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Non-linear relationship between real commodity price volatility and real effective exchange rate: The case of commodity-exporting countries

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ABSTRACT

The aim of this paper is to contribute to the existing literature by exploring the relationship between the real commodity price volatilities and the real effective exchange rate (REER) of commodity-exporting countries, taking into account the transition variable of financial market integration. To this end, we consider a sample of 42 commodity-exporting countries subdivided into 4 panels: food and beverages, energy, metals, and raw materials. Our results highlight that the relationship between real commodity price volatility and REER is non-linear and depends on the degree of financialization of the commodity market. Specifically, when a country is poorly integrated financially, the volatility of the real commodity price has a strong and negative impact on the variation in REER. However, for periods when a country is better integrated financially, we observe a decrease in the impact of real commodity price volatility on REER, especially for the two panels of food and beverages as well as energy. Our findings also highlight the growth of financialization of commodities post-2000, particularly in the case of the energy sector.

1. Introduction

For countries in which the majority of revenue emanates from export activities, the real effective exchange rate (REER) appears to be a crucial variable in determining trade capabilities. The REER measures the real value of a specific currency of a given country against its main trade partners. In addition, working on the fluctuation in REER allows a comprehensive study, as the REER does not fluctuate randomly and is expected to react to certain macroeconomic variables, which have been found to be a key determinant of its dynamics in the medium term. However, in the literature there are many different views and there is no consensus regarding the main factors impacting exchange rates. The empirical research on this topic has evolved over time and evidenced many results based on different approaches to monetary factors, or to other factors such as volatilities in world prices for domestic exports. In their seminal paper, Meese and Rogoff (1983) showed that the random walk model outperforms a range of fundamentals-based models of exchange rate determination at different horizons. Following this result, the literature, and most researchers, have concluded that macro-economic fundamentals do not play a role in exchange rate fluctuations.[1] However, as noted by Rogoff (2008) or, more recently, Ferraro et al. (2015), the findings of Meese and Rogoff (1983) are limited to major floating currencies and not necessarily relevant to emerging market currencies (where interest and inflation differentials are often much larger). Moreover, a large body of literature (for instance, Amano and van Norden, 1998a; 1998b; Chen and Rogoff, 2003; Cayen et al., 2010; Alquist et al., 2011) has been

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[1] See, for example, Rogoff and Stavrakeva (2008) for a literature review.

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developed and found that real commodity prices could be a key explanatory variable for the real exchange rate. Finally, as demonstrated by Rossi (2006) or Engle et al. (2007), according to the forecasting horizon (short or long), monetary models help to forecast changes in exchange rates, and therefore exchange rates do not follow a random walk.[2]

For the special case of net commodity-exporting countries, almost all are developing economies, and an extensive body of literature has focused on the determinants of their real exchange rate. They provided evidence that real commodity-export prices are the preponderant factor in the determination of the real exchange rates of these commodity-exporting developing countries (Cashin et al., 2004). This finding led to the labelling of such real exchange rates as "commodity currencies". This denomination is widely used nowadays: for example, the Forex market uses it to gather currencies from commodity exporters whose economies are developed, such as Australia and Canada, as well as a number of currencies issued by emerging commodity exporters.

Furthermore, the intensification of practices such as portfolio rebalancing and hedging has led to a growing impact in the financialization of the commodities on the determination of their prices (Cheng and Xiong, 2013). Indeed, the volume of crude oil futures traded on the New York Mercantile Exchange (NYMEX) has more than quintupled since the early 2000s (Fratzscher et al., 2014). Therefore, the REER of some countries may be impacted more depending on whether they are more or less developed financially. In addition, investment funds, which are most likely to impact commodity prices through their actions as a result of their high purchasing power tend to buy their futures commodity contracts based on commodity price indices. Consequently, we should be able to capture most of the effect generated by the financialization of the commodity markets by selecting the commodity price indices in respect to the main type of commodity exported by the different countries.

In this paper our goal is to contribute to the existing literature by exploring the potential non-linear impact of the volatility of real commodity price indices on REER variations when analysing commodity-exporting countries, by considering the degree of financial integration as one of the most important transmission channels. Indeed, considering the growing financialization of the commodity markets, it seems that the level of financial integration of a country may play a role in the transmission channel, from real commodity price volatilities to the REER. Moreover, the existing literature focuses mainly on the impact of oil price volatility on the REER of energy-exporting countries. Our aim is to fill the existing gap in the current literature in different ways. First, we extend our study to many types of commodity, not just to the oil market, in order to take into account the heterogeneity that may exist across countries and their reaction to the dynamics of the transition variable. To this end, we subdivide our commodity-exporting countries into four panels: food and beverages, energy, metals, and raw materials. Second, as our main variable of interest is the volatility of the real commodity price indices, each panel will be respectively linked to a different index in adequacy, with the main type of commodity exported by the countries included in the panel. Third, we test a new transition variable linked to the financial market, namely, the degree of financial integration, to consider the growing financialization of the commodity markets. To check the robustness of our results, we test alternative measures of the degree of financial integration, such as M2 in percentage of GDP, private credit in percentage of GDP and foreign direct investment in percentage of GDP. To the best of our knowledge, no previous studies have included the degree of financial integration as the transition variable in the relationship between real commodity price volatilities and REER variations.

We consider a sample of 42 commodity-exporting countries, subdivided into 4 panels, as mentioned above. We rely on a panel smooth transition regression (PSTR) model proposed by González et al. (2005, 2017) in order to consider the non-linear impact of the volatility of the real commodity price indices on the real effective exchange rate variations of commodity-exporting countries. Our results show that the short-term dynamics of the real exchange rate of commodity-exporting countries are affected by their respective real commodity price index volatility, depending on whether the country is better integrated financially. Our findings also highlight the growth of financialization of commodities post-2000, particularly in the case of the energy sector.

This paper is structured as follows. Section 2 reviews the existing literature. Section 3 describes the econometric methodology used. Section 4 describes the data and its statistical properties. Section 5 is devoted to commenting on the results found and the specification tests. Section 6 concludes.

2. Literature review

For countries that depend highly on the exports of primary commodities, it is important to understand the behaviour of commodity prices and their volatilities, particularly for the formulation of their economic policy. Indeed, Deaton and Laroque (1992),[3] using different theoretical and applied frameworks, analysed the behaviour of commodity prices and established various properties regarding asymmetry, non-linearity, volatility and their main determinants (in short- and long-term horizons). Their study of 13 commodities confirmed the existence of rare but intense explosions in prices, coupled with a high degree of price autocorrelation in more normal times.

The issue of real commodity price volatility is of particular importance given the role that it can play as a key determinant of the real effective exchange rate in commodity-exporting countries. Indeed, the recent literature has overturned the long-held Meese and Rogoff (1983) puzzle that exchange rate models cannot outperform the random walk in out-of-sample forecasting of the exchange rate. For instance, Chen and Rogoff (2003) focused on three advanced commodity-exporting countries namely, Australia, Canada and New Zealand, finding a positive link between the real commodity prices and the real exchange rates, which led to the denomination of "commodity currencies". Cashin et al. (2004) confirmed the same relationship for a large set of commodity-exporting developing

[2] See also, for example, Morana (2009).

[3] See also Deaton and Laroque (1996, 2003) and Arezki et al. (2011) or Oglend and Kleppe (2017) for a review.

countries.

