bank of China has stopped releasing the data on the exchange rate transactions. (The earlier data are available at http://www.pbc.gov.cn/publish/html/2005S11.htm)

[15] See speech by the Governor of the People's Bank of China, August 10, 2005 (http://www.pbc.gov.cn/publish/english/956/1943/19432/19432_.html)

[16] Since the exchange rate is defined in terms of logs, the EMP given in Figures 1-3 may be directly interpreted as a per cent deviation from market equilibrium.

Now consider the case of the Japanese yen, reported in Figure 2. Clearly, the bars in both the upper and lower parts of the figure suggest that there were pressures for the yen to appreciate during the early part of the sample period, especially in 2002 and 2003. Figure 2 also shows that the yen tended to be undervalued during the period 2002Q1 through 2003:Q3 relative to the dollar. In fact, during 2002 and 2003 the Bank of Japan intervened massively in the foreign exchange market, selling yen and buying dollars, thus resisting market pressures to appreciate the yen (Fatum and Hutchison, 2010). As shown in the lower part of the figure, which plots the EMP using the average value of the TVC estimates, there was pressure on the yen to appreciate against the dollar during 2002 and 2003. From the beginning in 2004 until the end of our sample period, both our EMP measures indicate that there was little pressure on the yen to either appreciate or depreciate; the actual movements of the yen indicate that the yen was allowed to float against the dollar.

Finally, consider the case of the pound sterling. The pound experienced both positive and negative pressures throughout the sample period (Figure 3). Yet, the magnitudes of the EMP indexes are relatively low. The pound experienced strong downward appreciation pressure, however, during 2000. This outcome appears to have occurred in response to gold sales by the Bank of England in 2000.

There is a substantial difference between the exchange market pressure computed using time-varying conversion coefficients (EMP_TVF) and the exchange market pressure with a constant conversion factor (EMP_CF). In general the constant conversion factors tend to give a more stable picture and we might think of these as better capturing the general situation. The time-varying factors seem to work better at detecting very short-lived events which perhaps do not really represent a fundamental misalignment, such as the U.K. sale of gold in 2000. However, it does not seem to be appropriate to prefer one set of results over the other; both methods of determining conversion factors have an interesting and useful light to shed on the issue of exchange market pressures.

4. Conclusions

Girton and Roper's (1977) formulation of a measure of exchange market pressure has been widely applied to determine the kind of exchange-rate regime followed by the monetary authorities and to determine the amount of speculative pressure in the foreign-exchange market. We used that formulation to measure currency misalignment. An underlying problem that has confronted previous empirical work concerns the underlying structural coefficients of the Girton-Roper model. Typically, these coefficients have been found to be incorrectly signed, reflecting such misspecification problems as omitted variables. For example, a missing variable from the Girton-Roper model is the domestic interest rate, which can be used to influence the exchange rate; indeed, some researchers have expanded the Girton-Roper model to include interest rates. Nevertheless, the problem of specification biases has remained, leading to the development of alternative methodologies for determining EMP that bypass direct estimation of the structural coefficients.

In this paper, we developed a TVC methodology that both (i) provides estimates of the underlying structural coefficients of the Girton-Roper model and (ii) eliminates specification biases. Our application of this methodology to the bilateral exchange rates against the U.S. dollar of the yen, the yuan, and sterling provided results that we believe match fairly well the consensus view of what happened to these currencies during the period 2000:Q1 to 2009:Q4. For the yen, our measure of currency pressure suggests undervaluation (relative to the market-clearing value) during the initial part of our estimation period, a period during which the Bank of Japan sold yen in the foreign exchange market. For the yuan, we find persistent undervaluation of that currency throughout the estimation period. A particular advantage of our time-varying methodology is that we are able to estimate how much stronger the yuan would have been in the absence of foreign-exchange market intervention; we estimate that the undervaluation of the yuan was around 8 per cent (on average) during the entire period. The undervaluation peaked at around 20 per cent in 2004 and 2007, before falling to about 10 to 12 per cent in 2008. For the pound, the results indicate low pressure - - suggesting a mainly free-floating currency - - throughout the sample period.

