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Abstract

A century after its development, the purchasing power parity theorem, which links exchange rates with prices, remains one of the most popular and influential economic theories. This study examines the relationship between exchange rates and prices from the perspectives of causality and spillovers. Using a panel of countries and advanced statistical methods, we estimate spillovers for all combinations of origins and destinations at different frequency bands, and show that their relationship is time-varying and multidirectional and has some validity at short and long time horizons. Furthermore, using exchange rate regimes, economic structures, currency crises, and trade openness, we identify economic conditions influencing the size and direction of spillovers.

JEL classification: F3, F4
Keywords: Purchasing power parity; spillover; causality; data frequency; variance decomposition; high dimensional vector autoregression

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1 Introduction

About a century ago, Cassel (1918) proposed the purchasing power parity (PPP) condition, linking exchange rates with prices, which has become one of the longest-standing and influential economic theories. Currently, PPP serves as one of the two most popular analytical tools, along with the interest parity condition, in studies on international finance. Indeed, many exchange rate models subsequently proposed are based on these theories. Moreover, PPP extends beyond the standard economic theory that is of interest only to researchers and serves as a basis for macroeconomic policies, for example, as a convergence criterion in the Maastricht Treaty, which states the eligibility requirements for countries to become Euro members. Moreover, statisticians have extensively used PPP, finding it convenient for demonstrating statistical theories such as unit root and cointegration tests, because of the simple specifications, and data availability.

In practice, PPP is often regarded as an economic concept for the international trade of economic goods. This is partly because of the availability of price data. Popular price indices, such as the consumer price index (CPI) and producer price index (PPI), which do not include asset prices, have been popularly used to test PPP. However, international trade involves transactions of not only economic goods but also financial assets that are not negligible in scale. Indeed, economists have been aware of their importance in the exchange rate determination for a long time and have proposed economic theories focusing on financial assets, such as the portfolio balance model, which provides explanations opposing those based on PPP. Partly due to this measurement problem and a violation of the underlying assumptions, empirical evidence in support of any PPP is scant.

The poor empirical evidence for the link between exchange rates and economic fundamentals, such as prices, is known as the exchange rate disconnect puzzle (Obstfeld and Rogoff 2001). Cointegration tests may find a long-run relationship but fail to support theoretical parameter values. The unit value of real exchange rates predicted by PPP is not supported by data, either. At a microeconomic level, the Big Mac index, which compares prices of hamburgers across global markets, is widely known to the public. Although the law of one price (LOOP) predicts the same value for the same product regardless of location, there are sizable differences in price, for example, in 2019, the price of a hamburger was USD 2.04 in Russia, while it was USD 6.54 in Switzerland. Similarly, Engel and Rogers (1996) show significant variations in the prices of similar products in Canada and the United States. These variations are reported to be proportional to the geographical distance between cities, and increase significantly when the products are sold in different countries (i.e., the border effect). The empirical results are also sensitive to model specifications—whether exchange rates or prices are treated as endogenous variables in the model affects the validity of PPP (Mark 1990). Therefore, a causal relationship is unclear and inconclusive in PPP despite what the economic theory suggests. In addition to the poor performance of PPP in in-sample analyses, the predictability of exchange rates using PPP is questionable, and a simple statistical model such as a random walk often outperforms PPP in an out-of-sample forecasting context (Meese and Rogoff 1982). The lack of practicability of the standard exchange rate model created a significant gap in the way academic researchers and foreign currency traders think about a mechanism of exchange rate dynamics under floating rate regimes.[1]

Therefore, researchers have tried to find explanations for the failure of this theory and statisticians have attempted to develop new tests with more statistical power to differentiate between null and alternative hypotheses. Efforts have also been made to identify the timing of the breakdown of the theory using structural break tests. Sabat et al. (2003) studied the peseta-sterling exchange rate from 1870 to 1935 and identified multiple breakpoints endogenously.

Against this background, we attempt to identify the economic circumstances in which the data relatively strongly or poorly support PPP, focusing on the causality between exchange rates and prices. Therefore, unlike many previous studies, our aim is not to decide whether PPP is a valid concept. Instead, we try to understand the PPP relationship by estimating spillovers, without assuming unidirectional causality, which is the basis of many previous studies. The time-varying spillovers from each origin to destination convey useful information about a causal relationship. Moreover, the PPP relationship is decomposed into different frequency components because PPP is currently considered, at best, as a long-term concept. This paper is structured as follows: Section 2 presents stylized facts about the exchange rate–price relationship using relative PPP based on data from advanced and emerging markets. Section 3 explains the statistical method we use to decompose the connectedness between these variables at different frequencies. Section 4 reports our main results, where we also provide explanations for the size and direction of spillovers, followed by a summary of our findings in Section 5.

2 Stylized facts

Using basic summary statistics and figures, we show the fit of relative PPP to some data sets. We focus on relative PPP because it relies on less strict assumptions than the absolute version of PPP. As mentioned above, currently, PPP is regarded, at best, as a long-term concept (Sarno and Taylor 2002), that is, absolute PPP is inadequate for one to understand volatility, with the exception of trends in exchange rates. Its theoretical deficiencies are apparent in Cassel (1918), who did not consider, for example, a time dimension or non-tradable goods when describing purchasing power. Dornbusch (1976) explained the temporary departures of exchange rates from PPP, known as overshooting exchange rates, using the phenomenon of price stickiness. Similarly, the exclusion of non-tradable goods in the calculation of PPP was addressed as the Balassa-Samuelson effect and the Backus-Smith puzzle (1993). With respect to a reference currency, most studies analyzed bilateral exchange rates vis-à-vis the

[1] This may reflect the differences in the interests of traditional researchers and traders. Although traders are more interested in exchange rate volatility, researchers are more concerned with the long-term trend. However, this gap has narrowed in recent decades; academic researchers have examined exchange rate volatility, making several theoretical and statistical developments. For example, a market microstructure model utilizes the informational content possessed by traders to explain short movements in exchange rates (Frankel et al. 1996). Evans (2010) has attempted to resolve the disconnect puzzle by using order flows of foreign currencies. Moreover, volatility models have been proposed, such as the autoregressive conditional heteroscedasticity model (Engle 1982).

US dollar (USD), because it is a key currency in modern times, with wide compilation and dissemination of exchange rates with respect to the USD to the public.

In a bilateral relationship, the log of absolute PPP at time t ($t = 1, ..., T$) can be expressed as

$$s_t = p_t - p_t^*, \tag{1}$$

where s represents the exchange rate, p is price, and the asterisk indicates the foreign variable. Therefore, $p*$ denotes the price in USD. In general, there is stronger empirical support for PPP under a fixed exchange rate regime than under a flexible one (Genberg 1978); moreover, the interpretation of this model differs by type of exchange rate regime. Under a floating exchange rate system, exchange rates are supposed to be determined by prices. Under an intermediate rate regime, a causal direction can be reversed, and exchange rates influence prices. However, unlike such theoretical predictions, there is empirical evidence of causality from exchange rates to prices, even under the floating rate regime, and the literature investigating the responsiveness of prices to exchange rate changes is the research on exchange-rate pass-through (Goldberg and Knetter 1997).

Relative PPP is the other popular version of PPP. Because it is based on changes in exchange rates and prices, in theory, this version is more likely to be supported by data than absolute PPP.[2] In a bilateral context, relative PPP can be expressed as

$$\Delta s_t = \Delta p_t - \Delta p_t^*, \tag{2}$$

where Δ is the difference operator. Relative PPP assumes that exchange rate changes are equal to the inflation differentials between countries, and under the fixed exchange rate regime, which has no movements in exchange rates, inflation rates must be equalized across countries (the convergence criterion in the Maastricht Treaty). As with absolute PPP, the direction of causality differs by type of exchange rate. Under a flexible regime, inflation differentials influence exchange rate depreciation; however, this direction may reverse in an intermediate exchange rate. Moreover, their relation disappears in a strict fixed regime, where $\Delta s = 0$, and no spillover exists between exchange rates and prices.

Table 1 shows the countries under investigation. We collected monthly exchange rates vis-à-vis USD, the consumer price index (CPI), and producer price index (PPI) from the International Financial Statistics of the International Monetary Fund (IMF). However, the CPI for the Euro area is obtained from the FRED database of the Federal Reserve Bank of St. Louis, and the PPI for the Euro area, Japan, Mexico, South Africa, and the United Kingdom from the Organisation for Economic Cooperation and Development (OECD). We cover both advanced and developing countries, namely, Brazil (BRL), Canada (CAD), China (CNY), Euro area (Euro), Japan (JPY), Mexico (MXN), South Africa (ZAR), Switzerland (CHF), Thailand (THB), the United Kingdom (GBP), and the United States (USD), where the currency abbreviations are shown in parentheses.[3] A long period of historical PPI data

[2]Relative PPP requires only the equalization of exchange rate changes and inflation, and thus, allows for differences in price levels across countries.

[3]These countries are chosen based on data availability, while considering geographical representation and

is not available for China, and thus, China is included only in the analysis based on CPI. Although the CPI is the most popular price index, the PPI, which contains proportionally fewer non-tradable goods, is expected to show stronger evidence in favor of PPP. Finally, the maximum sample period is from 1999M1 to 2019M2, where the starting period (1999) coincides with the introduction of the Euro.

[Table 1]

The type of exchange rate regime likely affects the size and direction of causality and the Annual Report on Exchange Arrangements and Exchange Restrictions of the IMF contains the official exchange rate regimes of member countries. However, because actual exchange rate regimes may differ from the official ones in some cases, researchers have investigated the *de facto* exchange rate regimes (Frankel and Wei 1994; Benassy-Quere et al. 2006; Ilzetzki et al. 2019). Subsequently, we follow the classification of exchange rate regimes in Ilzetzki et al. (2019), who reviewed the exchange rate arrangements and restrictions of 194 countries during 1946–2016. Their study classifies countries according to the flexibility of exchange rates, using several criteria, and evaluates them based on whether currencies are pegged to the major currencies or a basket of currencies. A fine classification categorizes countries into 15 blocks and a coarse classification into 6, on both annual and monthly bases.[4] We use the monthly coarse classification, according to which the countries in the present study are classified in one of the following categories:[5]

Category

0. No separate legal tender; Pre-announced peg or currency board arrangement; Pre-announced horizontal band that is narrower than or equal to ±2%; De facto peg.
1. Pre-announced crawling peg; Pre-announced crawling band that is narrower than or equal to ±2%; De facto crawling peg; De facto crawling band that is narrower than or equal to ±2%
2. Pre-announced crawling band that is wider than or equal to ±2%; De facto crawling band that is narrower than or equal to ±5%; Moving band that is narrower than or equal to ±2% (i.e., allows for both appreciation and depreciation over time); Managed floating.
3. Freely floating.
4. Freely falling.
5. Dual market in which parallel market data are missing

The exchange rate regimes become generally more flexible as the category number increases, and no country in our data set belongs to Category 0 or 5. Among these categories,

the size of economies.

[4]The classification of an exchange rate regime is available in the online appendix of Ilzetzki et al. (2019).

[5]In the absence of classification information for the Euro area, we use the exchange rate regimes for Germany. This treatment may cause a bias toward more rigid exchange rate systems, as the German currency is essentially fixed against that of other member countries.

the freely falling category is when the home currency is pegged to no anchor or reference currency, and it usually corresponds to countries that have often experienced prolonged economic crises. In our data set, only Brazil experienced a freely falling regime but the implementation period was limited only from 1999M2 to 1999M8. The freely floating category includes the CAD, JPY, and USD; the ZAR is also categorized in this group in most time periods. Our remaining countries are included in Category 2, with the exception of the CNY, which is classified as Category 1.

Table 1 also reports the summary statistics of the exchange rate changes (Δs) and inflation (Δp) and shows that the countries have diversified economic backgrounds. Half of our countries experienced home currency appreciation, and the rest experienced currency depreciation. Historical inflation rates also differ across countries. Japan exhibited the lowest inflation rates and Brazil the highest. Furthermore, inflation scenarios based on the PPI reflect greater economic depression than those on the CPI; many advanced countries experienced deflation when the PPI was used as a proxy for prices.

We also study the stationarity of exchange rate changes and inflation differentials, because the stationarity of data is often assumed in the standard statistical estimation methods. We employ three panel unit root tests developed by Levin et al. (2002), Im et al. (2003), and Maddala and Wu (1999), which are popular in economic research. All these tests examine the null hypothesis of a unit root process and reject this hypothesis in favor of stationarity at the 1% significance level (Table 2). The results show that both the exchange rate changes and inflation differentials are generally stationary. Our finding of stationary inflation differentials is not inconsistent with the financial bubbles that are often observed in many countries, where prices may be explosive and are integrated of an order higher than 1.

[Table 2]

Moreover, Figure 1 depicts the relationship between exchange rate changes and inflation differentials (in terms of PPI).[6] Consistent with the theoretical prediction, there is often a positive relationship between these variables; however, the predicted points summarizing their relationship are not on the 45-degree line, providing only weak evidence in favor of relative PPP. A more formal analysis is conducted by considering possible bidirectional causality in PPP. Table 3 summarizes the PPP relationship obtained from the following two equations: Eq. (3), which assumes a unidirectional causality from inflation to exchange rates, and Eq. (4), a unidirectional causality from exchange rates to inflation. Thus, Eq. (3) may be more suitable for countries with flexible exchange rates and Eq. (4) for those with fixed rates.

$$\Delta s_t = \alpha_s + \beta_s(\Delta p_t - \Delta p_t^*) + u_{st} \tag{3}$$

$$(\Delta p_t - \Delta p_t^*) = \alpha_p + \beta_p \Delta s_t + u_{pt}, \tag{4}$$

where $\beta_s = \beta_p = 1$ in theory. The obtained estimates of β are often well below the theoretical value of unity and statistically non-significant in some countries. Moreover, this PPP relationship is weaker when the CPI is used as a proxy for prices; notably, β_s and β_p are both

[6] Owing to space limitations, the figures in the main text only present the PPI results. The CPI results are in the supplementary materials.

negative for Japan. In contrast, in many instances, both βs are positive and significant. The statistical significance of both parameters implies bidirectional causality in relative PPP, and thus, shows that many previous studies hinged on the inappropriate assumption of a unidirectional causality. Based on these preliminary investigations, we will calculate time-varying spillovers for all combinations of origins and destinations and quantify time-varying causality and its magnitude.

[Table 3, Figure 1]

3 Decomposing spillover effects

This study uses spillovers to understand causality. As spillovers are unobservable, we calculate pairwise directional spillovers, using statistical methods, for each origin to destination, which convey causal information in the data set. When directional spillovers from A to B are greater than those from B to A, one may draw a general conclusion that causality is running from A to B. Understanding causality is important because they are related to an endogeneity problem that is known to influence empirical outcomes in PPP studies (Mark 1990). This problem may be pronounced in our data set, as it contains countries with different exchange rate regimes. Our PPP analysis is unique, as we utilize disaggregate and time-varying directional spillovers, without making any assumptions about their size and direction.

Among others, Diebold and Yilmaz (2009, 2012) and Barunik and Krehlik (2018) have provided recent methods for calculating spillovers.[7] Diebold and Yilmaz (2009, 2012) proposed measurements for total and directional spillovers, and Barunik and Krehlik (2018) incorporated a frequency domain in these spillovers. These techniques are based on data decomposition and use generalized impulse response functions ($GIRF$s) from the Vector Auto-Regression (VAR) model (Pesaran and Shin 1998). Because all variables are endogenous in the VAR model, this method can address a potential endogeneity problem and enables us to construct directional spillover indices from each origin to all destinations. In this respect, this approach differs from Generalized Autoregressive Conditional Heteroscedastic (GARCH)-type methods (Engle 2002). Although both use variance information, the latter are not designed to find time-varying directional spillovers, but correlation. Moreover, the approach used here is considered a study on interdependence, which investigates the correlation of variables in broad time periods, unlike studies on contagion, which are restricted to crisis periods.

