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Third-country effects on the exchange rate☆

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ABSTRACT

Predictive regressions for bilateral exchange rates are typically run on variables from the associated bilateral pairs of countries. These regressions characteristically have low explanatory power, which leaves room for an omitted variables interpretation. We test whether these omitted variables are from third-countries. When third-country macro factors are added to bilateral exchange rate regressions, they enter significantly and increase the adjusted R^2. A three-country exchange rate model illustrates potential channels for third-country spillovers to affect the bilateral rate.

1. Introduction

This paper addresses the *exchange-rate disconnect puzzle*, which is the term coined by Obstfeld and Rogoff (2000) to describe the "exceedingly weak relationship (except, perhaps, in the longer run) between the exchange rate and virtually *any* macroeconomic aggregates." There are two facets to the puzzle. On one side, whether a country's exchange rate floats, is fixed, or takes some intermediate regime seems to be irrelevant for macroeconomic performance. Baxter and Stockman (1989) and Flood and Rose (1995) find neither economic growth nor macro aggregate volatility to be sensitive to a country's exchange rate regime while Reinhart and Rogoff (2004), Levy-Yeyati and Sturzenegger (2003), Dubas et al. (2010), and Tavlas et al. (2008) report mixed results.

This paper focuses on the other side of the puzzle, which is that macroeconomic variables have little explanatory or predictive power for exchange rate movements. This is puzzling since the exchange rate is itself a macroeconomic variable. One interpretation is that the poor explanatory power is due, at least in part, to an omitted variables problem. Our paper tests the idea that variables from countries beyond the two associated with the bilateral exchange rate are omitted. These are what we refer to as "third-country" effects, or equivalently, spillover effects from the 'rest of the world.' Our strategy to investigate third-country spillovers is motivated by recent research employing factor analysis, that finds multiple common factors (sources of cross-sectional correlation) in panels of bilateral exchange rates (Engel et al. (2015), Verdelhan (2013); Greenaway-Mcgrevy et al. (2012)). The *multiplicity* of these common factors suggests the presence of third-country spillovers in exchange rates. Our third-country approach is also foreshadowed by Hodrick and Vassalou (2002) who found that multi-country models are better able to explain the dynamics of exchange rates than two-country models.

The factors used in existing empirical work on exchange rates are principal components constructed from exchange rates.[1] We extend the literature by studying the role of factors extracted from inflation, the output gap, and interest rates from an international panel data set of countries. These are variables that are featured in frameworks where monetary policy is conducted through Taylor-type interest rate feedback rules.[2] The third-country (rest-of-the-world) interpretation emerges

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[1] We use the terms factors and principal components interchangeably. The factors in this paper are principal components.

[2] Empirical exchange rate research has intensively examined the explanatory/predictive power of monetary and purchasing-power parity fundamentals (Mark (1995), Chinn and Meese (1995), Cheung et al. (2005), Mark and Sul (2001), Rapach and Wohar (2002), Groen (2005), and Cerra and Saxena (2010)). More recent work incorporates monetary policy endogeneity via interest-rate feedback rules (Engel and West (2006), Mark (2009), Molodtsova and Papell (2009), Molodtsova et al. (2008, 2011)).

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naturally in our framework since the factors are cross-sectional linear combinations of *all* of the variables in the panel.

To put some structure on the empirical work as to why these third country effects might matter, we first draw on a partial-equilibrium exchange rate model. The mechanism through which third-country effects impinge on the exchange rate is heterogeneity in the way countries conduct monetary policy.[3] One way that we allow monetary policies to differ is to let Country 2 engage in exchange rate management with respect to Country 3 while Country 1 is concerned only with domestic objectives. Alternatively, monetary policies can differ across countries if Country 2 follows the lead of Country 3 in conducting monetary policy while Country 1 remains concerned only with its domestic objectives. These differences in policy then cause interest rates in Countries 1 and 2 to respond differently to shocks from Country 3, which generates fluctuations in the exchange rate between 1 and 2.

In the empirical work, we analyze the data for evidence of this proposed mechanism. Here, we estimate Taylor-type interest rate reaction functions augmented by real exchange rate factors and interest rate factors. Both factors are found to enter the estimated policy functions significantly.[4] Having found support for a key element of the model, we proceed to test for the presence of third-country effects in exchange rate movements. Guided by the theory, we run predictive regressions of the exchange rate depreciation on bilateral determinants and macrofactors constructed from inflation rates, output gaps and interest rates. After controlling for bilateral determinants, t-ratios on these third-country factors are found to be significant and generally raise the adjusted R^2.

This evidence for third-country effects, however, are from reduced form regressions and the partial-equilibrium model used to motivate them is not explicit about cause and effect. To make the connection between cause and effect explicit, and to explore additional mechanisms for exogenous third-country spillovers into exchange rate movements, we extend the analysis to a three-country general equilibrium environment. The framework we use extends Benigno (2004) to incorporate a third country. Here, we study the role of both monetary policy heterogeneity and cross-country differences in the duration of nominal contracts. Both features of the model create independent pathways for exogenous third-country effects on exchange rate fluctuations. Impulse response analysis performed on the parameterized model shows that exogenous Country 3 shocks can be as quantitatively important and have as large an impact on the bilateral rate as Country 2 shocks. The exchange rate response to third-country shocks, however, varies depending on the underlying cross-country structural heterogeneity. For example, a third-country technology shock causes a Country 1 appreciation when countries differ only by exchange rate management but generates a Country 1 depreciation when countries differ by degree of price stickiness. In a small Monte Carlo experiment using the general equilibrium model as the data generating process, we explore the model's implications for the presence of third-country effects in the reduced form regressions.

Our work is related to Evans (2012) who also seeks to solve the exchange-rate disconnect puzzle. His explanation for low explanatory power in exchange rate regressions is that most exchange-rate variation is driven by unobserved, non-fundamental risk (taste) shocks, whereas we emphasize observed third-country spill-overs. Other papers that directly confront the bilateral disconnect puzzle include Engel and West (2005) and Devereux and Engel (2002). Those authors rationalize bilateral disconnect by deriving conditions under which the exchange rate is theoretically disconnected from the macroeconomy. Our approach, by contrast, investigates the extent to which third country information helps to reduce the disconnect puzzle.

The remainder of the paper is organized as follows. The next section presents an illustrative partial equilibrium model in which third country

Table 1
Taylor rule augmented by exchange-rate factors.

	f_1		f_2		f_3		Wald
	t-ratio	p-value	t-ratio	p-value	t-ratio	p-value	p-value
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
AUS	1.171	(0.518)	**−6.114**	**(0.004)**	−0.810	(0.600)	**(0.036)**
BRA	**−5.529**	**(0.004)**	**−5.118**	**(0.018)**	−1.019	(0.654)	**(0.007)**
CAN	0.804	(0.644)	−2.091	(0.202)	1.521	(0.654)	(0.627)
CHI	1.533	(0.454)	−0.979	(0.548)	0.422	(0.800)	(0.765)
CZE	0.285	(0.854)	−0.932	(0.512)	1.472	(0.378)	(0.647)
HUN	**−4.319**	**(0.024)**	−3.555	(0.118)	−0.770	(0.676)	**(0.073)**
ISL	−1.572	(0.362)	−3.240	(0.108)	1.263	(0.386)	(0.244)
IND	−0.432	(0.810)	**2.703**	**(0.088)**	−0.032	(0.980)	(0.368)
INA	**−14.163**	**(0.000)**	**2.871**	**(0.094)**	2.135	(0.146)	**(0.000)**
ISR	0.049	(0.974)	1.445	(0.348)	−0.687	(0.818)	(0.772)
JPN	1.236	(0.280)	−0.270	(0.774)	1.398	(0.342)	(0.518)
MEX	1.653	(0.422)	−4.288	(0.116)	2.518	(0.374)	(0.241)
NZL	−0.269	(0.866)	0.299	(0.812)	0.363	(0.816)	(0.944)
NOR	−1.499	(0.338)	1.052	(0.490)	−0.018	(0.996)	(0.767)
POL	−1.179	(0.398)	−1.416	(0.294)	1.729	(0.342)	(0.381)
ROU	**−9.815**	**(0.000)**	−1.198	(0.502)	1.399	(0.282)	**(0.001)**
RSA	**−2.889**	**(0.092)**	−2.772	(0.166)	0.217	(0.894)	(0.213)
SWE	0.267	(0.852)	−0.329	(0.802)	−0.258	(0.874)	(0.984)
SWZ	**−7.106**	**(0.002)**	**5.588**	**(0.002)**	−0.513	(0.708)	**(0.001)**
KOR	−0.254	(0.884)	0.236	(0.882)	0.331	(0.978)	(0.998)
TAI	**−2.568**	**(0.080)**	**3.231**	**(0.028)**	**3.347**	**(0.032)**	**(0.023)**
TUR	0.768	(0.569)	−1.166	(0.376)	−0.222	(0.854)	0.704
GBR	0.768	(0.568)	−1.166	(0.376)	−0.222	(0.854)	(0.704)
EUR	−1.264	(0.290)	−1.180	(0.278)	−0.573	(0.596)	(0.475)
Joint*		**(0.000)**		**(0.006)**		(0.970)	

Notes: (7): p-value of Wald-type test that coefficients on factors are jointly zero. Bold entries indicate significance at the 10% level.
* :p-value of test that factor coefficients across countries are jointly zero.

Table 2
Taylor rule augmented by interest-rate factors.

	f_1		f_2		f_3		Wald
	t-ratio	p-value	t-ratio	p-value	t-ratio	p-value	p-value
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
AUS	−0.625	(0.698)	−0.376	(0.782)	0.841	(0.560)	(0.773)
BRA	0.307	(0.830)	1.048	(0.440)	−2.301	(0.110)	(0.261)
CAN	2.896	(0.122)	**4.130**	**(0.006)**	0.941	(0.494)	**(0.029)**
CHI	−0.140	(0.934)	0.500	(0.762)	2.773	(0.116)	(0.346)
CZE	0.397	(0.744)	**2.866**	**(0.038)**	0.019	(0.930)	(0.184)
HUN	0.672	(0.644)	0.975	(0.504)	1.013	(0.580)	(0.788)
ISL	−0.786	(0.246)	1.560	(0.202)	1.079	(0.190)	(0.236)
IND	**2.070**	**(0.080)**	1.187	(0.172)	**−2.796**	**(0.048)**	**(0.039)**
INA	0.673	(0.572)	−1.546	(0.214)	−1.130	(0.366)	(0.369)
ISR	−0.063	(0.732)	−1.930	(0.116)	−0.291	(0.626)	(0.307)
JPN	**2.071**	**(0.090)**	1.401	(0.134)	−0.687	(0.470)	(0.176)
MEX	−0.249	(0.866)	0.044	(0.976)	−0.266	(0.880)	(0.995)
NZL	1.187	(0.316)	−0.211	(0.774)	−0.282	(0.742)	(0.604)
NOR	2.862	(0.132)	−1.303	(0.456)	**−5.847**	**(0.008)**	**(0.015)**
POL	2.524	(0.134)	2.063	(0.116)	0.327	(0.830)	(0.163)
ROU	0.439	(0.180)	0.258	(0.206)	0.181	(0.222)	(0.236)
RSA	1.918	(0.212)	−0.136	(0.878)	**−2.594**	**(0.084)**	(0.120)
SWE	2.202	(0.138)	1.893	(0.178)	**−2.855**	**(0.060)**	**(0.039)**
SWZ	−0.891	(0.508)	2.222	(0.130)	−2.459	(0.110)	(0.194)
KOR	**5.059**	**(0.042)**	−0.535	(0.724)	**−3.229**	**(0.042)**	**(0.020)**
TAI	**3.141**	**(0.086)**	1.210	(0.370)	−0.423	(0.704)	(0.125)
TUR	−0.195	(0.853)	0.345	(0.735)	−0.325	(0.785)	0.932
GBR	−0.195	(0.852)	0.345	(0.734)	−0.325	(0.786)	(0.932)
EUR	1.615	(0.230)	1.055	(0.318)	−0.462	(0.658)	(0.365)
Joint*		(0.185)		(0.207)		**(0.075)**	

Notes: (7): p-value of Wald-type test that coefficients on factors are jointly zero. Bold entries indicate significance at the 10% level.
* :p-value of test that factor coefficients across countries are jointly zero.

[3] Country-level heterogeneity is also emphasized by Verdelhan (2013), as key in identifying bilateral exchange rate variation from global shocks and by Benigno (2004), as a necessary feature in generating real exchange rate persistence.

[4] See Dong (2013) who also finds that central banks respond to exchange rate movements.

spillover effects arise from heterogeneity in monetary policy reaction functions. Section 3 presents the empirical evidence that third-country effects factor into countries' monetary policy decisions and evidence that they contribute to bilateral exchange rate movements. Section 4 presents the complete three-country general equilibrium model. The model's properties and predictions are discussed in Sections 5 and 6 concludes.

2. Policy heterogeneity and third-country spillovers onto bilateral exchange rates

We show both empirically and theoretically that third-country effects are important in understanding bilateral exchange rate movements. To guide the empirical work, this section develops a partial equilibrium model as in Engel and West (2006) and Mark (2009), that follows the asset-approach where the exchange rate is represented as the present value of future observable and unobservable fundamentals. Endogenous monetary policy is conducted through interest rate feedback rules, which we refer to as 'Taylor rules.' We allow heterogeneity in monetary policy across countries. These cross-country differences then create a channel for third-country spillovers onto the bilateral exchange rate.

While we have in mind a many-country world, the main points can be made with three countries. To outline the model, let Country 1 be the U.S., Country 2 be 'home' and Country 3 be the rest of the world. For Country $j = 1, 2, 3$, let $\pi_{j,t}$ be its general price level inflation from t–1 to t, $i_{j,t}$ be its interest rate and $\tilde{y}_{j,t}$ be its output gap. Suppressing constant terms, the monetary authorities in Country 1 respond to expected domestic inflation and the output gap,

$$i_{1,t} = \lambda E_t\left(\pi_{1,t+1}\right) + \phi\tilde{y}_{1,t} + \epsilon_{1,t}, \tag{1}$$

where $\epsilon_{1,t}$ is a shock to monetary policy.

For simplicity, we assume that the inflation target is zero. Empirical formulations typically include the lagged policy rate to capture the central bank's desire for interest rate smoothing. We omit the lagged rate here since it complicates the algebra and obscures the insight. In the general equilibrium model, we include the lagged interest rate.