As crude oil is the most traded commodity worldwide in terms of volume, many studies have focused on the relationship between crude oil prices and exchange rates.[4] Basher et al. (2012) used a SVAR model for some emerging markets and provided evidence of the short-term effects of oil price shocks on exchange rates. Specifically, a positive oil price shock leads to an immediate decrease in the trade-weighted exchange rate. This result has a statistically significant impact for approximately three months. Beckmann and Czudaj (2013b) identified that fluctuations in nominal oil prices generate real exchange rate effects. Fratzscher et al. (2014) focused on daily data, finding that a 10 per cent increase in the price of oil leads to a depreciation in the US dollar effective exchange rate by 0.28 per cent. Furthermore, Dauvin (2014) detected evidence of a positive long-term relationship between energy prices and the real effective exchange rate of energy-exporting countries: a 10 per cent increase in energy prices led to a 2.5 per cent appreciation in their domestic currency. In a more recent study based on a Markov-switching approach, Basher et al. (2016) showed that oil demand shocks have stronger effects on oil-exporter exchange rates compared to oil supply shocks. The authors found evidence of exchange rate appreciation pressures in oil-exporting economies after oil demand shocks.

Nevertheless, Gomes (2016) found that for oil-exporting countries the price of oil affects their real exchange rate only if US dollar appreciation does not reach a high level. Furthermore, using a structural VAR model, Buetzer et al. (2016) studied the response of the exchange rates of oil-exporting countries to various shocks in real oil prices. They found no systematic evidence that the domestic currencies of oil-exporting countries appreciate after oil shocks.

Therefore, several studies in the previous literature have shown that there exists a significant and close link between oil prices and the real exchange rate. However, as highlighted by recent research, some have queried this relationship. To discuss this issue further, we now focus on the nature of the relationship (linear versus non-linear) between real commodity prices and the REER. Previously, some studies have tried to elucidate how the volatility of commodity prices could be transmitted to the REER. For instance, Krugman (1983) and Golub (1983), among others, used a three-country framework to introduce the concept of the wealth effect channel through petrodollar recycling. This theoretical concept was developed in order to describe how oil-producing countries use the revenue from their oil exports, and also to describe its impact on the exchange rate. The main findings were that, in the short term, oil price increases will significantly appreciate the US dollar. This appreciation in the US dollar can be explained by oil-exporting countries reinvesting their revenues in US dollar assets. This reinvestment leads to a growth in demand for US dollar assets that strengthens the dollar rate. However, the long-term reaction of the US dollar compared to other currencies is determined by the dependence of the US on oil imports relative to the weight of US exports to oil-exporter countries. Furthermore, when an oil price rise occurs, wealth is transferred to oil-exporting countries and will have the effect of improving their current account balance in domestic currency terms.

As a counter-example, Wiegand (2008) studied the mechanism of petrodollar recycling and its importance for emerging market economies. However, he highlighted that if the relative importance of deposit flows differs between emerging countries, they will experience a crash in funding in the event of a drop in oil prices. Consequently, the currencies of oil-exporting countries tend to appreciate, while the currencies of oil importers tend to depreciate in real effective terms following a rise in oil prices (Beckmann and Czudaj, 2013a).

In more recent studies, authors have considered other channels that could justify the impact of commodity prices on exchange rates. Indeed, Amano and Van Norden (1998a) considered the commodity terms of trade as one of the channels that could support the impact of oil prices on exchange rates. Moreover, Cashin et al. (2004) studied the relationship between real commodity export prices and the real exchange rate in 58 developed and developing countries. They found, in approximately one-third of the 58 commodity-exporting countries that they analysed, that the commodity terms of trade affect the REER. The authors also highlighted that in the majority of commodity currencies it is the real exchange rate that will adjust in order to restore the long-term equilibrium in real commodity prices. Therefore, real commodity prices for many commodity-exporting countries are a fundamental determinant value for their exchange rates (Chen et al., 2010). A clear demonstration of this process could be that higher prices in commodities will improve the terms of trade for commodity exporters, resulting in an appreciation of their currency without affecting their trade account.

To support this theory, Dauvin (2014) used a PSTR non-linear model to provide evidence of the existence of a threshold level beyond which the real effective exchange rate of commodity exporters responds to oil price volatility via the commodity terms of trade channel. When the oil market is highly volatile, the commodity terms of trade become an important driver of the real exchange rate of commodity-exporting countries. The study of Coudert et al. (2015) corroborates this result, highlighting the commodity terms of trade as a significant driver of exchange-rate variations when the oil price is highly volatile. Specifically, the authors divided the countries by main exported commodities, and demonstrated that changes in the commodity terms of trade are significant in regimes with high volatility, especially for groups of energy and metal commodities.

Furthermore, since the mid-2000s, researchers have focused on the financialization of the commodity markets, specifically in the energy sector (Henderson et al., 2015).[5] Indeed, the growth in the volume of commodity markets due to its financialization could justify consideration of the financial markets as an important channel when analysing the effect of commodity price volatilities on exchange rates. Fratzscher et al. (2014) displayed the growing relevance of this financial channel, as the volume of crude oil futures traded on NYMEX has more than quintupled since the early 2000s. This may be due to the intensification of recent practices such as portfolio rebalancing and hedging, in respect to the development of commodity futures (Domanski and Heath, 2007). Consequently,

[4] See, for example, Coudert and Mignon (2016) for a literature review.
[5] See Chari and Christiano (2017) for a complete literature review.

the rise in commodity futures has introduced an arbitrage between financial assets and commodity contracts. Coudert and Mignon (2016) dispense a comprehensive justification of the negative relationship between the US dollar and commodity prices due to the growth of financialization of the commodity markets. They confirm that the negative relationship between the two variables is derived from the fact that, if the dollar is expected to increase, then commodities are less alluring to investors. Equity markets may also play a key role in the foundation of oil prices: a positive equity market shock will generate a growth in the expected income of listed firms and increase global economic activity, which will engender a rise in oil prices. Finally, Büyükşahin and Robe (2014) found empirical evidence of growing cross-market correlations between equity returns and commodity returns caused by speculators.

As demonstrated, the previous literature has focused on two main ideas. First, the majority has paid particular attention to the relationship between oil price fluctuations and exchange rates. However, other types of commodity, such as metals, food and beverages, and raw materials, can also play an important role as fundamental determinants of real exchange rates in their respective exporting countries. In this study, our objective is to extend the analysis to other types of commodity[6]: energy (oil, gas and coal), metals (copper, aluminium, iron, ore, tin, nickel, zinc, lead and uranium), food and beverages, and raw materials (timber, cotton, wool, rubber and hides). The commodity-exporting countries that belong to the same panel can be heterogeneous based on the type of main commodity exported by the country. Second, the literature has shown that the impact of commodity prices on the exchange rate, if it exists, can be non-linear through the transition variable of the commodity terms of trade or oil price fluctuations. In our investigation the relationship between these commodity price indices and the REER is studied using a non-linear approach, while considering financial market integration as a potential transition variable.