Based on our finding of stationary exchange rate changes and inflation differentials, we consider a stationary N-variate VAR(p) model with white noise errors $\epsilon \sim N(0, \Sigma)$:

$$x_t = \sum_{i=1}^{p} \Phi_i x_{t-i} + \epsilon_t, \tag{5}$$

where t is time ($t = 1, ..., T$). To express the behaviors of x_t in response to economic shocks,

[7] Instead of spillovers, connectedness is used as a term to describe the correlation between variables in these studies. See Dungey et al. (2005) for a review of statistical approaches to investigating spillovers.

we can write this VAR model using the following moving average (MA) representation:

$$x_t = \sum_{i=0}^{\infty} A_i \epsilon_{t-i}, \tag{6}$$

where $A_i = \Phi_1 A_{i-1} - \Phi_2 A_{i-2} + ... + \Phi_p A_{i-p}$. As economic data are persistent, this representation often consists of many lagged variables, and is difficult to interpret in an economically meaningful way. To understand the dynamic implications of the MA form better, economic analyses commonly employ the variance decomposition method. For the time forecasting horizon h, Pesaran and Shin (1998) proposed the following $GIRF$ for a shock occurring in variable j as follows:

$$GIRF_j(h) = \sqrt{\Sigma_{jj}} A_h \Sigma e_j, \tag{7}$$

where e_j is equal to 1 at j and 0 otherwise. The advantage of $GIRF$ over the standard impulse response function based on the recursive method is that outcomes are invariant to the order of variables in the VAR model. In the recursive model, researchers need to determine the causality and exogeneity of variables under investigation, which requires them to decide the order of variables in the VAR. This is often problematic, as researchers do not possess such information.

Using the aforementioned generalized impulse responses, Barunik and Krehlik (2018) derived the generalized error variance decomposition based on Diebold and Yilmaz (2009).

$$(\theta(H))_{k,j} = \frac{\Sigma_{j,j}^{-1} \sum_{h=0}^{H} ((A_h \Sigma)_{k,j})^2}{\sum_{h=0}^{H} (A_h \Sigma A_h')_{k,k}} \tag{8}$$

This represents the shares of the h-step forecast error variances in variable k due to a shock in j. Because the shocks to variables are not orthogonalized, the row sums of $\theta(H)$ do not need to be equal to 1. Thus, normalizing it for convenience by using the row sum, Eq. (8) becomes

$$(\tilde{\theta}(H))_{k,j} = \frac{(\theta(H))_{k,j}}{\sum_{j=1}^{N} (\theta(H))_{k,j}}. \tag{9}$$

This equation measures the pairwise directional spillover from j to k, and by construction, $\sum_{j=1}^{N} (\tilde{\theta}(H))_{k,j} = 1$ and $\sum_{k,j=1}^{N} (\tilde{\theta}(H))_{k,j} = N$, where $k \neq j$. With N variables in the system, there will be $N^2 - N$ directional spillover measures. Table 4 summarizes the directional spillover effects by distinguishing between spillover origins and destinations. In this table, off-diagonal elements represent pairwise directional spillovers, and diagonal elements are not spillovers, because they are shocks that occurred and remained in their origins. The total directional spillovers from others to j are shown as $\sum_{j=1, j \neq k}^{N} \tilde{\theta}(H)_{jk}$, and the total directional spillovers from j to others are obtained as $\sum_{k=1, j \neq k}^{N} \tilde{\theta}(H)_{kj}$. The grand total spillovers are equal to $\frac{1}{N} \Sigma_{k,j=1, k \neq j}^{N} \tilde{\theta}(H)_{kj}$. Spillovers will be shown in such a way that the total economic shocks generated by exchange rates and inflation will be equal to those received by these variables.

[Table 4]

Barunik and Krehlik (2018) defined a scaled generalized variance decomposition on a specific frequency band, $d = (a, b)$, where $a < b$ and $a, b \in (-\pi, \pi)$, which comes from a set of intervals D.[8] By dropping the notation of the forecasting time horizon (H) for simplicity, the frequency-specific spillovers can be written as follows:

$$(\tilde{\theta_d})_{k,j} = \frac{(\theta_d)_{k,j}}{\sum_k (\theta_\infty)_{k,j}.} \tag{10}$$

This is equivalent to Eq. (9) with the specification of a frequency band (d), and Barunik and Krehlik (2018) showed that frequency-specific spillovers can be calculated, using the trace operator (Tr), as follows:

$$C_d = \left(\frac{\sum \tilde{\theta}_d}{\sum \tilde{\theta}_\infty} - \frac{\mathrm{Tr}\{\tilde{\theta}_d\}}{\sum \tilde{\theta}_\infty} \right) \times 100 \tag{11}$$

For operational purposes, each component of C_d is obtained by defining the generalized causation spectrum over frequencies $\omega \in (-\pi, \pi)$. Using the definition of the spectral density of x_t ($S_x(\omega) = \sum_{h=-\infty}^{\infty} E(x_t x'_{t-h}) e^{-i\omega h} = \Psi(\mathrm{e}^{-\mathrm{i}\omega}) \Sigma \Psi'(\mathrm{e}^{+\mathrm{i}\omega})$, where $\Psi(\mathrm{e}^{-\mathrm{i}\omega})$ is the Fourier transform of the impulse response), Barunik and Krehlik (2018) defined the proportion of the spectrum of variable k at frequency w due to shocks in variable j, as

$$(f(\omega))_{k,j} \equiv \frac{\sigma_{kk}^{-1} \left| (\Psi(\mathrm{e}^{-\mathrm{i}\omega}) \Sigma)_{j,k} \right|^2}{(\Psi(\mathrm{e}^{-\mathrm{i}\omega}) \Sigma \Psi'(\mathrm{e}^{+\mathrm{i}\omega}))_{j,j}}. \tag{12}$$

Using this specification, we can express the components of C_d, that is, Eq. (10), for stationary data, as follows:

$$(\theta_\infty)_{k,j} = \frac{1}{2\pi} \int_{-\pi}^{\pi} \Gamma_j(\omega) (f(\omega))_{k,j} \mathrm{d}\omega \tag{13}$$

and

$$(\theta_d)_{k,j} = \frac{1}{2\pi} \int_d \Gamma_j(\omega) (f(\omega))_{k,j} \mathrm{d}\omega, \tag{14}$$

where

$$\Gamma_j(\omega) = \frac{(\Psi(\mathrm{e}^{-\mathrm{i}\omega}) \Sigma \Psi'(\mathrm{e}^{+\mathrm{i}\omega}))_{j,j}}{\frac{1}{2\pi} \int_{-\pi}^{\pi} (\Psi(\mathrm{e}^{-\mathrm{i}\lambda}) \Sigma \Psi'(\mathrm{e}^{+\mathrm{i}\lambda}))_{j,j} \mathrm{d}\lambda}. \tag{15}$$

As many types of economic data are persistent, several topics in economics utilize this technique to decompose data by frequency, such as volatility spillovers in foreign exchange markets (Barunik et al. 2017), risks in the US equity market (Barunik and Krehlik 2018), oil and stock prices (Antonakakis et al. 2017), and energy prices (Wang et al. 2019). The number of different applications of this method reflects the interest of many researchers in the fluctuations and in causality of prices of consumer goods and financial assets. After all, economics investigates the causality of economic activities in societies. Considering PPP as a long-term concept, we investigate this relationship at different frequencies and expect significant spillovers at both high and low frequency bands.

[8] See also Kenourgios et al. (2019), who utilized a wavelet coherence analysis that is also based on the Fourier spectral approach.

4 Empirical results

4.1 Bivariate analysis

Initially, we estimate directional spillovers for each pair of countries using the 100-step ahead forecast error variance decomposition based on VAR(2). Table 5 presents directional spillovers for each country, expressed in terms of contributions of each variable to overall spillovers, and shows evidence of bidirectional causality between exchange rate changes and inflation differentials. Economic shocks originate from both variables, and a large proportion of these shocks are transmitted to both exchange rates and inflation. Moreover, the size of the proportion of spillovers is rather different by country. Approximately, 7% to 64% of price shocks (40% on average) are transmitted to exchange rates when the CPI is used as a proxy for prices, and 24% to 69% of the shocks (57% on average) to exchange rates when the PPI is used. The higher average proportion of spillovers to exchange rates with the PPI is consistent with the PPI's characteristic of containing proportionally more tradable goods than the CPI. Moreover, to show time-varying characteristics, we calculate rolling spillovers with a window size of 30 over the sample period. Figure 2 shows the rolling overall spillovers based on the PPI, where large spillover values indicate a close connection between exchange rates and inflation.[9] Our estimated spillover indices show that the overall spillovers are very volatile.

[Table 5, Figure 2]

Moreover, we calculate net spillovers based on the directional spillovers. Maintaining the notation of pairwise directional spillovers, we can define the net spillovers for country k, as the differences between the directional spillovers $\tilde{\theta}(H)_{k,j} - \tilde{\theta}(H)_{j,k}$, where $k \neq j$. Thus, positive net spillovers indicate more inflows of spillovers to k than outflows to j. Figure 3 shows the net spillovers to exchange rates and those to the PPI separately. Like overall spillovers, net spillovers are very volatile, and because these are bivariate analyses, the spillovers to exchange rates increase when those to prices decrease. Moreover, this figure clearly shows that spillover behaviors are rather different across countries, and it is not obvious whether a common trend exists in their behaviors.

[Figure 3]

Finally, using the statistical method proposed by Barunik and Krehlik (2018), we decompose spillovers at different frequencies for each pair of countries. The spillovers are decomposed into high, medium, and low frequency bands, which correspond to movements in less than three months, three months to one year, and over one year, respectively. Table 6 summarizes the results for relative PPP using the PPI-based inflation. Clearly, as the data frequency band becomes smaller, there are proportionally fewer spillovers to exchange rates. At a high frequency level, 51% to 87% (63% on average) of price shocks are transmitted to exchange rates, and at a low frequency level, this proportion declines to 2% to 70% (34% on average). Notably, this proportion is the lowest in Japan, which experienced the lowest inflation among the countries studied. Moreover, the transmission speed of price shocks seems to differ among countries. Thailand shows the highest proportion of spillovers at the low

[9] Please see the online materials for the results when using the CPI.

frequency level, implying slow adjustments in response to price changes. The average speed of disappearing price shocks (from 63% to 34%) is largely consistent with an average half-life of 1.55 years in Kunkler and MacDonald (2015), who obtained this value by addressing the aggregation bias. Given the sizable spillovers remained at a low frequency band, their relationship is viewed better to have some validity at both short and long time horizons.

[Table 6]

4.2 Group analysis

To check the robustness of our findings from the bivariate analysis, we study a causal relationship in the context of a group of countries. This group analysis treats the inflation rates of each country separately and allows us to accommodate the correlation between home and non-US inflation, which our bivariate study on inflation differentials did not consider. Therefore, this approach is more comprehensive than the bivariate analysis in terms of capturing complex spillover transmission mechanisms between exchange rates and prices in the global market. However, this advantage of the group analysis comes with a cost. Because it is not feasible to estimate a high-dimensional VAR ($N = 19$) model, which is known as the curse of dimensionality problem, we use the Lasso penalty function, which helps reduce the model's dimension.[10]

Table 7 reports the directional spillovers based on the PPI. The country coverage and the sample period remain the same as those in the bivariate investigation. However, it is the inflation in each country, not the inflation differentials, which comprise our panel, in addition to the exchange rates. Thus, x in Eq. (5) consists of Δs_1, Δs_2, ...,Δp_1, Δp_2,..., and, notably, US inflation is separately included in this analysis. Fitting the group model, we find that economic shocks originate fairly evenly from our variables, regardless of exchange rates and inflation ("From others (%)" column). In contrast, the inflation rates of some territories/countries such as the Euro area and the United States are more prone to influence spillovers than those of other countries ("To others (%)" column). Similarly, Mexican inflation influences the inflation of other countries, particularly at a low frequency level, although the Mexican economy is much smaller than the Euro and US markets. This might be because the Mexican inflation rate is relatively similar to the US rate (see Table 1) and a potential problem of Lasso, which reduces selection performance in the presence of highly correlated covariates. Figure 4 shows these findings, where the price shocks from these three large transmitters of price shocks in black. This figure also suggests that spillovers are multi-directional, which we could not infer from bivariate analysis.

[Figure 4, Table 7]

Frequency-specific spillovers are calculated for the same panel of countries. As in the previous subsection, directional spillovers are decomposed into high, medium, and low fre-

[10] The least absolute shrinkage and selection operator (Laso) is the standard regression analysis method for variable selection. A rolling cross-validation requires a gridsearch for selecting penalty parameters between $T/3$ and $2T/3$ where T is the number of observations. Here, the grid of penalty values is set at 50. Nicholson et al. (2017) showed that 10 grid-points produce adequate forecasting performance and they are used to check the sensitivity of our findings; however, the general conclusion remains unchanged.

quencies, and are reported in Tables 8, 9, and 10, respectively. Again, we see significant inflation spillovers from the Euro area, Mexico, and the United States to other countries, regardless of data frequency. In contrast, at the low frequency level, there is relatively more influence from overseas on the inflation of Brazil and South Africa. Thus, these countries are more vulnerable to overseas economic developments, confirming the existence of asymmetric price shocks in global markets. We do not observe such prominent differences at the high frequency band, which implies that the effects of international transmission of spillovers are persistent for these countries. Moreover, given the large direct spillovers between inflation rates, we conclude that exchange rates are not the dominant transmission channel of price shocks; as in our previous analysis, other factors likely affect inflation, such as productivity shocks, which the PPP theorem does not capture directly.

[Tables 8, 9, 10]

4.3 Exchange rate regimes, currency crises, and trade openness

Because spillovers are volatile, we attempt to capture some characteristics of spillovers and provide economic explanations about time-varying and directional causality. Previous studies have indicated economic factors such as type of exchange rate regime, economic structure, and openness to the rest of the world, which may influence the size and direction of spillovers. For example, Backus and Smith (1993) indicate that the non-tradable sector attributes to the poor performance of the PPP. Moreover, considering several currency crises, we examine the behavior of spillovers in different time periods. Usually, the relationship among economic fundamentals (i.e., exchange rates and prices) weakens during financial crises, and investors' speculation becomes more significant in the market. This phenomenon is in line with the present value model of rational bubbles in financial and real estate markets (Campbell and Shiller 1987).

One methodological difficulty in such research is the identification of crisis periods. These periods are unobservable and have to be estimated. To identify crisis periods, we use the explosive unit root tests developed by Phillips et al. (2011, 2015).[11] They proposed several tests based on right-sided tests. Here, we implement three such tests: the right-sided Augmented Dickey-Fuller (ADF), Supremum ADF (SADF), and Generalized SADF (GSADF). They examine the null hypothesis that the data follow a unit root process ($d = 1$) against the alternative hypothesis that the data are integrated of order higher than 1 ($d > 1$), where d refers to the order of integration of the data. This alternative hypothesis differs from that of the standard left-sided unit root tests, which is that $d < 1$.[12] Phillips et al. (2011, 2015) showed that these tests possess stronger statistical power to detect recurrent bubbles than conventional tests. As the data are assumed to be non-stationary, the standard distributions are not applicable to these tests. Therefore, the critical values are obtained from experiments.

These tests have been developed to detect the timing and duration of financial bubbles

[11] While implementing the advanced method here, the identification of financial and real estate bubbles is always questionable, as they are unobservable and sensitive to the model specification and statistical tests (Nagayasu, 2020).

[12] See the Appendix for a description of these explosive unit root tests.

in equity markets and also applied to bubble analyses in real estate markets. Exchange rates are somewhat different from financial assets and real estate. Equity and home prices are non-negative in theory and are expected to exhibit financial bubbles at times of extremely high prices. In contrast, exchange rates are ratios of currencies and can exhibit chaotic moments at both extremely high and low currency values (Blanchard and Watson 1982). Therefore, standard exchange rate bubble studies do not use explosive unit root tests. However, as our focus is on currency crises, the explosive tests are applicable because we focus only on high levels of exchange rates.

We apply these tests to the real exchange rates ($q_t = s_t - p_t + p_t^*$) of each country.[13] Therefore, consistent with the definition of currency crises, our approach identifies crises as when nominal exchange rates are unusually high relative to prices. Table 11 shows that the identification of explosive behavior differs by test type; however, the most reliable test (GSADF) shows evidence of crises in more than half of the countries in our samples. When this test shows evidence of currency crises, we also report the estimated crisis periods in this table.

[Table 11]

Next, we check the determinants of the spillovers using the information of crisis periods, exchange rate regimes, countries' openness, economic structures, and cross-border capital flows, as exchange rates are also used for transactions involving financial assets. Based on our results for directional spillovers and crisis periods for each country i ($i = 1, ..., N$) and time t ($t = 1, ..., T$), we can estimate the time-varying characteristics of the three types of spillovers (*Spillover*) (i.e., overall spillovers, spillovers to exchange rates, and spillovers to inflation) separately. We can represent our panel data model as

$$\begin{aligned} Spillover_{it} = \alpha + \gamma_i + \mu_t + \kappa Regime_{it} + \beta Crises_{it} + \delta Openness_{it} \\ + \phi Service_{it} + \theta Capitalflow_{it} + u_{it}, \end{aligned} \tag{16}$$

where

$$\begin{cases} Crises_{it} = 1 & \text{for crisis periods} \\ Crises_{it} = 0 & \text{for tranquil periods} \end{cases}$$

and α is a common constant for all countries, γ_i is country-specific fixed effects, and μ_t is a time dummy variable. *Spillover* is overall spillovers, spillovers to exchange rates, or spillovers to inflation. *Openness* represents countries' openness to the rest of the world, measured by (Import+Export)/GDP (%), and *Service* the proportion of services in GDP (%) that are traditionally considered non-tradable. These data are obtained from the World Development Indicators of the World Bank.[14] *Regime* is the type of exchange rate regime according to Ilzetzki et al. (2019) (see Section 2), and *Capitalflow* is bilateral capital flows obtained from the Locational Banking Statistics of the Bank for International Settlements.[15] Finally, the

[13] Pavlidis et al. (2017) detected currency crises using the forward premium. The use of prices as economic fundamentals is more consistent with our analysis.