Table 1 Estimates of money demand function, price equation and conversion factor

	Money demand equation (Eq. 19)			Price equation (Eq. 20)		Conversion factor (Eq. 34)
	(1)	(2)	(3)	(4)	(5)	(6)
	$\hat{\bar{b}}_0$	$\hat{\bar{b}}_1$	$\hat{\bar{b}}_2$	$\hat{\bar{a}}_0$	$\hat{\bar{a}}_1$	$\hat{\bar{\eta}}$
A. Averages of the time-varying coefficients of the money demand equation, the price equation and the conversion factor						
China						
Total effect ($\hat{\bar{\gamma}}_j$)	*-0.599*	*0.938*	***-0.793***	*0.216*	***-0.232***	-
	[0.877]	[0.2648]	[0.265]	[0.072]	[0.078]	
Bias free effect*	-	-	**-0.071**	-	**0.359**	***-2.325***
			[0.095]		[11.738]	
Japan						
Total effect	*4.582*	*0.117*	**-0.010**	*0.097*	**-0.043**	-
	[0.602]	[0.284]	[0.005]	[0.050]	[0.014]	
Bias free effect*	-	-	**-0.011**	-	**0.364**	***-2.669***
			[0.156]		[3.112]	
U.K.						
Total effect	*0.991*	*1.241*	***0.001***	*0.010*	***0.034***	-
	[0.819]	[0.321]	[0.072]	[0.005]	[0.016]	
Bias free effect*	-	-	**-0.109**	-	**0.045**	***-6.477***
			[0.210]		[0.141]	
B. OLS estimates of the money demand equation, price equation and conversion factor (in levels of variables)						
	b_0	b_1	b_2	a_0	a_1	η
China	-0.349	0.822	**-0.452**	0.005	**0.002**	**-2.203**
	[0.139]	[0.042]	[0.160]	[0.045]	[0.050]	
Japan	6.069	-0.582	**0.018**	-0.926	**0.455**	**-2.288**
	[0.814]	[0.387]	[0.012]	[0.280]	[0.137]	
U.K.	0.891	1.298	**-0.072**	-0.004	**-0.025**	**-21.277**
	[0.154]	[0.061]	[0.012]	[0.002]	[0.011]	
C. OLS estimates of the money demand equation, price equation and conversion factor (in first-differences of variables)						
	b_0	b_1	b_2	a_0	a_1	η
China	0.004	0.646	**0.328**	-0.001	**-0.287**	**1.626**
	[0.009]	[0.037]	[0.302]	[0.001]	[0.279]	
Japan	0.002	-0.042	**-0.008**	-0.003	**-0.071**	**15.873**
	[0.001]	[0.093]	[0.003]	[0.001]	[0.026]	
U.K.	0.007	0.115	**0.006**	0.000	**0.019**	**-76.923**
	[0.002]	[0.170]	[0.012]	[0.000]	[0.023]	

Notes:
1) Estimation period is from 2000:Q01 to 2009:Q04.
2) *Since our interest is in the bias-free elasticities a_1 and b_2 only, we did not compute bias-free estimates of the other variables.
3) Standard errors are given in brackets below the coefficient estimates .
4) For OLS regression in levels, money demand function is given by $m_t - p_t = b_{0t} + b_1 y_t + b_2 i_t + u_t$ and price equation is given by $p_t - fp_t = a_0 + a_1 e_t + u_t$.
5) For OLS regression in first difference, money demand function is given by $\Delta(m_t - p_t) = b_{0t} + b_1 \Delta y_t + b_2 \Delta i_t + u_t$ and price equation is given by $\Delta(p_t - fp_t) = a_0 + a_1 \Delta e_t + u_t$.

Table 2 The average change in the exchange rate and exchange market pressure

	ER	d(ER)	Lg(ER)	dLg(ER)	EMP_TVF	EMP_CF	Depreciation, d(ER)		Depreciation pressure, EMP_TVF		Depreciation pressure, EMP_CF	
Average for the period							No. of observations	in %	No. of observations	in %	No. of observations	in %
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*
China	*7.922*	*-0.037*	*0.898*	*-0.002*	*-0.065*	*-0.077*	*8*	*21%*	*2*	*5%*	*0*	*0%*
Japan	*112.57*	*-0.280*	*2.050*	*-0.001*	*-0.022*	*-0.013*	*19*	*49%*	*17*	*44%*	*7*	*18%*
U.K.	*0.596*	*0.000*	*-0.228*	*0.000*	*-0.009*	*-0.003*	*15*	*38%*	*17*	*44%*	*15*	*38%*
Total number of observations*							**39**	**100%**	**39**	**100%**	**39**	**100%**

Notes: Period is 2000:Q01 to 2009:Q03;
*Total number of observations for each country are 39 (not to be confused with overall number of observations for all 3 countries, which are 117);
Depreciation of the currency is a decrease in the value of the currency;
Positive values of the exchange market pressure imply depreciation pressure.

Mnemonic and description:

ER – Exchange rate, national currency against one U.S. dollar;
d(ER) – Exchange rate change (from previous quarter);
Lg(ER) – Common logarithm of the exchange rate, e_t;
dLg(ER) – Changes in common logarithms of the exchange rate (from previous quarter), Δe_t;
EMP_TVF – Exchange market pressure, with **time-varying conversion factors** computed using time-varying parameters a_{1t} and b_{2t};
EMP_CF – Exchange market pressure, with a **constant conversion factor** computed using averages of a_{1t} and b_{2t}.

