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Dimitris Christopoulos and Miguel A. León-Ledesma

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Dimitris Christopoulos,[‡] Miguel A. León-Ledesma[§][*]
[‡]Panteion University
[§]University of Kent

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Abstract

This note revisits the temporal causality between exchange rates and fundamentals put forward by Engel and West (2005). We analyze the causal link within multivariate VARs by making use of the concept of *multi-step causality.* Our results show that, considering information content beyond one-period ahead, the causal link between exchange rates and fundamentals is stronger than previously reported. We find Granger-causality running from exchange rates to fundamentals at *some* horizon in 49% of our tests and running from fundamentals to exchange rates in 59% of them.

JEL Classification: F31, F37, C32.
Keywords: Granger-causality, multi-step, exchange rates, fundamentals.

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[*] **Address for correspondence**: Miguel Leon-Ledesma, Department of Economics, Keynes College, University of Kent, Canterbury, Kent, CT27NP, UK. Email: m.a.leon-ledesma@kent.ac.uk Phone: 00 44 1227 823026.

1 Introduction

The weak empirical link between exchange rates and monetary fundamentals constitutes one of the key puzzles in international macroeconomics ever since Meese and Rogoff (1983). A large literature emerged during the 1990s and 2000s attempting to address this problem. The emergence of works such as Mark (1995) and Mark and Sul (2001) lent support to the idea that fundamentals could be helpful in forecasting exchange rates, but only at long-horizons. Cheung *et al.* (2005), however, show that this is not necessarily a robust finding, since models tend to do well only for certain currencies and periods.[1]

The contribution of Engel and West (2005) is crucial in this literature as they explain that exchange rates and fundamentals are linked in a way that is broadly consistent with asset-pricing models. This is formalized through two important propositions. First, if the discount factor approaches unity and fundamentals are $I(1)$ variables, then the exchange rate should behave *approximately* as a random walk.[2] Second, since the standard asset price (monetary) approach implies that exchange rates reflect the discounted value of present and future expected fundamentals, the exchange rate should be a good predictor of fundamentals. These ideas are discussed further by Engel *et al.* (2007), who propose other ways of evaluating exchange rate models beyond standard forecast performance benchmarked against the random walk. Sarno and Sojli (2009) directly test the first proposition by estimating the discount factor using survey data on expectations. They find point estimates in the range of 0.98-0.99, rendering support for Engel and West (2005).

Our paper focuses on the second proposition. Engel and West (2005) analyze bi-variate Granger-causality tests between exchange rates and a set of macroeconomic fundamentals for the G6 countries.[3] They find that there is significant information content in exchange rate changes about future changes in fundamentals. However, there is no evidence of information content running the other way around. They then perform Granger-causality tests within multivariate VARs. Out of 108 tests (both for each fundamental and as a block) they could not reject

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[1] Rogoff and Stavrakeva (2008), for instance, also show that exchange rate forecasts are not robust to the choice of forecasting window.

[2] See also Engel and West (2004).

[3] Canada, France, Germany, Italy, Japan and the UK all relative to the US.

the null of no causality from exchange rates to fundamentals in 35 cases, but only in 4 cases running from fundamentals to exchange rates.[4] They conclude that (our emphasis): "[...], while the evidence is *far from overwhelming*, there does appear to be a link from exchange rates to fundamentals, going in the direction that exchange rates help forecast fundamentals" (pp. 507). This, together with the well-known near-random walk behavior of exchange rates, is taken as modest evidence in favor of asset price models of the exchange rate.

Engel *et al.* (2007) extend the bi-variate Granger-causality analysis to 18 countries and an longer sample period. For the 18 countries, they find support for causality running from fundamentals to exchange rates in 52% of the cases, and in 33% for causality from exchange rate to fundamentals. For the original countries contained in the Engel and West (2005) tests, however, these proportions are substantially different (23% and 43% respectively). Rossi (2007), in her comment to Engel *et al.* (2007), analyzes the robustness of these results to parameter instability.[5] She concludes that the Engel and West (2005) results that exchange rates predict future fundamentals are very robust to the presence of parameter instabilities at unknown times. Furthermore, she finds some evidence that there is Granger-causality from fundamentals to exchange rates for some fundamentals and some countries, although such a relationship is unstable over time.