The monetary policy rule in Country 2 is

$$i_{2,t} = \lambda E_t\left(\pi_{2,t+1}\right) + \phi\tilde{y}_{2,t} + F_{2,*,t} + \epsilon_{2,t}. \tag{2}$$

The assumption that the policy parameters λ and ϕ are identical across countries is made for convenience, but does not impact the general message. $F_{2,*,t}$ is a factor in addition to expected inflation and the output gap that Country 2 policy makers react to in setting the interest rate. If Country 2 manages its exchange rate against Country 1 and views purchasing power parity (PPP) as the 'natural level' of the bilateral rate (Engel and West (2006), Clarida et al. (2000)), then stabilizing responses to deviations from PPP can be represented by $F_{2,*,t} = \sigma_{2,1}q_{2,1,t}$, where $\sigma_{2,1} > 0$ and $q_{2,1,t}$ is the log real exchange rate between 2 and 1. Although the U.S. dollar is the dominant currency in foreign exchange markets, geography, trade and other considerations might influence Country 2 to pursue a management policy with respect to countries *other* than Country 1. If, for example, Country 2 manages against a basket formed by currencies 1 and 3, then $F_{2,*,t} = \sigma_{2,1}q_{2,1,t} + \sigma_{2,3}q_{2,3,t}$.[5] Alternatively, policy dependence could take a simpler form where Country 2's monetary policy follows the lead of Country 3. In this case, $F_{2,*,t} = \varphi_{2,3}i_{3,t}$. We can make our essential points by assuming that Country 2 manages the bilateral rate between itself and Country 3, so we set $F_{2,*,t} = \sigma_{2,3}q_{2,3,t}$.

To see how cross-country policy differences create a channel for third-country spillovers, let the exchange rate–interest rate relation be given by the quasi-interest parity condition

$$E_t\left(e_{1,2,t+1}\right) - e_{1,2,t} = i_{1,t} - i_{2,t} + \zeta_{1,2,t}, \tag{3}$$

where $\zeta_{1,2,t}$ is an exogenous deviation from uncovered interest parity, often referred to as a 'risk premium.' To cut down on notation, let $\pi_{i,j,t} = \pi_{i,t} - \pi_{j,t}$ be the inflation differential between i and j and $\tilde{y}_{i,j,t} = \tilde{y}_{i,t} - \tilde{y}_{j,t}$ be the output gap differential between i and j. Substitute the Taylor rules (1) and (2) into (3), then subtract $E_t(\pi_{1,2,t+1})$, the expected inflation differential between 1 and 2, from both sides. This gives a stochastic difference equation in the real exchange rate, $q_{1,2,t}$, between 1 and 2, which depends on $q_{2,3,t}$. Note that $q_{2,3,t} = q_{1,3,t} - q_{1,2,t}$. Collecting terms and iterating forward on the implied stochastic difference equation gives the representation of $q_{1,2,t}$ as the expected present value of future bilateral variables (output gaps, inflation and risk premia) and future values of the real exchange rate $q_{1,3,t}$,

$$q_{1,2,t} = \delta E_t\left(\sum_{j=0}^{\infty}\delta^j\left[G_{1,2,t+j} + \sigma_{2,3}q_{1,3,t+j}\right]\right), \tag{4}$$

where $G_{1,2,t} = (1-\lambda)E_t(\pi_{1,2,t+1}) - \phi\tilde{y}_{1,2,t} - \zeta_{1,2,t} - \epsilon_{1,2,t}$ and $\delta = (1+\sigma_{2,3})^{-1}$. The expected real depreciation is,

$$E_t\left(q_{1,2,t+1}\right) - q_{1,2,t} = (1-\delta)E_t\left(\sum_{j=1}^{\infty}\delta^j\left[G_{1,2,t+j} + \sigma_{2,3}q_{1,3,t+j}\right]\right) - \delta\left[G_{1,2,t} + \sigma_{2,3}q_{1,3,t}\right]. \tag{5}$$

To obtain the expected nominal depreciation, add the expected bilateral inflation differential to both sides of Eq. (5).

An increase at date t of an element of $G_{1,2,t}$ or $q_{1,3,t}$ is seen to cause a Country 1 real depreciation (increasing $q_{1,2,t}$). It typically also raises $E_t(q_{1,2,t+1})$, but to a lesser extent so the initial shock leads to an expected appreciation of currency 1. This can be seen concretely if the driving processes for inflation, the output gap, the deviation from UIP and the real exchange rate between 1 and 3 are independent first-order autoregressive (AR(1)) processes with respective autoregressive coefficients ρ_π, ρ_y, ρ_ζ and ρ_q. This simplified structure gives the expected nominal depreciation,

$$E_t\left(e_{1,2,t+1}\right) - e_{1,2,t} = \left(\frac{\lambda(\rho_\pi-1)-\sigma_{2,3}}{1+\sigma_{2,3}-\rho_\pi}\right)\rho_\pi\pi_{2,1,t} + \frac{\phi\left(\rho_y-1\right)}{1+\sigma_{2,3}-\rho_y}\tilde{y}_{2,1,t} + \ldots + \left(\frac{\sigma_{2,3}\left(\rho_q-1\right)}{1+\sigma_{2,3}-\rho_q}q_{1,3,t} + \frac{\left(\rho_\zeta-1\right)}{1+\sigma_{2,3}-\rho_\zeta}\zeta_{2,1,t} - \frac{1}{1+\sigma_{2,3}}\epsilon_{2,1,t}\right). \tag{6}$$

If Country 3's policy rule is symmetric to Country 1's,

$$i_{3,t} = \lambda E_t\left(\pi_{3,t+1}\right) + \phi\tilde{y}_{3,t} + \epsilon_{3,t}, \tag{7}$$

and has the quasi-UIP relationship between 1 and 3,

$$E_t\left(e_{1,3,t+1}\right) - e_{1,3,t} = i_{1,t} - i_{3,t} + \zeta_{1,3,t}, \tag{8}$$

then by Eqs. (1), (7), and (8) and the implied AR(1) processes for inflation and output gaps, the solution for the real cross rate is,

$$q_{1,3,t} = \frac{\rho_\pi(\lambda-1)}{1-\rho_\pi}\pi_{3,1,t} + \frac{\phi}{1-\rho_y}\tilde{y}_{3,1,t} + \frac{1}{1-\rho_\zeta}\zeta_{3,1,t} + \epsilon_{3,1,t}. \tag{9}$$

[5] Sokolov (2012) finds that the central banks of Russia, China and Malaysia manage against baskets of currencies.

Table 3
Taylor rule augmented by interest-rate (I) factors or exchange-rate (E) factors.

		f_1		f_2		f_3		Wald
		t-ratio	p-value	t-ratio	p-value	t-ratio	p-value	p-value
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
AUS	I1,E2	**6.954***	**0.010**	**−6.195**	**0.006**	–	–	**0.000**
BRA	I3,E2	**−6.277**	**0.007**	**−5.477**	**0.012**	–	–	**0.000**
CAN	I3,E3	**−6.471**	**0.003**	**6.634**	**0.008**	–	–	**0.001**
CHI	I3,E1	−0.156	0.918	1.490	0.428	–	–	0.670
CZE	I3,E3	**−4.407**	**0.016**	**5.942**	**0.004**	–	–	**0.000**
HUN	I1,E2	**−5.358**	**0.012**	**−8.399**	**0.008**	–	–	**0.000**
ISL	I1,E1	**5.321**	**0.004**	**−4.112**	**0.011**	–	–	**0.004**
IND	I1,E1	**2.933**	**0.073**	−3.271	0.126	–	–	**0.000**
INA	I1,I3,E3	**−5.881**	**0.002**	**−5.084**	**0.004**	**3.159**	**0.051**	**0.000**
ISR	I3	**−3.285**	**0.086**	–	–	–	–	–
JPN	I1,I2,E2	**3.415**	**0.043**	**−2.146**	**0.062**	**2.444**	**0.053**	**0.000**
MEX	I1,E2	**3.540**	**0.077**	−3.379	0.194	–	–	**0.000**
NZL	E3	2.612	0.112	–	–	–	–	–
NOR	E1,E2	−2.312	0.161	1.076	0.718	–	–	0.471
POL	E3	2.169	0.263	–	–	–	–	–
ROU	I3,E1	**−3.903**	**0.017**	**−8.469**	**0.002**	–	–	**0.000**
RSA	I1,E1	**4.534**	**0.040**	**−4.579**	**0.024**	–	–	**0.000**
SWE	I1,E1	2.797	0.111	**−3.203**	**0.068**	–	–	**0.000**
SWZ	E1,E2	**−7.295**	**0.001**	**5.618**	**0.002**	–	–	**0.000**
KOR	I1,E3	**3.622**	**0.068**	**5.407**	**0.078**	–	–	**0.000**
TAI	I1	**6.381**	**0.017**	–	–	–	–	–
TUR	I1	1.411	0.356	–	–	–	–	–
GBR	I1	1.411	0.356	–	–	–	–	–
EUR	I2,I3	**3.403**	**0.015**	**−2.939**	**0.057**	–	–	**0.017**

Notes: (7): p-value of Wald-type test that coefficients on factors are jointly zero. Bold entries indicate significance at the 10% level.

Substituting Eq. (9) into Eq. (6) and solving, gives the expected bilateral nominal depreciation between 1 and 2 as a linear function of the Taylor-rule fundamentals for Countries 1, 2, and 3,

$$E_t\left(e_{1,2,t+1}\right)-e_{1,2,t}=\frac{\sigma_{2,3}\left(\rho_q-1\right)\rho_\pi(\lambda-1)}{\left(1+\sigma_{2,3}-\rho_q\right)(1-\rho_\pi)}\pi_{3,t}+\frac{\sigma_{2,3}\left(\rho_q-1\right)\phi}{\left(1+\sigma_{2,3}-\rho_q\right)\left(1-\rho_y\right)}\tilde{y}_{3,t}+\dots \\ +G\left(\pi_{1,t},\pi_{2,t},\tilde{y}_{1,t},\tilde{y}_{2,t}\right)+v_{1,2,t+1}, \tag{10}$$

where $G(\pi_{1,t}, \pi_{2,t}, \tilde{y}_{1,t}, \tilde{y}_{2,t})$ is a linear function and $v_{1,2,t+1}$ is a composite regression error that contains the UIP deviations $\zeta_{2,1,t}$ and $\zeta_{3,1,t}$.[6] Eq. (10) instructs us to look for third-country impacts after controlling for bilateral exchange rate determinants $G(\pi_{1,t}, \pi_{2,t}, \tilde{y}_{1,t}, \tilde{y}_{2,t})$. Assuming that the Taylor principal is satisfied ($\lambda > 1$), the predicted signs on $\pi_{3,t}$ and $\tilde{y}_{3,t}$ are negative, but because the so-called risk premia $\zeta_{2,1,t}$ and $\zeta_{3,1,t}$ are impounded in the regression error, their correlation with the third country variables could bias the estimated coefficients and violate the sign predictions.

We note that the specific form of exchange-rate management assumed is not critical to imply third-country effects. While we assume that the authorities react to variations in the real exchange rate, cross-rate influence will also appear if Country 2's policy rate reacts to the *change* in its exchange rate with Country 3.[7]

3. Evidence of third-country spillovers

The previous section lays out a mechanism for third-country effects on the exchange rate when there are differences across countries in how monetary policy responds to external factors. In this section we ask if the evidence supports this mechanism, by testing whether countries respond to third-country exchange rates or interest rates when setting their own interest rates. Our results find that they do. Having found evidence to support the third-country transmission mechanism, we examine whether third-country macro factors contribute explanatory power in nominal exchange-rate movements after controlling for bilateral inflation and output gaps.

Subsection 3.1 describes the data that we use. Subsection 3.2 reports evidence that the types of policy dependence that we assumed exist in the data. Subsection 3.3 investigates third-country spillover effects onto bilateral exchange rates.

3.1. The data

The empirical analysis centers on 24 countries plus the Euro area for which we have industrial production, price, interest rate and exchange rate observations. They are the United States (USA), Australia (AUS), Brazil (BRA), Canada (CAN), Chile (CHI), Czech Republic (CZE), Hungary (HUN), Iceland (ISL), India (IND), Indonesia (INA), Israel (ISR), Japan (JPN), Mexico (MEX), New Zealand (NZL), Norway (NOR), Poland (POL), Romania (ROU), South Africa (RSA), Sweden (SWE), Switzerland (SWZ), Korea (KOR), Taiwan (TAI), Turkey (TUR), Great Britain (GBR), and the Euro area (EUR).[8]

Interest rates, consumer prices and industrial production were obtained from the FRED database at the Federal Reserve Bank of St. Louis. Interest rates are 3-month inter-bank yields. Output gaps are the deviation between industrial production and the Hodrick–Prescott (HP) trend. The HP filter is applied recursively to prevent future information from being impounded into current observations. Inflation is given by the rate of change in the CPI. Lastly, nominal exchange rates were obtained from Bloomberg.

[6] $G(\pi_{1,t},\pi_{2,t},\tilde{y}_{1,t},\tilde{y}_{2,t})=\left(-\frac{\sigma_{2,3}(\rho_q-1)(\lambda-1)}{(1+\sigma_{2,3}-\rho_q)(1-\rho_\pi)}-\frac{\lambda(\rho_\pi-1)-\sigma_{2,3}}{(1+\sigma_{2,3}-\rho_\pi)}\right)\rho_\pi\pi_{1,t}+\left(\frac{\lambda(\rho_\pi-1)-\sigma_{2,3}}{(1+\sigma_{2,3}-\rho_\pi)}\right)\rho_\pi\pi_{2,t}$ $+\frac{\phi\left(\rho_y-1\right)}{\left(1+\sigma_{2,3}-\rho_y\right)}\tilde{y}_{2,t}-\left(\frac{\phi\left(\rho_y-1\right)}{\left(1+\sigma_{2,3}-\rho_y\right)}+\frac{\sigma_{2,3}\left(\rho_q-1\right)\phi}{\left(1+\sigma_{2,3}-\rho_q\right)\left(1-\rho_y\right)}\right)\tilde{y}_{1,t}$, and $v_{1,2,t+1}=\frac{\left(\rho_\zeta-1\right)}{\left(1+\sigma_{2,3}-\rho_\zeta\right)}\zeta_{2,1,t}$ $-\frac{1}{1+\sigma_{2,3}}\epsilon_{2,1,t}+\frac{\sigma_{2,3}\left(\rho_q-1\right)}{\left(1+\sigma_{2,3}-\rho_q\right)\left(1-\rho_\zeta\right)}\zeta_{3,1,t}+\frac{\sigma_{2,3}\left(\rho_q-1\right)}{1+\sigma_{2,3}-\rho_q}\epsilon_{3,1,t}$.

[7] In this case, UIP implies a second-order stochastic difference equation. The solution has the same qualitative implication that the exchange rate between 1 and 2 depends in part on the expected present value of the cross rate.

[8] International Olympic Committee three-letter country codes in parentheses except for Taiwan.