3. Econometric methodology: the PSTR framework

To evaluate the potential relationship between the real commodity price index and the real effective exchange rate, different methodologies may be followed. The first method consists of using a causality test or cointegration relationship, which tests a short- and a long-term link between commodity prices and exchange rates. These tests account for a linear relationship and do not take into account the transition variable of the impact between the two markets (i.e. exchange rate market and commodity market). The second methodology consists of explicitly modelling the non-linearity using a panel smooth transition regression (PSTR) model proposed by González et al. (2005, 2017). According to this specification, the regression coefficients are allowed to vary across countries, and with time, depending on the commodity price index and the transition variable. More precisely, the observations are divided into two regimes delimited by a threshold reached by the transition variable, with estimated coefficients that vary depending on the considered regime. With this methodology, countries can be distinguished from one another based on the value of the transition variable. Our PSTR specification focuses only on the short-term dynamics of the relationship between the REER and the explanatory variables.[7] Denoting the dependent variable with $\Delta LREER$, the variation of the logarithm of the real effective exchange rate, the PSTR model is given by:

$$\Delta LREER_{i,t} = \alpha_i + \beta_0' X_{i,t} + [\beta_1' X_{i,t} * F(S_{i,t};\gamma, c)] + \varepsilon_{i,t} \tag{1}$$

for $t = 1, \ldots, T$ and $i = 1, \ldots, N$, with t denoting time and i the country. Furthermore, α_i denotes the country fixed effects and $X_{i,\,t}$ represents the vector of real exchange rate determinants, including the volatility of the real commodity price index and the three other fundamental variables that have been evidenced in the literature: the country's net foreign asset position, the commodity terms of trade, and the Balassa-Samuelson effect. These three fundamental variables are expressed in the first difference. $X_{i,\,t}$ also include the transition variable (i.e. the financial integration degree). The volatility of the real commodity price index is proxied by the absolute value of the variation in the real commodity price index.[8] F is a transition function, $S_{i,\,t}$ stands for the transition variable, defined here by the financial integration level and $\varepsilon_{i,\,t}$ is an independent and identically distributed (i.i.d.) error term. Transition function $F(S_{i,\,t}; \gamma, c)$ is a continuous function of $S_{i,\,t}$ and is normalized to be bounded between 0 and 1, and these extreme values are associated with regression coefficients β_0 and $\beta_0 + \beta_1$. This transition function is given by:

$$F(S_{i,t};\gamma, c) = \left(1 + \exp\left(-\gamma \prod_{j=1}^{m} (S_{i,t} - c_j)\right)\right)^{-1} \tag{2}$$

with $\gamma > 0$ and $c_1 < c_2 < \cdots < c_m$, γ is the slope parameter of the transition function and c_j $(j = 1, 2, \ldots, m)$ are the threshold parameters. According to González et al. (2005, 2017), in practice, it is usually sufficient to consider $m = 1$ (logistic) and $m = 2$ (logistic quadratic). In the case of $m = 1$, the dynamics is asymmetric and the two extreme regimes are associated with low and high values of the transition variable, where the change is centred around the threshold (c_1). In the case of $m = 2$, the dynamics is symmetric, and the transition function has its minimum at $(c_1 + c_2)/2$ and attains the value of 1 at both low and high values of the transition variable.

[6] As mentioned previously, Coudert et al. (2015) have studied the relationship between commodity terms of trade and real exchange rates for 69 commodity-producing countries (energy, metals, food and beverages, and raw materials) using a non-linear approach. However, they included a different transition variable linked to oil price volatilities.

[7] Indeed, the previous literature found clear evidence of a short-term relationship between commodity price shocks (mainly in the oil sector) and exchange rate fluctuations (see, for example, Basher et al., 2012 or Ferraro et al., 2015).

[8] We also calculated the implied volatility from a GARCH (1,1) model. Results, available upon request from the authors, are very close to the proxy used.

In our study, the transition variable is the level of financial integration measured by *M2/GDP*.[9] Depending on the realization of this variable, the relationship between the real effective exchange rate and its determinants is specified by the regression coefficients β_0 (in the first regime) and $\beta_0 + \beta_1$ (in the second regime). In our model, depending on the level of financial integration, the explanatory variables, including the real commodity price index volatility, have a different impact on the real effective exchange rate (i.e. appreciation or depreciation). This impact varies between commodity-exporting countries and time according to the value taken by the transition function, as follows:

$$\frac{\delta \Delta LREER_{i,t}}{\delta \Delta X_{i,t}} = \beta_0 + \beta_1 F(S_{i,t};\, \gamma,\, c)\ \forall\ m = (1,\, 2) \tag{3}$$

Using a non-linear model such as the PSTR model requires a specific procedure, which consists of specification, estimation and evaluation stages. The first stage of specification includes testing homogeneity (versus non-linearity), selecting the transition variable and, if homogeneity is rejected, finding the appropriate form of the transition function (i.e. determining the value of m in Eq. (2)). The second stage consists of the PSTR model estimation using the non-linear least squares (NLLS) method. In the last stage, misspecification tests are conducted to evaluate the PSTR estimation results by testing parameter constancy and no remaining heterogeneity.

In more detail, the estimation methodology of the PSTR model proposed by González et al. (2005, 2017) is conducted in two steps. In the first step, a within transformation is done to eliminate the individual fixed effects, α_i, by centring the variables on their individual means. In a second step, the parameters of the transition function γ_j and c_j are estimated by applying NLLS to the transformed model. Thus, for the given values of $\hat{\gamma}_j$ and $\hat{c}_j$, it is possible to estimate the parameters α and β. However, the convergence issue of this estimation procedure is greatly dependent upon the chosen starting values of γ_j and c_j. For our model, it is often suggested that sensible starting values can be obtained by means of a grid search across the parameters in the transition function. Given these grids, OLS regressions are performed for all combinations of the initial values to estimate the corresponding parameters α and β.

According to González et al. (2005, 2017), an evaluation of the estimated PSTR model is a key stage of the model-building procedure. As mentioned above, the authors consider two misspecification tests of parameter constancy and no remaining heterogeneity. The first test consists of testing parameter constancy against the parameters in Eq. (1) as they change smoothly over time. Under the alternative hypothesis the model may be called the Time-Varying Panel Smooth Transition Regression (TV-PSTR) model, and it is defined as follows:

$$\begin{aligned} \Delta LREER_{i,t} \;&=\; \alpha_i + (\beta_{10}' X_{i,t} + \beta_{11}' X_{i,t} {*} F(S_{i,t};\, \gamma_1,\, c_1\,)) \\ &\quad + g\left(\frac{t}{T};\, \gamma_2,\, c_2\right)(\beta_{20}' X_{i,t} + \beta_{21}' X_{i,t} {*} F(S_{i,t};\, \gamma_1,\, c_1\,)) + \varepsilon_{i,t} \end{aligned} \tag{4}$$

where $F(S_{i,\,t};\, \gamma_1,\, c_1\,)$ is defined in Eq. (2) and $g(\frac{t}{T};\, \gamma_2,\, c_2)$ is another transition function. González et al. (2005, 2017) defined the null hypothesis of parameter constancy as follows: H_0: $\gamma_2 = 0$. To implement this test, they proposed replacing the new transition function $g(\frac{t}{T};\, \gamma_2,\, c_2)$ in Eq. (4) with its first-order Taylor expansion around $\gamma_2 = 0$ in order to overcome some identification problems.

The second evaluation consists of testing no remaining heterogeneity. The idea is to test the hypothesis that a two-regime PSTR model represented by Eqs. (1) and (2) adequately captures the heterogeneity in the panel data. Indeed, we consider an additive PSTR model with two transition functions, as follows:

$$\Delta LREER_{i,t} = \alpha_i + \beta_0' X_{i,t} + [\beta_1' X_{i,t} {*} F_1(S_{i,t}^{(1)};\, \gamma_1,\, c_1\,)] + [\beta_2' X_{i,t} {*} F_2(S_{i,t}^{(2)};\, \gamma_2,\, c_2\,)] + \varepsilon_{i,t} \tag{5}$$

where the transition variables $S_{i,t}^{(1)}$ and $S_{i,t}^{(2)}$ can, but need not, be the same. The null hypothesis of this test is formulated as: H_0: $\gamma_2 = 0$. As previously, implementation of the test is complicated by the presence of an unidentified nuisance parameter and requires the replacement of the second transition function $F_2(S_{i,t}^{(2)};\, \gamma_2,\, c_2\,)$ in Eq. (5) with a Taylor expansion around $\gamma_2 = 0$. We then compute the LM statistic and its F-version as defined by Gonzales et al. (2005, 2017).