[14] These two measures are converted from annual to monthly using the Denton-Cholette method.

[15] *Capital flow* is measured as the total liabilities of home countries and are converted from quarterly to monthly using the Denton-Cholette method.

residual u_{it} follows a normal distribution with zero mean ($u_{it} \sim N(0, \sigma^2)$).

A parameter of interest, β, captures the unique behaviors of spillovers during crisis periods, and we expect this parameter to be negative, as the relationship between exchange rates and economic fundamentals weakens during chaotic periods. Another parameter of interest, δ, is expected to be positive, as the more open a country, the more influence its markets experience from overseas. The estimated parameter of *Regime* may take a positive or negative sign. As regimes that are more flexible have smaller category values in the classification of exchange rate regimes, a negative sign may arise in spillovers to exchange rates in flexible regimes. However, a positive sign may emerge in spillovers to inflation, consistent with the direction of causality under more fixed exchange rate regimes. *Service* measures the importance of non-tradable goods in the market, and non-tradable goods are expected to reduce spillovers between exchange rates and prices regardless of the direction of causality. Due to the data availability, we focus on the PPP relationship using the PPI again and the sample period through 2016M12.

Table 12 summarizes the empirical results obtained from different specifications based on Eq. (16). The model fit indicator, R^2, is higher for the more comprehensive model of overall spillovers, but is still only 0.403, implying that there are potentially missing explanatory variables. However, the results are generally consistent with our expectations and are robust to the model specification. The number of cases of the three types of spillovers all decline during currency crises, suggesting that non-economic fundamentals are increasingly important during chaotic times. Furthermore, the service sector hinders the PPP relationship, as its estimated parameter is negative, showing that it is negatively associated with spillovers. In contrast, countries' openness to the rest of the world tends to increase spillovers, although this effect is non-significant for spillovers to prices. Moreover, we confirm that the direction of spillovers is important for determining the sign of the estimated parameter for *Regime*. Indeed, consistent with PPP theory, our results imply more spillovers to exchange rates under flexible exchange rate regimes and more spillovers to inflation under inflexible exchange rate regimes. Consequently, these two effects offset each other, and *Regime* effects become non-significant in overall spillovers. Finally, capital flows are reported to be non-significant in all types of spillovers. This is not surprising as our model is based on the PPI, which does not capture international financial transactions.

[Table 12]

5 Conclusion

PPP is one of the most popular economic theories. However, a century after its development, despite its popularity, it is generally recognized that its theoretical validity is scant. Taking this view as a stylized fact, we studied the performance of PPP from the perspectives of causality and frequency of data. To understand multi-directional causality, we estimated directional spillovers from each origin using a statistical method. Moreover, the decomposition of the PPP relationship implemented in this study is useful for identifying the size of spillovers for all combinations of origins and destinations and for obtaining economic characteristics at times of solid or poor PPP relationships. In short, this study shows that PPP theory is not perfect but PPP contains useful information for economic analyses. The size and direction of spillovers are in line with the theoretical prediction of PPP.

More specifically, for data from advanced and emerging markets, we found that the causality measured by spillovers has time-varying and multi-directional characteristics, which makes PPP difficult to establish as a solid economic theory and explains the mixed results obtained in previous studies. Moreover, our study indicates that price shocks are not transmitted solely through exchange rates. Thus, it confirms the theoretical deficiencies of PPP that does not provide any explanation, other than exchange rate changes, about a direct link between inflation among countries.

Finally, the validity of PPP, as analyzed by causality, is influenced by the exchange rate regimes of countries, economic structures, and openness to the rest of the world. The PPP relationship is very unlikely to hold for a closed country with currency crisis experiences and a high proportion of non-tradable goods. Moreover, our frequency analysis shows that PPP is a long-term concept at best. Price shocks may smoothen quickly but last more than a year. Although we can infer these findings from previous studies, we have showed them from different perspectives, that is, causality and frequency. Therefore, PPP provides investors planning to make a long-term investment in insurance and pension funds with a rough guide about the future trend in exchange rates. Moreover, the direction of causality inconsistent with exchange rate regimes becomes a sign of unsustainable exchange rate policies and a concern for investors and policymakers.

Appendix

We summarize following the explosive unit root tests developed by Phillips et al. (2011, 2015). These tests are right-tailed unit root tests and they have the same null hypothesis and test specification as the standard left-tailed unit root tests, such as the Augmented Dickey-Fuller (ADF) test. Therefore, the stationarity of time-series data y_t can be tested using the following specification with an appropriate lag length p:

$$\Delta y_t = \alpha + c y_{t-1} + \sum_{i=1}^{p} \theta_i \Delta y_{t-i} + \epsilon_t, \tag{17}$$

where ϵ_t is the normal residual and $c = \rho - 1$. The null hypothesis of $c = 0$ can be examined against the explosive alternative, $c > 0$. The test statistic of the ADF test can be obtained for the full sample and for the sub-samples. The SADF test is an application of the recursive method to the ADF test, and the largest test statistic among the test statistics from different sub-samples is used to evaluate the statistical hypothesis. When the entire sample interval is [0, 1] and the ending point of the sub-samples is r_2, the SADF test statistic obtained from the recursive estimation of Eq. (17) by incrementing the window size can be expressed as follows:

$$SADF(r_0) = \sup_{r_2 \in [r_0, 1]} ADF_0^{r_2},$$

where r_0 ($0 < r_0 < r_2$) is the initial window size. We estimate Eq. (17) recursively with a window size of $(0.01 + 1.8/\sqrt{T}) \times T$. The critical values for these tests are obtained from a Monte Carlo simulation with 10,000 replications, and a test statistic value greater than the critical values indicates the presence and duration of bubbles.

One drawback of the SADF test is that it fixes the initial point of sub-samples (i.e., r_0). The GSADF test extends the SADF test by considering variations of the initial point. Maintaining the window size r_0 and denoting the starting point of sub-samples as r_1, the GSADF test statistic can be written as follows:

$$GSADF(r_0) = \sup_{\substack{r_2 \in [r_0, 1] \\ r_1 \in [0, r_2 - r_1]}} ADF_{r_1}^{r_2} .$$

Therefore, the GSADF test addresses the sensitivity of the SADF test to the initial point of the sub-samples and is deemed more suitable for detecting multiple periodically collapsing bubbles (Phillips et al. 2015).

Data dissemination

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Table 1: The summary of data

	T	Mean	SD	Median	Trim	Mad	Min	Max	Range	Skew	Kurtosis	SE
Exchange rate changes, Δs												
Brazil	247	0.40	4.15	-0.12	0.17	3.53	-11.31	24.24	35.55	1.24	5.31	0.26
Canada	247	-0.05	1.91	0.00	-0.04	1.77	-6.16	11.29	17.45	0.56	4.59	0.12
China	247	-0.06	0.65	-0.01	-0.10	0.18	-2.53	3.84	6.37	1.61	9.44	0.04
Euro	247	0.02	2.31	-0.03	0.03	2.08	-6.55	7.57	14.12	0.01	0.33	0.15
Japan	247	-0.03	2.32	-0.01	-0.04	2.17	-6.20	7.41	13.6	0.13	0.48	0.15
Mexico	247	0.27	2.49	-0.05	0.18	1.80	-8.86	16.52	25.38	1.09	7.13	0.16
S Africa	247	0.38	3.83	0.15	0.30	3.42	-15.18	19.02	34.20	0.51	3.72	0.24
Switzerland	247	-0.14	2.37	-0.01	-0.08	2.20	-7.59	11.70	19.29	0.14	2.03	0.15
Thailand	247	-0.07	1.42	-0.15	-0.12	1.34	-3.61	4.92	8.53	0.35	0.28	0.09
UK	247	0.12	2.19	0.12	0.07	1.98	-6.00	9.57	15.57	0.56	2.05	0.14
CPI inflation, Δp												
Brazil	247	0.51	0.38	0.46	0.47	0.27	-0.23	2.98	3.21	2.04	8.65	0.02
Canada	247	0.16	0.37	0.18	0.17	0.34	-1.04	1.15	2.19	-0.18	0.29	0.02
China	247	0.17	0.64	0.10	0.16	0.59	-1.4	2.57	3.97	0.39	0.65	0.04
Euro	247	0.14	0.43	0.17	0.17	0.32	-1.56	1.34	2.90	-0.63	2.09	0.03
Japan	247	0.01	0.30	0.00	0.01	0.30	-0.81	2.03	2.84	1.14	7.55	0.02
Mexico	247	0.38	0.36	0.41	0.39	0.30	-0.74	1.69	2.43	-0.18	0.74	0.02
S Africa	247	0.42	0.44	0.37	0.40	0.37	-1.14	1.69	2.83	0.32	0.80	0.03
Switzerland	247	0.04	0.35	0.06	0.04	0.27	-1.05	1.13	2.18	0.06	0.69	0.02
Thailand	247	0.16	0.47	0.15	0.16	0.32	-3.06	2.15	5.21	-0.99	10.15	0.03
UK	247	0.17	0.29	0.23	0.19	0.23	-0.70	0.88	1.58	-0.76	0.73	0.02
USA	247	0.18	0.37	0.18	0.19	0.35	-1.93	1.21	3.15	-0.90	4.04	0.02
PPI inflation, Δp												
Brazil	241	0.50	1.52	0.29	0.38	1.18	-3.15	7.25	10.4	1.26	3.66	0.10
Canada	241	-0.08	0.97	-0.04	-0.08	0.68	-3.20	5.29	8.49	0.52	4.41	0.06
Euro	241	-0.09	0.79	-0.08	-0.11	0.50	-2.76	3.97	6.73	0.75	4.69	0.05
Japan	241	-0.23	0.92	-0.21	-0.27	0.55	-3.14	3.93	7.07	0.90	4.32	0.06
Mexico	241	0.23	1.10	0.11	0.17	0.73	-2.37	7.70	10.07	1.80	9.61	0.07
S Africa	241	0.28	1.07	0.25	0.23	0.71	-2.66	5.43	8.10	1.05	4.62	0.07
Switzerland	241	-0.21	0.96	-0.29	-0.26	0.59	-2.74	5.22	7.96	1.67	8.02	0.06
Thailand	241	0.01	1.00	-0.04	-0.02	0.77	-3.23	3.85	7.07	0.41	1.62	0.06
UK	241	-0.05	0.80	-0.08	-0.07	0.58	-3.83	3.63	7.46	0.48	4.75	0.05
USA	241	0.22	1.03	0.26	0.26	0.56	-5.49	2.94	8.42	-1.47	7.72	0.07

Note: Trim is trimmed mean with trim defaulting to 0.1. The MAD is median absolute deviation from the median. SD and SE are standard deviation and error, respectively; Ranges measures a distance between Min and Max.

Table 2: Panel unit root tests

	Const	p-value	Const+Trend	p-value
Exchange rate changes, Δs				
Levin-Lin-Chu	-42.607	0.000	-51.770	0.000
Im-Pesaran-Shin	-37.285	0.000	-38.898	0.000
Maddala-Wu	945.690	0.000	813.920	0.000
Inflation differentials (CPI), $\Delta p - \Delta p^*$				
Levin-Lin-Chu	-5.813	0.000	-5.862	0.000
Im-Pesaran-Shin	-25.442	0.000	-26.093	0.000
Maddala-Wu	593.400	0.000	492.990	0.000
Inflation differentials (PPI), $\Delta p - \Delta p^*$				
Levin-Lin-Chu	-30.184	0.000	-35.266	0.000
Im-Pesaran-Shin	-36.915	0.000	-38.637	0.000
Maddala-Wu	893.050	0.000	765.280	0.000

Note: The null hypothesis of a unit root is tested with US inflation being Δp^*. The lag length is determined by the Schwarz information criterion with the maximum length of 12.

Table 3: The PPP relationship

	Brazil	Canada	China	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK
CPI	Dependent variable: Δs									
$\Delta p - \Delta p^*$	1.287**	1.290***	−0.0004	0.507	−0.163	0.772***	1.077**	0.948**	0.346	1.162***
	(0.502)	(0.427)	(0.058)	(0.321)	(0.375)	(0.276)	(0.519)	(0.384)	(0.234)	(0.328)
Constant	−0.031	−0.030	−0.064	0.039	−0.049	0.113	0.107	−0.004	−0.064	0.133
	(0.310)	(0.119)	(0.042)	(0.146)	(0.161)	(0.165)	(0.272)	(0.158)	(0.090)	(0.136)
R^2	0.026	0.036	0.00000	0.010	0.001	0.031	0.017	0.024	0.009	0.049
Adjusted R^2	0.022	0.032	−0.004	0.006	−0.003	0.027	0.013	0.020	0.005	0.045
Residual SE	4.101	1.872	0.652	2.299	2.325	2.449	3.799	2.348	1.420	2.142
	Dependent variable: $\Delta p - \Delta p^*$									
Δs	0.020**	0.028***	−0.0005	0.020	−0.005	0.040***	0.016**	0.025**	0.026	0.042***
	(0.008)	(0.009)	(0.070)	(0.013)	(0.011)	(0.014)	(0.008)	(0.010)	(0.017)	(0.012)
Constant	0.326***	−0.018	−0.008	−0.035	−0.172***	0.190***	0.235***	−0.135***	−0.018	−0.019
	(0.033)	(0.017)	(0.046)	(0.029)	(0.025)	(0.036)	(0.029)	(0.024)	(0.025)	(0.026)
R^2	0.026	0.036	0.00000	0.010	0.001	0.031	0.017	0.024	0.009	0.049
Adjusted R^2	0.022	0.032	−0.004	0.006	−0.003	0.027	0.013	0.020	0.005	0.045
Residual SE	0.515	0.274	0.714	0.455	0.395	0.557	0.462	0.385	0.386	0.406
PPI	Dependent variable: Δs									
$\Delta p - \Delta p^*$	0.765***	0.612***		0.473***	0.033	0.493***	0.547***	0.350***	0.150***	0.450***
	(0.105)	(0.055)		(0.078)	(0.079)	(0.072)	(0.121)	(0.075)	(0.055)	(0.076)
Constant	0.171	0.127		0.163	−0.003	0.254*	0.315	0.014	−0.034	0.234*
	(0.242)	(0.102)		(0.140)	(0.153)	(0.146)	(0.234)	(0.149)	(0.091)	(0.132)
R^2	0.179	0.342		0.130	0.001	0.161	0.078	0.082	0.030	0.127
Adjusted R^2	0.175	0.339		0.126	−0.003	0.157	0.074	0.079	0.026	0.123
Residual SE	3.764	1.562		2.162	2.330	2.284	3.666	2.284	1.410	2.052
	Dependent variable: $\Delta p - \Delta p^*$									
Δs	0.233***	0.559***		0.274***	0.022	0.326***	0.142***	0.235***	0.198***	0.282***
	(0.032)	(0.050)		(0.045)	(0.052)	(0.048)	(0.031)	(0.050)	(0.073)	(0.047)
Constant	0.190	−0.269***		−0.318***	−0.451***	−0.076	0.009	−0.398***	−0.200*	−0.299***
	(0.133)	(0.096)		(0.105)	(0.121)	(0.119)	(0.119)	(0.120)	(0.104)	(0.104)
R^2	0.179	0.342		0.130	0.001	0.161	0.078	0.082	0.030	0.127
Adjusted R^2	0.175	0.339		0.126	−0.003	0.157	0.074	0.079	0.026	0.123
Residual SE	2.078	1.492		1.646	1.893	1.859	1.866	1.873	1.619	1.623

Note: *p<0.1; **p<0.05; ***p<0.01. Newey-West standard errors with a lang length of four. SE stands for the standard error.