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Appendix A: The evolution of ρ

Eq. (7) captures the impact of the central bank's exchange rate policy on foreign reserves. That equation, therefore, is of interest since the estimate of ρ provides an indication of the amount of foreign exchange intervention. The equation is as follows:

$$\Delta r_t = -\rho_t \Delta e_t \qquad (7)$$

Below, we give estimates of ρ, calculated as a seven-period centred moving average of $-\frac{\Delta r_t}{\Delta e_t}$. The reason for using a centred moving average is that there are a number of factors that may cause foreign exchange reserves to fluctuate other than as a reaction to the exchange rate. For example, even under a pure float, central banks maintain some foreign exchange reserves and these will fluctuate as a central bank (on behalf of the government) makes payments abroad and receives payments from abroad. These changes in reserves are typically small compared with the changes when a central bank is actively manipulating its currency, but they can nevertheless distort the estimate of ρ over short periods. Taking a centred moving average helps average out these (irrelevant) fluctuations.

Figures 4, 5, and 6 display the time profiles of the estimated ρ's for China, Japan, and the U.K., respectively. As shown in Figure 4, the estimate of ρ for China is very high until 2006, indicating a very high degree of intervention up until that year. This corresponds almost exactly with the results presented in Figure 1 in the text. After 2005, ρ becomes much smaller (although not negative as it appears in the figure because of scaling), more in line with what we would expect under a managed-floating arrangement.

Figure 5 shows the estimate of ρ for Japan. The evolution of ρ for Japan is quite similar to Figure 2, which showed considerable exchange market pressure up until 2004 and then very little after 2004. Figure 5 shows a value for ρ which is consistently positive until 2004 and 2005, and subsequently is effectively zero, indicating a free float.

For the U.K., there was no significant market intervention over the estimation period and so the estimated values for ρ are very small (Figure 6). A negative value for ρ indicates that reserves were actually moving in a way that would add to the movement in the exchange rate rather than dampen it, that is, reserves were "moving with the wind." This simply emphasises the point that, over this period, reserves were not being used to target the exchange rate at all and were moving for reasons unrelated to an exchange-rate target.

Overall, it is clear that the value of ρ in the case of China during the first half of the period was much higher than for the other two countries considered here, indicating strong market intervention. Even in the second half of the period, the value of ρ for China was around 10, which is higher than for either the U.K. or Japan (although of a more similar order of magnitude with the ρ 's of the other two countries).

Appendix B: Technical Exposition of TVC Estimation

Typically, standard regressions in econometrics are based on five strong assumptions: (i) a structural model explaining the dependent variable has the correct functional form; (ii) the net effect of independent variables not included in the structural model are captured by an error term; (iii) data on the independent variables included in the model do not contain measurement errors; (iv) the coefficients and the error term of the model are unique; and, (v) the error term is not arbitrary. The essence of the TVC technique is that it does not depend on these assumptions that are false. Moreover, for each period this TVC model gives a new estimate of each coefficient which can be partitioned into three distinct elements: (i) the bias-free partial derivative of the true value of a dependent variable with respect to the true value of a regressor, (ii)) the indirect effects of regressors *omitted* from the model and (iii) an effect of measurement errors.[17] It should be noted that we allow the coefficients of Eqs. (3) - (7) to vary freely so that they can capture all possible misspecifications in these equations.

We employ a TVC regression to estimate the time-varying conversion factor $\eta_t = -(a_{1t} - b_{2t})^{-1}$. The bias-free component of the coefficient b_{2t} is computed using the money demand equation (Eq. 3) and that of the coefficient a_{1t} using the price equation (Eq. 4). Below, we provide detailed derivation of a TVC equation.

The unknown true functional form of any one of Eqs. (3) and (4) can be captured by writing it as

$$y_t^* = \beta_{0t} + \beta_{1t} x_{1t}^* + \beta_{2t} x_{2t}^* + \sum_{g=3}^{m} \beta_{gt} x_{gt}^* \qquad \text{(A1)}$$

where y_t^* is the true value of a dependent variable, x_{1t}^* and x_{2t}^* are the true values of the observable variables treated as the included regressors, x_{gt}^* with $g > 2$ are the true values of the variables treated as excluded regressors, the coefficient on each regressor is the partial derivative of y_t^* with respect to the regressor, and β_{0t} = y_t^* -

[17] Recent applications of this technique can be found in Hall, Hondroyiannis, Swamy, and Tavlas (2008), Hall, Hondroyiannis, Swamy, and Tavlas (2009), Hall, Hondroyiannis, Swamy and Tavlas (2010), Hall, Swamy, Tavlas and Kenjegaliev (2011).