Table 4
One-quarter ahead depreciation regressed on inflation factors. Taylor-rule control variables. USD numeraire.

	f_1		f_2		f_3		Wald			
	t-ratio	p-value	t-ratio	p-value	t-ratio	p-value	p-value	$\overline{R}^2(1)$	$\overline{R}^2(2)$	p-value
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
AUS	**2.687**	**(0.000)**	**2.597**	**(0.000)**	**−1.936**	**(0.006)**	**(0.000)**	−0.012	**0.130**	**(0.092)**
BRA	0.105	(0.968)	−0.371	(0.886)	**−2.802**	**(0.000)**	**(0.006)**	−0.039	0.028	(0.309)
CAN	1.075	(0.320)	−0.037	(0.990)	**−1.587**	**(0.024)**	(0.135)	0.168	**0.178**	**(0.059)**
CHI	−0.236	(0.926)	−0.496	(0.856)	**−3.784**	**(0.000)**	**(0.000)**	−0.055	0.110	(0.105)
CZE	**2.424**	**(0.000)**	0.382	(0.890)	**−1.658**	**(0.016)**	**(0.002)**	0.001	0.066	(0.189)
HUN	**3.242**	**(0.000)**	**3.015**	**(0.000)**	−1.277	(0.122)	**(0.000)**	−0.045	0.026	(0.304)
ISL	**1.459**	**(0.094)**	1.275	(0.154)	**−2.643**	**(0.000)**	**(0.000)**	−0.002	**0.178**	**(0.022)**
IND	1.331	(0.164)	0.631	(0.788)	**−1.733**	**(0.012)**	**(0.041)**	0.070	0.098	(0.107)
INA	0.752	(0.706)	0.641	(0.794)	−1.174	(0.196)	(0.490)	−0.007	−0.019	(0.439)
ISR	−0.970	(0.454)	0.440	(0.876)	**−1.960**	**(0.002)**	**(0.060)**	−0.047	−0.019	(0.400)
JPN	**1.694**	**(0.046)**	−0.222	(0.946)	−0.006	(1.000)	(0.293)	−0.050	−0.087	(0.362)
MEX	0.004	(0.998)	−0.049	(0.990)	**−1.783**	**(0.008)**	(0.339)	−0.045	−0.004	(0.464)
NZL	**2.115**	**(0.002)**	**2.958**	**(0.000)**	**−1.769**	**(0.010)**	**(0.001)**	0.033	**0.158**	**(0.062)**
NOR	**2.559**	**(0.000)**	**2.685**	**(0.000)**	**−1.738**	**(0.010)**	**(0.000)**	−0.022	**0.152**	**(0.048)**
POL	0.655	(0.746)	0.552	(0.822)	−1.690	(0.014)	(0.158)	−0.037	0.010	(0.379)
ROU	**4.192**	**(0.000)**	0.908	(0.574)	**−3.523**	**(0.000)**	**(0.000)**	0.081	**0.226**	**(0.004)**
RSA	0.890	(0.550)	1.120	(0.298)	**−3.568**	**(0.000)**	**(0.000)**	0.012	**0.139**	**(0.053)**
SWE	**1.685**	**(0.046)**	0.793	(0.696)	**−2.087**	**(0.000)**	**(0.002)**	0.029	**0.147**	**(0.038)**
SWZ	**3.018**	**(0.000)**	**1.829**	**(0.008)**	−0.897	(0.488)	**(0.001)**	−0.034	−0.012	(0.420)
KOR	−0.601	(0.764)	−0.695	(0.762)	**−3.931**	**(0.000)**	**(0.000)**	−0.002	**0.187**	**(0.018)**
TAI	0.494	(0.818)	0.410	(0.884)	**−3.255**	**(0.000)**	**(0.000)**	−0.015	0.063	(0.187)
TUR	**1.602**	**(0.078)**	**1.791**	**(0.020)**	−1.344	(0.102)	**(0.007)**	0.040	0.095	(0.189)
GBR	**2.630**	**(0.002)**	**2.010**	**(0.006)**	**−1.602**	**(0.032)**	**(0.001)**	−0.026	**0.161**	**(0.065)**
EUR	**1.716**	**(0.018)**	1.171	(0.162)	−0.753	(0.640)	**(0.061)**	0.051	0.048	(0.216)
Joint*		**(0.000)**		**(0.000)**		**(0.000)**				**(0.013)**

Notes: (7): p-value of Wald-type test that coefficients on factors are jointly zero. (8): $\overline{R}^2(1)$ is adjusted R^2 from regression that includes only the control variables. (9): $\overline{R}^2(2)$ is adjusted R^2 when including both controls and third-country factors. (10) p-value of test that $\overline{R}^2(2) = \overline{R}^2(1)$. Bold entries indicate significance at the 10% level.
* : p-value of test that the increment $\overline{R}^2$ or factor coefficients across countries are jointly zero.

The factors we employ are the first three principal components of inflation, output gaps, interest rates, and real exchange rates.[9] Factors are constructed recursively so that future information does not get incorporated into current observations.

The quarterly time-series data ranges from 1999Q1 to 2013Q4. We focus on this relatively short time span for two reasons. First, the time-series for several countries do not extend very far back in time, so to obtain a broad cross-section of countries some sacrifice of time-series observations was necessary. Secondly, Greenaway-Mcgrevy et al. (2012) find that the post euro-creation period constitutes a separate regime. Due to the important role played by the euro in international finance, and to avoid complications from estimation across different regimes, we limit our empirical analysis to the period since the launch of the euro.

3.2. Factor augmented Taylor-rule regressions

This section tests if third-country real exchange rate factors and/or interest rate factors influence the setting of interest rates. As in Clarida et al. (1998, 2000), we allow for interest rate smoothing by the authorities in the empirical work. If the target rate i_t^T is given by Eq. (2), interest rate smoothing of the policy rate is represented as $i_{j,t} = \alpha + \rho i_{j,t-1} + (1-\rho) i_{j,t}^T + \epsilon_{j,t}$, where $\epsilon_{j,t}$ is a policy shock. Hence, we estimate monetary policy feedback rules where the form of the target rate is,

$$i_{j,t}^T = \lambda E_t\left(\pi_{j,t+1}\right) + \phi \tilde{y}_{j,t} + \sum_{i=1}^{3} \theta_{i,j} f_{i,t}, \quad (11)$$

and the $f_{j,t}$ is either the real exchange rate or interest rate factors. The standard closed-economy formulation sets $\theta_{i,j} = 0$.

We substitute $E_t(\pi_{j,t+1}) = \pi_{j,t+1} + v_{j,t+1}$ in Eq. (11) where $v_{j,t+1}$ is the rational expectation forecast error, and estimate the resulting equation by generalized method of moments. T-ratios are based on Newey and West (1983) standard errors and p-values are computed from a sieve nonparametric bootstrap distribution based on 6000 samples with observations built from resampling of the residuals.[10] We use the lagged policy rate and current and three lagged values of inflation, the output gap, and current values of the factors as instruments.

We first consider the real exchange rate factors using the recursively constructed real exchange rate factors with the U.S. as the numeraire country. Table 1 reports Newey–West t-ratios and bootstrapped p-values for real-exchange rate factor coefficients in the Taylor rule. The first factor, which has the dimensionality of USD real exchange rates, generally enters with a negative sign. This is to be expected if the country's monetary policy has an exchange rate management component.[11]

[9] Interest rate, exchange rate and price data (but not industrial production) is also available for the Philippines, Thailand, Colombia, and Singapore. We also include these countries in the panel for extraction of interest rate, real exchange rate and inflation factors.

[10] The bootstrap design is described in the online Appendix 1.

[11] To obtain sign restrictions, suppose Country 2's interest rate reacts to a basket of currency 1 and 3 with the rule,

$$i_{2,t} = \lambda E_t(\pi_{2,t+1}) + \phi \tilde{y}_{2,t} + (\sigma_{2,1} q_{2,1,t} + \sigma_{2,3} q_{2,3,t}) + \epsilon_{2,t},$$

but we estimate the policy rule

$$i_{2,t} = \lambda E_t(\pi_{2,t+1}) + \phi \tilde{y}_{2,t} + \theta_{2,1} f_{1,t} + \epsilon_{2,t},$$

where we represent the first factor, $f_{1,t} = (q_{1,2,t} + q_{1,3,t})/2$, as the cross-sectional average of real exchange rates. If $Var\ (q_{1,3,t}) = Var\ (q_{1,2,t})$ and since $q_{2,1,t} = -q_{1,2,t}$ and $q_{2,3,t} = q_{1,3,t} - q_{1,2,t}$, the covariance between the factor and the exchange rate management term is

$$Cov\left(f_{1,t}, \left(\sigma_{2,1} q_{2,q,t} + \sigma_{2,3} q_{2,3,t}\right)\right) = -\left(\frac{\sigma_{2,1}}{2}\right)\left(Var(q_{1,2,t}) + Cov(q_{1,2,t}, q_{1,3,t})\right).$$

Due to the extensive positive cross-sectional dependence exhibited by real exchange rates (Engel et al. (2015), Greenaway et al. (2014), Verdelhan (2013)), the presumption is that $Cov(q_{1,2,t}, q_{1,3,t}) > 0$.

Table 5
Four-quarter ahead depreciation regressed on inflation factors. Taylor-rule control variables. USD numeraire.

	f_1		f_2		f_3		Wald			
	t-ratio	p-value	t-ratio	p-value	t-ratio	p-value	p-value	$\overline{R}^2(1)$	$\overline{R}^2(2)$	p-value
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
AUS	**4.402**	**(0.000)**	**1.841**	**(0.042)**	−1.152	(0.330)	**(0.001)**	0.169	**0.370**	**(0.079)**
BRA	**2.046**	**(0.056)**	0.254	(0.916)	**−2.474**	**(0.006)**	**(0.013)**	−0.056	0.087	(0.622)
CAN	**3.565**	**(0.002)**	1.261	(0.220)	**−1.794**	**(0.046)**	**(0.001)**	0.202	0.263	(0.169)
CHI	**3.295**	**(0.004)**	1.287	(0.262)	**−1.607**	**(0.096)**	**(0.010)**	0.029	0.163	(0.410)
CZE	**2.477**	**(0.028)**	**−1.858**	**(0.044)**	−1.018	(0.486)	**(0.008)**	0.210	0.314	(0.140)
HUN	**1.928**	**(0.066)**	**1.588**	**(0.098)**	−0.310	(0.902)	(0.153)	−0.057	−0.001	(0.804)
ISL	1.401	(0.180)	1.505	(0.128)	**−1.638**	**(0.070)**	**(0.062)**	0.114	0.195	(0.333)
IND	**2.622**	**(0.014)**	0.203	(0.934)	**−2.011**	**(0.026)**	**(0.012)**	0.159	0.213	(0.361)
INA	**3.185**	**(0.004)**	−0.159	(0.958)	−0.546	(0.806)	**(0.014)**	0.289	**0.400**	**(0.071)**
ISR	1.347	(0.202)	−0.116	(0.964)	**−2.606**	**(0.002)**	**(0.024)**	−0.033	0.147	(0.412)
JPN	**3.661**	**(0.002)**	−0.121	(0.968)	**1.650**	**(0.054)**	**(0.004)**	−0.006	0.174	(0.273)
MEX	−1.003	(0.500)	−0.862	(0.636)	**−3.661**	**(0.000)**	**(0.015)**	−0.004	0.262	(0.246)
NZL	**3.596**	**(0.002)**	1.449	(0.154)	−0.697	(0.750)	**(0.008)**	0.280	0.361	(0.112)
NOR	**1.991**	**(0.058)**	**1.683**	**(0.072)**	−0.582	(0.796)	(0.135)	0.037	0.071	(0.571)
POL	−0.772	(0.668)	−0.309	(0.910)	**−1.557**	**(0.098)**	(0.576)	0.016	0.135	(0.423)
ROU	**4.736**	**(0.000)**	−0.518	(0.830)	**−3.372**	**(0.002)**	**(0.000)**	0.430	**0.621**	**(0.003)**
RSA	**2.044**	**(0.058)**	0.738	(0.734)	**−1.771**	**(0.050)**	**(0.044)**	0.232	**0.405**	**(0.070)**
SWE	**3.728**	**(0.002)**	0.139	(0.954)	−0.760	(0.716)	**(0.004)**	0.057	0.180	(0.323)
SWZ	**3.714**	**(0.002)**	0.973	(0.568)	0.121	(0.966)	**(0.008)**	0.008	0.076	(0.577)
KOR	0.752	(0.696)	−0.170	(0.948)	**−2.252**	**(0.012)**	**(0.089)**	0.118	0.195	(0.353)
TAI	**3.947**	**(0.000)**	0.724	(0.758)	**−4.459**	**(0.000)**	**(0.000)**	−0.005	**0.368**	**(0.088)**
TUR	**2.169**	**(0.044)**	1.518	(0.132)	**−1.824**	**(0.056)**	**(0.014)**	0.290	**0.446**	**(0.065)**
GBR	1.292	(0.272)	1.259	(0.302)	−1.047	(0.476)	(0.238)	−0.017	0.044	(0.737)
EUR	**2.771**	**(0.004)**	1.287	(0.210)	−0.217	(0.938)	**(0.025)**	0.073	0.135	(0.377)
Joint*		**(0.000)**		(0.479)		**(0.000)**				**(0.010)**

Notes: (7): p-value of Wald-type test that coefficients on factors are jointly zero. (8): $\overline{R}^2(1)$ is adjusted R^2 from regression that includes only the control variables. (9): $\overline{R}^2(2)$ is adjusted R^2 when including both controls and third-country factors. (10) p-value of test that $\overline{R}^2(2) = \overline{R}^2(1)$. Bold entries indicate significance at the 10% level.
* : p-value of test that the increment $\overline{R}^2$ or factor coefficients across countries are jointly zero.

We find that about half of the countries in our sample are influenced by exchange rates when conducting monetary policy. Looking across all countries, the first and second factors seem to be about equally important. The third factor is generally not significant. Notably, exchange rate factors are insignificant for Euro area monetary policy.