Table 4: The decomposition of spillovers

To k	From j x_1	x_2	$\cdots$	x_N	From others
x_1	$\tilde{\theta}(H)_{11}$	$\tilde{\theta}(H)_{12}$	$\cdots$	$\tilde{\theta}(H)_{1N}$	$\Sigma_{j=1}^{N}\tilde{\theta}(H)_{1j}, j \neq 1$
x_2	$\tilde{\theta}(H)_{21}$	$\tilde{\theta}(H)_{22}$	$\cdots$	$\tilde{\theta}(H)_{2N}$	$\Sigma_{j=1}^{N}\tilde{\theta}(H)_{2j}, j \neq 2$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
x_N	$\tilde{\theta}(H)_{N1}$	$\tilde{\theta}(H)_{N2}$	$\cdots$	$\tilde{\theta}(H)_{NN}$	$\Sigma_{j=1}^{N}\tilde{\theta}(H)_{Nj}, j \neq N$
To others	$\Sigma_{k=1}^{N}\tilde{\theta}(H)_{k1}$ $k \neq 1$	$\Sigma_{k=1}^{N}\tilde{\theta}(H)_{k2}$ $k \neq 2$	$\cdots$	$\Sigma_{k=1}^{N}\tilde{\theta}(H)_{kN}$ $k \neq N$	$\frac{1}{N}\Sigma_{k,j=1}^{N}\tilde{\theta}(H)_{kj}$ $k \neq j$

Table 5: Bivariate analyses of spillovers

	CPI				PPI			
	Δs	$\Delta p - \Delta p*$	From others	%	Δs	$\Delta p - \Delta p*$	From others	%
Brazil								
Δs	93.67	6.33	6.33	22.15	90.61	9.39	4.70	23.73
$\Delta p - \Delta p*$	22.25	77.75	22.25	77.85	30.18	69.82	15.09	76.27
To others	22.25	6.33	28.58		30.18	9.39	39.57	
%	77.85	22.15		100.00	76.27	23.73		100.00
Canada								
Δs	93.31	6.69	6.69	32.67	86.80	13.20	6.60	49.46
$\Delta p - \Delta p*$	13.79	86.21	13.79	67.33	13.49	86.51	6.75	50.54
To others	13.79	6.69	20.48		13.49	13.20	26.69	
%	67.33	32.67		100.00	50.54	49.46		100.00
Euro								
Δs	89.14	10.86	10.86	43.37	89.68	10.32	5.16	69.12
$\Delta p - \Delta p*$	14.18	85.82	14.18	56.63	4.61	95.39	2.31	30.88
To others	14.18	10.86	25.04		2.31	5.16	7.46	
%	56.63	43.37		100.00	30.88	69.12		100.00
Japan								
Δs	97.33	2.67	2.67	38.75	91.90	8.10	4.05	63.88
$\Delta p - \Delta p*$	4.22	95.78	4.22	61.25	4.58	95.42	2.29	36.12
To others	4.22	2.67	6.89		4.58	8.10	12.68	
%	61.25	38.75		100.00	36.12	63.88		100.00
Mexico								
Δs	87.84	12.16	12.16	47.04	86.85	13.15	6.58	54.50
$\Delta p - \Delta p*$	13.69	86.31	13.69	52.96	10.98	89.02	5.49	45.50
To others	13.69	12.16	25.85		5.49	6.58	12.07	
%	52.96	47.04		100.00	45.50	54.50		100.00
S Africa								
Δs	97.70	2.30	2.30	7.08	78.38	21.62	10.81	61.65
$\Delta p - \Delta p*$	30.20	69.80	30.20	92.92	13.45	86.55	6.73	38.35
To others	30.20	2.30	32.50		13.45	21.62	35.07	
%	92.92	7.08		100.00	38.35	61.65		100.00
Switzerland								
Δs	92.47	7.53	7.53	64.14	78.38	21.62	10.81	61.65
$\Delta p - \Delta p*$	4.21	95.79	4.21	35.86	13.45	86.55	6.73	38.35
To others	4.21	7.53	11.74		13.45	21.62	35.07	
%	35.86	64.14		100.00	38.35	61.65		100.00
Thailand								
Δs	94.65	5.35	5.35	44.81	89.52	10.48	5.24	67.74
$\Delta p - \Delta p*$	6.59	93.41	6.59	55.19	4.99	95.01	2.49	32.26
To others	6.59	5.35	11.94		4.99	10.48	15.47	
%	55.19	44.81		100.00	32.26	67.74		100.00
UK								
Δs	92.24	7.76	7.76	45.92	90.25	9.75	4.88	58.04
$\Delta p - \Delta p*$	9.14	90.86	9.14	54.08	7.05	92.95	3.53	41.96
To others	9.14	7.76	16.90		7.05	9.75	16.80	
%	54.08	45.92		100.00	41.96	58.04		100.00
China								
Δs	95.98	4.02	4.02	53.67				
$\Delta p - \Delta p*$	3.47	96.53	3.47	46.33				
To others	3.47	4.02	7.49					
%	46.33	53.67		100.00				

Note: The decomposition of spillover between exchange rates (Δs) and relative inflation ($\Delta p - \Delta p*$) is based on Diebold and Yilmaz (2012).

Table 6: Frequency analyses of spillovers (PPI)

Frequency	High				Medium				Low			
	Δs	$\Delta p - \Delta p*$	From others	%	Δs	$\Delta p - \Delta p*$	From others	%	Δs	$\Delta p - \Delta p*$	From others	%
Brazil												
Δs	40.75	5.17	5.17	58.48	31.04	7.15	7.15	31.44	15.34	0.55	0.55	3.72
$\Delta p - \Delta p*$	3.67	27.23	3.67	41.52	15.59	29.13	15.59	68.56	14.23	10.15	14.23	96.28
To others	3.67	5.17			15.59	7.15			14.23	0.55		
%	41.52	58.48		100.00	68.56	31.44		100.00	96.28	3.72		100.00
Canada												
Δs	36.27	16.79	16.79	50.91	23.26	10.57	10.57	50.05	10.12	2.99	2.99	35.98
$\Delta p - \Delta p*$	16.19	39.23	16.19	49.09	10.55	20.62	10.55	49.95	5.32	8.09	5.32	64.02
To others	16.19	16.79			10.55	10.57			5.32	2.99		
%	49.09	50.91		100.00	49.95	50.05		100.00	64.02	35.98		100.00
Euro												
Δs	44.38	7.83	7.83	58.00	29.71	5.76	5.76	50.35	9.95	2.38	2.38	49.17
$\Delta p - \Delta p*$	5.67	46.94	5.67	42.00	5.68	31.44	5.68	49.65	2.46	7.80	2.46	50.83
To others	5.67	7.83			5.68	5.76			2.46	2.38		
%	42.00	58.00		100.00	49.65	50.35		100.00	50.83	49.17		100.00
Japan												
Δs	46.31	5.32	5.32	61.57	33.08	2.46	2.46	86.01	12.79	0.03	0.03	2.34
$\Delta p - \Delta p*$	3.32	55.75	3.32	38.43	0.40	29.73	0.40	13.99	1.25	9.54	1.25	97.66
To others	3.32	5.32			0.40	2.46			1.25	0.03		
%	38.43	61.57		100.00	13.99	86.01		100.00	97.66	2.34		100.00
Mexico												
Δs	42.80	10.37	10.37	52.08	24.84	11.89	11.89	49.13	6.99	3.11	3.11	44.30
$\Delta p - \Delta p*$	9.54	34.62	9.54	47.92	12.31	29.17	12.31	50.87	3.91	10.45	3.91	55.70
To others	9.54	10.37			12.31	11.89			3.91	3.11		
%	47.92	52.08		100.00	50.87	49.13		100.00	55.70	44.30		100.00
S Africa												
Δs	38.93	13.28	13.28	86.68	26.66	4.40	4.40	45.31	11.16	5.57	5.57	38.63
$\Delta p - \Delta p*$	2.04	53.19	2.04	13.32	5.31	15.73	5.31	54.69	8.85	14.88	8.85	61.37
To others	2.04	13.28			5.31	4.40			8.85	5.57		
%	13.32	86.68		100.00	54.69	45.31		100.00	61.37	38.63		100.00
Switzerland												
Δs	51.67	10.09	10.09	68.64	27.35	3.24	3.24	37.33	6.42	1.22	1.22	30.89
$\Delta p - \Delta p*$	4.61	43.92	4.61	31.36	5.44	33.59	5.44	62.67	2.73	9.71	2.73	69.11
To others	4.61	10.09			5.44	3.24			2.73	1.22		
%	31.36	68.64		100.00	62.67	37.33		100.00	69.11	30.89		100.00
Thailand												
Δs	38.23	6.14	6.14	56.49	35.63	4.06	4.06	54.94	13.98	1.97	1.97	70.11
$\Delta p - \Delta p*$	4.73	64.33	4.73	43.51	3.33	21.61	3.33	45.06	0.84	5.15	0.84	29.89
To others	4.73	6.14			3.33	4.06			0.84	1.97		
%	43.51	56.49		100.00	45.06	54.94		100.00	29.89	70.11		100.00
UK												
Δs	44.75	7.25	7.25	69.78	28.16	6.16	6.16	50.99	11.69	1.99	1.99	33.11
$\Delta p - \Delta p*$	3.14	49.66	3.14	30.22	5.92	26.08	5.92	49.01	4.02	11.19	4.02	66.89
To others	3.14	7.25			5.92	6.16			4.02	1.99		
%	30.22	69.78		100.00	49.01	50.99		100.00	66.89	33.11		100.00

Note: The decomposition of spillover between exchange rates (Δs) and relative inflation ($\Delta p - \Delta p^*$) is based on Barunik and Krehlik (2018). High, medium, and low frequency refers to movements in less than three months, three to twelve months, and over a year, respectively.

Table 7: Panel analysis of spillover (PPI): Overall

	Exchange rate changes (Δs)									Inflation (Δp)											
	Brazil	Canada	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK	Brazil	Canada	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK	USA	From others	%
Δs																					
Brazil	3.52	1.87	4.88	1.65	5.67	2.32	2.70	1.87	2.35	3.70	3.10	13.60	7.20	12.52	3.52	6.32	1.76	6.69	14.74	96.46	5.44
Canada	2.27	2.84	5.94	1.54	4.62	3.37	2.82	2.76	3.17	2.71	2.47	11.50	8.54	12.27	3.09	4.63	1.74	10.36	13.37	97.17	5.48
Euro	1.03	2.49	7.58	1.39	4.92	1.66	2.44	1.80	1.78	1.89	3.56	14.31	5.74	13.85	1.96	6.00	1.75	8.11	17.74	92.42	5.21
Japan	1.45	2.99	4.34	3.24	5.85	1.80	3.42	2.96	1.43	1.41	4.02	17.44	5.38	12.36	1.83	5.42	2.06	6.31	16.29	96.76	5.46
Mexico	1.36	1.81	4.34	2.03	6.49	2.97	2.67	2.59	2.32	2.80	2.49	17.33	5.78	12.58	3.22	5.07	1.14	8.50	14.51	93.51	5.27
S Africa	1.03	1.78	6.34	1.16	5.31	4.01	2.15	1.53	2.36	2.62	1.88	16.47	5.65	12.27	3.27	6.45	1.76	8.66	15.31	96.00	5.42
Switzerland	1.12	2.19	7.18	1.09	4.64	1.44	4.95	1.66	2.07	1.74	2.35	17.51	5.67	12.71	1.57	5.12	2.05	10.53	14.42	95.06	5.36
Thailand	1.18	2.53	5.77	1.71	5.27	1.67	3.18	4.23	2.32	2.05	3.44	16.11	6.82	11.78	2.30	5.18	1.71	7.13	15.63	95.78	5.40
UK	1.08	1.72	5.30	1.25	4.78	1.73	2.00	1.30	2.98	1.94	2.73	16.94	5.83	13.70	2.47	6.16	1.50	8.26	18.34	97.03	5.47
Δp																					
Brazil	2.58	2.06	3.81	1.21	5.72	2.15	1.51	2.47	2.77	3.80	3.59	10.84	7.72	13.98	2.75	7.03	2.46	8.19	15.37	96.21	5.43
Canada	1.50	2.44	4.89	1.08	5.78	2.47	2.22	2.18	2.02	2.28	4.86	15.11	5.96	15.09	2.70	5.19	1.89	7.86	14.48	95.14	5.37
Euro	0.93	1.59	3.11	1.13	4.65	1.84	1.90	1.91	1.39	2.30	3.36	20.18	5.85	13.06	2.27	7.09	2.84	7.54	17.08	79.84	4.50
Japan	0.90	1.78	3.63	0.99	4.97	1.92	2.31	1.66	1.64	2.64	3.20	17.57	6.00	12.76	2.72	6.21	3.21	8.15	17.75	94.01	5.30
Mexico	0.93	1.78	3.77	1.41	3.90	2.45	2.20	1.91	2.16	3.15	3.33	16.54	5.96	11.49	3.36	7.00	2.28	9.55	16.83	88.51	4.99
S Africa	1.18	1.64	3.45	1.34	5.09	1.67	1.95	1.35	1.74	2.39	2.84	18.06	4.47	14.18	3.83	4.46	2.41	10.49	17.44	96.15	5.42
Switzerland	1.09	1.57	3.77	1.27	5.15	2.23	2.17	1.40	1.93	2.76	3.57	16.45	5.15	14.24	2.46	7.35	2.45	8.19	16.80	92.65	5.23
Thailand	1.00	2.03	3.81	1.36	3.70	1.32	1.56	1.04	1.41	1.99	3.25	21.87	6.42	11.70	2.37	5.37	4.05	7.59	18.16	95.95	5.41
UK	1.42	1.63	3.65	1.21	4.68	1.72	1.88	1.95	1.35	2.21	3.15	21.38	5.67	10.43	1.94	5.90	2.99	9.22	17.63	90.79	5.12
USA	1.13	1.56	3.44	1.33	4.91	2.27	2.12	1.69	2.34	2.76	3.52	17.33	5.45	13.26	2.97	6.10	2.59	8.64	16.58	83.41	4.70
To others	23.18	35.46	81.42	24.15	89.61	37.00	41.20	34.03	36.55	43.34	55.85	296.36	109.26	232.74	46.77	104.70	38.59	150.75	291.89		
%	1.31	2.00	4.59	1.36	5.05	2.09	2.32	1.92	2.06	2.44	3.15	16.72	6.16	13.13	2.64	5.91	2.18	8.50	16.46		100.00

Note: The decomposition of spillover between exchange rates (Δs) and inflation (Δp) is based on Diebold and Yilmaz (2012).

Table 8: Panel and frequency analysis of spillover (PPI): High frequency

	Exchange rate changes (Δs)									Inflation (Δp)											
	Brazil	Canada	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK	Brazil	Canada	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK	USA	From others	%
Δs																					
Brazil	1.93	1.06	2.89	0.70	2.87	0.77	1.70	0.78	0.86	2.09	1.80	8.62	3.98	7.53	1.06	4.49	0.85	2.47	10.32	54.84	5.22
Canada	1.58	1.65	2.66	0.91	2.48	1.58	1.87	2.05	1.17	1.20	1.42	5.62	4.79	6.48	1.11	2.92	0.97	5.28	8.85	52.94	5.04
Euro	0.71	1.16	3.69	0.55	2.32	0.68	1.84	1.04	0.96	1.05	2.04	7.28	3.55	7.37	1.02	4.39	1.00	3.81	13.64	54.41	5.18
Japan	1.04	1.51	2.96	1.69	3.38	1.47	3.00	1.89	0.72	1.03	1.96	10.00	2.40	6.65	1.08	3.73	1.37	3.44	12.28	59.91	5.70
Mexico	1.12	0.93	2.79	1.18	3.12	1.64	1.99	1.60	0.91	1.87	1.24	9.14	3.02	6.43	2.02	3.98	0.62	5.36	7.88	53.72	5.11
S Africa	0.75	0.65	2.72	0.69	2.50	2.05	1.60	0.96	0.86	1.31	1.04	9.65	3.18	4.81	1.40	4.51	0.72	3.67	11.64	52.66	5.01
Switzerland	0.87	1.36	4.91	0.63	3.16	0.67	3.99	1.26	1.15	1.21	1.57	11.69	4.04	7.99	0.92	3.63	1.31	6.47	11.04	63.88	6.08
Thailand	0.57	1.55	3.86	0.75	3.09	0.56	2.04	1.64	1.14	1.38	2.47	8.24	4.17	6.90	1.20	3.49	1.04	2.34	12.32	57.11	5.43
UK	0.80	0.69	2.79	0.32	1.93	0.65	1.63	0.91	1.80	1.13	1.67	9.19	3.56	6.47	0.99	3.92	0.74	4.43	14.32	56.14	5.34
Δp																					
Brazil	0.53	1.00	1.02	0.48	1.08	0.66	0.79	0.63	0.49	1.97	1.64	5.44	3.21	4.00	0.54	4.55	0.86	3.71	9.11	39.74	3.78
Canada	0.99	1.42	2.55	0.69	3.45	1.31	1.86	1.81	0.58	1.23	3.46	10.11	3.64	8.49	0.94	3.67	1.13	5.16	11.55	60.58	5.77
Euro	0.52	0.92	1.53	0.58	2.26	0.85	1.38	1.09	0.43	1.24	1.93	12.78	2.95	6.21	1.05	4.49	1.56	5.30	12.86	47.15	4.49
Japan	0.53	1.02	2.32	0.53	2.96	1.09	1.82	0.94	0.62	1.89	1.94	13.06	2.97	7.75	1.75	4.19	2.11	6.09	13.67	64.28	6.12
Mexico	0.45	1.02	1.97	0.57	1.97	1.06	1.55	1.13	0.61	1.65	1.47	8.95	2.24	6.03	1.62	4.60	1.43	6.84	10.94	50.07	4.76
S Africa	0.63	1.04	2.27	1.03	2.98	0.67	1.44	0.55	0.77	1.83	1.60	13.51	3.06	9.31	2.88	2.84	1.56	8.34	11.24	64.67	6.15
Switzerland	0.52	0.85	1.69	0.71	2.58	0.85	1.44	0.84	0.35	1.36	1.85	9.33	2.30	7.25	0.95	4.75	1.36	4.59	12.15	50.97	4.85
Thailand	0.85	1.59	2.69	1.07	2.48	0.98	1.31	0.62	0.71	1.39	2.69	16.89	4.82	6.58	1.58	4.24	3.10	4.53	15.10	70.12	6.67
UK	0.93	1.02	2.27	0.73	2.95	1.05	1.57	1.23	0.52	1.43	1.84	14.75	2.88	5.90	1.13	3.47	1.95	6.64	14.13	59.75	5.69
USA	0.41	0.72	1.25	0.53	1.93	0.77	1.24	0.80	0.37	1.22	1.54	8.69	2.17	5.81	1.10	3.47	1.38	4.48	10.95	37.88	3.60
To others	13.80	19.51	45.14	12.65	46.37	17.31	30.07	20.13	13.22	25.51	31.71	180.16	59.96	121.93	21.46	70.58	21.96	86.31	213.04		
%	1.31	1.86	4.30	1.20	4.41	1.65	2.86	1.92	1.26	2.43	3.02	17.14	5.71	11.60	2.04	6.72	2.09	8.21	20.27		100.00

Note: The decomposition of spillover between exchange rates (Δs) and inflation (Δp) is based on Barunik and Krehlik (2018).