$\sum_{\ell=1}^{m} \frac{\partial y_t^*}{\partial x_{\ell t}^*} x_{\ell t}^*$. These partial derivatives have the correct but unknown functional forms.[18]

The coefficients in these equations are direct effects of the true values of the regressors on the true value of the explained variable. Each period, the coefficients of Eq. (A1) can change their values. Additionally, the number of variables in this equation treated as excluded regressors can also vary from one period to the next.

Now suppose that the variables treated as excluded regressors are correlated with the variables treated as the included regressors, and this correlation for the variables appearing in Eq. (A1) is given as

$$x_{gt}^* = \psi_{0gt} + \psi_{1gt} x_{1t}^* + \psi_{2gt} x_{2t}^* \qquad (\mathrm{g} = 3, \ldots, m) \quad \text{(A2)}$$

where for j = 1, 2: $\psi_{jgt} = \frac{\partial x_{gt}^*}{\partial x_{jt}^*}$ and $\psi_{0gt} = x_{gt}^* - \sum_{j=1}^{2} \frac{\partial x_{gt}^*}{\partial x_{jt}^*} x_{jt}^*$, and the coefficients have the correct, but unknown, functional forms and are unique.

The first term on the right-hand side of Eq. (A2) can be interpreted as the part of x_{gt}^* remaining after the effects of x_{1t}^* and x_{2t}^* on x_{gt}^* have been subtracted from x_{gt}^*. Substituting the right-hand side of Eq. (A2) for x_{gt}^* in Eq. (A1) yields

$$y_t^* = \left(\beta_{0t} + \sum_{g=3}^{m} \beta_{gt} \psi_{0gt} \right) + \left(\beta_{1t} + \sum_{g=3}^{m} \beta_{gt} \psi_{1gt} \right) x_{1t}^* + \left(\beta_{2t} + \sum_{g=3}^{m} \beta_{gt} \psi_{2gt} \right) x_{2t}^* \qquad \text{(A3)}$$

where the term $\sum_{g=3}^{m} \beta_{gt} \psi_{0gt}$ is the correct function of the 'sufficient' sets ψ_{0gt}'s, of excluded variables and hence is the correct error term.[19]

Assuming that each observable variable is the sum of its true value and a measurement error we can write: $y_t = y_t^* + \nu_{0t}$, $x_{1t} = x_{1t}^* + \nu_{1t}$, $x_{2t} = x_{2t}^* + \nu_{2t}$.

Now, it is possible to show the relationship between the observed dependent and observed independent variables:

$$\begin{aligned} y_t &= \left(\beta_{0t} + \sum_{g=3}^{m} \beta_{gt} \psi_{0gt} + \nu_{0t} \right) + \\ &+ \left(\left\{ \beta_{1t} + \sum_{g=3}^{m} \beta_{gt} \psi_{1gt} \right\} \times \left\{ 1 - \frac{\nu_{1t}}{x_{1t}} \right\} \right) x_{1t} + \left(\left\{ \beta_{2t} + \sum_{g=3}^{m} \beta_{gt} \psi_{2gt} \right\} \times \left\{ 1 - \frac{\nu_{2t}}{x_{2t}} \right\} \right) x_{2t} \end{aligned} \qquad \text{(A4)}$$

[18] The coefficients of Eq. (A1) are unique, (see Swamy and Tavlas, (2001).

[19] The coefficients and the error term of Eq. (A3)) are unique (see Swamy and Tavlas, 2001).

This equation should be changed if either one or both of x_{1t} and x_{2t} take the value zero with positive probability.

Eq. (A4) can be rewritten more compactly as:

$$y_t = \gamma_{0t} + y_{1t} x_{1t} + \gamma_{2t} x_{2t} \tag{A5}$$

where $\gamma_{0t} = \left(\beta_{0t} + \sum_{g=3}^{m} \beta_{gt} \psi_{0gt} + \nu_{0t} \right)$, $\gamma_{1t} = \left(\left\{ \beta_{1t} + \sum_{g=3}^{m} \beta_{gt} \psi_{1gt} \right\} \times \left\{ 1 - \frac{\nu_{1t}}{x_{1t}} \right\} \right)$ and

$\gamma_{2t} = \left(\left\{ \beta_{2t} + \sum_{g=3}^{m} \beta_{gt} \psi_{2gt} \right\} \times \left\{ 1 - \frac{\nu_{2t}}{x_{2t}} \right\} \right)$.

It is evident that each slope coefficient of Eq. (A5) consists of three components: the direct effect of an included regressor, the indirect effects of excluded regressors and the effects of measurement error. However, the problem here is that, in practice, none of these components is observable.