Table 6
One-quarter ahead depreciation regressed on output-gap factors. Taylor-rule control variables. USD numeraire.

	f_1		f_2		f_3		Wald			
	t-Ratio	p-Value	t-Ratio	p-Value	t-Ratio	p-Value	p-Value	$\overline{R}^2(1)$	$\overline{R}^2(2)$	p-Value
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
AUS	−1.183	(0.182)	**−1.869**	**(0.004)**	**−2.010**	**(0.004)**	**(0.018)**	−0.012	0.053	(0.240)
BRA	−0.758	(0.680)	−1.236	(0.120)	0.117	(0.972)	(0.567)	−0.040	−0.007	(0.374)
CAN	**−2.035**	**(0.008)**	−0.032	(0.988)	**−1.761**	**(0.016)**	**(0.022)**	0.168	**0.178**	**(0.070)**
CHI	−1.262	(0.132)	**−1.688**	**(0.008)**	−1.038	(0.428)	**(0.056)**	−0.056	−0.053	(0.398)
CZE	−1.053	(0.326)	−0.379	(0.882)	−1.266	(0.116)	(0.392)	0.001	−0.021	(0.375)
HUN	−0.583	(0.788)	0.517	(0.826)	−1.213	(0.160)	(0.675)	−0.045	−0.020	(0.404)
ISL	**−1.563**	**(0.028)**	0.217	(0.936)	**−3.155**	**(0.000)**	**(0.001)**	−0.002	0.101	(0.120)
IND	−1.187	(0.208)	**−1.672**	**(0.010)**	**−1.435**	**(0.060)**	**(0.026)**	0.070	0.057	(0.207)
INA	**−2.676**	**(0.000)**	−0.701	(0.756)	**−2.483**	**(0.000)**	**(0.001)**	−0.007	0.099	(0.109)
ISR	−0.799	(0.640)	−0.129	(0.962)	−0.547	(0.852)	(0.971)	−0.047	−0.082	(0.359)
JPN	**−1.995**	**(0.004)**	**−1.855**	**(0.002)**	−0.954	(0.538)	**(0.002)**	−0.050	−0.036	(0.326)
MEX	−1.183	(0.196)	0.548	(0.818)	−0.213	(0.938)	(0.839)	−0.045	−0.076	(0.439)
NZL	**−1.352**	**(0.082)**	−1.177	(0.210)	**−2.635**	**(0.002)**	**(0.004)**	0.033	0.113	(0.125)
NOR	**−1.288**	**(0.094)**	**1.754**	**(0.006)**	**−2.204**	**(0.000)**	**(0.004)**	−0.022	0.052	(0.173)
POL	−0.852	(0.636)	1.228	(0.158)	−0.570	(0.816)	(0.478)	−0.038	−0.067	(0.426)
ROU	−1.041	(0.340)	0.213	(0.936)	**−1.613**	**(0.024)**	(0.204)	0.081	**0.098**	**(0.094)**
RSA	**−3.048**	**(0.000)**	−0.680	(0.752)	**−2.891**	**(0.000)**	**(0.000)**	0.012	**0.197**	**(0.018)**
SWE	−0.892	(0.572)	0.733	(0.718)	**−1.679**	**(0.012)**	(0.153)	0.029	0.042	(0.211)
SWZ	−0.072	(0.972)	0.355	(0.878)	**−1.464**	**(0.044)**	(0.507)	−0.034	−0.049	(0.411)
KOR	**−2.111**	**(0.004)**	0.253	(0.924)	**−1.713**	**(0.014)**	**(0.014)**	−0.002	0.074	(0.177)
TAI	−1.129	(0.244)	−1.032	(0.386)	**−1.557**	**(0.026)**	**(0.094)**	−0.015	−0.027	(0.442)
TUR	**−2.151**	**(0.002)**	−0.329	(0.890)	**−1.813**	**(0.010)**	**(0.009)**	0.040	0.080	(0.201)
GBR	−0.719	(0.700)	−0.121	(0.958)	**−1.662**	**(0.012)**	(0.279)	−0.026	0.044	(0.231)
EUR	−0.161	(0.946)	0.161	(0.934)	−0.999	(0.330)	(0.926)	0.051	0.019	(0.283)
Joint*		**(0.000)**		(0.216)		**(0.000)**				**(0.028)**

Notes: (7): p-value of Wald-type test that coefficients on factors are jointly zero. (8): $\overline{R}^2(1)$ is adjusted R^2 from regression that includes only the control variables. (9): $\overline{R}^2(2)$ is adjusted R^2 when including both controls and third-country factors. (10) p-Value of test that $\overline{R}^2(2) = \overline{R}^2(1)$. Bold entries indicate significance at the 10% level.
* p-Value of test that the increment $\overline{R}^2$ or factor coefficients across countries are jointly zero.

Table 7
Four-quarter ahead depreciation regressed on output-gap factors. Taylor-rule control variables. USD numeraire.

	f_1		f_2		f_3		Wald			
	t-ratio	p-value	t-ratio	p-value	t-ratio	p-value	p-value	$\overline{R}^2(1)$	$\overline{R}^2(2)$	p-value
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
AUS	−1.115	(0.334)	−1.265	(0.218)	**−2.374**	**(0.004)**	**(0.038)**	0.169	0.292	(0.132)
BRA	**−2.089**	**(0.020)**	**−3.317**	**(0.000)**	−1.402	(0.132)	**(0.001)**	−0.056	0.129	(0.424)
CAN	**−3.231**	**(0.000)**	0.002	(1.000)	**−2.950**	**(0.002)**	**(0.002)**	0.202	**0.323**	**(0.086)**
CHI	**−1.620**	**(0.078)**	**−4.342**	**(0.000)**	**−1.715**	**(0.044)**	**(0.001)**	0.029	0.319	(0.118)
CZE	**−2.222**	**(0.012)**	0.377	(0.870)	0.090	(0.972)	(0.163)	0.210	0.247	(0.166)
HUN	−0.560	(0.800)	0.698	(0.732)	**−2.111**	**(0.010)**	(0.132)	−0.057	0.039	(0.659)
ISL	0.099	(0.966)	0.043	(0.988)	**−2.400**	**(0.004)**	(0.119)	0.114	0.251	(0.206)
IND	**−1.757**	**(0.050)**	**−2.298**	**(0.006)**	**−3.210**	**(0.000)**	**(0.002)**	0.159	0.263	(0.212)
INA	**−1.675**	**(0.062)**	−0.665	(0.768)	−1.284	(0.214)	(0.165)	0.290	0.325	(0.121)
ISR	**−3.006**	**(0.002)**	−1.208	(0.264)	**−3.352**	**(0.000)**	**(0.001)**	−0.034	0.179	(0.275)
JPN	**−2.817**	**(0.002)**	**−2.237**	**(0.004)**	−1.291	(0.162)	**(0.004)**	−0.006	0.187	(0.196)
MEX	−1.037	(0.476)	−0.468	(0.834)	−0.396	(0.870)	(0.895)	−0.004	−0.037	(0.783)
NZL	−0.348	(0.876)	−0.441	(0.860)	**−2.773**	**(0.002)**	**(0.040)**	0.280	**0.351**	**(0.089)**
NOR	0.453	(0.840)	0.981	(0.516)	**−1.558**	**(0.060)**	(0.234)	0.037	0.103	(0.410)
POL	−0.792	(0.700)	0.289	(0.902)	−0.974	(0.568)	(0.871)	0.016	0.007	(0.752)
ROU	**−2.349**	**(0.012)**	0.630	(0.760)	**−1.793**	**(0.050)**	**(0.034)**	0.430	**0.520**	**(0.015)**
RSA	**−4.518**	**(0.000)**	**−1.914**	**(0.020)**	**−3.529**	**(0.000)**	**(0.000)**	0.232	**0.610**	**(0.002)**
SWE	−1.368	(0.146)	−0.096	(0.972)	**−2.020**	**(0.010)**	**(0.087)**	0.057	0.162	(0.288)
SWZ	−0.964	(0.518)	0.354	(0.882)	**−2.221**	**(0.008)**	(0.107)	0.008	0.076	(0.528)
KOR	−1.026	(0.488)	−1.286	(0.204)	**−1.708**	**(0.042)**	**(0.098)**	0.118	0.196	(0.309)
TAI	**−2.609**	**(0.004)**	**−3.557**	**(0.000)**	**−2.622**	**(0.000)**	**(0.000)**	−0.005	0.307	(0.112)
TUR	**−3.538**	**(0.000)**	−1.281	(0.216)	**−2.555**	**(0.002)**	**(0.001)**	0.290	**0.503**	**(0.016)**
GBR	0.681	(0.732)	−0.667	(0.740)	**−2.174**	**(0.010)**	(0.156)	−0.017	0.142	(0.420)
EUR	−1.139	(0.336)	0.424	(0.872)	**−2.981**	**(0.000)**	**(0.021)**	0.074	0.191	(0.233)
Joint*		**(0.000)**		**(0.001)**		**(0.000)**			**(0.000)**	**(0.011)**

Notes: (7): p-value of Wald-type test that coefficients on factors are jointly zero. (8): $\overline{R}^2(1)$ is adjusted R^2 from regression that includes only the control variables. (9): $\overline{R}^2(2)$ is adjusted R^2 when including both controls and third-country factors. (10) p-value of test that $\overline{R}^2(2) = \overline{R}^2(1)$. Bold entries indicate significance at the 10% level.
* : p-value of test that the increment $\overline{R}^2$ or factor coefficients across countries are jointly zero.

Next, we consider the possibility that, instead of managing one's currency, a country follows the lead of a third country in setting its interest rate. Table 2 reports results when the target rate of the Taylor rule is augmented by the first three recursively constructed interest rate factors. Interest rate factors are seen to enter significantly for about half of the countries. Many of the entries might

Table 8
One-quarter ahead depreciation regressed on interest-rate factors. Taylor-rule control variables. USD numeraire.

	f_1		f_2		f_3		Wald			
	t-ratio	p-value	t-ratio	p-value	t-ratio	p-value	p-value	$\overline{R}^2(1)$	$\overline{R}^2(2)$	p-value
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
AUS	−0.383	(0.852)	**1.575**	**(0.030)**	0.409	(0.848)	(0.333)	−0.025	−0.023	(0.482)
BRA	0.574	(0.814)	**2.183**	**(0.002)**	0.950	(0.582)	**(0.043)**	−0.047	0.020	(0.399)
CAN	−0.563	(0.760)	**2.179**	**(0.000)**	0.382	(0.854)	**(0.045)**	0.165	**0.182**	**(0.063)**
CHI	−0.267	(0.930)	**1.731**	**(0.006)**	**3.126**	**(0.000)**	**(0.000)**	−0.057	0.005	(0.450)
CZE	−0.512	(0.846)	**1.468**	**(0.030)**	−0.161	(0.958)	(0.588)	−0.014	−0.032	(0.499)
HUN	−0.655	(0.776)	**1.753**	**(0.006)**	−0.342	(0.898)	(0.315)	−0.038	−0.034	(0.506)
ISL	**−1.840**	**(0.014)**	**1.860**	**(0.002)**	0.199	(0.948)	**(0.014)**	−0.001	**0.162**	**(0.033)**
IND	−0.903	(0.646)	**3.640**	**(0.000)**	0.321	(0.920)	**(0.001)**	0.073	**0.176**	**(0.016)**
INA	−0.133	(0.962)	0.851	(0.676)	0.731	(0.736)	(0.868)	0.080	0.050	(0.228)
ISR	0.164	(0.956)	**1.500**	**(0.034)**	0.306	(0.914)	(0.498)	−0.050	−0.077	(0.513)
JPN	1.212	(0.324)	−0.388	(0.894)	0.109	(0.972)	(0.857)	−0.053	−0.095	(0.490)
MEX	−0.693	(0.752)	1.183	(0.220)	0.806	(0.710)	(0.330)	−0.043	−0.049	(0.517)
NZL	−0.867	(0.666)	**2.259**	**(0.002)**	0.100	(0.970)	**(0.058)**	0.019	0.086	(0.224)
NOR	−0.692	(0.782)	**1.829**	**(0.004)**	−0.057	(0.986)	(0.212)	−0.023	−0.002	(0.458)
POL	−0.818	(0.690)	**2.292**	**(0.000)**	0.664	(0.786)	**(0.024)**	−0.046	0.011	(0.467)
ROU	−0.743	(0.734)	1.171	(0.224)	1.390	(0.120)	**(0.071)**	0.046	0.053	(0.243)
RSA	**−2.125**	**(0.002)**	**2.591**	**(0.000)**	1.407	(0.128)	**(0.000)**	0.004	0.081	(0.168)
SWE	−0.854	(0.690)	**1.619**	**(0.010)**	0.396	(0.888)	(0.204)	0.027	0.034	(0.319)
SWZ	−0.278	(0.894)	−0.212	(0.918)	−0.563	(0.806)	(0.984)	−0.029	−0.089	(0.505)
KOR	**−2.698**	**(0.000)**	**2.299**	**(0.000)**	−0.040	(0.988)	**(0.001)**	0.031	**0.168**	**(0.031)**
TAI	−0.169	(0.958)	0.940	(0.540)	**1.523**	**(0.068)**	(0.207)	0.007	−0.016	(0.534)
TUR	−1.077	(0.404)	**3.106**	**(0.000)**	−0.359	(0.876)	**(0.005)**	−0.001	0.031	(0.360)
GBR	**−1.544**	**(0.082)**	**2.177**	**(0.002)**	−0.977	(0.566)	**(0.051)**	−0.030	0.102	(0.134)
EUR	0.135	(0.960)	**1.997**	**(0.000)**	−1.267	(0.148)	**(0.054)**	0.038	0.024	(0.325)
Joint*		(0.502)		**(0.000)**		(0.901)			**(0.108)**	**(0.043)**

Notes: (7): p-value of Wald-type test that coefficients on factors are jointly zero. (8): $\overline{R}^2(1)$ is adjusted R^2 from regression that includes only the control variables. (9): $\overline{R}^2(2)$ is adjusted R^2 when including both controls and third-country factors. (10) p-value of test that $\overline{R}^2(2) = \overline{R}^2(1)$. Bold entries indicate significance at the 10% level.
* : p-value of test that the increment $\overline{R}^2$ or factor coefficients across countries are jointly zero.