Table 9: Panel and frequency analysis of spillover (PPI): Medium frequency

	Exchange rate changes (Δs)									Inflation (Δp)											
	Brazil	Canada	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK	Brazil	Canada	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK	USA	From others	%
Δs																					
Brazil	0.79	0.51	1.66	0.66	1.19	1.00	0.46	0.86	1.28	1.21	0.85	4.40	2.70	3.35	1.71	1.57	0.71	4.06	2.89	31.07	5.43
Canada	0.39	0.87	2.94	0.40	1.72	1.27	0.50	0.45	1.69	1.34	0.80	4.79	3.01	5.44	1.66	1.49	0.67	4.64	2.92	36.12	6.31
Euro	0.24	1.15	2.83	0.57	1.78	0.71	0.45	0.53	0.73	0.68	1.41	5.96	1.81	4.43	0.88	1.52	0.65	3.78	3.48	30.76	5.38
Japan	0.32	1.23	0.93	1.11	1.55	0.30	0.40	0.99	0.47	0.35	1.96	7.14	2.54	4.70	0.71	1.57	0.67	2.84	3.38	32.05	5.60
Mexico	0.17	0.69	1.38	0.74	2.50	0.80	0.38	0.74	1.14	0.84	0.98	7.20	2.31	5.12	0.79	0.98	0.41	2.83	5.51	33.01	5.77
S Africa	0.14	0.91	3.04	0.39	1.95	1.29	0.36	0.38	1.31	1.09	0.55	5.87	2.16	6.16	1.68	1.62	0.89	4.49	2.26	35.25	6.16
Switzerland	0.22	0.73	1.88	0.40	0.97	0.65	0.85	0.33	0.77	0.44	0.71	4.81	1.35	2.99	0.61	1.40	0.65	3.60	3.00	25.51	4.46
Thailand	0.42	0.78	1.67	0.74	1.59	0.70	0.78	2.29	1.03	0.49	0.77	7.28	2.31	3.98	0.97	1.30	0.61	4.29	3.07	32.78	5.73
UK	0.17	0.82	2.37	0.61	2.23	0.83	0.28	0.25	1.08	0.78	0.91	5.92	2.15	6.06	1.43	2.21	0.61	2.92	3.54	34.09	5.96
Δp																					0.00
Brazil	0.96	0.72	2.20	0.64	1.08	0.93	0.54	1.35	1.72	1.67	1.05	4.87	4.29	2.79	1.38	1.90	1.25	3.90	5.16	36.73	6.42
Canada	0.20	0.76	2.13	0.27	1.46	1.00	0.22	0.20	1.16	0.96	1.02	4.57	2.13	5.28	1.48	1.25	0.69	2.58	2.25	28.59	5.00
Euro	0.15	0.53	1.44	0.41	1.41	0.84	0.45	0.70	0.77	0.90	1.15	7.11	2.82	4.49	1.06	2.43	1.22	2.15	3.72	26.64	4.66
Japan	0.15	0.45	1.17	0.33	1.12	0.71	0.39	0.57	0.77	0.66	0.89	4.02	2.59	3.50	0.77	1.88	1.00	1.81	2.57	22.76	3.98
Mexico	0.12	0.59	1.49	0.58	1.66	0.95	0.38	0.52	0.96	1.22	1.50	6.37	3.39	4.67	1.24	2.14	0.77	2.33	5.10	31.31	5.47
S Africa	0.14	0.29	0.63	0.22	0.55	0.38	0.24	0.46	0.43	0.31	0.50	3.53	1.12	1.67	0.33	0.99	0.76	1.80	2.43	16.45	2.88
Switzerland	0.19	0.58	1.95	0.40	1.83	1.09	0.59	0.47	1.28	1.09	1.43	6.09	2.73	5.05	1.29	2.26	1.04	3.26	3.76	34.12	5.96
Thailand	0.12	0.39	1.00	0.23	0.94	0.33	0.25	0.28	0.63	0.55	0.45	4.92	1.29	4.42	0.71	1.03	0.88	3.03	2.70	23.27	4.07
UK	0.10	0.43	1.18	0.35	1.07	0.57	0.28	0.66	0.55	0.68	0.88	5.99	2.66	3.30	0.67	2.24	0.91	2.16	3.18	25.70	4.49
USA	0.20	0.60	1.97	0.45	2.02	1.14	0.53	0.69	1.50	1.12	1.53	7.01	2.95	5.59	1.50	2.39	1.17	3.60	4.58	35.96	6.28
To others	4.40	12.16	31.03	8.39	26.12	14.20	7.48	10.43	18.19	14.71	18.32	100.74	43.72	78.32	20.54	29.91	14.68	57.91	60.92		
%	0.77	2.13	5.42	1.47	4.57	2.48	1.31	1.82	3.18	2.57	3.20	17.61	7.64	13.69	3.59	5.23	2.57	10.12	10.65		100.00

Note: The decomposition of spillover between exchange rates (Δs) and inflation (Δp) is based on Barunik and Krehlik (2018).

Table 10: Panel and frequency analysis of spillover (PPI): Low frequency

	Exchange rate changes (Δs)									Inflation (Δp)											
	Brazil	Canada	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK	Brazil	Canada	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK	USA	From others	%
Δs																					
Brazil	0.80	0.29	0.32	0.29	1.61	0.55	0.54	0.24	0.21	0.40	0.45	0.58	0.52	1.64	0.76	0.27	0.21	0.15	1.53	10.56	7.05
Canada	0.30	0.32	0.34	0.22	0.42	0.52	0.45	0.26	0.30	0.17	0.25	1.09	0.74	0.35	0.31	0.22	0.10	0.43	1.60	8.07	5.39
Euro	0.08	0.18	1.06	0.27	0.81	0.27	0.16	0.23	0.09	0.17	0.11	1.06	0.38	2.05	0.06	0.09	0.10	0.52	0.62	7.25	4.84
Japan	0.09	0.24	0.45	0.44	0.93	0.03	0.03	0.08	0.24	0.03	0.10	0.30	0.43	1.01	0.05	0.11	0.02	0.03	0.63	4.80	3.21
Mexico	0.07	0.19	0.18	0.11	0.87	0.52	0.31	0.24	0.27	0.09	0.27	1.00	0.46	1.03	0.41	0.11	0.10	0.31	1.12	6.79	4.53
S Africa	0.14	0.22	0.57	0.08	0.86	0.67	0.19	0.19	0.19	0.22	0.28	0.95	0.32	1.30	0.19	0.32	0.16	0.50	1.41	8.09	5.40
Swit	0.02	0.09	0.39	0.06	0.51	0.12	0.11	0.07	0.15	0.10	0.07	1.01	0.29	1.72	0.04	0.08	0.09	0.47	0.38	5.66	3.78
Thailand	0.20	0.20	0.23	0.22	0.59	0.41	0.36	0.30	0.15	0.18	0.20	0.59	0.34	0.90	0.13	0.39	0.06	0.50	0.24	5.89	3.93
UK	0.11	0.21	0.13	0.32	0.62	0.24	0.08	0.14	0.09	0.03	0.16	1.83	0.13	1.17	0.05	0.03	0.15	0.91	0.47	6.78	4.53
Δp																					
Brazil	1.09	0.34	0.59	0.09	3.56	0.55	0.18	0.49	0.56	0.15	0.90	0.53	0.22	7.19	0.83	0.58	0.35	0.58	1.10	19.73	13.18
Canada	0.32	0.26	0.20	0.13	0.88	0.17	0.14	0.17	0.28	0.09	0.38	0.43	0.19	1.31	0.28	0.26	0.06	0.13	0.67	5.97	3.99
Euro	0.26	0.15	0.14	0.15	0.99	0.14	0.07	0.12	0.18	0.16	0.28	0.29	0.08	2.37	0.16	0.17	0.06	0.09	0.50	6.07	4.05
Japan	0.21	0.31	0.14	0.12	0.89	0.12	0.10	0.15	0.24	0.10	0.38	0.49	0.43	1.51	0.20	0.14	0.09	0.25	1.51	6.95	4.64
Mexico	0.36	0.17	0.30	0.26	0.26	0.45	0.27	0.25	0.59	0.29	0.36	1.22	0.33	0.80	0.50	0.26	0.08	0.38	0.79	7.12	4.76
S Africa	0.40	0.30	0.55	0.09	1.55	0.62	0.27	0.33	0.54	0.26	0.75	1.02	0.29	3.20	0.63	0.63	0.09	0.36	3.76	15.01	10.02
Swit	0.38	0.14	0.13	0.16	0.75	0.29	0.14	0.09	0.29	0.30	0.29	1.03	0.12	1.94	0.21	0.34	0.04	0.33	0.89	7.52	5.02
Thailand	0.03	0.06	0.12	0.05	0.28	0.02	0.01	0.14	0.07	0.05	0.11	0.07	0.31	0.70	0.08	0.09	0.06	0.03	0.36	2.58	1.72
UK	0.39	0.17	0.20	0.14	0.65	0.10	0.03	0.06	0.28	0.11	0.42	0.65	0.13	1.23	0.14	0.18	0.13	0.42	0.31	5.32	3.55
USA	0.52	0.24	0.22	0.35	0.96	0.35	0.35	0.20	0.47	0.41	0.45	1.63	0.33	1.86	0.37	0.25	0.05	0.56	1.05	9.57	6.39
To others	4.97	3.76	5.20	3.11	17.12	5.47	3.68	3.45	5.10	3.16	5.83	15.48	5.61	32.48	4.77	4.18	1.94	6.53	17.89		
%	3.32	2.51	3.47	2.08	11.43	3.65	2.46	2.30	3.41	2.11	3.89	10.34	3.75	21.69	3.19	2.79	1.30	4.36	11.95		100.00

Note: The decomposition of spillover between exchange rates (Δs) and relative prices (Δp) is based on Barunik and Krehlik (2018).

Table 11: Crisis periods

	tstat	90%	95%	99%	Start	End	Start	End	Start	End
Brazil										
ADF	-1.311	-0.496	-0.104	0.629	Nov-02	Dec-02	Nov-07	Sep-08	Apr-15	May-15
SADF	0.362	1.130	1.399	1.976	Jul-15	Mar-16				
GSADF	2.372	1.887	2.111	2.725						
Canada										
ADF	-0.837	-0.496	-0.104	0.629	Jul-03	Aug-03	Nov-03	Dec-03	Feb-04	Mar-04
SADF	0.796	1.130	1.399	1.976	Nov-04	Dec-04	Jun-06	Jul-06	Nov-07	Dec-07
GSADF	2.691	1.887	2.111	2.725	May-11	Jun-11	Jan-15	Apr-16		
Euro										
ADF	-1.291	-0.496	-0.104	0.629	Feb-03	Mar-03	Jun-03	Jul-03	Jan-04	Mar-04
SADF	-0.354	1.130	1.399	1.976	Apr-08	May-08	Feb-15	Sep-15	Dec-15	Jan-16
GSADF	3.355	1.887	2.111	2.725	Feb-16	Mar-16				
Japan										
ADF	-1.399	-0.496	-0.104	0.629	Nov-05	Jan-06	Jan-09	Feb-09	Mar-13	Oct-13
SADF	-0.194	1.130	1.399	1.976	Jan-14	Feb-14	Dec-14	Jan-16		
GSADF	2.762	1.887	2.111	2.725						
Mexico										
ADF	-1.584	-0.496	-0.104	0.629						
SADF	-0.431	1.130	1.399	1.976						
GSADF	2.073	1.887	2.111	2.725						
S Africa										
ADF	-1.783	-0.496	-0.104	0.629	Nov-01	Apr-02	Jan-04	Feb-04	Oct-15	Nov-15
SADF	2.114	1.130	1.399	1.976	Dec-15	Apr-16				
GSADF	3.106	1.887	2.111	2.725						
Switzerland										
ADF	-1.879	-0.496	-0.104	0.629						
SADF	0.042	1.130	1.399	1.976						
GSADF	1.106	1.887	2.111	2.725						
Thailand										
ADF	-0.717	-0.496	-0.104	0.629						
SADF	1.682	1.130	1.399	1.976						
GSADF	1.800	1.887	2.111	2.725						
UK										
ADF	-1.104	-0.496	-0.104	0.629	Feb-04	Mar-04	Dec-08	Apr-09	Feb-16	Apr-16
SADF	-0.308	1.130	1.399	1.976	Aug-16	Feb-17	Apr-17	May-17		
GSADF	2.495	1.887	2.111	2.725						

Note: The explosive unit root tests are applied to real exchange rates. Without a lag term in the specifications, the critical values of the tests are obtained from the Monte Carlo experiments with 2000 replication. The crisis periods are identified by the GSADF.

Table 12: The sensitivity of spillovers to currency crises, exchange rates regimes, service sectors

	Time dummy	Time dummy fixed effect	Time dummy fixed effect	Time dummy fixed effect	Time dummy fixed effect	Time dummy fixed effect
			Dependent variable: Overall spillovers			
Crises	−8.331***	−8.755***	−8.791***	−10.473***	−10.633***	−10.717***
	(1.245)	(1.035)	(1.037)	(1.012)	(1.007)	(1.008)
Regime			0.203	0.316	0.384	0.401
			(0.374)	(0.360)	(0.358)	(0.358)
Service				−6.634***	−5.438***	−5.485***
				(0.722)	(0.796)	(0.796)
Openness					0.596***	0.591***
					(0.171)	(0.171)
Capital flow						−0.00004
						(0.00003)
R^2	0.044	0.341	0.341	0.394	0.401	0.403
Residual SE	14.172	11.778	11.782	11.305	11.241	11.233
			Dependent variable: Spillovers to exchange rates			
Crises	−3.779***	−3.853***	−3.593***	−4.359***	−4.537***	−4.575***
	(1.009)	(1.002)	(0.997)	(1.005)	(0.999)	(1.000)
Regime			−1.440***	−1.389***	−1.313***	−1.305***
			(0.360)	(0.357)	(0.355)	(0.355)
Service				−3.025***	−1.707**	−1.729**
				(0.717)	(0.789)	(0.790)
Openness					0.658***	0.655***
					(0.170)	(0.170)
Capital flow						−0.00002
						(0.00003)
R^2	0.014	0.028	0.044	0.062	0.076	0.076
Residual SE	11.484	11.408	11.320	11.223	11.143	11.146
			Dependent variable: Spillovers to prices			
Crises	−4.551***	−4.902***	−5.199***	−6.113***	−6.097***	−6.142***
	(1.053)	(0.885)	(0.875)	(0.875)	(0.877)	(0.878)
		(0.125)	(0.124)	(0.122)	(0.173)	(0.173)
Regime			1.643***	1.705***	1.698***	1.707***
			(0.316)	(0.311)	(0.312)	(0.312)
Service				−3.608***	−3.731***	−3.757***
				(0.624)	(0.693)	(0.693)
Openness					−0.061	−0.064
					(0.149)	(0.149)
Capital flow						−0.00002
						(0.00002)
R^2	0.019	0.309	0.327	0.350	0.350	0.351
Residual SE	11.992	10.072	9.939	9.777	9.781	9.782

Note: The crisis period is identified by the GSADF test (See Table 11) and is equal to one. *p<0.1; **p<0.05; ***p<0.01. The estimation is based on Eq. (16).