In order to estimate γ_{jt} we need to introduce a set of variables not included in model (A4) but which help to deal with the correlations between the coefficients and included regressors of Eq. (21). These variables are called coefficient drivers.[20]

Suppose that the coefficient drivers are: a constant term, and up to three lags of the first differences of the regressors of Eq. (A4). Then, utilizing these coefficient drivers the coefficients of Eq. (A4) are given by

$$\gamma_{0t} = \pi_{00} + \pi_{01} \Delta x_{1t-1} + \pi_{02} \Delta x_{1t-2} + \pi_{03} \Delta x_{1t-3} + \pi_{04} \Delta x_{2t-1} + \pi_{05} \Delta x_{2t-2} + \pi_{06} \Delta x_{2t-3} + \varepsilon_{0t} \tag{A6}$$

$$\gamma_{1t} = \pi_{10} + \pi_{11} \Delta x_{1t-1} + \pi_{12} \Delta x_{1t-2} + \pi_{13} \Delta x_{1t-3} + \pi_{14} \Delta x_{2t-1} + \pi_{15} \Delta x_{2t-2} + \pi_{16} x_{2t-3} + \varepsilon_{1t} \tag{A7}$$

$$\gamma_{2t} = \pi_{20} + \pi_{21} \Delta x_{1t-1} + \pi_{22} \Delta x_{1t-2} + \pi_{23} \Delta x_{1t-3} + \pi_{24} \Delta x_{2t-1} + \pi_{25} \Delta x_{2t-2} + \pi_{26} \Delta x_{2t-3} + \varepsilon_{2t} \tag{A8}$$

where the variables on the right-hand side of Eqs. (A6), (A7) and (A8) are the coefficient drivers with $E(\varepsilon_{jt} \mid \Delta x_{1t-1}, \Delta x_{1t-2}, \Delta x_{1t-3}, \Delta x_{2t-1}, \Delta x_{2t-2}, \Delta x_{2t-3}) = E(\varepsilon_{jt}) = 0$, for $j = 0,1,2$, $\varepsilon_{jt} = \phi_{jj} \varepsilon_{jt-1} + \tau_{jt}$, $-1 < \phi_{jj} < 1$, $E(\tau_{jt}) = 0$, $Var(\tau_{jt}) = \sigma_{jj}^2$ and $Cov(\tau_{jt}) = \sigma_{jj}$.

Substituting the right-hand sides of Eqs. (A6), (A7) and (A8) for the coefficients of Eq. (A5) yields the following

[20] See Swamy and Tavlas (2001, pp. 418-423) and Swamy, Tavlas, Hall and Hondroyiannis (2010, pp. 8-10) for a formal definition of the coefficient drivers.

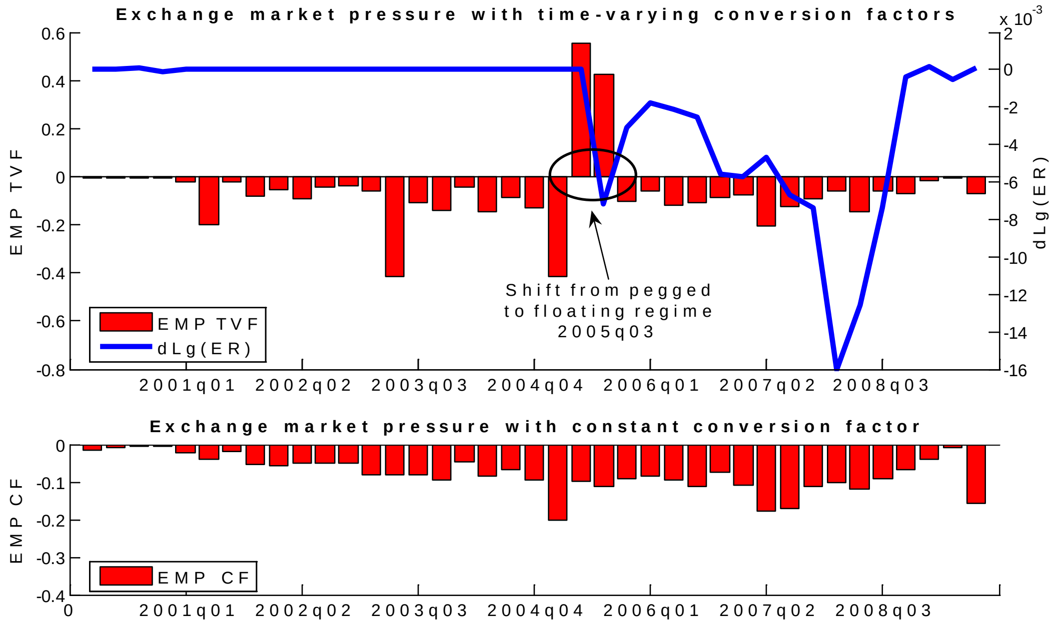
$$y_t = \pi_{00} + \sum_{j=1}^{3} \pi_{0j} \Delta x_{1t-j} + \sum_{j=4}^{6} \pi_{0j} \Delta x_{2t-j+3} + \pi_{10} x_{1t} + \sum_{j=1}^{3} \pi_{1j} \Delta x_{1t-j} x_{1t} +$$
$$+ \sum_{j=4}^{6} \pi_{1j} \Delta x_{2t-j+3} x_{1t} + \pi_{20} x_{2t} + \sum_{j=1}^{3} \pi_{2j} \Delta x_{1t-j} x_{2t} + \sum_{j=4}^{6} \pi_{2j} \Delta x_{2t-j+3} x_{2t} + \quad \text{(A9)}$$
$$+ \varepsilon_{0t} + \varepsilon_{1t} x_{1t} + \varepsilon_{2t} x_{2t}$$