Table 9
Four-quarter ahead depreciation regressed on interest-rate factors. Taylor-rule control variables. USD numeraire.

	f_1		f_2		f_3		Wald			
	t-ratio	p-value	t-ratio	p-value	t-ratio	p-value	p-value	$\bar{R}^2(1)$	$\bar{R}^2(2)$	p-value
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
AUS	0.215	(0.936)	1.233	(0.276)	0.303	(0.914)	(0.816)	0.144	0.136	(0.491)
BRA	0.999	(0.616)	**1.879**	**(0.030)**	1.177	(0.438)	(0.149)	−0.059	0.090	(0.725)
CAN	−0.545	(0.834)	**2.435**	**(0.002)**	−0.220	(0.930)	**(0.084)**	0.204	0.290	(0.133)
CHI	1.110	(0.530)	0.935	(0.606)	1.438	(0.220)	(0.447)	0.011	0.092	(0.655)
CZE	−0.375	(0.896)	**1.900**	**(0.014)**	−0.947	(0.624)	(0.312)	0.172	0.250	(0.242)
HUN	−1.286	(0.350)	**3.222**	**(0.000)**	**−2.324**	**(0.014)**	**(0.006)**	−0.049	0.196	(0.400)
ISL	−1.362	(0.286)	0.875	(0.636)	0.148	(0.958)	(0.553)	0.107	0.238	(0.312)
IND	−0.591	(0.826)	**3.095**	**(0.000)**	−0.202	(0.946)	**(0.028)**	0.155	0.281	(0.257)
INA	0.537	(0.842)	0.322	(0.900)	0.884	(0.662)	(0.977)	0.449	0.449	(0.034)
ISR	0.848	(0.744)	**1.969**	**(0.018)**	0.929	(0.682)	(0.183)	−0.036	0.090	(0.699)
JPN	1.311	(0.346)	−0.165	(0.944)	−1.590	(0.122)	**(0.076)**	−0.018	0.073	(0.697)
MEX	−1.165	(0.440)	**2.193**	**(0.008)**	**2.189**	**(0.018)**	**(0.006)**	0.022	0.320	(0.152)
NZL	−0.216	(0.948)	**1.680**	**(0.066)**	−0.135	(0.962)	(0.567)	0.190	0.209	(0.405)
NOR	−0.654	(0.802)	**2.363**	**(0.002)**	−0.209	(0.936)	(0.118)	0.007	0.125	(0.541)
POL	**−2.214**	**(0.020)**	**3.695**	**(0.000)**	1.029	(0.568)	**(0.001)**	−0.013	**0.439**	**(0.038)**
ROU	**−2.292**	**(0.014)**	**1.588**	**(0.080)**	1.208	(0.410)	**(0.012)**	0.357	**0.508**	**(0.009)**
RSA	−0.665	(0.798)	0.104	(0.966)	**2.116**	**(0.028)**	(0.100)	0.204	0.280	(0.244)
SWE	−0.712	(0.790)	1.245	(0.278)	−0.274	(0.916)	(0.816)	0.043	0.065	(0.755)
SWZ	−0.225	(0.942)	0.535	(0.822)	−1.492	(0.192)	(0.668)	0.025	0.020	(0.838)
KOR	−2.132	(0.036)	0.987	(0.554)	−0.027	(0.992)	(0.178)	0.149	0.312	(0.188)
TAI	0.504	(0.850)	0.986	(0.534)	**1.765**	**(0.076)**	(0.322)	0.000	0.107	(0.671)
TUR	−0.165	(0.960)	0.953	(0.606)	−1.007	(0.536)	(0.866)	0.264	0.280	(0.265)
GBR	−1.500	(0.220)	**1.985**	**(0.022)**	−1.092	(0.526)	(0.167)	−0.031	0.137	(0.644)
EUR	−0.145	(0.962)	1.269	(0.258)	**−1.760**	**(0.070)**	(0.194)	0.048	0.103	(0.612)
Joint*		(0.844)		**(0.000)**		(0.341)			**(0.064)**	**(0.011)**

Notes: (7): p-value of Wald-type test that coefficients on factors are jointly zero. (8): $\bar{R}^2(1)$ is adjusted R^2 from regression that includes only the control variables. (9): $\bar{R}^2(2)$ is adjusted R^2 when including both controls and third-country factors. (10) p-value of test that $\bar{R}^2(2) = \bar{R}^2(1)$. Bold entries indicate significance at the 10% level.
* : p-value of test that the increment $\bar{R}^2$ or factor coefficients across countries are jointly zero.

be considered marginally significant (p-values between 0.1 and 0.15 say). Here, each of the three factors appears to be important to some extent.

Neither exchange rate factors nor interest rate factors alone are significant for every country's policy reactions. Taken together, however, the results are supportive of some sort of third-country effect on monetary policy rules. That is, for those countries where interest rate factors are generally insignificant, real exchange rate factors are, and vice-versa. For example, the second exchange rate factor is significant for Australia but interest rate factors are not, whereas the first interest rate factor is significant for Japan, but exchange rate factors are not.

This leads us to ask if there is evidence that at least one real exchange rate factor or one interest rate factor exerts a significant influence on the majority of the countries' Taylor rules? In Table 3 we selectively choose combinations of the interest rate and exchange rate factors to include in the Taylor rule specification. In this admittedly, exercise in data mining, we find significant evidence of either a third-country interest rate or real exchange rate influence in 17 of the 24 Taylor rules.

3.3. Factor augmented exchange rate regressions

Having found evidence to support the model's transmission mechanism for third-country spillovers, we now test for the presence of these effects in bilateral exchange rates. The USA serves as the numeraire country and is designated as Country 1. Exchange rates are quoted as (log) U.S. dollar (USD) price of currency $j = 2,..., 24$ so an increase in $e_{1j,t}$ means that the USD depreciates (relative to j). Guided by Eq. (10), which is a predictive regression, we run regressions of the form,

$$e_{1,j,t+k} - e_{1,j,t} = G'_{1,j,t}\beta + \sum_{i=1}^{3}\theta_{i,j} f_{i,t} + u_{1,j,t+k}, \quad (12)$$

at horizons $k = 1$ and $k = 4$. $G_{1,j,t}$ is a vector of control variables containing period t inflation rates and output gaps for Countries 1 and j and $(f_{1,t}, f_{2,t}, f_{3,t})$ are the third-country factors.

Although Eq. (12) is a predictive regression, we do not evaluate out-of-sample forecasts due to the relatively short time-span of our data and because the paper is not about forecasting per se. Because forecasting works best with lightly parameterized models, the model that forecasts best in a small sample could easily be misspecified. Instead, we assess predictive content by t-tests and Wald-tests on coefficients from third-country factors from in-sample predictive regressions. We draw on Inoue and Kilian (2005) to defend this decision. They show that in-sample tests have power advantages over out-of-sample tests of predictive content and they conclude that if one's goal is to test whether or not a predictive relationship exists in population, in-sample tests may be preferred to out-of-sample tests.

Tables 4 through 9 report Newey and West (1983) t-ratios on the third-country factors and adjusted R^2 from including and excluding the factors. Due to the small time-series dimension, p-values are computed from the nonparametric sieve bootstrap.

Table 4 reports results for the one-period horizon regressions with inflation factors. After controlling for bilateral exchange rate determinants, the inflation factors are seen to enter significantly for nearly every exchange rate. The third factor enters significantly most often, followed by the first and second factors.

The first factor loosely has the magnitude of the underlying observations, whereas higher-order factors have the dimensionality of

Table 10
Parameterization.

	Preferences		Symmetric price setting			Monetary policy	
γ_1	2		α_j	0.75	$(j = 1,2,3)$	ρ	0.95
γ_2	2					λ	1.5
$d_{i,j}$	$\frac{1}{3}$	$(i, j = 1, 2, 3)$	Asymmetric price setting			ϕ	0.5
β	0.99		α_1	0.407		σ_q	0.5
			α_2	0.890		σ_i	0.75
			α_3	0.650		Technology	
						ψ	0.9

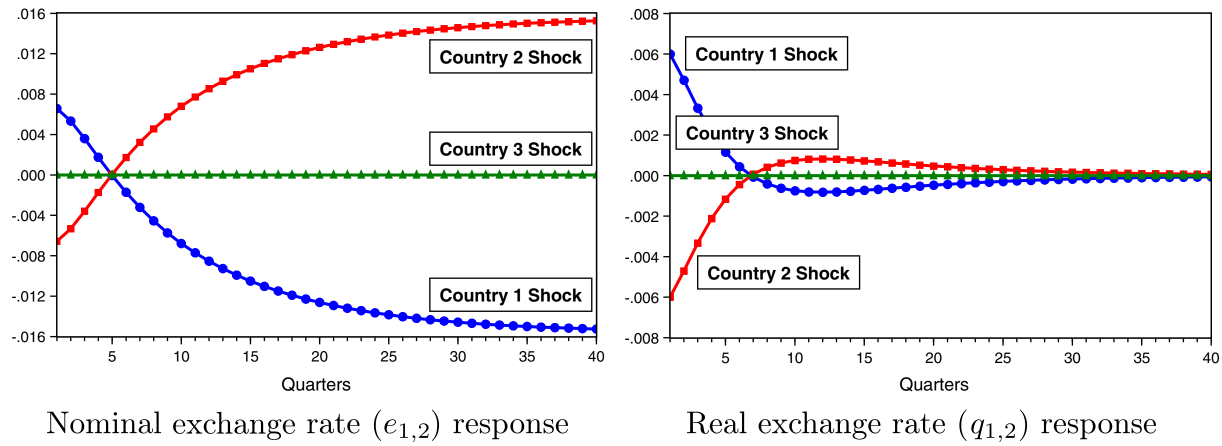

Fig. 1. Exchange rate response to technology shock under Environment 1 (independent policy, symmetric stickiness). Nominal exchange rate $(e_{1,2})$ response. Real exchange rate $(q_{1,2})$ response.

residuals. Based on the partial equilibrium model, we might expect the first inflation factor to enter the regressions negatively. An increase in third-country inflation should lead to a real dollar depreciation against the third-country, and by Eq. (10), an expected home-currency depreciation. The significant t-ratios on the first inflation factor are positive, which runs counter to predictions of the partial-equilibrium model, but that intuition is not air tight since there remains the unobserved forward exchange risk premium ζ_t as an omitted variable, which if correlated with the factors, can bias the estimates. Additionally, more complicated interrelationships might be evident if interest rate smoothing, where the lagged interest rate should be included in the policy functions, is accounted for. Obtaining a sign prediction on the second factor is complicated since it is the linear combination of the observations that is most correlated with the part not explained by the first factor. Analogously, the third factor is the linear combination of the observations most correlated with the part unexplained by the first two factors.

The average adjusted R^2 increases from 0.002 to 0.086 when including inflation factors. Sampling properties of the adjusted R^2 are relatively noisy in the sense that the incremental $\overline{R}^2$ is sometimes not significant even though the associated t-ratios are. This can happen when the significance on the bilateral control variables is replaced by significance on the factors.

Table 5 reports the four-period horizon regression results with inflation factors. After controlling for bi-lateral determinants, the sign on significant t-ratios for the first factor remains positive, and negative on significant third factors. Here, the first factor is most often significant. Addition of the factors raises the average adjusted R^2 from 0.106 to 0.234.

Evidence for third-country output-gap spillovers onto bilateral exchange rates is nearly as strong. Table 6 shows the results from the one-period depreciation regressions with the output-gap factors. Here, the first factor, which has the dimensionality of the output gap, enters with the expected negative sign. An increase in the third country output gap causes Country 3 to raise its interest rate, leading to a Country 3 appreciation. The corresponding Country 1 depreciation (relative to 3) should lead to an expected currency 1 appreciation ($E_t e_{1,2,t+1} - e_{1,2,t} < 0$). The third factor enters significantly most often, followed by the first and second factors. Inclusion of the factors raises the average adjusted R^2 statistics from 0.002 to 0.032. A similar picture emerges in Table 7, which shows the results from regressions of the four-period depreciation on output gap factors. Inclusion of third-country factors raises the average adjusted R^2 statistics from 0.106 to 0.237.

In Tables 8 and 9 we examine whether third-country interest rate factors directly impact exchange rate dynamics. At the one-period horizon, the second interest rate factor enters significantly for 19 of 24 exchange rates (the first and third factors are largely insignificant). The factors raise the average adjusted R^2 from 0.001 to 0.032. A similar pattern is seen at the 4-quarter horizon, but the evidence is weaker with fewer significant coefficients. Here, the factors raise the average adjusted R^2 from 0.098 to 0.206.

To summarize, after controlling for bilateral inflation and output gaps in exchange rate predictive regression, we find evidence that third-country macrofactors are present in exchange rate dynamics. We have also run, but do not report, analogous regressions that control for the numeraire country. In these regressions, third-country factors continue to enter significantly but the results are not as strong. Controlling for the numeraire is not seen as critical, however, since the USD is the primary vehicle and invoice currency in international contracts, serves as the major reserve currency and is the most heavily traded currency in foreign exchange markets. In short, the currency exchange rate that people care most about is with respect to the USD.

4. A three country general equilibrium exchange-rate model

The partial equilibrium model motivates the predictive regressions but is not explicit about how exogenous third country shocks cause exchange rate fluctuations. In this section, we make the dependence of the exchange rate on *exogenous* third-country shocks explicit with a three-country general equilibrium model. We use the model to study the nature of this dependence and to assess the relative importance of third-country shocks in driving the exchange rate. We work within the familiar structure of the New Keynesian model that has been popular for studying a variety of exchange rate and international business cycle issues (Chari et al. (2002), Benigno (2004), Bergin (2006), Kollmann (2001), Steinsson (2008)). The model provides the minimum amount of structure needed to get a useful theory of nominal exchange rates and their dependence on third-country effects. The sticky-price aspect delivers a theory for the nominal exchange rate and our extension to three countries allows an explicit examination of third-country effects.

As such, it is not a theory of everything. Specifically, the model does not provide a theory for deviations from UIP. For some authors, deviations from UIP play a prominent role in their analyses (Kollmann (2001), Devereux and Engel (2002), Bergin (2006), Evans (2012)) and they incorporate features in their models to generate such deviations. Kollmann (2001) and Bergin (2006) introduce exogenous UIP deviations, Devereux and Engel (2002) feature a noise-trader component and Evans (2012) introduces taste shocks that affect agents' risk-tolerance. Unlike these papers, it is not necessary to create deviations from UIP to make our point. To avoid unnecessary complications, the model is presented in a complete market environment where UIP

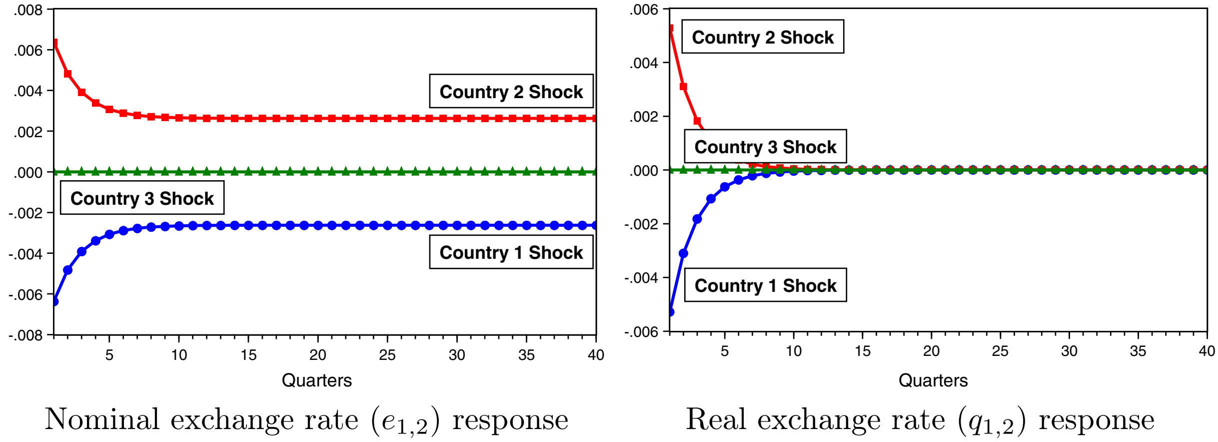

Fig. 2. Exchange rate response to monetary policy shock under Environment 1 (independent policy, symmetric stickiness). Nominal exchange rate ($e_{1,2}$) response. Real exchange rate ($q_{1,2}$) response.