4. Data

4.1. Sample of countries and fundamental variables

We consider yearly data for a panel of 42 commodity-exporting countries spanning from 1980 to 2016. The list of countries is given in Table A.1 (in the Appendix), together with the main type of commodity exported by each one, which are – except for energy-exporting countries – derived from Cashin et al. (2004) and used for the construction of our panels (see Table A.2 in the Appendix). Among the different panels, the energy panel is the largest, with 13 energy-exporting countries, of which 7 countries belong to OPEC (Indonesia, Iran, Kuwait, Kingdom of Saudi Arabia, Nigeria, United Arab Emirates and Venezuela), 2 are other Gulf countries (Bahrain and Oman), 1 is a leading oil exporter (Mexico), 1 is a coal exporter (Australia) and another 2 are gas- and oil-exporting countries (Algeria and Norway). This is followed by the food and beverages panel, in which 7 are food-exporting countries (Argentina, India, Malaysia, Paraguay, the Philippines, Thailand and Uruguay) and 5 are beverage-exporting countries (Colombia, Ivory

[9] We also use other measures of financial integration level such as foreign direct investment in percentage of GDP, as well as private credit in percentage of GDP.

Coast, Honduras, Kenya and Uganda). The two other panels are raw materials and metals, which are respectively composed of 9 and 8 exporting countries. We decided to discard and remove some countries derived from the initial list of 52 countries of Cashin et al. (2004) based on the lack of available data or extensive periods of war, which would have distorted the results (Syria, Libya, Central African Republic, etc.).

The dependent variable is the variation of the real effective exchange rate expressed in logarithm ($\Delta LREER$ hereafter) and is provided by the Bank of International Settlements and Bruegel databases.[10]

The exogenous variables are derived from the previous empirical studies on the REER and its main determinants. Following the previous literature, for example, Clark and MacDonald (1998), Chinn (2005) or Ricci et al. (2008), we retain three main fundamentals variables as determinants of the real effective exchange rate: (i) the relative productivity in the traded-goods sectors (relative to the non-traded goods one) as a proxy for the Balassa-Samuelson effect; (ii) the country's net foreign asset position in percentage of GDP; and (iii) the country's commodity terms of trade.

The Balassa-Samuelson effect, or *productivity differential,* states that a country experiencing high productivity growth in tradable goods, relative to non-tradable goods, will experience a growth in wages (in both sectors). It will inexorably give rise to higher prices in non-tradable goods. Consequently, the real exchange rate appreciates. The Balassa-Samuelson effect is approximated by the GDP per capita measured in purchasing power parity (PPP) relative to the trading partners. The weights (w_j) correspond to the shares in the world PPP GDP per capita, calculated on average over the period 1980–2016. Both variables, PPP GDP and GDP data, are extracted from the IMF International Financial Statistics (IFS) database.[11]

$$BS_{i,t} = \frac{PPPGDPcapita_{i,t}}{\prod_{j=1,j\neq i}^{137} PPPGDPcapita_{j,t}^{(wj)}} \tag{6}$$

where $w_j = GDP_j / \sum_{k=1}^{137} GDP_k$ and $\sum_{k=1}^{137} w_j = 1$.

The net foreign asset position (NFA) refers to the value of the sum of foreign assets held by monetary authorities and deposit money banks, less the value of domestic assets owned by foreigners. It is expressed in percentage points of GDP. The net foreign asset position is a measure of indebtedness, indicating whether or not the country is a net creditor or debtor to the rest of the world. The NFA position can drive changes in exchange rates, since a country that faces a growing current account deficit needs to increase its trade surpluses, which can be done by depreciating its exchange rate. Another reason that could justify the impact of the net foreign asset position is that the currencies of countries with a significant negative NFA position and growing current account deficits may appear to be vulnerable to currency speculators, who may seek to drive it lower. The NFA series are taken from Lane and Milesi-Ferretti's database for the period 1980–2011.[12] For all the subsequent years (2012 to 2016), we compute the variable by adding the previous NFA position to the contemporaneous current account:

$$NFA_{i,t} = NFA_{i,t-1} + CA_{i,t} \tag{7}$$

and consider the variable as a percentage of GDP. The current account and GDP (in US dollars) data is taken from the IMF World Economic Outlook (WEO).

The commodity terms of trade are calculated in the same way as in Cashin et al. (2004). Consequently, the country's commodity terms of trade are a weighted average price of the three main commodities exported by the country, deflated by the manufactured unit value (MUV).[13] Therefore, the commodity terms of trade are expressed as:

$$ToT_{i,t}^{com} = \frac{\sum_{k=1}^{3} share_i^k \times p_t^k}{MUV_t} \tag{8}$$

where $share_i^k$ is the share of commodity k among the three main commodities exported by country i (they are displayed in Table A.2 in the Appendix), p_t^k is the price of commodity k extracted from the World Bank's GEM database, and MUV_t is the manufactured unit value extracted from the IMF World Economic Outlook (WEO) database.

The list of exogenous variables can also include the country's degree of financial integration. Following Levine et al. (2000), the degree of financial integration is measured by a standard indicator, that is, the ratio of M2 to GDP, and taken from Datastream. We also use two other indicators as robustness checks of the financial integration degree, such as the ratio of private credit to GDP and the ratio of foreign direct investment to GDP. These two ratios are taken from the World Bank database (*World Development Indicators*). Table A.3 (in the Appendix) provides some descriptive statistics on our data.

[10] We used the real effective exchange rates provided by the Bank of International Settlements (BIS) and Bruegel databases because, with those databases, we have a balanced panel. Indeed, real effective exchange rates from the IMF database (*International Financial Statistics*), for some countries, are either not available or incomplete. For countries with data availability, we calculated a correlation coefficient between our initial series (from BIS and Bruegel databases) and those of the IMF. Correlation is very strong, except for Cameroon, Iran, Nigeria and Togo. Detailed results are available upon request from the authors.

[11] For robustness check, we also use Balassa-Samuelson effect data from the *EQCHANGE* database (Cepii). Results, available upon request from the authors, are very similar.

[12] http://www.philiplane.org/EWN.html. See Lane and Milesi-Ferretti (2007).

[13] For oil-exporting countries, the terms of trade are calculated as the oil price deflated by the manufactured unit value (MUV). This is done for the 11 oil-exporting countries where the oil price stands for 100% of the weight.

4.2. The commodity price index

In order to investigate the non-linear relationship between real commodity price volatilities and real exchange rates, we select the real commodity price index in accordance with the main type of commodity exported by the countries present in our panels. All price indices are extracted from the IMF database (*Primary Commodity Prices*). For the energy panel, we use the “energy price index”, which includes the crude oil (petroleum), natural gas and coal price indices.[14] For the food and beverages panel, we have opted for the “food and beverage price index”. For the metals group, we select the “metals price index”, which incorporates the copper, aluminium, iron, ore, tin, nickel, zinc, lead and uranium price indices. Finally, for the raw materials panels, we choose the “agricultural raw materials index”, which incorporates the timber, cotton, wool, rubber and hides price indices. If we take a closer look at the descriptive statistics of the yearly volatility in price indices, we can highlight some interesting findings. The results are reported in Table 1 and highlight that the average of the raw materials price index is nearly as high as that of the metals, which makes these two indices the ones with the highest average yearly volatility. Furthermore, the standard deviation of the food and beverages panel is the lowest encountered in all the indices, with a value of 6.81 per cent.