The unknown parameters in Eq. (A9) are π_{0j}, π_{1j}, π_{2j}, ϕ_{jj} and $\sigma_{jj'}$. Using an iterative rescaled generalized least squares method[21], we estimate Eq. (A9) to obtain the time-varying coefficients of Eq. (A5) and their components.

In order to compute the bias-free components of the coefficients of Eq. (A5), or the direct effects of the included regressors, we need to decompose these coefficients. This decomposition is based on the following assumption: Let $z_{0t} \equiv 1, z_{1t}, z_{2t}, z_{3t}, z_{4t}, z_{5t}, z_{6t}$, denote $1, \Delta x_{1t-1}, \Delta x_{1t-2}, \Delta x_{1t-3}, \Delta x_{2t-1}, \Delta x_{2t-2}, \Delta x_{2t-3}$, respectively. Then, the 7 coefficient drivers in Eqs. (A6)-(A8) are assigned to three groups, denoted by A_{1jt}, A_{2jt}, and A_{3jt}, such that for *j* = 0, $\sum_{h \in A_{1jt}} z_{ht} \pi_{jh}$, $\sum_{h \in A_{2jt}} z_{ht} \pi_{jh}$, and $\sum_{h \in A_{3jt}} z_{ht} \pi_{jh} + \varepsilon_{jt}$ have the same sign, magnitude, and the same temporal movements as β_{0t}, $\sum_{g=3}^{m} \beta_{gt} \psi_{0gt}$, and ν_{0t}, respectively; for *j* = 1, $\sum_{h \in A_{1jt}} z_{ht} \pi_{jh}$, $\sum_{h \in A_{2jt}} z_{ht} \pi_{jh}$, and $\sum_{h \in A_{3jt}} z_{ht} \pi_{jh} + \varepsilon_{jt}$ have the same sign, magnitude, and the same temporal movements as β_{1t}, $\sum_{g=3}^{m} \beta_{gt} \psi_{1gt}$, and $\left(\left\{ \beta_{1t} + \sum_{g=3}^{m} \beta_{gt} \psi_{1gt} \right\} \times \left\{ -\frac{\nu_{1t}}{x_{1t}} \right\} \right)$, respectively; for *j* = 2, $\sum_{h \in A_{1jt}} z_{ht} \pi_{jh}$, $\sum_{h \in A_{2jt}} z_{ht} \pi_{jh}$, and $\sum_{h \in A_{3jt}} z_{ht} \pi_{jh} + \varepsilon_{jt}$ have the same sign, magnitude, and the same temporal movements as β_{2t}, $\sum_{g=3}^{m} \beta_{gt} \psi_{2gt}$, and $\left(\left\{ \beta_{2t} + \sum_{g=3}^{m} \beta_{gt} \psi_{2gt} \right\} \times \left\{ -\frac{\nu_{2t}}{x_{2t}} \right\} \right)$, respectively, during estimation and forecasting periods. In what follows, we apply this TVC procedure.

[21] See Chang, Hallahan and Swamy 1992; Chang, Swamy, Hallahan and Tavlas 2000; and Swamy, Tavlas, Hall and Hondroyiannis 2010

Figure 1. Exchange market pressure and changes in the log of the exchange rate, China (CNY)