Figure 1: Exchange rate changes and inflation differentials (PPI)

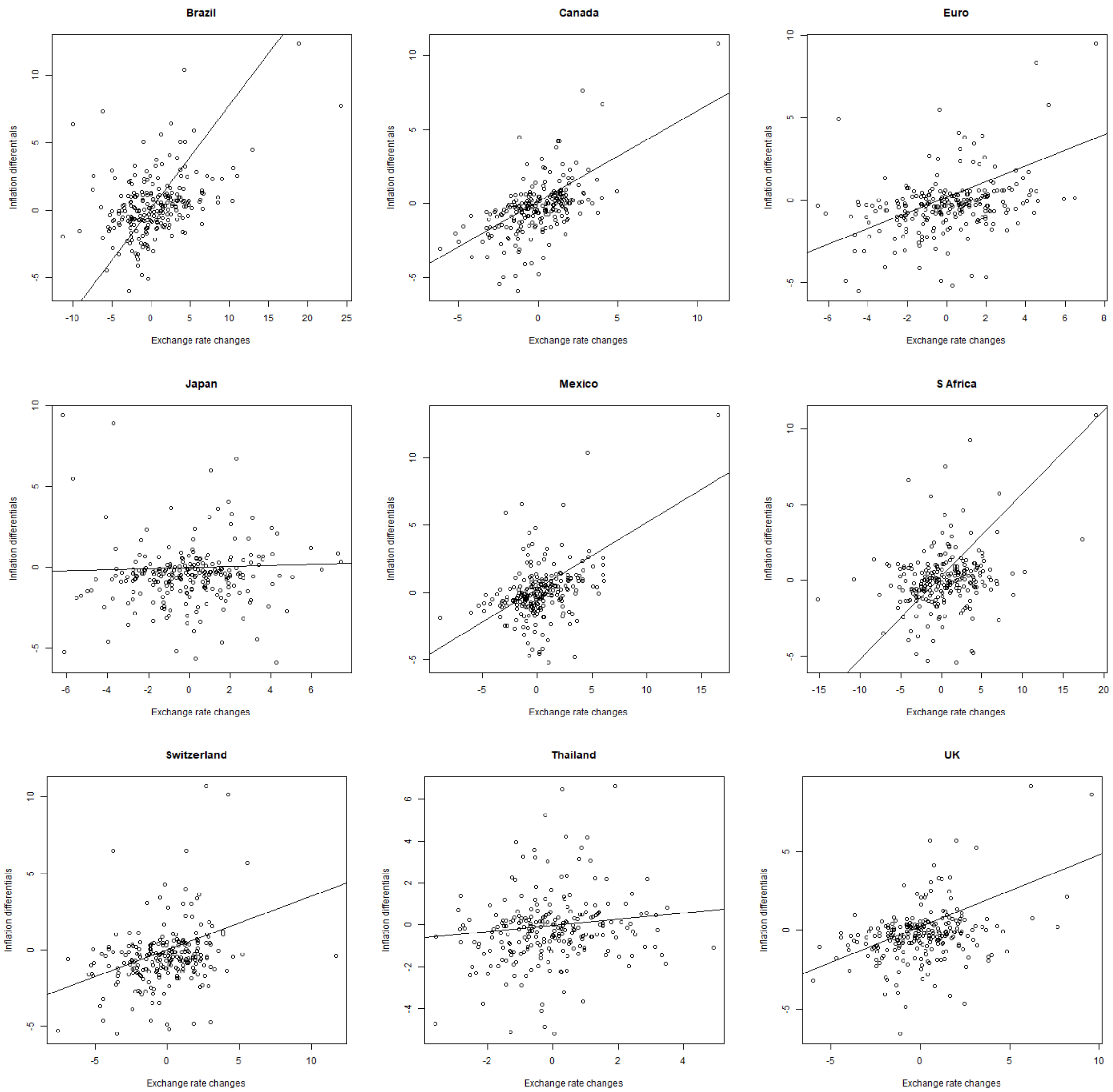


Figure 2: Overall spillover (PPI)

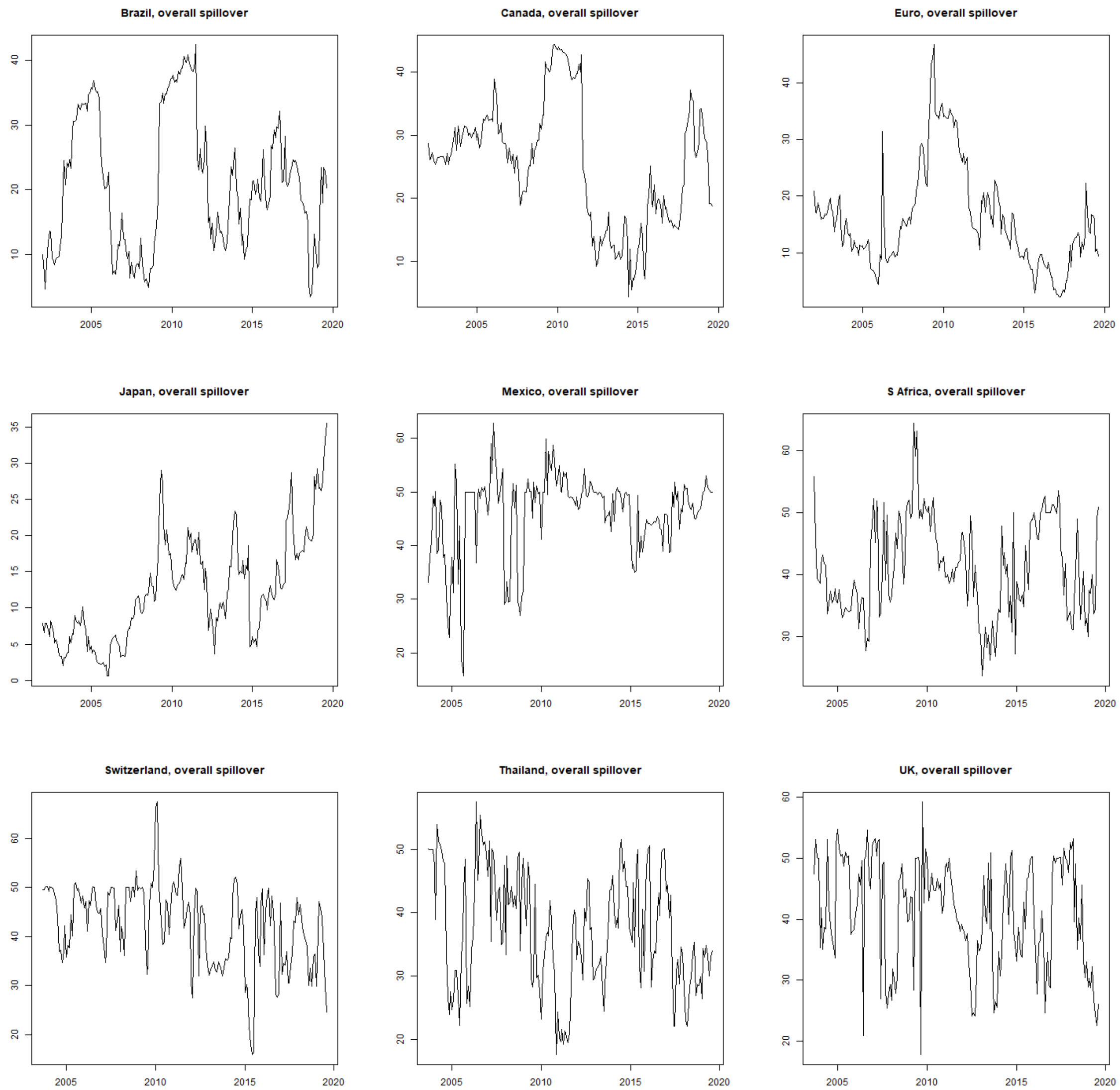


Figure 3: Net spillover (PPI)

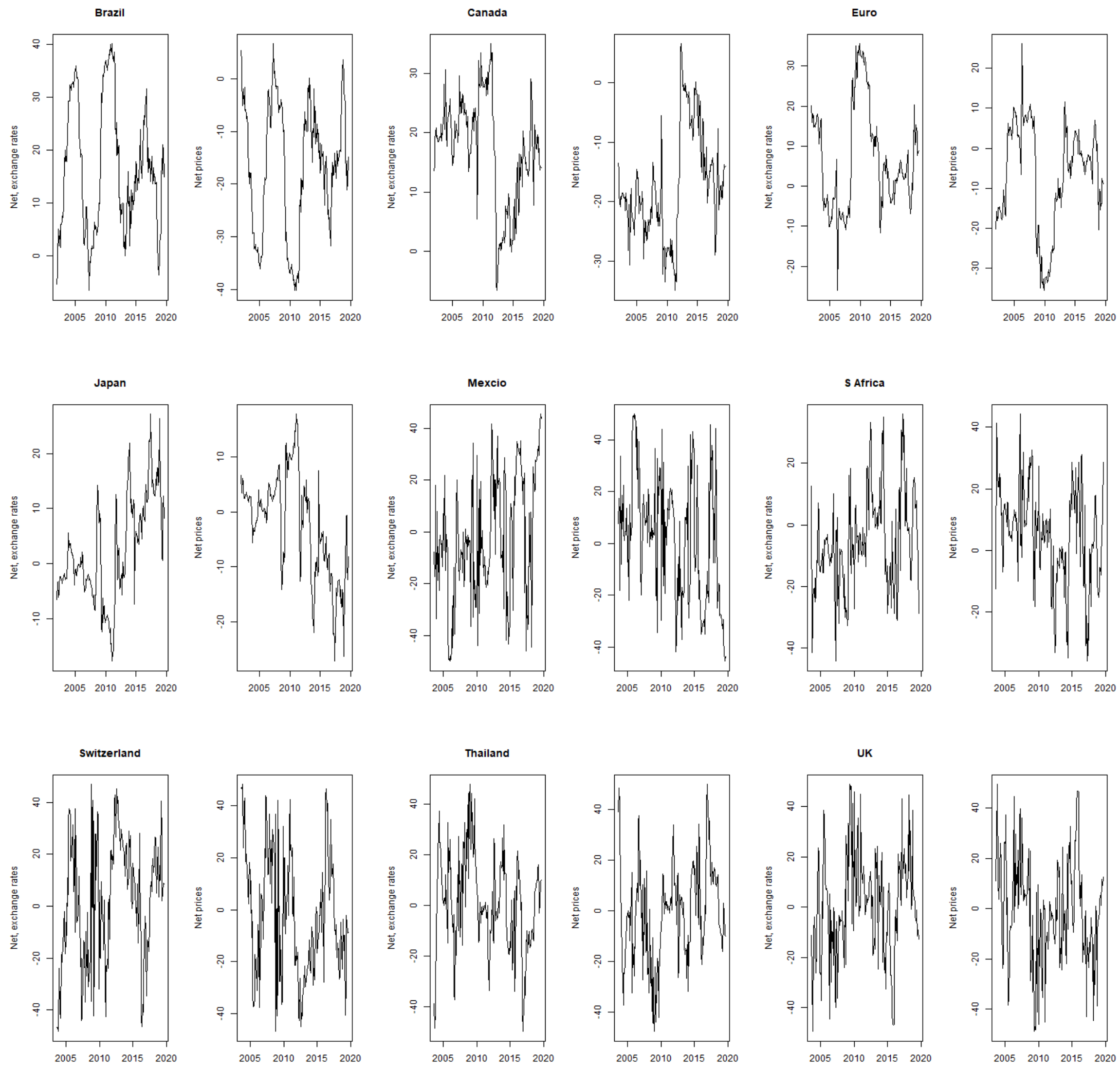
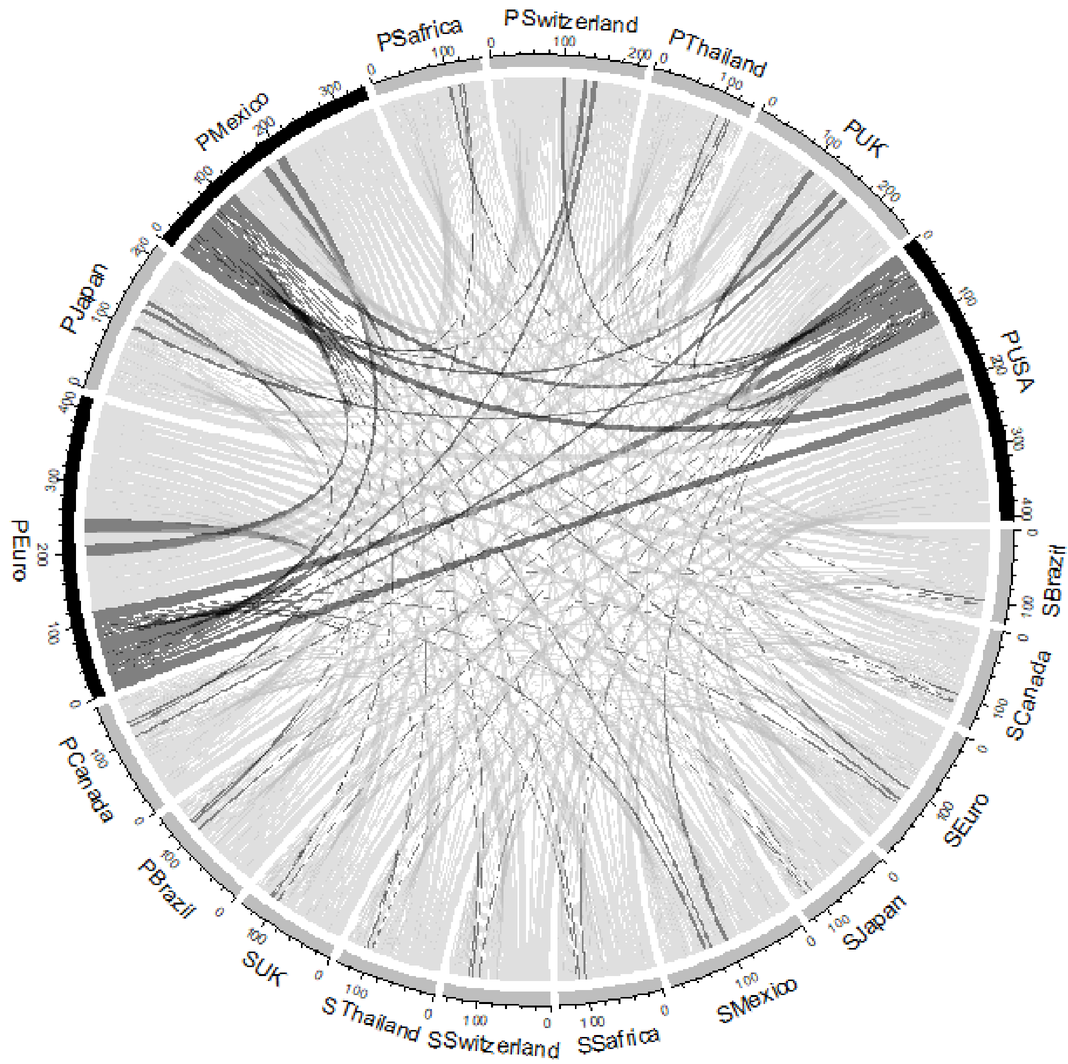


Figure 4: Directional spillovers from a group analysis (PPI)



Note: Price shocks originated from the Euro area, Mexico and the USA are highlighted in black. "S" and "P" in front of country names indicate exchange rates and inflation, respectively.