Moving away from simple bi-variate VAR models, however, can have important implications for causality analysis. From the point of view of exchange rate models, and as emphasized by Engel *et al.* (2007), the modern conduct of monetary policy implies that variables such as money supply become endogenous when monetary policy is well approximated by simple policy rules. More importantly for our purposes, a fundamental (X_t) may appear to be of little use in forecasting exchange rates (S_t) one period-ahead (S_{t+1}) on its own. However, if this fundamental can help predict a third one (Z_{t+1}) which, in turn, can predict the exchange rate one period ahead, then X_t can help predict S_t *two periods ahead*. This is the concept of *multi-step* causality put forward by Lütkepohl (1993), Dufour and Renault (1998) and Dufour *et al.* (2006). In the context of more realistic formulations of modern macroeconomic policy, this can be of especial relevance for exchange

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[4] At the 10% level.

[5] She also notices that using a lag augmentation of 1 instead of the 4 used by Engel and West (2005) does not affect the results.

rates forecasting. For instance, we may observe that changes in inflation do not Granger-cause changes in the exchange rate. But if the monetary authority adjusts interest rates reacting to changes in inflation and the output gap, this will trigger changes in interest rates which, in turn, can affect exchange rates subsequently. Of course, the temporal sequence will heavily depend on expectations formation by private agents and the timing of the policy rule.[6] However, it is clear that in this context, Granger-causality in a multivariate setting may not capture the forecast information content of the variables involved if we focus only on one-step ahead analysis.

We present a brief overview of the methodology in Section 2. The data and results are discussed in Section 3, while Section 4 concludes.

2 Methodology: multi-step causality

Within the standard framework of Granger-causality [Granger (1968)] if a variable X_{it} does not affect the predictability of another variable X_{jt} (beyond past and contemporaneous values of X_{jt}) one period ahead, we talk about Granger non-causality from X_{it} to X_{jt}. Of course, in a bi-variate context, this concept implies causation at all horizons. However, Lütkepohl (1993), Dufour and Renault (1998) and Dufour *et al.* (2006) have pointed out that in a multivariate VAR environment, where a set of auxiliary variables X_{kt} is used together with X_{it} and X_{jt}, indirect *multi-step* ahead causality from X_{it} to X_{jt} can occur. In other words, they propose definitions of (non-)causality in terms of (non-)predictability at any number of periods ahead. In this context, for any two variables, we may observe non-causality at horizons $1, 2, \ldots, h$ but causality for $h + 1$. According to Dufour and Renault (1998) and Dufour *et al.* (2006), this might attributed to the fact that X_{it} may help predict X_{kt} one period ahead, which in turn has an effect on X_{jt} at a subsequent period.

Following Dufour *et al.* (2006), to derive a testable model for causality at different horizons we assume the following VAR model of order k:

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[6] See Schmitt-Grohé and Uribe (2007) for a welfare analysis of different policy rules in a sticky price model of the business cycles.

$$X_t = \mu + \sum_{j=1}^{k} \Theta_j X_{t-j} + e_t \tag{1}$$

Where $X_t = [X_{1t}, X_{2t}, ...X_{nt}]'$ is a $n \times 1$ random vector of time-series, $\mu = [\mu_1, \mu_2, ...\mu_t]'$ is a $n \times 1$ vector of intercept terms, Θ_j is a $n \times n$ matrix of coefficients and e_t is a Gaussian white noise process with mean zero and non singular covariance matrix $\sum_{ee}$.