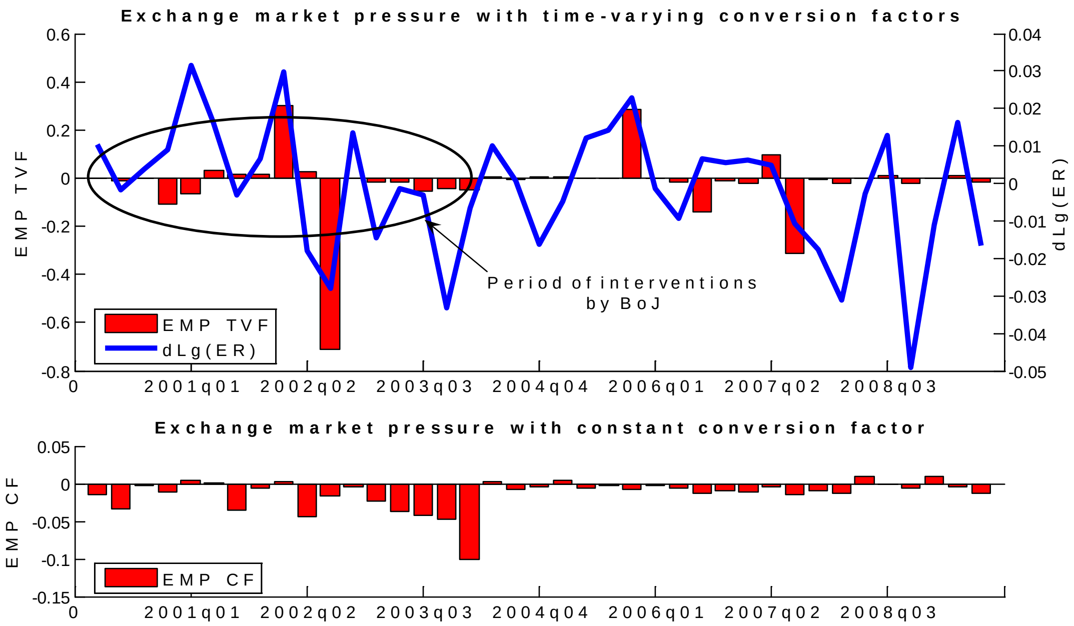


Notes: dLg(ER) – Changes in the log of the exchange rate;

EMP_TVF – exchange market pressure with **time-varying conversion factors** computed using time-varying parameters a_{1t} and b_{2t};

EMP_CF – exchange market pressure with a **constant conversion factor** computed using averages of a_{1t} and b_{2t}.

Figure 2. Exchange market pressure and changes in the log of the exchange rate, Japan (JPY)

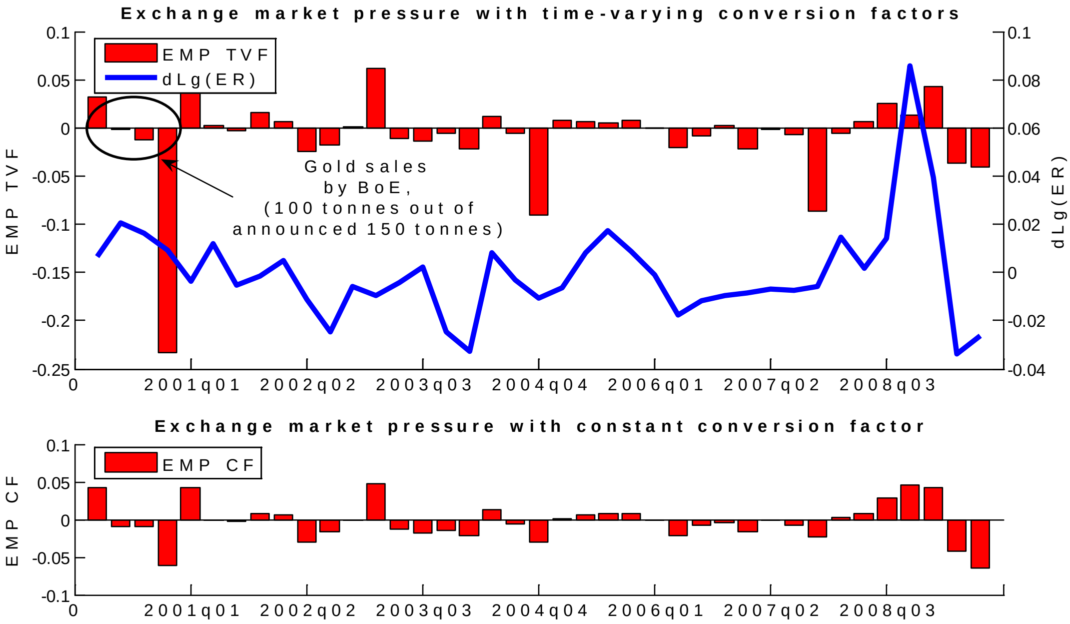


Notes: dLg(ER) – Changes in the log of the exchange rate;

EMP_TVF – exchange market pressure with **time-varying conversion factors** computed using time-varying parameters a_{1t} and b_{2t};

EMP_CF – exchange market pressure with a **constant conversion factor** computed using averages of a_{1t} and b_{2t}.