Online (unpublished) materials: Spillover effects based on the CPI

Table 13: Frequency analysis of overall spillovers (CPI)

Frequency	High				Medium				Low			
	Δs	$\Delta p - \Delta p*$	From others	%	Δs	$\Delta p - \Delta p*$	From others	%	Δs	$\Delta p - \Delta p*$	From others	%
Brazil												
Δs	44.17	2.74	2.74	49.37	31.97	3.54	3.54	37.15	17.57	0.01	0.01	0.07
$\Delta p - \Delta p*$	2.81	32.14	2.81	50.63	5.99	35.66	5.99	62.85	13.60	9.80	13.60	99.93
To others	2.81	2.74	5.55		5.99	3.54	9.53		13.60	0.01	13.61	
%	50.63	49.37		100.00	62.85	37.15		100.00	99.93	0.07		100.00
Canada												
Δs	52.19	2.47	2.47	26.17	27.13	3.03	3.03	47.20	12.63	2.56	2.56	45.15
$\Delta p - \Delta p*$	6.97	67.13	6.97	73.83	3.39	15.14	3.39	52.80	3.11	4.25	3.11	54.85
To others	6.97	2.47	9.44		3.39	3.03	6.42		3.11	2.56	5.67	
%	73.83	26.17		100.00	52.80	47.20		100.00	54.85	45.15		100.00
China												
Δs	37.95	0.72	0.72	18.18	34.80	1.80	1.80	93.26	23.50	1.24	1.24	100.00
$\Delta p - \Delta p*$	3.24	45.31	3.24	81.82	0.13	47.14	0.13	6.74	0.00	4.18	0.00	0.00
To others	3.24	0.72	3.96		0.13	1.80	1.93		0.00	1.24	1.24	
%	81.82	18.18		100.00	6.74	93.26		100.00	0.00	100.00		100.00
Euro												
Δs	46.65	4.84	4.84	36.69	31.69	3.95	3.95	64.33	7.87	5.00	5.00	87.11
$\Delta p - \Delta p*$	8.35	77.38	8.35	63.31	2.19	10.27	2.19	35.67	0.74	1.08	0.74	12.89
To others	8.35	4.84	13.19		2.19	3.95	6.14		0.74	5.00	5.74	
%	63.31	36.69		100.00	35.67	64.33		100.00	12.89	87.11		100.00
Japan												
Δs	48.97	1.87	1.87	53.58	35.26	0.91	0.91	50.28	12.95	0.04	0.04	2.17
$\Delta p - \Delta p*$	1.62	54.00	1.62	46.42	0.90	34.05	0.90	49.72	1.80	7.63	1.80	97.83
To others	1.62	1.87	3.49		0.90	0.91	1.81		1.80	0.04	1.84	
%	46.42	53.58		100.00	49.72	50.28		100.00	97.83	2.17		100.00
Mexico												
Δs	12.95	0.04	0.04	2.17	30.41	4.75	4.75	29.09	8.90	0.19	0.19	9.79
$\Delta p - \Delta p*$	1.80	7.63	1.80	97.83	11.58	55.47	11.58	70.91	1.75	4.09	1.75	90.21
To others	1.80	0.04	1.84		11.58	4.75	16.33		1.75	0.19	1.94	
%	97.83	2.17		100.00	70.91	29.09		100.00	90.21	9.79		100.00
S Africa												
Δs	51.35	1.77	1.77	19.71	30.65	1.14	1.14	22.49	13.56	1.53	1.53	6.97
$\Delta p - \Delta p*$	7.21	39.42	7.21	80.29	3.93	15.92	3.93	77.51	20.42	13.11	20.42	93.03
To others	7.21	1.77	8.98		3.93	1.14	5.07		20.42	1.53	21.95	
%	80.29	19.71		100.00	77.51	22.49		100.00	93.03	6.97		100.00
Switzerland												
Δs	54.23	7.47	7.47	60.24	27.86	2.40	2.40	57.28	6.33	1.71	1.71	69.80
$\Delta p - \Delta p*$	4.93	68.63	4.93	39.76	1.79	21.81	1.79	42.72	0.74	2.10	0.74	30.20
To others	4.93	7.47	12.40		1.79	2.40	4.19		0.74	1.71	2.45	
%	39.76	60.24		100.00	42.72	57.28		100.00	30.20	69.80		100.00
Thailand												
Δs	44.43	1.66	1.66	20.07	34.78	3.11	3.11	72.66	15.24	0.77	0.77	89.53
$\Delta p - \Delta p*$	6.61	62.47	6.61	79.93	1.17	23.11	1.17	27.34	0.09	6.54	0.09	10.47
To others	6.61	1.66	8.27		1.17	3.11	4.28		0.09	0.77	0.86	
%	79.93	20.07		100.00	27.34	72.66		100.00	10.47	89.53		100.00
UK												
Δs	47.33	5.66	5.66	60.60	27.04	6.69	6.69	68.76	12.01	1.27	1.27	36.18
$\Delta p - \Delta p*$	3.68	62.43	3.68	39.40	3.04	24.15	3.04	31.24	2.24	4.46	2.24	63.82
To others	3.68	5.66	9.34		3.04	6.69	9.73		2.24	1.27	3.51	
%	39.40	60.60		100.00	31.24	68.76		100.00	63.82	36.18		100.00

Note: The decomposition of spillover between exchange rates (Δs) and relative inflation ($\Delta p - \Delta p*$) is based on Diebold and Yilmaz (2012).

Table 14: Group analysis of overall spillovers (CPI)

	Δs										Δp												
Δs	Brazil	Canada	China	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK	Brazil	Canada	China	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK	USA	From others	%
Brazil	3.03	4.18	2.41	31.53	2.53	0.81	1.08	5.99	2.3	1.05	0.87	3.73	9.67	0.96	0.63	1.61	3.97	5.99	13.65	2.67	1.34	96.97	4.87
Canada	2.33	8.14	2.54	28.19	2.76	4.6	0.83	5.49	1.92	1.71	0.76	2.81	7.64	0.93	1.04	1.36	4.44	5.34	10.4	5.81	0.96	91.86	4.61
China	2.9	5.48	2.76	31.21	2.63	1.94	0.96	5.95	1.9	1.19	0.79	3.37	8.8	0.96	0.75	1.43	4.38	5.63	11.92	3.81	1.23	97.23	4.88
Euro	2.78	5.71	2.69	28.69	2.41	3.11	1.01	5.58	2.2	1.48	0.97	3.3	8.15	0.88	1.09	1.51	4.88	5.58	11.61	5.2	1.18	71.32	3.58
Japan	3.13	4.74	2.63	30.8	2.42	1.93	1.04	5.96	2.23	1.2	0.9	3.54	8.85	0.94	0.89	1.55	4.53	5.6	12.02	3.79	1.3	97.57	4.90
Mexico	1.9	11.97	2.89	24.04	2.31	8.09	0.64	4.71	1.91	2.59	0.85	2.04	6.03	0.9	1.78	1.22	6.14	4.79	5.87	8.67	0.68	91.93	4.61
S Africa	2.94	4.4	2.68	31.16	2.8	1.11	1.02	6.02	2.05	0.98	0.89	3.45	8.75	0.94	0.66	1.46	4.2	5.64	14.31	3.28	1.26	98.98	4.97
Switzerland	2.83	5.35	2.56	29.38	2.51	2.38	1.05	5.83	2.09	1.41	0.99	3.45	8.28	0.86	1	1.55	4.49	5.77	12.44	4.55	1.21	94.15	4.73
Thailand	1.6	12.86	3.26	21.37	1.94	10.44	0.45	4.02	1.53	2.97	0.8	1.4	4.74	0.87	1.92	1.14	6.47	4.11	5.42	12.23	0.44	98.45	4.94
UK	2.32	8.32	2.93	25.26	2.32	6.02	0.75	4.8	2.03	1.94	0.82	2.52	6.86	0.86	1.35	1.29	5.59	4.84	9.69	8.6	0.9	98.07	4.92
Δp																							
Brazil	3.15	3.97	2.51	30.8	2.66	1.06	1.1	5.84	2.65	0.98	0.85	3.64	9.3	0.98	0.69	1.59	3.97	5.81	13.68	3.46	1.33	99.17	4.98
Canada	2.97	4.48	2.45	31.23	2.41	1.34	1.07	5.95	2.2	1.14	0.87	3.7	9.35	0.95	0.76	1.62	4.14	6.03	12.53	3.49	1.32	96.30	4.83
China	3.08	4.88	2.64	31.43	2.53	1.6	1	5.87	2.27	1.07	0.82	3.54	9.22	0.98	0.75	1.5	4.51	5.75	12.03	3.23	1.32	90.80	4.56
Euro	2.42	7.25	2.58	26.95	2.38	4.15	1	5.39	2.16	1.86	1.03	3.11	7.39	0.8	1.24	1.55	4.87	5.67	10.89	6.31	1.02	99.22	4.98
Japan	2.93	4.01	2.43	31.39	2.96	0.37	1.11	6.26	1.94	0.95	0.91	3.67	8.92	0.89	0.57	1.5	3.75	5.94	15.53	2.67	1.31	99.44	4.99
Mexico	2.73	6.89	2.89	28.52	2.43	4.04	0.88	5.44	2.12	1.48	0.88	2.98	7.91	0.91	1.21	1.35	5.43	5.14	10.39	5.29	1.1	98.66	4.95
S Africa	3.54	4.89	2.67	29.31	3.55	1.47	1.35	5.83	3.85	1.2	0.91	3.44	8.72	1.07	0.8	1.62	4.28	5.35	10.67	4.21	1.27	95.72	4.81
Switzerland	2.82	4.82	2.57	30.06	2.98	1.56	0.96	5.83	2.01	1.01	0.78	3.33	8.54	0.9	0.64	1.39	4.05	5.41	14.9	4.22	1.22	94.59	4.75
Thailand	3.14	3.83	2.54	32.21	2.51	0.6	1.09	6.11	2.26	0.93	0.86	3.8	9.58	0.97	0.63	1.59	4.16	6.04	13.08	2.67	1.39	86.91	4.36
UK	2.23	7.55	2.14	29.54	2.84	2.99	1	6.07	1.59	1.71	0.9	3.21	7.83	0.86	0.9	1.57	3.49	6.06	12.24	4.28	0.99	95.71	4.80
USA	2.4	7.59	2.71	26.31	2.21	4.97	0.93	5.14	2.1	1.96	0.96	2.9	7.28	0.85	1.33	1.47	5.14	5.48	10.07	7.2	0.99	99.00	4.97
TO others	54.14	123.17	52.72	580.69	51.67	56.49	19.30	112.25	43.78	28.87	17.56	63.23	162.59	18.46	20.06	29.52	92.60	110.56	230.26	101.36	22.77		
%	2.72	6.18	2.65	29.15	2.59	2.84	0.97	5.63	2.20	1.45	0.88	3.17	8.16	0.93	1.01	1.48	4.65	5.55	11.56	5.09	1.14		100.00

Note: The decomposition of spillovers between exchange rates (Δs) and inflation (Δp) is based on Diebold and Yilmaz (2012).

Table 15: Group and frequency analysis of spillover, high frequency (CPI)

	Δs										Δp												
	Brazil	Canada	China	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK	Brazil	Canada	China	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK	USA	From others	%
Δs																							
Brazil	3.02	4.06	2.40	31.41	2.48	0.78	1.07	5.94	2.27	1.03	0.86	3.72	9.65	0.96	0.62	1.61	3.94	5.96	13.47	2.66	1.34	96.23	4.90
Canada	2.29	8.11	2.46	27.83	2.71	4.42	0.82	5.44	1.91	1.70	0.76	2.80	7.58	0.92	1.03	1.36	4.39	5.32	10.10	5.46	0.96	90.26	4.60
China	2.85	5.44	2.71	31.05	2.62	1.91	0.94	5.94	1.82	1.19	0.78	3.34	8.71	0.96	0.71	1.42	4.20	5.60	11.89	3.79	1.21	96.37	4.91
Euro	2.77	5.60	2.69	28.41	2.40	3.08	0.99	5.51	2.18	1.44	0.96	3.25	8.04	0.87	1.09	1.47	4.88	5.47	11.56	5.07	1.17	70.49	3.59
Japan	3.10	4.68	2.63	30.62	2.41	1.88	1.02	5.92	2.18	1.17	0.89	3.51	8.78	0.92	0.88	1.52	4.51	5.53	11.99	3.69	1.29	96.71	4.93
Mexico	1.89	11.78	2.87	23.73	2.25	7.73	0.64	4.66	1.86	2.58	0.83	2.04	5.99	0.88	1.71	1.21	6.09	4.77	5.78	8.44	0.67	90.67	4.62
S Africa	2.88	4.39	2.64	30.79	2.80	1.08	1.00	5.96	1.98	0.96	0.86	3.40	8.62	0.92	0.63	1.44	4.08	5.56	14.24	3.27	1.24	97.74	4.98
Switzerland	2.81	5.21	2.56	28.92	2.50	2.37	1.03	5.74	2.08	1.37	0.98	3.39	8.13	0.85	1.00	1.51	4.49	5.62	12.43	4.48	1.20	92.93	4.74
Thailand	1.55	12.60	3.17	21.31	1.93	10.39	0.44	4.01	1.47	2.92	0.78	1.40	4.72	0.86	1.87	1.13	6.20	4.08	5.24	11.99	0.43	97.02	4.94
UK	2.31	8.21	2.90	25.21	2.31	5.98	0.75	4.79	2.02	1.91	0.81	2.51	6.83	0.86	1.32	1.28	5.49	4.80	9.39	8.39	0.90	97.06	4.95
Δp																							
Brazil	3.11	3.87	2.49	30.57	2.63	0.99	1.08	5.80	2.59	0.96	0.83	3.63	9.23	0.96	0.66	1.58	3.93	5.76	13.39	3.42	1.32	97.97	4.99
Canada	2.95	4.46	2.44	31.00	2.40	1.31	1.07	5.93	2.18	1.13	0.87	3.68	9.24	0.93	0.75	1.61	4.14	5.99	12.41	3.47	1.32	95.60	4.87
China	3.08	4.87	2.63	31.41	2.51	1.54	0.99	5.87	2.24	1.06	0.82	3.53	9.19	0.98	0.74	1.50	4.49	5.73	11.93	3.11	1.31	90.34	4.60
Euro	2.40	7.03	2.57	26.29	2.36	4.10	0.98	5.28	2.15	1.83	1.02	3.06	7.20	0.78	1.22	1.51	4.86	5.53	10.85	6.26	1.01	97.51	4.97
Japan	2.88	3.96	2.39	30.87	2.94	0.36	1.08	6.17	1.91	0.93	0.89	3.59	8.75	0.87	0.56	1.47	3.67	5.81	15.42	2.67	1.28	97.91	4.99
Mexico	2.71	6.87	2.88	28.48	2.43	3.89	0.87	5.43	2.07	1.46	0.86	2.95	7.88	0.90	1.17	1.33	5.37	5.10	10.37	5.17	1.09	97.95	4.99
S Africa	3.21	4.15	2.59	27.73	3.38	1.14	1.25	5.55	3.49	1.03	0.78	3.37	8.40	0.91	0.74	1.45	3.95	5.15	10.35	3.67	1.24	89.58	4.57
Switzerland	2.78	4.82	2.52	29.87	2.94	1.55	0.94	5.79	2.00	1.01	0.76	3.31	8.50	0.90	0.61	1.39	3.95	5.38	14.51	4.11	1.21	93.47	4.76
Thailand	3.12	3.82	2.53	32.01	2.51	0.58	1.08	6.08	2.23	0.92	0.86	3.77	9.49	0.96	0.62	1.58	4.14	5.98	13.02	2.62	1.38	86.28	4.40
UK	2.15	7.40	2.05	28.43	2.78	2.84	0.98	5.91	1.57	1.71	0.89	3.14	7.55	0.82	0.90	1.54	3.45	5.93	12.12	4.14	0.97	93.13	4.75
USA	2.37	7.35	2.69	25.70	2.20	4.88	0.90	5.04	2.08	1.91	0.96	2.84	7.07	0.83	1.30	1.43	5.11	5.31	9.90	7.08	0.98	96.95	4.94
To others	53.21	120.57	52.10	573.23	51.08	55.07	18.92	111.02	42.81	28.31	17.22	62.55	160.36	18.06	19.57	29.01	91.38	109.00	227.34	98.82	22.54		
%	2.71	6.14	2.66	29.21	2.60	2.81	0.96	5.66	2.18	1.44	0.88	3.19	8.17	0.92	1.00	1.48	4.66	5.56	11.59	5.04	1.15		100.00

Note: The decomposition of spillover between exchange rates (Δs) and inflation (Δp) is based on Diebold and Yilmaz (2012).