Equation (1) can be written at times $t+1$ and $t+2$ as follows:

$$X_{t+1} = \mu + \sum_{j=1}^{k} \Theta_j X_{t+1-j} + e_{t+1} \tag{2}$$

$$X_{t+2} = \mu + \sum_{j=1}^{k} \Theta_j X_{t+2-j} + e_{t+2} \tag{3}$$

By substituting (2) into (3) we get:

$$X_{t+2} = (I + \Theta_1)\mu + \sum_{j=1}^{k} (\Theta_1 \Theta_j + \Theta_{j+1}) X_{t+1-j} + (e_{t+2} + \Theta_1 e_{t+1}) \tag{4}$$

The VAR model (4) is an autoregression at horizon 2. Similarly, as Dufour and Renault (1998) and Dufour *et al.* (2006) have shown, we can obtain the autoregression VAR Model (1) at horizon h:

$$X_{t+h} = \mu^h + \sum_{j=1}^{k} \Theta_j^h X_{t+1-j} + \sum_{i=0}^{h-1} \delta_i e_{t+h-i}, \tag{5}$$

where $\delta_0 = I_n$, $h < T$ and

$$\Theta_j^{h+1} = \Theta_{j+h} + \sum_{l=1}^{h} \Theta_{h-l+1} \Theta_j^l = \Theta_{j+1}^h + \Theta_1^h \Theta_j,$$

$$\Theta_1^0 = I_n,\ \Theta_j^1 = \Theta_j,\ \mu^h = \sum_{l=0}^{h-1} \Theta_1^l \mu_{h-l}, \text{ and } \delta_i = \Theta_1^h \text{ for every } h \geq 0.$$

Dufour and Renault (1998) show that testing for causality in VAR model (5) is not a trivial issue. This happens since imposing some zero restrictions on the non linear functions of the coefficients might lead to non standard asymptotic limiting distributions and rank problems. They thus propose estimating the following unrestricted model:

$$X_{t+h} = \mu^h + \sum_{j=1}^{k} \Theta_j^{*h} X_{t+1-j} + \sum_{i=0}^{h-1} \delta_i e_{t+h-i}, \tag{6}$$

where μ^h is a vector of constants at horizon h, and Θ_j^{*h} is an $n \times n$ matrix with ms^{th} element Θ_{msj}^{*h} providing the impact of $X_{s,t+1-j}$ on $X_{m,t+h}$.

The null hypothesis that X_{st} does *not* cause X_{mt} at horizon h takes the following form:

$$H^h_{s \nrightarrow m} : \Theta_{msj}^{*h} = 0,\ j = 1, \ldots, k \tag{7}$$

where $\Theta_j^{*h} = [\Theta_{msj}^{*h}]_{m,s=1,\ldots,n}$, $j = 1, \ldots, k$. This provides a set of causality tests at each horizon $h = 1, \ldots, H$ $(H < T)$.

A standard Wald static can be used to test the null hypothesis (7). However, since tests based on asymptotic critical values become increasingly inaccurate in finite samples, the use of bootstrap methods is recommended. We employ the "wild" bootstrap approach developed in Liu (1988). Recently, Davidson and Flachair (2008) discuss the properties of this method and recommend the use of a symmetric "wild" bootstrap. This method has several advantages with respect to other parametric bootstrapping techniques: (a) it may provide a good description of DGPs that exhibit heteroskedasticity and, (b) it assumes that the 'true' residual distribution is symmetric, offering thus advantages over simple residual sampling for smaller sample sizes. The bootstrap p-values were obtained using the following procedure:

1. Estimate (6) and obtain the Wald statistic for non-causality.

2. Estimate model (6) under the null, save the parameter values, and obtain the estimated residuals $\tilde{e}_t$

3. From these residuals, form a bootstrap sample of t observations $e_t^* \hat{=} \tilde{e}_t v_t$ where v_t is a random sequence with $E(v_t) = 0$ and $E(v_t^2) = 1$. The pseudo-

disturbances v_t are generated according a Rademacher distribution

$$v_t = \begin{cases} 1 \text{ with probability} = 0.5 \\ -1 \text{ with probability} = 0.5 \end{cases}.$$

4. Generate an artificial series using the parameters of the model under the null and the bootstrapped residuals.
5. Estimate (6) with the artificial data and calculate the Wald statistic.
6. Repeat steps 3-5 above 2,500 times to form a bootstrapping distribution. The p-value of the test can be obtained as the proportion of times the Wald test is smaller than the bootstrapped-Wald test.