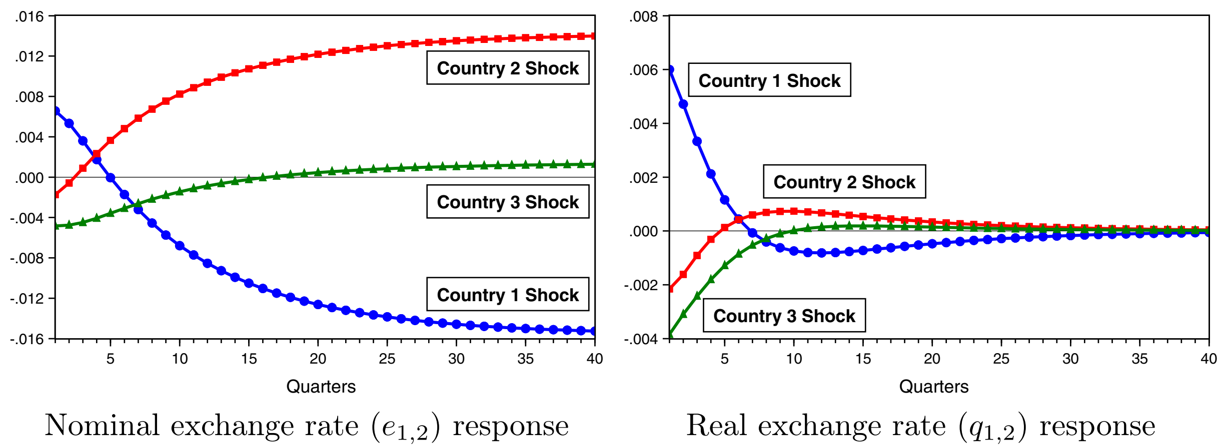

Fig. 3. Exchange rate response to technology shock under Environment 2 (managed float between 2 and 3, symmetric stickiness). Nominal exchange rate ($e_{1,2}$) response. Real exchange rate ($q_{1,2}$) response.

holds. A similar set of comments apply to the Backus and Smith (1993) condition, which is also implied by the model but rejected by the data. Although the model has some counterfactual implications, they do not invalidate its predictions about third-country effects on bilateral exchange rates.

4.1. The model

As in the previous section, we loosely think of the U.S. as Country 1 and a representative home country as Country 2. Country 3 is the third country, which can be viewed as a 'stand-in' for the rest of the

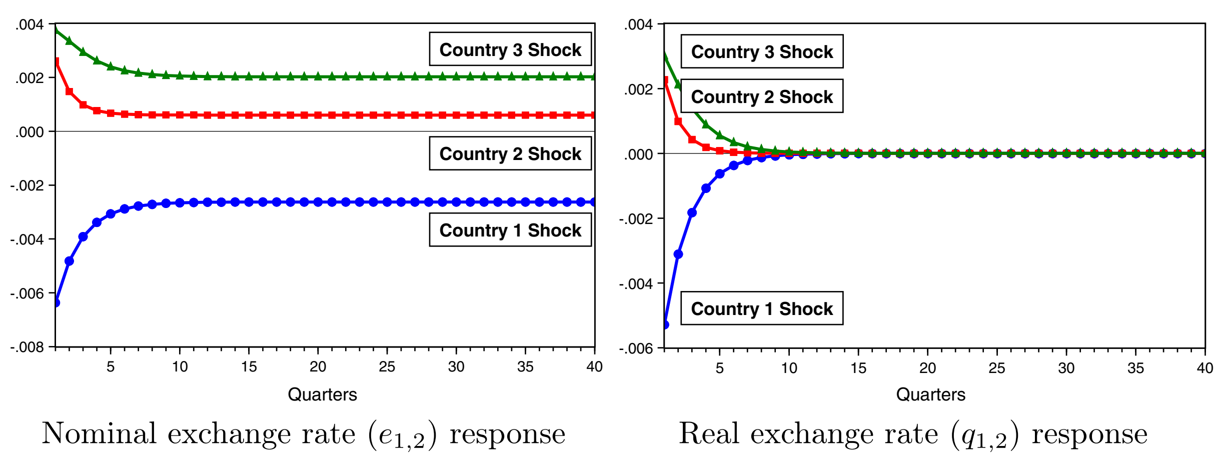

Fig. 4. Exchange rate response to monetary policy shock under Environment 2 (managed float between 2 and 3, symmetric stickiness). Nominal exchange rate ($e_{1,2}$) response. Real exchange rate ($q_{1,2}$) response.

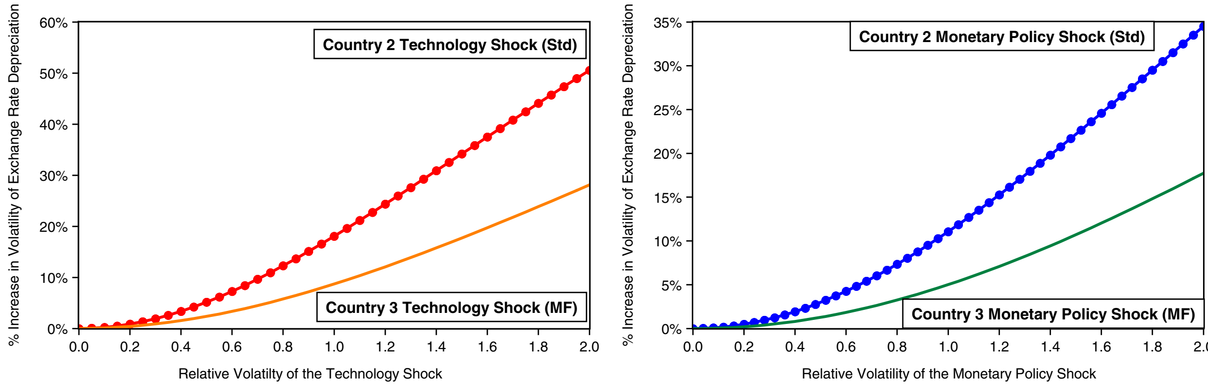

Fig. 5. Volatility of $\Delta e_{1,2}$ and relative volatility of Countries 2 and 3 shocks.

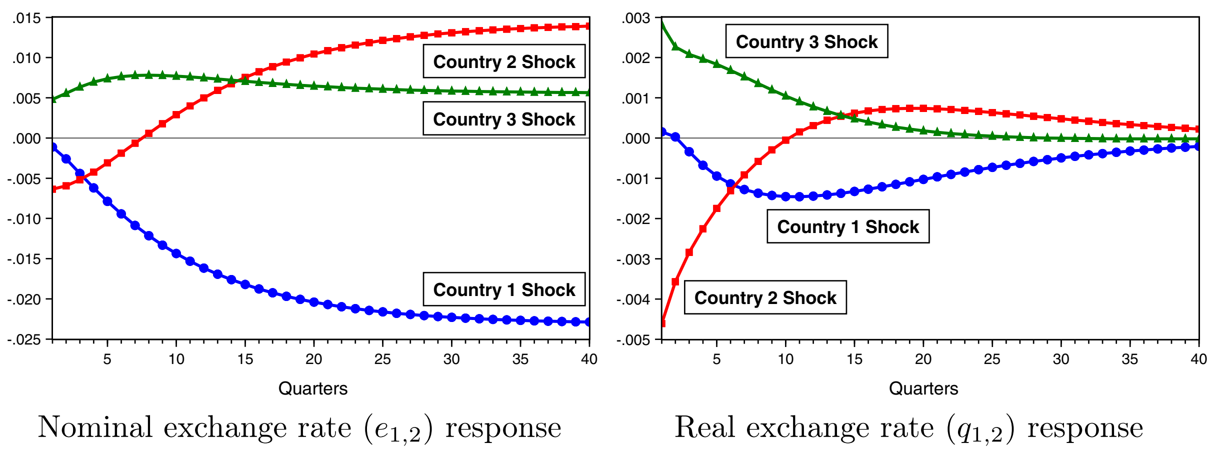

Fig. 6. Exchange rate response to technology shock under Environment 3 (independent policy, heterogeneous stickiness by origin). Nominal exchange rate ($e_{1,2}$) response. Real exchange rate ($q_{1,2}$) response.

world. There is no capital in the model and the production technology requires only labor. Each country is populated by a continuum of economic agents with population size proportional to the range of produced goods. The model is quite standard and our presentation of its formal structure is brief.[12]

4.1.1. The household's problem

In period t, any one of N possible states of nature can occur. Let s_t denote the state at t and $s^t = (s_t, s_{t-1},..., s_0)$ denote the history. Financial markets are complete. A full set of state contingent bonds with payoffs in Country 1 money are traded internationally. Output is supplied by a continuum of monopolistically competitive firms each producing a differentiated product using only labor. Ownership of the firms is not internationally traded. Hence, households of Country $j = 1,2,3$ own their country's firms and claims to their profits. Household resources accrue from firm profits, $\Pi_j(s^t)$, sales of labor, $n_j(s^t)$, and payoffs from the state-contingent bonds.

Let $C_j(s^t)$ be the household's consumption index (elaboration of the composition of the index follows below), $P_j(s^t)$ be the general price level, $Q(s_{t+1}|s^t)$ be the Country 1 currency price of a state-contingent security, $W_j(s^t)$ be the nominal wage, $B_j(s_t)$ be the number of state s_t securities held, and $e_{i,j}(s^t)$ be the nominal exchange rate expressed as the Country i currency price of a unit of Country j money. Households face the sequential budget constraints

$$C_j\left(s^t\right) + \sum_{s_{t+1}} \frac{Q\left(s_{t+1}|s^t\right) B_j(s_{t+1})}{e_{1,j}(s^t) P_j(s^t)} = \frac{W_j\left(s^t\right) n_j\left(s^t\right)}{P_j(s^t)} + \frac{\Pi_j\left(s^t\right)}{P_j(s^t)} + \frac{B_j(s_t)}{e_{1,j}(s^t) P_j(s^t)} \tag{13}$$

where current period resources are on the right side and uses of those resources on the left side of Eq. (13).

Preferences are defined over consumption, C_j, and leisure, $(1-n_j)$, where the functional form for flow utility is

$$u\left(C_j, \left(1-n_j\right)\right) = \left(\frac{C_j^{1-\gamma_1}-1}{1-\gamma_1}\right) + \theta_2 \left(\frac{\left(1-n_j\right)^{1-\gamma_2}-1}{1-\gamma_2}\right). \tag{14}$$

A household in Country $j = 1,2,3$ maximizes lifetime expected utility

$$\sum_{t=0}^{\infty} \beta^t \sum_{s^t} \pi\left(s^t\right) u\left(C_j\left(s^t\right), \left(1-n_j\left(s^t\right)\right)\right), \tag{15}$$

subject to Eq. (13) and the functional form Eq. (14). Due to the complete-market environment, the real exchange rate in this model (as in Chari et al. (2002), Benigno (2004); Steinsson (2008)) has the Backus and Smith (1993) form.

[12] Complete derivations of the model's equations are given in the online Appendix 2.

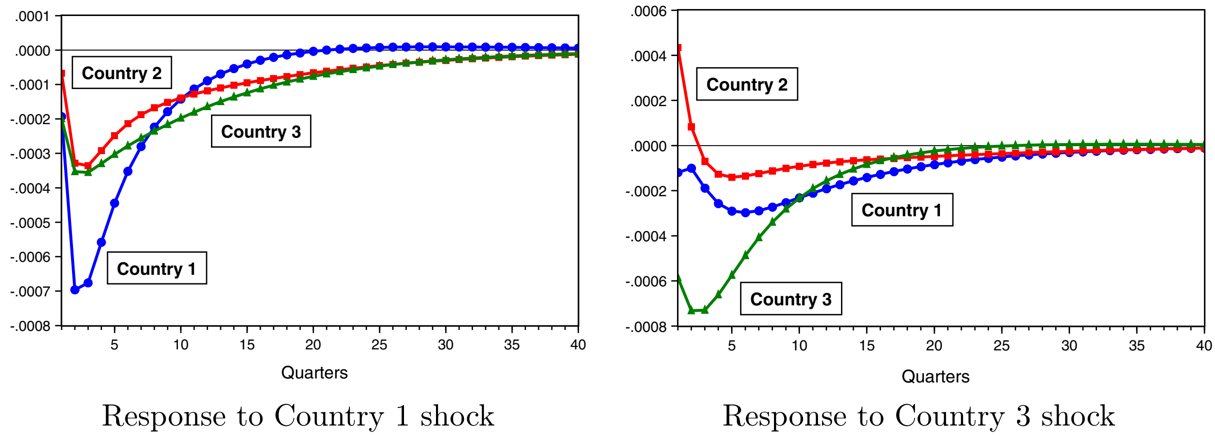

Fig. 7. Real interest rate response to technology shock under Environment 3 (independent policy, heterogeneous stickiness by origin). Response to Country 1 shock. Response to Country 3 shock.

4.1.2. The demand system

The household's consumption problem is broken into two parts. The first part is the intertemporal decision of expenditures and savings discussed above. The second part is a cost-minimizing problem for allocating consumption expenditures across the different choices of goods, which we now describe.