Table 16: Group and frequency analysis of spillovers, Medium frequency (CPI)

	Δs										Δp												
	Brazil	Canada	China	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK	Brazil	Canada	China	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK	USA	From others	%
Δs																							
Brazil	0.01	0.10	0.01	0.12	0.03	0.02	0.01	0.03	0.02	0.02	0.01	0.01	0.02	0.00	0.01	0.00	0.02	0.03	0.15	0.00	0.00	0.61	2.61
Canada	0.03	0.03	0.06	0.27	0.04	0.14	0.00	0.04	0.01	0.01	0.00	0.01	0.04	0.01	0.00	0.00	0.04	0.01	0.23	0.28	0.01	1.23	5.27
China	0.05	0.03	0.04	0.12	0.00	0.03	0.01	0.01	0.07	0.00	0.01	0.02	0.07	0.01	0.03	0.01	0.14	0.02	0.03	0.02	0.02	0.70	3.00
Euro	0.01	0.09	0.00	0.22	0.00	0.03	0.01	0.05	0.01	0.04	0.00	0.04	0.08	0.01	0.00	0.03	0.00	0.09	0.03	0.11	0.01	0.64	2.74
Japan	0.03	0.05	0.01	0.16	0.01	0.03	0.01	0.03	0.05	0.03	0.01	0.02	0.05	0.01	0.01	0.02	0.02	0.05	0.03	0.07	0.01	0.70	3.00
Mexico	0.01	0.15	0.01	0.25	0.05	0.30	0.01	0.04	0.04	0.01	0.02	0.00	0.03	0.01	0.05	0.00	0.05	0.02	0.07	0.20	0.00	1.02	4.37
S Africa	0.04	0.01	0.03	0.29	0.00	0.02	0.01	0.05	0.05	0.01	0.02	0.04	0.10	0.01	0.03	0.02	0.09	0.06	0.06	0.01	0.02	0.96	4.11
Switzerland	0.02	0.11	0.00	0.35	0.01	0.01	0.02	0.08	0.01	0.04	0.01	0.05	0.11	0.01	0.00	0.03	0.00	0.11	0.01	0.05	0.01	0.96	4.11
Thailand	0.04	0.21	0.07	0.06	0.01	0.04	0.00	0.01	0.04	0.04	0.01	0.00	0.02	0.01	0.04	0.01	0.21	0.03	0.13	0.20	0.01	1.15	4.93
UK	0.01	0.09	0.03	0.05	0.00	0.04	0.01	0.01	0.00	0.02	0.01	0.00	0.02	0.00	0.02	0.01	0.08	0.03	0.21	0.17	0.00	0.79	3.38
Δp																							
Brazil	0.03	0.08	0.02	0.22	0.02	0.06	0.02	0.04	0.05	0.02	0.01	0.01	0.07	0.02	0.03	0.02	0.04	0.04	0.25	0.03	0.01	1.08	4.63
Canada	0.02	0.02	0.01	0.19	0.00	0.03	0.01	0.02	0.02	0.00	0.00	0.01	0.08	0.01	0.01	0.01	0.01	0.03	0.09	0.02	0.01	0.59	2.53
China	0.01	0.01	0.00	0.01	0.01	0.06	0.00	0.00	0.03	0.01	0.00	0.01	0.02	0.00	0.01	0.01	0.02	0.01	0.07	0.10	0.00	0.37	1.59
Euro	0.02	0.17	0.01	0.52	0.01	0.04	0.01	0.09	0.00	0.02	0.00	0.05	0.15	0.02	0.01	0.03	0.01	0.12	0.03	0.04	0.01	1.34	5.74
Japan	0.04	0.04	0.03	0.37	0.02	0.00	0.02	0.07	0.03	0.01	0.01	0.06	0.12	0.01	0.01	0.02	0.05	0.09	0.08	0.01	0.02	1.10	4.71
Mexico	0.01	0.01	0.00	0.03	0.00	0.12	0.01	0.01	0.04	0.01	0.02	0.02	0.02	0.00	0.03	0.01	0.05	0.02	0.02	0.09	0.01	0.52	2.23
S Africa	0.25	0.53	0.06	1.31	0.11	0.28	0.08	0.20	0.23	0.08	0.03	0.06	0.24	0.13	0.04	0.14	0.30	0.16	0.26	0.29	0.02	4.50	19.28
Switzerland	0.03	0.00	0.03	0.13	0.03	0.01	0.01	0.03	0.01	0.00	0.01	0.02	0.03	0.00	0.02	0.00	0.08	0.02	0.29	0.10	0.01	0.84	3.60
Thailand	0.01	0.02	0.01	0.16	0.00	0.01	0.01	0.02	0.02	0.01	0.00	0.02	0.07	0.01	0.01	0.01	0.01	0.05	0.04	0.04	0.01	0.50	2.14
UK	0.06	0.12	0.07	0.87	0.04	0.12	0.01	0.13	0.01	0.01	0.00	0.06	0.22	0.03	0.00	0.02	0.04	0.11	0.09	0.11	0.02	2.03	8.70
USA	0.03	0.20	0.02	0.51	0.01	0.08	0.03	0.08	0.02	0.04	0.00	0.04	0.17	0.03	0.02	0.03	0.03	0.14	0.12	0.11	0.01	1.71	7.33
To others	0.75	2.04	0.48	5.99	0.39	1.17	0.29	0.96	0.72	0.41	0.17	0.54	1.71	0.32	0.37	0.42	0.99	1.22	2.25	1.94	0.21	0.50	
%	3.21	8.74	2.06	25.66	1.67	5.01	1.24	4.11	3.08	1.76	0.73	2.31	7.33	1.37	1.59	1.80	4.24	5.23	9.64	8.31	0.90		100.00

Note: The decomposition of spillover between exchange rates (Δs) and inflation (Δp) is based on Diebold and Yilmaz (2012).

Table 17: Group and frequency analysis of spillovers, low spillovers (CPI)

	Δs Brazil	Canada	China	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK	Δp Brazil	Canada	China	Euro	Japan	Mexico	S Africa	Switzerland	Thailand	UK	USA	From others	%
Δs																							
Brazil	0.00	0.02	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.00	0.00	0.09	1.48
Canada	0.01	0.00	0.02	0.09	0.01	0.04	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.07	0.07	0.00	0.35	5.77
China	0.01	0.01	0.01	0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.02	0.00	0.01	0.00	0.03	0.00	0.00	0.00	0.00	0.13	2.14
Euro	0.00	0.02	0.00	0.06	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.03	0.00	0.00	0.01	0.00	0.02	0.01	0.02	0.00	0.14	2.31
Japan	0.00	0.01	0.00	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.02	0.00	0.03	0.00	0.16	2.64
Mexico	0.00	0.03	0.00	0.06	0.01	0.06	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.02	0.03	0.00	0.20	3.29
S Africa	0.01	0.00	0.01	0.08	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.03	0.00	0.01	0.00	0.03	0.02	0.01	0.00	0.01	0.25	4.12
Switzerland	0.00	0.03	0.00	0.11	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.02	0.04	0.00	0.00	0.01	0.00	0.03	0.00	0.01	0.00	0.26	4.28
Thailand	0.01	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.06	0.00	0.05	0.04	0.00	0.25	4.12
UK	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.09	0.04	0.00	0.19	3.13
Δp																							
Brazil	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.07	1.15
Canada	0.00	0.00	0.00	0.05	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.12	1.98
China	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.00	0.06	0.99
Euro	0.00	0.05	0.00	0.14	0.00	0.01	0.00	0.02	0.00	0.01	0.00	0.01	0.04	0.00	0.00	0.01	0.00	0.03	0.01	0.00	0.00	0.33	5.44
Japan	0.01	0.02	0.01	0.15	0.01	0.00	0.01	0.03	0.01	0.01	0.00	0.02	0.05	0.00	0.00	0.01	0.02	0.04	0.03	0.00	0.01	0.44	7.25
Mexico	0.00	0.00	0.00	0.01	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.00	0.02	0.00	0.12	1.98
S Africa	0.08	0.21	0.02	0.26	0.06	0.05	0.02	0.09	0.13	0.09	0.09	0.02	0.08	0.03	0.02	0.03	0.03	0.04	0.05	0.25	0.01	1.63	26.85
Switzerland	0.01	0.00	0.01	0.06	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.02	0.01	0.10	0.02	0.00	0.28	4.61
Thailand	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.11	1.81
UK	0.02	0.03	0.02	0.24	0.01	0.03	0.00	0.04	0.00	0.00	0.00	0.02	0.06	0.01	0.00	0.01	0.01	0.03	0.03	0.03	0.01	0.57	9.39
USA	0.00	0.04	0.00	0.11	0.00	0.01	0.00	0.02	0.00	0.01	0.00	0.01	0.04	0.00	0.00	0.01	0.00	0.02	0.04	0.01	0.00	0.32	5.27
To others	0.16	0.55	0.12	1.48	0.13	0.20	0.04	0.28	0.20	0.16	0.11	0.17	0.50	0.04	0.09	0.09	0.23	0.28	0.63	0.57	0.04		
%	2.64	9.06	1.98	24.38	2.14	3.29	0.66	4.61	3.29	2.64	1.81	2.80	8.24	0.66	1.48	1.48	3.79	4.61	10.38	9.39	0.66		100.00

Note: The decomposition of spillover between exchange rates (Δs) and inflation (Δp) is based on Diebold and Yilmaz (2012).

Figure 5: Exchange rate changes and inflation differentials (CPI)

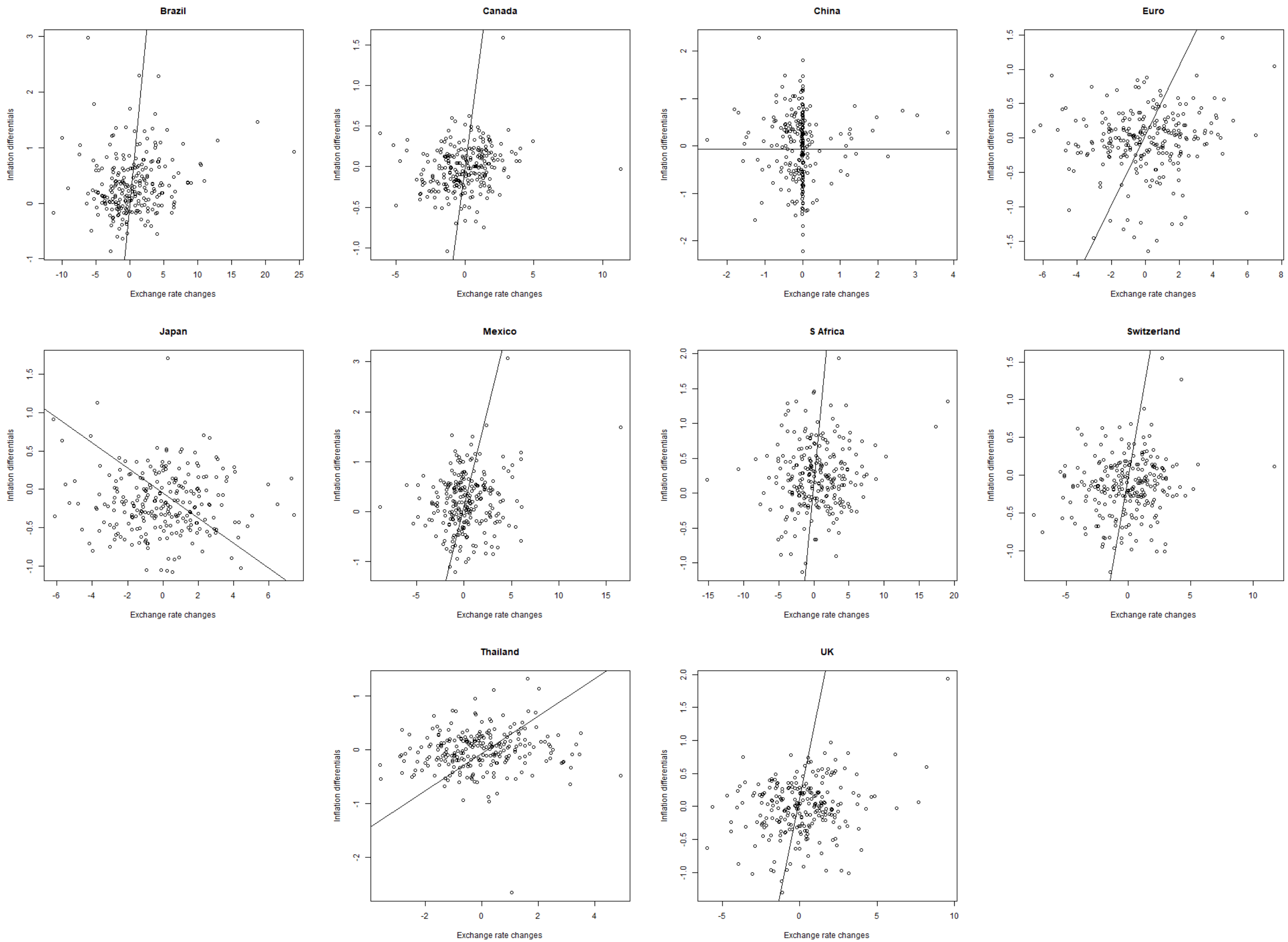


Figure 6: Overall spillover (CPI)

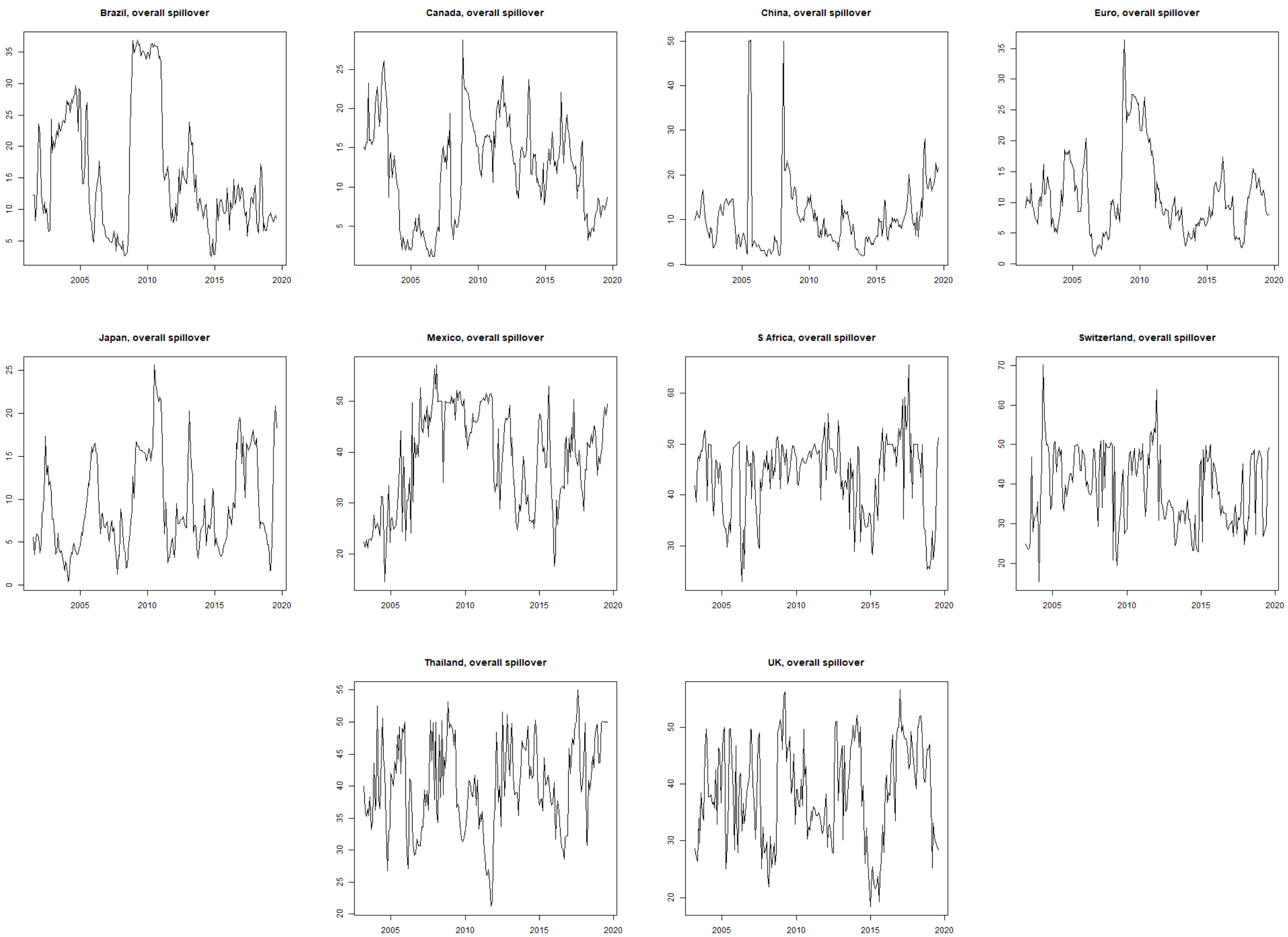


Figure 7: Net spillover (CPI)