3 Results

For comparability, we employed the Engel and West (2005) dataset. They collect quarterly data for the 1974:1-2001:3 period for bilateral US dollar nominal exchange rates and a set of macroeconomic fundamentals for Canada, France, Germany, Italy, Japan and the UK.[7] In what follows, when we refer to any fundamental, say money supply (m_{it}), we refer to (log) US money supply relative to country i's ($m_{USt} - m_{it}$), and the (log) exchange rate (s_t) is US dollars per unit of foreign currency.

The causality tests were performed on four different VAR models including different combinations of exchange rates and fundamentals:[8]

- Model 1: $[\ \Delta s_t \quad \Delta y_t \quad \Delta m_t \quad \Delta(r - r^*)_t\ ]$.
- Model 2: $[\ \Delta s_t \quad \Delta y_t \quad \Delta m_t\ ]$.
- Model 3: $[\ \Delta s_t \quad \Delta f_t \quad \Delta(r - r^*)_t\ ]$.
- Model 4: $[\ \Delta s_t \quad \Delta p_t \quad \Delta(r - r^*)_t\ ]$.

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[7] We refer the reader to Engel and West (2005) for a detailed explanation. The data was downloaded from Charles Engel's web site at http://www.ssc.wisc.edu/∼cengel/data.htm.

[8] The variables were entered in first differences because, following Engel and West (2005), pre-tests mostly favor lack of cointegration between the variables.

Where all variables are in logs except for interest rates, and s_t is the nominal exchange rate, m_t is relative money supply, y_t is relative output, $(r-r^*)_t$ is relative short-term interest rate, $f_t = m_t - \lambda y_t$, and Δ is the first difference operator. For all the experiments we set $\lambda = 1$. All models include a constant term. These four models capture a wide variety of possible combinations of fundamentals arising from asset-price models of the exchange rate. We also estimated the models entering the interest rate differential in levels, rather than in first difference, but this did not affect our results in a significant way.

To follow closely Engel and West (2005), we chose a VAR lag augmentation of k of 4.[9] Due to the relatively short sample period and the number of observations lost in estimation, we used a maximum causality horizon H of 11 quarters. We report the results in **Tables 1 to 8**. The tables report the bootstrapped p-value of the bi-variate causality tests running from exchange rates to fundamentals and from fundamentals to exchange rates for each of the four models and for each causality horizon $h = 1, 2, \ldots, 11$. We only report the significant results at the 10% level or below.[10]

We can observe that, when using a causality horizon of one, there are only a handful of rejections of the no-causality null. Out of 54 tests, we only reject the null in 6 and 7 instances for causality from fundamentals to exchange rates and viceversa respectively. Similar results are found for horizons of 2 and 3 quarters. As we move beyond 3 quarters, we start finding increasing evidence of rejection of the null. The null of non-causality running from fundamentals to the exchange rate is rejected for *at least* one horizon in 32 out of 54 pairings (59%). For the null of non-causality running from exchange rates to fundamentals, we reject for *at least* one horizon in 24 cases (44%). This reveals a much stronger link between exchange rates and fundamentals than previously reported. This is especially the case for our finding of a strong causal link from fundamentals to exchange rates.[11]

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[9] Using the Bayesian Information Criterion (BIC) we would select one lag, as in Rossi (2007). However, the causality results are robust to using $k = 1$.

[10] We also used asymptotic p-values. In general, we find slightly lower levels of rejection of the null, but the difference is not large enough to change our main conclusions.

[11] If we consider all tests at all horizons, the proportion is obviously much smaller. Out of a total of 594 tests, we reject the null of non-causality from fundamentals to exchange rates for *every* horizon in about 14% of the cases, and in 11% of the cases for non-causality from fundamentals to exchange rates. This criterion, however, is too demanding, as it requires causality at *every* single horizon.

Long-horizon predictability, such as that reported in Mark (1995) and Mark and Sul (2001), is justified in Engel *et al* (2007) on the basis of the existence of unobserved fundamentals such as risk premia that follow a stationary autoregressive process, even if the discount factor approaches unity. It is possible that, by conditioning on other observable fundamentals, our method reduces the persistence of the unobserved (omitted) component, hence leading to better forecasting results. We nevertheless note that our method differs from the long-horizon forecast model of Mark (1995).