Additionally, Fig. 1 displays the evolution and yearly variations of the four real commodity price indices used in our study. Fig. 1 allows us to discern some evidence of high fluctuations for some periods.

For the food and beverages index, we can observe three major peaks in the fluctuation of the index: in 1987 (−24%), in 2008 (+24%) and, finally, in 2011 (+19.8%). The highest decrease in 1987 is mainly due to the price of coffee dropping strongly (−42%). The spike in prices in 2008 can be explained by the world food price crisis (2007–8). The initial cause of the food price crisis was droughts in grain-producing countries in late 2006, which, combined with increasing demand from the Asian population, resulted in a decrease in the world's food stockpiles. This diminution of the world's reserves was coupled with an increase in oil prices, which led to a reduction in the profitability of agricultural production. The increase of 2011 was mainly due to cereal prices, which rose by 35 per cent.

Turning to the raw materials index, there are two major spikes in variations in the real commodity price index. The first one occurred in 1987, and was mainly due to cotton prices increasing by more than 60 per cent in one year. The second major spike occurred in 2011 (+33%), mostly as a result of the increase in cotton prices (+45%) to an all-time high for more than 150 years. This spike in cotton prices can be explained by floods in major cotton-producing areas in Australia, Pakistan and China, which reduced the forecast supply, and by a soar in demand by China. The metals price index has experienced multiple positive shocks over the period, with the most significant taking place in 1987 (+54%) and 2006 (+56%). The surge in the metal price index in 1987 was due to a world supply shortage in the same year of aluminium, zinc and nickel. In addition, the lead industry witnessed a growth in demand due to an increase in the production of lead-based batteries. In 2006 the increase was caused mainly by zinc, which experienced a production deficit for the third consecutive year in 2006. Copper played a major role in the surge in the metal index, and the sharp rise in prices coincided with an assessment made by industry analysts of the near-term availability of copper supply.

Finally, the energy price index experienced various positive and negative shocks. We propose focusing on the three largest cases of variations, which took place in 1986 (−48%), 2000 (+55%) and, more recently, in 2015 (−44%). Starting with the year 1986, the sudden decrease in the index was the result of a decision by Saudi Arabia and some of its neighbours to increase their share of the oil market. The positive shock appeared in 2000 because of the decision taken in April 1999 by the 10 members of OPEC to reduce their production of oil by 1.72 million barrels per day in order to increase oil prices. This decision, combined with the growing demand emanating from East Asian countries, pushed oil prices up. Finally, in more recent years, the energy price index decreased by 44 per cent in 2015. Numerous factors contributed to the drop in oil prices experienced in late 2014, which carried on into 2015. The first factor is the increased production of countries such as Canada and the United States of America, which were seeking to counter the rise in oil prices because of the negative effect on their economies. As a result of their actions, world production increased, while the demand for oil was reduced by China and other large developing economies such as India and Brazil. Furthermore, the price of gas followed the same trajectory. The first factor was that, although oil and gas are not substitutes for each other, gas prices are linked to oil prices. In addition, demand was lower than expected as a result of the low cost of coal and the fall in the cost of renewable energy, which made gas a less attractive option for the energy industry.

5. Results

5.1. PSTR estimation

The first step in the modelling procedure consists of testing the null hypothesis of linearity against the PSTR alternative using LM and F tests, as explained by González et al. (2005, 2017). Indeed, the PSTR model is not identified if the data-generating process is homogenous. According to the authors, the PSTR model defined by Eqs. (1) and (2) can be reduced to a homogenous model under the null hypothesis as follows: H_0: $\gamma = 0$ or H_0': $\beta_1 = 0$. Implementation of this test may face some unidentified nuisance parameters. To circumvent this problem, González et al. (2005, 2017) replaced the transition function in Eq. (1) with its first-order Taylor expansion around $\gamma = 0$. The new model version is represented as follows:

[14] For oil-exporting countries, the oil price index is calculated as a simple average of US dollar prices in three major markets: Brent, Dubai and West Texas.

Table 1
Descriptive statistics of the volatility of the commodity price indices.

	Food and beverages	Metals	Raw materials	Energy
Mean	9.46%	19.09%	16.90%	8.48%
Median	10.35%	15.92%	13.57%	5.53%
StdDev	6.81%	14.89%	13.29%	7.96%
Max	24.22%	55.79%	56.19%	33.19%
Min	0.26%	0.68%	0.31%	0.21%

Note: StdDev is the standard deviation.

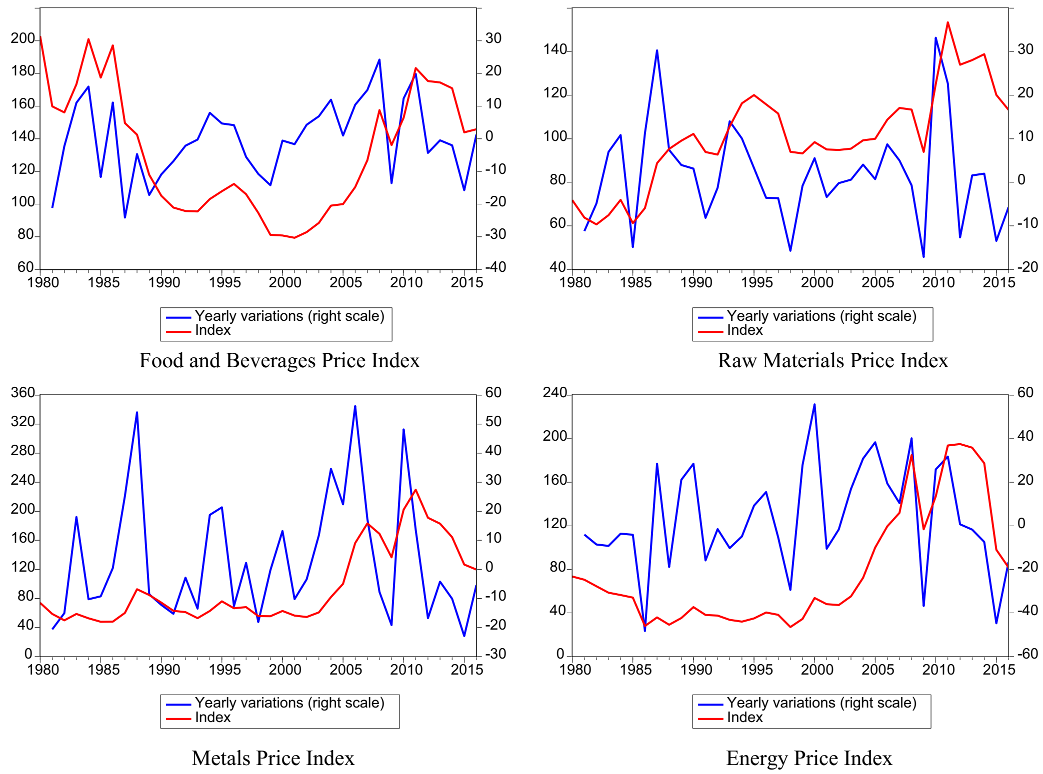

Fig. 1. Evolution of commodity prices index (base 100: 2005).

$$\Delta LREER_{i,t} = \alpha_i + \beta_0^{'*}X_{i,t} + \beta_1^{'*}X_{i,t}S_{i,t} + \cdots + \beta_m^{'*}X_{i,t}S_{i,t}^m + \varepsilon_{i,t}^* \quad (9)$$

where the parameter vectors β_1^*, $...\beta_m^*$ are multiples of γ, and $\varepsilon_{i,t}^* = \varepsilon_{i,t} + R_m\beta_1'X_{i,t}$, where R_m is the remainder of the Taylor expansion. Therefore, the linearity test of H_0: $\gamma = 0$ in Eq. (1) is equivalent to testing H_0^*: $\beta_1^*=...=\beta_m^* = 0$ in Eq. (9).