Figure 3. Exchange market pressure and changes in the log of the exchange rate, U.K. (BP)



Notes: dLg(ER) – Changes in the log of the exchange rate;

EMP_TVF – exchange market pressure with **time-varying conversion factors** computed using time-varying parameters a_{1t} and b_{2t};

EMP_CF – exchange market pressure with a **constant conversion factor** computed using averages of a_{1t} and b_{2t}.

Figure 4. Estimated ρ for China

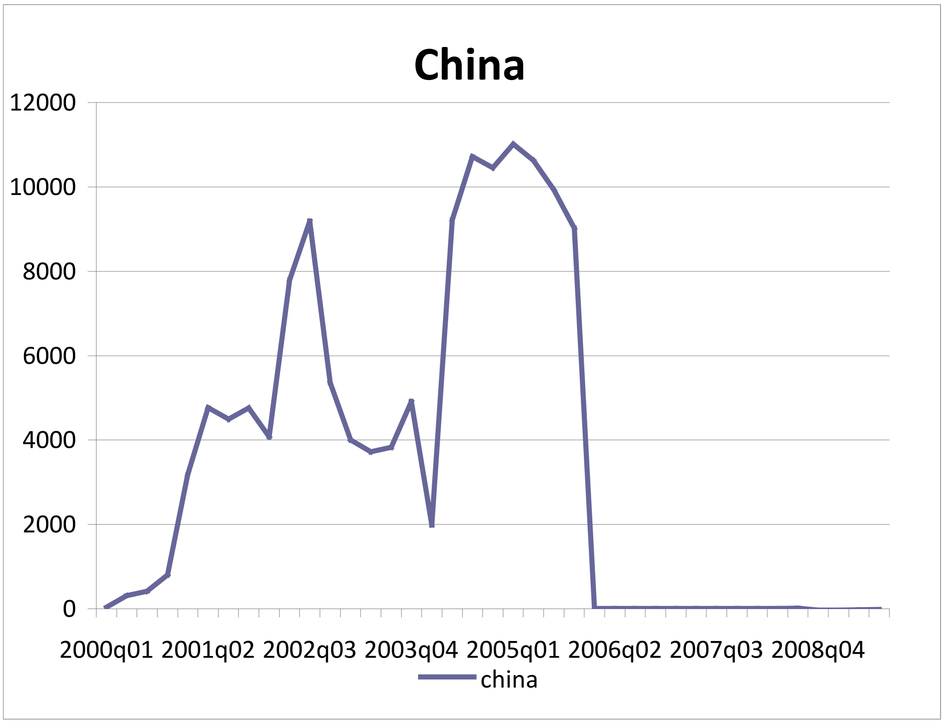


Figure 5. Estimated ρ for Japan

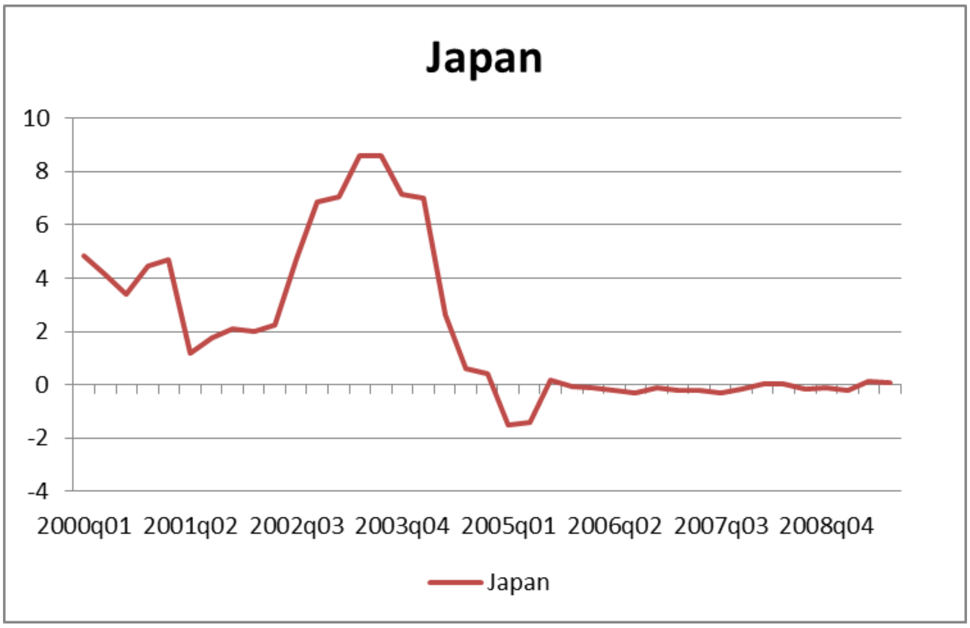


Figure 6. Estimated ρ for the U.K.