At this point, we lighten the notation by suppressing the functional dependence on the state. The underlying goods are differentiated on a unit interval continuum with Country 1 producing goods on $\omega \in [a_0, a_1)$, Country 2 on $\omega \in [a_1, a_2)$ and Country 3 on $\omega \in [a_2, a_3]$ where $(0 = a_0 < a_1 < a_2 < a_3 = 1)$. Our notational convention is that the first subscript indicates where the good is consumed and the second subscript indicates where the good is produced ($C_{i,j,t}$ is produced in j and exported to i at time t). The consumption index for the household of Country j is formed by the CES (constant elasticity of substitution) index

$$C_{j,t} = \left(\left(d_{j,1}\right)^{\frac{1}{\mu}} \left(C_{j,1,t}\right)^{\frac{\mu-1}{\mu}} + \left(d_{j,2}\right)^{\frac{1}{\mu}} \left(C_{j,2,t}\right)^{\frac{\mu-1}{\mu}} + \left(d_{j,3}\right)^{\frac{1}{\mu}} \left(C_{j,3,t}\right)^{\frac{\mu-1}{\mu}} \right)^{\frac{\mu}{\mu-1}},$$

of consumption subindices, $0 \le \mu \le \infty$ is the elasticity of substitution, and $d_{j,1} + d_{j,2} + d_{j,3} = 1$. The general price level associated with this consumption index is

$$P_{j,t} = \left(d_{j,1} \left(P_{j,1,t}\right)^{1-\mu} + d_{j,2} \left(P_{j,2,t}\right)^{1-\mu} + d_{j,3} \left(P_{j,3,t}\right)^{1-\mu} \right)^{\frac{1}{1-\mu}}.$$

Each of the underlying consumption baskets $C_{i,j,t}$ is themselves CES indices of the individual goods purchased, $c_{i,j,t}(\omega)$, from Country j and consumed by residents of Country i,

$$C_{i,j,t} = \left(\left(\frac{1}{a_j - a_{j-1}} \right)^{\frac{1}{\sigma}} \int_{a_{j-1}}^{a_j} c_{i,j,t}(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}} \quad j = 1, 2, 3,$$

and have corresponding CES price indices $P_{i,j,t}$ of the individual good prices, $p_{i,j,t}(\omega)$, produced in Country j and consumed by residents of Country i,

$$P_{i,j,t} = \left(\left(\frac{1}{a_j - a_{j-1}} \right) \int_{a_{j-1}}^{a_j} p_{i,j,t}(\omega)^{1-\sigma} d\omega \right)^{\frac{1}{1-\sigma}} \quad j = 1, 2, 3.$$

The solution to the cost-minimization problem gives the demand functions for the underlying goods

$$c_{i,j,t}(\omega) = \phi_{i,j,t} \left(\frac{p_{i,j,t}(\omega)}{P_{i,j}, t} \right)^{-\sigma} C_{i,t}, \tag{16}$$

where

$$\varphi_{i,j,t} = \left\{ \left(\frac{d_{i,j}}{a_j - a_{j-1}} \right) \left(\frac{P_{i,j,t}}{P_{i,t}} \right)^{-\mu} \right\}.$$

4.1.3. The firm's problem

Firms in Country j have access to a linear (in labor input) technology

$$y_{j,t}(\omega) = A_{j,t} n_{j,t}(\omega), \tag{17}$$

where $A_{j,t}$ is an economy-wide technology shock and $n_{j,t}(\omega)$ is the labor input into producing commodity ω. The firm's output is demand determined so that

$$y_{j,t}(\omega) = c_{1,j,t}(\omega) + c_{2,j,t}(\omega) + c_{3,j,t}(\omega). \tag{18}$$

Real current period profits for a firm in Country j is

$$\Pi_{j,t}(\omega) = \sum_{i=1}^{3} \frac{e_{j,i,t}}{P_{j,t}} p_{i,j,t}(\omega) c_{i,j,t}(\omega) - \frac{W_{j,t}}{P_{j,t}} n_{j,t}(\omega). \tag{19}$$

Substituting $n_{j,t}(\omega)$ from Eq. (17), $y_{j,t}(\omega)$ from Eq. (18) and the individual goods demands from Eq. (16) into Eq. (19) gives current period profits as

$$\Pi_{j,t}(\omega) = \sum_{i=1}^{3} \left(\frac{e_{j,i,t}}{P_{j,t}} p_{i,j,t}(\omega) - \frac{W_{j,t}}{A_{j,t} P_{j,t}} \right) \phi_{i,j,t} \left(\frac{p_{i,j,t}(\omega)}{P_{i,j,t}} \right)^{-\sigma} C_{i,t}. \tag{20}$$

Firms engage in local-currency pricing and prices are sticky in the sense of Calvo (1983). As in Benigno (2004), we allow heterogeneity in price stickiness by country of origin. That is, firms of Country j can reset prices of all its sales (whether they be domestic sales or exports) with probability $(1 - \alpha_j)$. A firm in Country j who is chosen to reset price this period does so to maximize

$$E_t \sum_{k=0}^{\infty} \left(\alpha_j \beta \right)^k C_{j,t+k}^{-\gamma_1} \Pi_{j,t+k}(\omega),$$

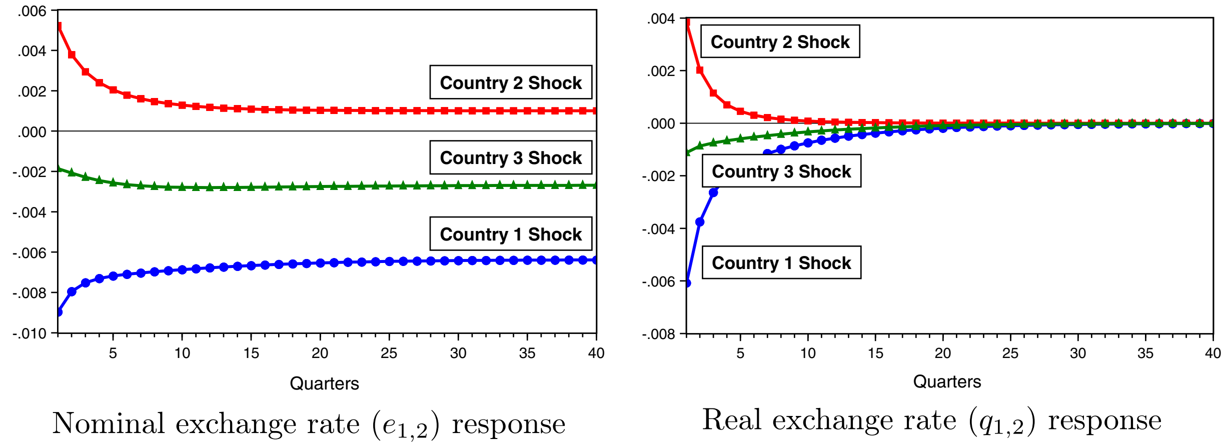

Fig. 8. Exchange rate response to monetary policy shock under Environment 3 (independent policy, heterogeneous stickiness by origin). Nominal exchange rate ($e_{1,2}$) response. Real exchange rate ($q_{1,2}$) response.

subject to Eq. (20). Rearrangement of the first-order condition gives the optimal price for the Country j firm who sells its product in Country i as

$$p^*_{i,j,t}(\omega) = \frac{\sigma}{(\sigma-1)} \frac{E_t \sum_{k=0}^{\infty} \left(\alpha_j \beta\right)^k C_{i,t+k} C_{j,t+k}^{-\gamma_1} \phi_{i,j,t+k} P^{\sigma}_{i,j,t+k} \frac{W_{j,t+k}}{A_{j,t+k} P_{j,t+k}}}{E_t \sum_{k=0}^{\infty} \left(\alpha_j \beta\right)^k C_{i,t+k} C_{j,t+k}^{-\gamma_1} \phi_{i,j,t+k} P^{\sigma}_{i,j,t+k} \frac{e_{j,i,t+k}}{P_{j,t+k}}}. \tag{21}$$

With the fraction $(1-\alpha_j)$ of the firms resetting price to the value of $p^*_{i,j,t}(\omega)$ and the fraction α_j that maintain price at the previous level, the price index of goods produced in j and sold in i evolves according to

$$P_{i,j,t}^{(1-\sigma)} = \left(1-\alpha_j\right)\left(p^*_{i,j,t}\right)^{(1-\sigma)} + \alpha_j P_{i,j,t-1}^{(1-\sigma)}. \tag{22}$$

4.1.4. Monetary policy

The monetary authorities conduct policy through interest rate reaction functions. We include the lagged interest rate to capture interest rate smoothing by the authorities. The form of the rule follows Benigno (2004) and Steinsson (2008). We consider two variants of policy, conduct-independent and managed float. Under *independence*, countries pursue only domestic objectives so that authorities in Country $j = 1,2,3$ set their interest rates according to

$$i_{j,t} = \delta + \rho i_{j,t-1} + \lambda E_t\left(\pi_{j,t+1}\right) + \phi \tilde{y}_{j,t} + \epsilon_{j,t}. \tag{23}$$

In a second variant, which we refer to as “managed float,” Countries 1 and 3 run policy according to Eq. (23) but Country 2's policy function also includes the real exchange rate between 2 and 3,

$$i_{2,t} = \delta + \rho i_{2,t-1} + \lambda E_t\left(\pi_{2,t+1}\right) + \phi \tilde{y}_{2,t} + \sigma_q q_{2,3,t} + \epsilon_{2,t}, \tag{24}$$

which is similar to the form studied in Section 2. Here, purchasing power parity is viewed as the equilibrium for the nominal exchange rate and the authorities intervene to stabilize the exchange rate against Country 3 around the PPP value.

In the third variant, Country 2 views Country 3 as the monetary policy leader and follows 3 according to,

$$i_{2,t} = \delta + \rho i_{2,t-1} + \lambda E_t\left(\pi_{2,t+1}\right) + \phi \tilde{y}_{2,t} + \sigma_i i_{3,t} + \epsilon_{2,t}. \tag{25}$$

4.1.5. Equilibrium

Equilibrium requires that national outputs, $Y_{j,t}$, be consumed,

$$Y_{j,t} = \sum_{i=1}^{3} C_{i,j,t} j = 1, 2, 3, \tag{26}$$

and labor supply be allocated,

$$n_{j,t} = \int_{a_{j-1}}^{a_j} n_{j,t}(\omega) d\omega j = 1, 2, 3. \tag{27}$$

An *equilibrium* for this economy is a collection of allocations for households of $C_{j,t}$, $n_{j,t}$, and $B_j(s_t)$, allocations and prices for producers, $y_{j,t}$ and $p_{i,j,t}$, final goods prices, $P_{j,t}$, wages, $W_{j,t}$, and bond prices, $Q(s^{t+1}|s_t)$, such that the household allocations solve the household's problem, goods prices solve the producer's problem, market clearing conditions hold, and monetary policies are conducted as described above.

We specify the exogenous monetary shocks to be $\epsilon_{j,t} \overset{iid}{\sim} (0, \sigma^2_{\epsilon})$ processes and the technology shocks to be univariate first-order autoregressive processes with no spill-overs,

$$ln\left(A_{j,t}\right) = \psi ln\left(A_{j,t-1}\right) + \nu_{j,t},$$

where $\nu_{j,t} \overset{iid}{\sim} \left(0, \sigma^2_{\nu}\right)$.

4.2. Solution method and parameterization

We take a first-order approximation around the zero-inflation steady state and then solve the model numerically.[13] Our model parameterization, which is summarized in Table 10, draws on values used in the literature and assumes that a period is one quarter. The subjective discount factor is set at $\beta = 0.99$ which implies an annualized steady state interest rate of 4%. Preference parameters for consumption (γ_1) and leisure (γ_2) are set at 2. There is no home bias in consumption ($d_{j,k} = \frac{1}{3}$ for $j, k = 1, 2, 3$). Also, following Benigno (2004), we set the elasticity of substitution between domestic and foreign goods (μ) to 1.5.

We begin with a benchmark specification of symmetry in price setting and policy rules. Here, we set $\alpha_j = 0.75$ for $j = 1, 2, 3$, which corresponds to firms updating prices, on average, once per year. To examine the impact of heterogeneity in price stickiness across countries, we assume the same degree of price-setting heterogeneity as Benigno (2004). His parameterizations are informed by estimates of U.S.

[13] The derivation of the approximated model is given in the online Appendix 2.

nominal price rigidity that range between 0.407 and 0.66 (Gali et al. (2001)) and estimates for the EMU area that range between 0.78 and 0.89 (Benigno and Lopez-Salido (2006)). Using these studies as guidance, we set Country 2 firms to experience the most price stickiness, followed by Country 3, and lastly Country 1 ($\alpha_2 = 0.89 > \alpha_3 = 0.65 > \alpha_1 = 0.407$).

The persistence of the exogenous productivity process (ψ) is set to 0.9. For the monetary policy rules we assume that the monetary policy interest rate is persistent, with a coefficient (ρ) equal to 0.95. We assume that the central bank adjusts the policy rate more than one-for-one with changes in inflation ($\lambda = 1.5$), but less than one-for-one with movements in the output gap ($\phi = 0.5$), as is standard in the literature. We set $\sigma_q = 0.5$, which is in line with empirical estimates by Dong (2013).[14] When Country 2 is a follower of Country 3's monetary policy, we set $\sigma_i = 0.75$.

5. Model implied third-country effects on the bilateral exchange rate between Countries 1 and 2

In this section, we investigate the model's predictions regarding third-country effects on the exchange rate. The analysis proceeds in two parts. First, we conduct an impulse response analysis for the bilateral exchange rate between Countries 1 and 2. We do this for both the nominal and real exchange rate. The purpose is to establish direct cause and effect from exogenous third-country shocks to the exchange rate between 1 and 2, and to determine whether Country 3 shocks exert a quantitatively important influence on the bilateral rate.

The second part of our analysis revisits the reduced form regressions in the context of the general equilibrium model to assess the extent to which the model can provide a quantitative explanation for the data. We run 'factor-augmented' predictive regressions on observations generated by the model. We examine how third-country variables enter into the reduced form regression both in population and in time-series of length 58, which corresponds to the length of our data.

Cross-country heterogeneity is necessary for third-country effects to be present. We consider two types of country heterogeneity. The first is, as in Section 3, differences in the monetary policy rules. The second source of heterogeneity is cross-country differences in the duration of nominal contracts or price stickiness.

5.1. Impulse response analysis

5.1.1. Environment 1. Independent monetary policy; symmetric price setting

We present impulse responses in an environment of symmetric monetary policies and price stickiness to establish a benchmark set of results against which responses under asymmetries can be compared. Since there are no differences across countries, these benchmark results for the exchange rate between 1 and 2 are identical to predictions that would be obtained from a two-country model under symmetry. Countries 1 and 2 have identical responses to any shocks originating in Country 3. Since the Country 3 shock does not induce any *relative* changes between 1 and 2, there is no effect on their bilateral exchange rate.

Fig. 1 shows impulse responses of the nominal exchange rate, $e_{1,2}$, and the real exchange rate, $q_{1,2}$, from a positive technology shock originating from each country. The favorable Country 1 technology shock generates Country 1 deflation as improved efficiency leads 1's firms to cut prices on home sales as well as on exports. Country 2 (and 3) experiences inflation as its firms raise prices in response to increasing demand. The divergent inflation responses lead the real interest rate to fall in 1 and to rise in 2. Relative consumption in 1 increases resulting in both real and nominal depreciations from Country 1's perspective (increases in $q_{1,2}$ and $e_{1,2}$).

Fig. 2 shows impulse responses to monetary policy (tightening) shocks. Monetary tightening in 1 causes its currency to appreciate relative to 2. $e_{1,2,t}$ and $q_{1,2,t}$ fall upon impact and there is instantaneous overshooting of the nominal exchange rate. The initial policy shock is persistent on account of interest rate smoothing which keeps 1's real interest rate above 2's for several periods. This pushes consumption in 1 below consumption in 2 which results in a Country 1 real and nominal appreciation relative to Country 2. We note that these monetary policy shocks generate exchange rate overshooting.

5.1.2. Environment 2. Managed float with symmetric price setting

We now introduce asymmetries in monetary policy rules by assuming that Country 2 pursues a managed float against Country 3's currency. Price stickiness across countries remains identical. We begin with exchange rate responses to technology shocks, which are shown in Fig. 3.