In our study, the linearity test is implemented taking into account the transition variable of financial integration degree measured by *M2/GDP*. If linearity is rejected, it means that the impact of real commodity price index volatility on the real effective exchange rate is different, depending on whether the financial integration level is low or high. The results are displayed in the upper part of Table 2 (full sample period). As expected, the null hypothesis of linearity is rejected in favour of the PSTR alternative with two regimes. This finding highlights the fact that real commodity price volatility impacts the real exchange rate differently, depending on the country's financial integration level.

We now proceed to the estimation of our PSTR specification for the whole sample and the four panels. The main objective of our first estimation is to capture the change in the behavioural relationship between the volatility of the real commodity price indices and the variations in real effective exchange rates, using the degree of financial integration as the transition variable. The first regime corresponds to the periods when the countries under study are poorly integrated financially. On the contrary, the second regime covers the periods when these countries are better integrated financially. Table 3 presents the PSTR estimation results.

The results show, for the whole sample, that the response of the REER to the commodity price index volatilities is different between the two regimes. In the first regime, when the financial integration level is low (less than 0.19), the REER is negatively impacted in the case of increasing volatility of the real commodity price index. In the second regime, better financial integration reduces the impact of price volatility on the REER, and the estimated coefficient becomes positive (0.006) but is low (tending to zero) compared to the first regime. For the other determinants of the REER included in Eq. (1), their estimated coefficients are significant

Table 2
Results of linearity tests against PSTR specification.

	Whole sample	Food and beverages	Energy	Metals	Raw materials
	Full sample period: 1980–2016				
LM	4.322	6.508	4.134	4.510	4.544
	(0.001)	(0.002)	(0.034)	(0.018)	(0.001)
F	3.554	5.728	3.060	3.605	11.273
	(0.003)	(0.000)	(0.038)	(0.069)	(0.000)
	Sub–period: 2000–2016				
LM	3.335	2.577	2.670	3.728	2.802
	(0.006)	(0.028)	(0.014)	(0.004)	(0.012)
F	5.975	2.493	3.424	2.438	2.490
	(0.000)	(0.078)	(0.037)	(0.021)	(0.019)

Note: LM and F are, respectively, the Lagrange multiplier and tests for linearity. *p*-values are given in parentheses.

Table 3
Estimation of the PSTR model (full sample period: 1980–2016).

	Transition variable: *M2/GDP*									
	Whole panel		Food and beverages		Energy		Metals		Raw materials	
	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2
$\Delta\, ComPI$	−0.2721***	0.0059***	−0.3723***	−0.0813***	−0.3736**	0.0115***	0.0565	0.1364	−0.2028*	−0.0737
ΔNFA	−0.0765***	−0.0169***	0.0098	−0.0124	−0.0397**	−0.0122*	−0.1148***	−0.0064***	−0.3445***	−0.0091***
ΔToT^{com}	0.1758***	0.0058***	0.7814***	0.0331***	−0.0447	−0.0099	−0.0379	0.1795**	−0.0494	0.0250
ΔLBS	0.7346***	0.0036***	0.2264	0.0694	0.1806**	−0.1132**	0.1090	−0.0784	0.0347	−0.2999
$M2/GDP$	0.3702***	0.076***	0.1268*	0.0033*	0.1526	0.0652	0.0664	0.0770	0.1169	0.0345
$\hat{c}$	0.1901		0.1307		0.3461		0.2992		0.2899	
$\hat{\gamma}$	364.65		984.41		1765.37		1520.27		25.81	

Estimation of Eq. (1).
$\Delta LREER$ stands for the variation of the real effective exchange rate (expressed in logarithm). $X_{i,\,t}$ represents the vector of the real effective exchange rate determinants, namely, the volatility of the real commodity price index ($\Delta\, ComPI$), the variation of net foreign assets (ΔNFA), the variation of the commodity terms of trade (ΔToT^{com}), the variation of Balassa-Samuelson effect (ΔLBS), and the degree of financial integration ($M2/GDP$). $\hat{c}$ represents the estimated threshold value, and $\hat{\gamma}$ is the estimated slope parameter of the transition function.
Significant coefficient at 1% (***), 5% (**) or 10% (*).

for the two regimes. The country's net foreign assets negatively affects the real exchange rate while the commodity terms of trade, the Balassa-Samuelson effect and the degree of financial integration have a positive and strong impact, notably in the first regime. To better understand the sign and the impact of these variables on the REER, we re-estimate the Eq. (1) for each panel. The detailed results of the four panels are presented in Table 3 and confirm the significant impact of the real commodity price index volatility on the REER, as well as the other fundamental variables. These findings are evidenced by the previous literature (Chen and Rogoff, 2003; Cashin et al., 2004; Rossi, 2006; Engle et al., 2007) which found that the real commodity prices could be a key explanatory variable for the real effective exchange rates, and therefore that exchange rates do not follow a random walk.

A detailed analysis of the estimated coefficients for each of the panels presented in Table 3 provides an insight into the response of the real exchange rates to the explanatory variables. For the food and beverages panels, our results show that the volatility of the real commodity price index has a very significant effect on the real effective exchange rate. Indeed, both coefficients (in the first and second regimes) are highly significant. In the first regime, the estimated coefficient is negative. Consequently, an increase in the volatility of the real commodity price will have the effect of strongly depreciating the REER for the periods when a country is poorly integrated financially (i.e. less than the threshold value equal to 0.13). In other words, when the volatility of the real commodity price increases by 10 per cent, the REER will decrease by 3.72 per cent. In addition, in the second regime, for the periods when a country is better integrated financially, the coefficient is still negative but smaller and tending to 0. Indeed, an increase of 10 per cent in the volatility of the real commodity price will result in a small depreciation of the REER by 0.81 per cent.

For the energy panel, we can highlight that the estimated value of the threshold ($\hat{c}$) is greater than in the food and beverages group. This could be explained by numerous facts, one being that energy producers have globally higher financial integration, which is supported by the median value of this variable (0.45) compared to the food and beverages group (0.32). Another explanation is that financial integration differs between both groups according to the needs of technology for the production of their commodity, which is greater in energy-exporting countries. Taking a closer look at the data, approximately 73 per cent of the observations in the energy panel belong to the second regime (high degree of financial integration). Considering the estimated coefficient of the volatility of the real price of energy index, we once again find very significant results in both regimes. In the first regime, a 10 per cent increase in the volatility of the energy price index leads to a depreciation in REER by −3.74 per cent. In the second regime, that is, for the period when the countries are better integrated financially, we can observe a positive relationship between the volatility of the energy prices and the variations in REER.

Turning to metals, the estimated value of threshold level ($\hat{c}$) is approximately 0.30. During the studied period, roughly 45 per cent of the observations belong to the second regime. The transition value cuts our observations into two groups, allowing a clear contrast to be seen between the periods when a country is better integrated financially (regime 2) and periods when integration is lower (regime 1). Considering the volatility of the real metals price index, we can observe that the estimated coefficient is not significant unlike other panels.