Looking at individual fundamentals, we can see a strong link running from output to exchange rates and inflation to exchange rates. Causality from inflation to the exchange rate is especially strong when considering it together with interest rate differentials. This could be evidence in support of Taylor-rule based models. Changes in inflation may not affect the exchange rate one period ahead, but since inflation leads to a policy reaction which, in turn, affects the prospective gains from holding a currency, we would observe a link between inflation and exchange rates more than one period ahead.

Exchange rate changes appear to be good predictors of output and money supply changes more than one period ahead, and of inflation both one and several periods ahead when considered together with interest rate differentials. Again, within the context of modern macroeconomic models with policy rules, exchange rates may be anticipating future changes in interest rates which, in turn, affect output and inflation (and *endogenous* money) several periods ahead.

The two countries for which the link between exchange rates and fundamentals appears to be weakest are Canada and the UK. For Canada, however, a link between exchange rates and output is present. This may be due to the fact that the Canadian dollar can be considered a “commodity currency” following Chen and Rogoff (2003), and commodity terms of trade shocks affect both output and exchange rates. For the UK, similar to the results in Engel and West (2005), there appears to be only a very weak link between exchange rates and fundamentals in both directions.

4 Conclusions

The weak link between fundamentals and exchange rates is one of the main empirical puzzles in international macroeconomics. Engel and West (2005) argue that this can be justified on the basis of standard asset-price monetary models of the exchange rate because, as the discount factor approaches unity and if fundamentals are I(1) variables, the exchange rate approximates a random walk. However, because the exchange rate is the present value of the expected future stream of fundamentals, the exchange rate should be a good predictor of fundamentals. Their work reports Granger-causality tests that lend reasonable but not strong support the latter contention. Other works have followed reporting similar results.

In this note, we make use of recent advances in the theory of time-series causality to reassess these results. Given the modern design of monetary policy, one would expect that the temporal link between exchange rates and fundamentals will depend on the timing of policy rules and expectations formation. A particular fundamental may not be useful to forecast the exchange rate one period ahead but it may do so more than one period ahead if it helps forecasting a third variable which, in turn, can help predict exchange rates one period ahead. We use this concept of *multi-step* causality to assess the causal link between fundamentals and the exchange rate.

Our findings show that this link is stronger than previously thought. We test for Granger-causality in multivariate VARs for causality horizons of up to 11 quarters for the US dollar against six major currencies. We find causality running from exchange rates to fundamentals at *some* (i.e. at least one) horizon in 49% of the cases and running from fundamentals to exchange rates in 59% of them. Our findings also appear to lend some support for exchange rate models where monetary policy is explicitly modeled as an interest rate rule.

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Tables

Table 1: Granger-causality from exchange rate to fundamentals.
p-values. Model 1.

	Horizon (quarters)										
	1	2	3	4	5	6	7	8	9	10	11
Country						$\Delta s \rightarrow \Delta y$					
Canada	0.03						0.06	0.06	0.05		
France								0.07	0.05	0.06	0.05
Germany											
Italy											
Japan											
UK											
						$\Delta s \rightarrow \Delta m$					
Canada											
France											
Germany			0.06	0.01	0.00	0.03					
Italy					0.02						
Japan				0.04	0.08						
UK											
						$\Delta s \rightarrow \Delta(r - r^*)$					
Canada											
France											
Germany											
Italy											
Japan	0.00				0.04					0.01	
UK											

Table 2: Granger-causality from fundamentals to exchange rates
p-values. Model 1.

	Horizon (quarters)										
	1	2	3	4	5	6	7	8	9	10	11
Country						$\Delta y \rightarrow \Delta s$					
Canada							0.03				
France				0.01	0.01	0.02	0.00	0.03			
Germany							0.05	0.05			
Italy				0.02	0.03	0.06	0.01				
Japan											
UK					0.06	0.03					0.08
						$\Delta m \rightarrow \Delta s$					
Canada						0.07					
France											
Germany								0.01	0.01		
Italy										0.02	
Japan	0.01					0.09					0.00
UK										0.08	
						$\Delta(r - r^*) \rightarrow \Delta s$					
Canada											
France											
Germany											
Italy											
Japan	0.02	0.03									
UK											

Table 3: Granger-causality from exchange rates to fundamentals. p-values. Model 2.