A favorable technology shock in Country 1 produces the same responses from $e_{1,2}$ and $q_{1,2}$ as under Environment 1 (independent policy, symmetric price setting). This is because the Country 1 shock affects 2 and 3 identically and therefore has no effect on $q_{2,3}$. Hence, the fact that 2 manages its exchange rate against 3 is of no consequence for the exchange rate between 1 and 2.

A favorable technology shock in Country 2 produces initial responses of $e_{1,2}$ and $q_{1,2}$ that are qualitatively the same as under Environment 1, but of smaller magnitude. Country 2's technology improvement lowers its marginal cost. Country 2 firms respond by lowering prices which leads to a period of deflation in 2. Countries 1 and 3 experience inflation as their firms raise prices of domestic sales and of exports to each other in response to rising demand. The relatively low Country 2 real interest rate and relatively high consumption in 2 relative to 3 generates a real Country 2 depreciation (increase in $q_{2,3}$), to which the monetary authorities respond. This depreciation causes 2's interest rate to be higher than it would be if it were not managing the exchange rate. The managed float policy response attenuates the increase in Country 2 consumption and therefore 2's currency depreciation against 1.

Under Environment 2, third-country technology shocks can have measurable effects on the exchange rate. A favorable technology shock in Country 3 produces an initial real and nominal appreciation of currency 1 relative to 2. The initial impact on the exchange rate between 1 and 2 is of the same order of magnitude as the impact effect of a Country 2 technology shock. The Country 3 technology shock generates Country 3 deflation and increases its consumption. It also generates inflation in Countries 1 and 2 (firms in 1 and 2 raise prices of domestic sales and exports to each other). This raises Country 3 consumption above Country 2 consumption and generates a real Country 2 appreciation relative to 3 ($q_{2,3}$ falls). Part of the managed float policy response in 2 is to lower the interest rate whereas the real interest rate in 1 increases as monetary policy in 1 reacts primarily to increased inflation. As a result, consumption in 2 rises above consumption in 1 which generates a Country 1 real and nominal appreciation relative to 2 (decrease in $q_{1,2}$ and $e_{1,2}$).

Fig. 4 shows the exchange rate responses to monetary policy shocks. The responses of $e_{1,2}$ and $q_{1,2}$ following a Country 1 monetary policy (tightening) shock are similar to the responses under Environment 1. The tightening affects Countries 2 and 3 symmetrically, which has no effect on $q_{2,3}$ and hence no difference in 2's policy response.

A Country 2 monetary policy shock results in initial responses of $e_{1,2}$ and $q_{1,2}$ that are dampened relative to the responses under Environment 1. Country 2's tightening initially generates a real appreciation in 2 relative to 1 and 3, but the decrease in $q_{2,3}$ causes 2's central bank to loosen. This subsequent loosening attenuates the effects of the initial shock on 2's exchange rate with 1.

A surprise Country 3 monetary tightening generates the same qualitative responses in $e_{1,2}$ and $q_{1,2}$ as that from a Country 2 monetary tightening, but the magnitude is larger. The tightening in 3 raises $q_{2,3}$ on

[14] Dong (2013) obtains estimates of this parameter of 0.35 for Australia and 0.59 for Canada.

Table 11
Reduced form regressions implied by the model.

Environ.		One-period horizon t-ratios on 3rd country variable				Four-period horizon t-ratios on 3rd country variable			
		Inflation	Interest	Gap	$\bar{R}^2$	Inflation	Interest	Gap	$\bar{R}^2$
1	Asy	−0.414	0.489	0.571	0.149	0.496	−0.348	0.704	0.288
	Mean	−0.019	0.018	−0.001	0.107	−0.003	0.004	0.020	0.320
2	Asy	**−198.206**	**202.133**	**−223.888**	0.259	**−307.557**	**303.347**	**−367.569**	0.629
	Mean	**−3.266**	**3.273**	**−3.707**	0.261	**−5.850**	**5.728**	**−7.192**	0.670
3	Asy	**24.164**	**−45.440**	**−18.673**	0.211	**49.423**	**−67.140**	**−9.194**	0.480
	Mean	0.491	−0.869	−0.117	0.184	1.116	−1.554	0.140	0.506
4	Asy	**46.282**	**91.135**	**32.926**	0.071	**61.268**	**91.232**	**37.716**	0.130
	Mean	0.155	0.990	0.056	0.104	0.410	1.164	0.159	0.274
5	Asy	**−16.121**	**17.267**	**−15.100**	0.153	**−14.466**	**15.629**	**−13.812**	0.297
	Mean	−0.159	0.171	−0.150	0.111	−0.195	0.209	−0.186	0.333
6	Asy	**59.691**	**−16.667**	**92.588**	0.238	**109.100**	**−35.896**	**101.444**	0.551
	Mean	1.006	−0.413	1.336	0.204	**2.084**	−0.873	**2.008**	0.549

Notes: Asy is from regression on a single time series of length 348,000 observations. Mean refers to the mean value from the Monte Carlo distribution built from 6000 samples of length 58. Environ. 1: Complete symmetry. Environ. 2: Exchange rate management by Country 2 against Country 3 currency. Environ. 3: Asymmetric price stickiness. Environ. 4: Combines Environ. 2 and 3. Environ. 5: Interest rate interdependence. Environ. 6: Combines Environ. 5 and 3.

impact. This causes 2 to raise its interest rate which leads to an appreciation of 2 relative to 1 (an increase in $e_{1,2}$ and $q_{1,2}$).

The third-country effects obtained thus far assume that shock volatility is the same across countries. Fig. 5 shows how varying relative shock volatility of Country 3 affects the volatility of the *depreciation* ($\Delta e_{1,2}$). To form a basis of comparison, we also show the effect of varying the volatility of Country 2 shocks.[15] The effect of varying the size of technology shocks is shown in the figure on the left and the effect of varying policy shocks is shown on the right. The line marked with symbols shows the relative increase in exchange rate depreciation volatility (measured as the standard deviation) for a relative increase in the volatility of Country 2 technology shocks obtained from a symmetric two-country model. The solid line shows the analogous information when varying the volatility of Country 3's technology shock under a Country 2 managed float. At 0.0 on the horizontal axis, the volatility of 1 and 2's technology shocks are equal. At 1.0, 2's technology shock is twice as volatile as 1's. Doubling the importance (volatility) of Country 3 is more than half as important as doubling the importance of Country 2 in a two-country model.

For monetary policy, doubling the size of the policy shock volatility contributes less to exchange rate volatility than a doubling of technology shock volatility. However, we see a similar contribution to exchange rate volatility (between 1 and 2) generated by increasing Country 3 policy volatility relative to increasing Country 2 volatility in a two-country environment; it is about half the size.

5.1.3. Environment 3. Independent monetary policies with asymmetric price stickiness

Here we assume different reset price probabilities but symmetric independent monetary policies (no exchange rate management). Prices are stickiest in Country 2 and most flexible in Country 1 ($\alpha_2 = 0.89 > \alpha_3 = 0.65 > \alpha_1 = 0.407$). Fig. 6 shows the exchange rate responses to technology shocks. They are considerably different from those obtained under the symmetric price stickiness case of Environment 1. The indirect channel created by price-stickiness asymmetries results in Country 3 shocks generating $e_{1,2}$ and $q_{1,2}$ responses of the same order of magnitude as shocks originating in Countries 1 and 2.

A Country 1 technology shock creates a small impact effect on the real and nominal exchange rates, but the delayed *appreciation* of 1's currency relative to 2 is relatively large. This contrasts with the response under Environment 1 where 1's technology shock initially led to a depreciation of 1 relative to 2. Under Environment 1, Country 2's real interest rate increases while Country 1's real interest rate declines on impact. Higher Country 1 consumption and lower Country 2 consumption result in a Country 1 depreciation (increase $q_{1,2}$) on impact. As seen on the left panel of Fig. 7, under Environment 3, the real interest rate in 2 declines initially and the resulting effect on Country 2 consumption mitigates the initial effect on the exchange rate. r_2 declines because of the initial impact on inflation. Country 1 firms lower prices while Countries 2 and 3 firms initially raise prices. Initially, due to longer contract duration, relatively few Country 2 firms can change prices. Even if the price of Country 1 exports to 2 declined by the same extent as in Environment 1, the lack of price movement by Country 2 firms now leads to a larger initial deflation in 2.

A technology shock in Country 2 generates responses of $e_{1,2}$ and $q_{1,2}$ that are both qualitatively and quantitatively similar to the responses under Environment 1. Here, Country 1's real interest rate increases upon impact (as under Environment 1) because Country 1 initially experiences some inflation. Countries 1 and 3 firms increase prices, but due to sluggish price cuts from Country 2 firms, the end result is inflation. The decline in Country 2's real interest rate and the increase in Country 1's real interest rate lead relative consumption levels and the exchange rate between 1 and 2 to respond similarly to the responses under Environment 1.

The technology shock of primary interest is a shock to Country 3. Under Environment 1, the favorable Country 3 technology shock results in Country 3 deflation and Country 1 and 2 inflation. Here, Country 1 firms raise prices while Country 3 firms lower prices. There is, at least initially, relatively little price response by Country 2 firms. Since Country 2 firms do not raise prices on exports to 1 or 3 by much, the demand for 2's goods increases as does 2's output gap. Due to the endogenous monetary policy responses, the real interest rate in Country 2 is high relative to the rate in Country 1. This raises Country 1 consumption relative to Country 2 and causes $e_{1,2}$ and $q_{1,2}$ to increase. The impulse responses of the real interest rates to the Country 3 shock are shown in the right panel of Fig. 7.

Turning now to monetary policy shocks, the responses of $e_{1,2}$ and $q_{1,2}$ to policy shocks originating in Countries 1 and 2 are qualitatively the same as those obtained under the fully symmetric model of Environment 1. However, a Country 3 monetary tightening now generates a decline in $e_{1,2}$ and $q_{1,2}$. In the symmetric environment both r_1 and r_2 decrease by the same amount in response to 3's tightening. Here, with price-stickiness heterogeneities, r_2 declines by more than r_1, primarily because of differences in output gap responses. Because Country 2's firm prices are the stickiest, it experiences the largest (negative) output gap whereas Country 1 experiences the smallest gap. The endogenous

[15] This is comparing the contribution to exchange rate (depreciation) volatility by the third country in a three-country model to the contribution from a second country in a two-country model.

monetary policy responses in 1 and 2 result in 2 lowering the interest rate by more than in 1. Consumption in 2 is higher than consumption in 1 which implies a decline in $e_{1,2}$ and $q_{1,2}$ (Fig. 8).

The impulse response analysis has shown that direct and indirect pathways can lead third-country effects to have a measurable impact on the bilateral exchange rate. While Country 3 shocks generally have a smaller effect than Countries 1 and 2 shocks, they are of similar orders of magnitude.

The model also sheds light on the exchange rate regressions. Recall that the estimated sign on the first inflation factor was positive when the partial equilibrium model predicted it to be negative. The explanation from the partial equilibrium model was that the unobserved risk premium is negatively correlated with the first inflation factor. The general equilibrium model offers a second explanation. It shows that the signs on reduced form correlations are fragile even when there is no risk premium. In the impulse response analysis, a third-country technology shock causes Country 1 to appreciate under Environment 2, but to depreciate under Environment 3. A similar reversal of the impact effects was observed for Country 3 monetary policy shocks.

5.2. Third-country fundamentals in the reduced form

Impulse responses demonstrated exchange rate dependence on third-country exogenous shocks. However, the reduced forms in the empirical work are not regressions on shocks but on endogenous variables. This section examines some implications of the three-country model for the reduced form.

Using the model as the data generating process, observations are generated under six environments. Environments 1 through 3 are as described above. Environment 4 allows differences in both monetary policy and price stickiness. In Environment 5, Country 3 is the monetary policy leader and Country 2 is the follower (setting interest rates according to Eq. (25)), in a setting of symmetric price stickiness. Environment 6 adds asymmetric price stickiness to the policy of Environment 5.

For each environment, we run the reduced form regression with a single realization of length $T = 348,000$, which we approximate as the regression in population. We then generate $N = 6000$ samples of length $T = 58$, which corresponds to the number of quarterly observations used in our empirical work. Reduced form regressions of one-period and four-period depreciations between Countries 1 and 2 are run on the Country 3 inflation rate, interest rate and output gap with bilateral control variables (Countries 1 and 2 inflation rates and output gaps). The Country 3 variables from the model correspond to the macrofactors employed in the data work. Mean values of Newey–West t-ratios on the third-country variables and adjusted regression R^2s are reported. Results are shown in Table 11.

Environment 1 is a check on the model. None of the third-country factors are significant in the long time series, which is to be expected. The explanatory power indicated by the adjusted R^2 statistics comes primarily from the bilateral control variables.

In Environments 2 through 6, asymptotic t-ratios on third-country variables are highly significant in the long time-series regressions. We note that the signs on these t-ratios change across environments. When country heterogeneity arises only from differences in monetary policy rules, the third country inflation and output gap enter negatively and third country interest rates enter positively, as also predicted by the partial equilibrium model. However, when countries differ in the degree of price stickiness, the signs on the third country inflation and interest rate variables flip. Third-country variables are seen to enter into the regression in population, but there is no presumption about the signs on those coefficients.

While third-country variables are present in population, detecting their significance in the small samples ($T = 58$, corresponding to our data) can be a challenge. Mean values of the t-ratios exceeding 2 are obtained at both horizons 1 and 4 only under exchange rate management (Environment 2), and at horizon 4 in Environment 6. One interpretation is that the strength of the results under Environment 2 is an additional piece of evidence that exchange rate movements influence countries when setting interest rates.

6. Conclusion

Predictive regressions for bilateral exchange rates are typically run on variables from the associated bilateral pairs of countries. These regressions characteristically have low explanatory power, which leaves room for an omitted variables interpretation. Motivated in part by recent research that employs factor analyses on exchange rates, this paper shows that third-country variables are significant drivers of bilateral exchange rate movements.

Our explanation of the third-country mechanism rests on structural differences across countries. The two forms of cross-country heterogeneity that we explored lies in the conduct of monetary policy, where countries set interest rates in response to third-country exchange rate or interest rate movements, and cross-country heterogeneity in price stickiness.[16] Empirical support consistent with the policy channel was found.

Our analysis makes some progress towards resolving the disconnect puzzle, but is not a complete solution. While we confine our study to the role of macroeconomic fundamentals in a very standard context, there remains room for microstructure considerations (e.g., Lyons (2001)) and non-fundamental influences (e.g., Mark and Wu (1998), Jeanne and Rose (2002), and Evans (2012)) to further improve our understanding of exchange rate movements.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jinteco.2015.03.003.

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[16] Of course, other sources of cross-country heterogeneity may lead to third-country effects – differences in financial development, taxation, or labor market flexibility – not captured in our model.

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