Focusing on the last panel, namely, raw materials, the threshold value ($\hat{c}$) occurs at 0.29, and approximately 52 per cent of the observations in the panel belong to the second regime. Like the metals panel, the volatility of the real commodity price index has a low impact on the variations in REER. Only the estimated coefficient of the first regime is significant. In this first regime, the coefficient is negative and vigorous. If the volatility of the prices increases by 10 per cent this results in a depreciation in REER by 2.03 per cent. Consequently, we can state that, for the metals and raw material panels, the impact of the volatility of the real commodity price index on the REER is minimized and independent of the country's financial integration level.

Shedding light on the other determinants of the real exchange rate, we can first observe that the variation of the commodity terms of trade are a significant determinant of variations in the real effective exchange rate only for the food and beverages panel in the two regimes. These results can be supported by the previous literature, where it has been found that, for example, in the case of the energy and metals panels, changes in commodity terms of trade are only a significant determinant of variations in REER for the periods when oil prices are subject to high volatility (Baffes, 2007; Coudert et al., 2015). For the net foreign asset position—which reflects the indebtedness of a country—the estimated coefficient is highly significant and negative for all panels, except for food and beverages. For example, in the case of the energy panel, the negative relationship can be explained by the well-known petrodollar recycling effect. Indeed, if a country tends to hold a larger amount of foreign assets, a better NFA would have a negative impact on its real effective exchange rate, as the foreign currencies would be requested more. Finally, the Balassa-Samuelson effect is significant and has a positive effect on REER variations only for the energy panel. Indeed, according to the literature, a country experiencing high productivity growth in tradable goods, relative to non-tradable goods, should experience a growth in wages, resulting in an appreciation of its real effective exchange rate.

For the last exogenous variable, which is the degree of financial integration, its impact on REER is mitigated and its interpretation has to be made in the light of commodity exporters' specific features (Allegret et al., 2014). Indeed, on the one hand, financial integration may be seen as reducing real exchange rate fluctuations given that a high level of financial integration may induce higher investment rates and improve credit conditions and financial intermediation (Arezki and Hasanov, 2013). On the other hand, a high level of financial integration could be associated with higher returns and lower risks of investment but more exposed to external shocks and crisis (Fecht et al., 2012). The results in Table 3 show that the impact of financial integration on the REER is significant and positive for the food and beverages panel only.

To sum up, it is evident that the volatility of the real commodity price index is a significant determinant of the variations in REER for all the panels (except the metals panel). In addition, we can find a common impact of real commodity price volatility on the variation in the real effective exchange rate. In the first regime, that is, for the periods when the commodity-exporting countries are poorly integrated financially, we can distinguish a negative relationship for all the panels (except the metals panel). Therefore, for this regime, the volatility of the real commodity prices will have the effect of depreciating the real effective exchange rate. On the contrary, for the periods when a country is better integrated financially, the volatility of the real commodity prices will have a lower impact on the real exchange rate. Indeed, in the second regime, the coefficients tend to be closer to 0 compared to the first regime. Finally, it is evident that the transition variable of financial integration level plays a key role in better understanding the existing non-linear relationship. Our findings are consistent with previous studies (Fratzscher et al., 2014; Coudert and Mignon, 2016) and support the idea that the growth in volume of the commodity markets due to its financialization can justify consideration of the financial market integration as an important transmission channel when analysing the effect of real commodity price volatilities on real exchange rate variations.

If one considers that this process of "financialization of commodity markets" has been developed recently, mainly for the post-2000 years, it is interesting to evaluate the relationship between the volatility of the real commodity price index and the real effective exchange rate during this period instead of the whole sample. The aim of this new investigation is to test the hypothesis that the non-linear effect has increased for the recent period, as the comparison can be made between the full sample period and the 2000–2016 sub-period, in terms of coefficient dynamics and transition threshold value.

As previously, the first step consists of testing the null hypothesis of linearity against the PSTR alternative using LM and F tests. The test results are displayed in the lower part of Table 2 for the 2000–2016 sub-period and show that the null hypothesis of linearity is rejected in favour of the PSTR alternative with two regimes. This finding highlights that real commodity price volatility impacts the real exchange rate differently, depending on the country's financial integration level. Indeed, financial integration increased during the period of 2000–2008, then went down during the global crisis of 2008–09, but has since risen (Adams and Glück, 2015).

The results of the PSTR estimation are given in Table 4 and they show that the real commodity price index effects on the REER are significant for the whole panel. If we focus on our four specific panels, the results are different. Indeed, the coefficients are significant for the energy panel only and in the first regime for the raw materials panel. This finding is evidenced by the literature and highlights the increasing financialization of the energy sector for the years post-2000 (Fratzscher et al., 2014; Henderson et al., 2015; Adams and Glück, 2015). Indeed, researchers have focused on the financialization process of the commodity markets, specifically in the energy sector and displayed the growing relevance of this financial channel, as the volume of crude oil futures traded on NYMEX has

Table 4
Estimation of the PSTR model (sub-period: 2000–2016).

	Transition variable: *M2/GDP*									
	Whole panel		Food and beverages		Energy		Metals		Raw materials	
	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2
Δ *ComPI*	−0.1175**	0.1294***	−0.0998	−0.1055	0.2491***	0.0640*	0.0003	0.0420	−0.1538**	0.0643
ΔNFA	−0.0094	−0.0153	−0.0068	−0.0055	−0.0034	−0.0065	−0.0056	−0.0023	−0.0664**	0.0069**
ΔToT^{com}	0.1147***	−0.0398***	−0.0115	0.0356	−0.1225**	0.1021	−0.0474	0.2871	0.0156	0.1756**
ΔLBS	0.7704***	−0.8126***	0.1331***	0.0042***	−0.5304**	−0.1723	0.4823*	0.0601***	0.2542	0.2138
M2/GDP	0.0817	0.0368	−0.0632	−0.0869	0.6425***	0.5160*	0.1255	0.2451	−0.0372	−0.0369
$\hat{c}$	0.3557		0.3063		0.5472		0.5045		0.5131	
$\hat{\gamma}$	29.45		2105.2		173.37		86.06		224.6	

Estimation of Eq. (1).
$\Delta LREER$ stands for the variation of the real effective exchange rate (expressed in logarithm). $X_{i,\,t}$ represents the vector of the real effective exchange rate determinants, namely, the volatility of the real commodity price index (Δ *ComPI*), the variation of net foreign assets (ΔNFA), the variation of the commodity terms of trade (ΔToT^{com}), the variation of Balassa-Samuelson effect (ΔLBS), and the degree of financial integration (*M2/GDP*). $\hat{c}$ represents the estimated threshold value, and $\hat{\gamma}$ is the estimated slope parameter of the transition function.
Significant coefficient at 1% (***), 5% (**) or 10% (*).

more than quintupled since the early 2000s. Moreover, Table 4 highlights another important result regarding the threshold value ($\hat{c}$), which is higher than the full sample period (for instance, for the energy panel it is equal to 0.55 instead of 0.35; and for the raw materials panel it is equal to 0.51 instead of 0.29). This finding shows the post-2000 financialization of the commodity markets, particularly for the energy sector.

5.2. Robustness checks

5.2.1. Other measures of financial integration degree

As explained previously, taking into account the financial channel in the investigation of the relationship between real commodity price index volatilities and real exchange rate variations depends on the recent growth in financialization of the commodity markets. As this process has been investigated only recently, the previous empirical results may include some drawbacks linked to data set accuracy, as well as the measure used to evaluate the degree of financial integration.