	Horizon (quarters)										
	1	2	3	4	5	6	7	8	9	10	11
Country	$\Delta s \rightarrow \Delta y$										
Canada	0.04						0.09	0.07	0.08		
France								0.09	0.04	0.06	0.03
Germany											
Italy			0.09								
Japan				0.04	0.09	0.05					
UK											
	$\Delta s \rightarrow \Delta m$										
Canada											
France											
Germany			0.06	0.01	0.00	0.02					
Italy					0.01						
Japan											
UK					0.08						

Table 4: Granger-causality from fundamentals to exchange rates. p-values. Model 2.

	Horizon (quarters)										
	1	2	3	4	5	6	7	8	9	10	11
Country	$\Delta y \rightarrow \Delta s$										
Canada	0.04						0.09	0.07	0.08		
France								0.09	0.04	0.06	0.03
Germany											
Italy			0.09								
Japan				0.04	0.09	0.05					
UK											
	$\Delta m \rightarrow \Delta s$										
Canada											
France											
Germany			0.06	0.01	0.00	0.02					
Italy					0.01						
Japan											
UK					0.08						

Table 5: Granger-causality from exchange rates to fundamentals. *p*-values. Model 3.

	Horizon (quarters)										
	1	2	3	4	5	6	7	8	9	10	11
Country	$\Delta s \rightarrow \Delta f$										
Canada											
France											
Germany				0.03	0.01	0.04					
Italy					0.02						
Japan				0.02	0.05						
UK					0.01						
	$\Delta s \rightarrow \Delta(r - r^*)$										
Canada											
France											
Germany											
Italy											
Japan					0.06					0.01	
UK											

Table 6: Granger-causality from fundamentals to exchange rates. *p*-values. Model 3.

	Horizon (quarters)										
	1	2	3	4	5	6	7	8	9	10	11
Country	$\Delta f \rightarrow \Delta s$										
Canada											
France											
Germany											
Italy											
Japan	0.03	0.05									
UK											
	$\Delta(r - r^*) \rightarrow \Delta s$										
Canada											
France					0.08	0.01					
Germany								0.04	0.02		
Italy					0.06					0.05	
Japan	0.01					0.03					0.00
UK											

Table 7: Granger-causality from exchange rates to fundamentals.
p-values. Model 4.

	Horizon (quarters)										
	1	2	3	4	5	6	7	8	9	10	11
Country	$\Delta s \rightarrow \Delta p$										
Canada					0.04						
France											
Germany	0.01	0.02		0.05							
Italy	0.00	0.03	0.04	0.00	0.00	0.03	0.03	0.00	0.00		
Japan	0.01	0.01	0.10	0.05							
UK											0.05
	$\Delta s \rightarrow \Delta(r - r^*)$										
Canada											
France											
Germany											
Italy											
Japan	0.00				0.08					0.06	
UK											

Table 8: Granger-causality from fundamentals to exchange rates.
p-values. Model 4.

	Horizon (quarters)										
	1	2	3	4	5	6	7	8	9	10	11
Country	$\Delta p \rightarrow \Delta s$										
Canada											
France									0.06	0.01	0.03
Germany							0.05		0.02	0.04	
Italy							0.09	0.01	0.00	0.00	0.00
Japan		0.04	0.09	0.05	0.00	0.02		0.07	0.07		
UK											
	$\Delta(r - r^*) \rightarrow \Delta s$										
Canada											
France		0.04								0.08	
Germany								0.05	0.02		0.08
Italy										0.09	
Japan	0.01	0.08			0.02	0.03					0.00
UK										0.07	

Notes to Tables 1 to 8: p-values from Granger-causality tests using 2,500 bootstrap draws of the ‘wild bootstrap’ procedure explained in the text. Only significant tests at the 10% or lower provided.

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