The methods used to measure the degree of financial integration have been widely studied in the empirical literature and include different proxies that can be *de jure* measures based on legal restrictions (Kose et al., 2006), de facto measures based on quantity approach (Lane and Milesi-Ferretti, 2007), and price-based approach.[15] Financial integration refers to a large set of indicators (IMF, 2006; Čihák et al., 2013). Beyond this large choice of measures, and the advantages and drawbacks that can be discussed, unfortunately working on a very large sample of 42 commodity-exporting countries reduces the number of measures that can be used to assess the degree of financial integration. To investigate the robustness of our results, and based on the data set availability, we select the following two financial indicators: private credit to GDP and foreign direct investment to GDP. These two measures allow us to test another financial channel when studying the impact of real commodity price index volatilities on REER variations. The first indicator is a financial depth measure, defined as the credit issued to the private sector by banks and other financial intermediaries, divided by GDP, and constitutes a measure of general financial intermediary activities provided to the private sector. The second indicator is defined as the sum of equity capital, reinvestment of earnings, and other long- and short-term capital, as shown in the balance of payments, divided by GDP, and constitutes an alternative measure of financial integration through international investment positions (Kučerová, 2009). Tables 5 and 6 present the PSTR estimation results. The same model specification is used, including three fundamental variables (ΔNFA, ΔToT^{com}, ΔLBS), as well as the degree of financial integration, as in previous sections.

Globally, the results highlight that our previous findings are robust to alternative measures of financial integration, specifically in the case of the indicator measured by foreign direct investment to GDP. Indeed, as shown in Table 5, the non-linear relationship is confirmed and the volatility of the real commodity price index is a very significant determinant of the variations in REER for almost all of the panels. The results also show a strong and negative relationship in the first regime when the degree of financial integration is low. However, the impact of commodity price index volatilities is reduced, and becomes positive in the second regime when the commodity-exporting countries are better integrated financially. Therefore, the robustness of our findings contributes to the existing literature by highlighting the preponderant role played by financial integration as a transition variable between the commodity and exchange rate markets.

5.2.2. Is there another transition variable for the impact of real commodity price index volatilities on the REER?

We now investigate the relationship between the volatility of the real commodity price index and the REER variations using the

[15] Indicators based on the uncovered interest rate parity and on asset prices. See, for example, Pasricha (2006).

Table 5
Estimation of the PSTR model (full sample period: 1980–2016).

	Transition variable: *FDI/GDP*									
	Whole panel		Food and beverages		Energy		Metals		Raw materials	
	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2
Δ *ComPI*	−0.0432	0.0992**	−0.1081**	−0.0157**	−0.1337**	0.0792**	0.0096	0.3396**	−0.5069**	0.0105*
Δ*NFA*	−0.0214***	−0.0014*	−0.1001***	−0.0003***	−0.0106**	−0.0811***	−0.0063	−0.0493	−0.5937***	0.0123***
ΔToT^{com}	0.0096	0.0630	−0.0438**	0.0073**	0.0278	−0.1490***	0.0124	0.1288	−0.2982**	0.1190**
Δ*LBS*	0.0470	0.9781***	0.0418	0.0841	0.2488**	−0.0994**	−0.0023	0.0950	−0.1376**	0.05648**
FDI/GDP	0.0860***	−0.0170***	0.1578**	0.0004**	−0.0807	−0.0499	0.3463*	−0.1420***	−0.1124**	−0.0111*
$\hat{c}$	0.4816		0.0823		0.230		0.2277		0.0963	
$\hat{\gamma}$	1026.59		4513.68		1264.31		1038.22		9.37	

Estimation of Eq. (1).
$\Delta LREER$ stands for the variation of the real effective exchange rate (expressed in logarithm). $X_{i,\,t}$ represents the vector of the real effective exchange rate determinants, namely, the volatility of the real commodity price index (Δ *ComPI*), the variation of net foreign assets (ΔNFA), the variation of the commodity terms of trade (ΔToT^{com}), the variation of Balassa-Samuelson effect (ΔLBS), and the degree of financial integration (measured by the ratio *FDI/GDP*). $\hat{c}$ represents the estimated threshold value, and $\hat{\gamma}$ is the estimated slope parameter of the transition function.
Significant coefficient at 1% (***), 5% (**) or 10% (*).

Table 6
Estimation of the PSTR model (full sample period: 1980–2016).

	Transition variable: *private credit/GDP*									
	Whole panel		Food and beverages		Energy		Metals		Raw materials	
	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2
Δ *ComPI*	−0.9988**	−0.0001**	−0.5925	−0.1637***	−0.0828	0.0377	0.0631	0.0301	−0.1060	–0.1257
Δ*NFA*	−0.0786	−0.0191	0.0690	−0.0109	−0.0202***	−0.0031*	−0.4004***	−0.0063***	−0.2648***	−0.0127***
ΔToT^{com}	0.6356	0.0185	0.1989***	0.0039***	0.0499	−0.0739*	0.0144	0.0106	−0.0123	0.0232
Δ*LBS*	−0.1670**	0.0018***	0.1784**	0.0712	0.0108	0.0644	0.1491	−0.0160	−0.1992	−0.1010*
PC/GDP	0.5799**	0.0078**	0.2653*	0.0001*	−0.0586	−0.0335	0.2819**	0.2138	0.0164	0.0139
$\hat{c}$	0.3205		0.0522		0.3045		0.0549		0.1968	
$\hat{\gamma}$	643.55		2198.39		1272.59		2235.7		1364.6	

Estimation of Eq. (1).
$\Delta LREER$ stands for the variation of the real effective exchange rate (expressed in logarithm). $X_{i,\,t}$ represents the vector of the real effective exchange rate determinants, namely, the volatility of the real commodity price index (Δ *ComPI*), the variation of net foreign assets (ΔNFA), the variation of the commodity terms of trade (ΔToT^{com}), the variation of Balassa-Samuelson effect (ΔLBS), and the degree of financial integration (measured by the ratio *private credit/GDP* (*PC/GDP*)). $\hat{c}$ represents the estimated threshold value, and $\hat{\gamma}$ is the estimated slope parameter of the transition function.
Significant coefficient at 1% (***), 5% (**) or 10% (*).

Table 7
Estimation of the PSTR model (full sample period: 1980–2016).

	Transition variable: commodity terms of trade									
	Whole panel		Food and beverages		Energy		Metals		Raw materials	
	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2
Δ *ComPI*	−0.0416	−0.0126	−0.4519**	−0.1737	−0.4753**	−0.0022**	0.0357	0.3038	−0.1583	−0.1478
Δ*NFA*	−0.3022***	−0.0152***	−0.1410***	0.0015***	−0.0064	−0.0133	−0.0093	−0.0384	−0.2931***	−0.0748***
ΔToT^{com}	0.3119	0.0113	−0.1111	0.0614	−0.5256**	−0.0627**	0.0708	−0.1802*	0.0975	0.0071
Δ*LBS*	0.1147	0.1105	−0.5872	1.1051***	0.6028**	−0.0001**	−0.0089	−0.2238***	0.2192	−0.2079**
$\hat{c}$	0.0886		0.1404		0.1261		0.2207		0.0256	
$\hat{\gamma}$	4687.02		19.88		2373.9		710.51		1313.35	

Estimation of Eq. (1).
$\Delta LREER$ stands for the variation of the real effective exchange rate (expressed in logarithm). $X_{i,\,t}$ represents the vector of the real effective exchange rate determinants, namely, the volatility of the real commodity price index (Δ *ComPI*), the variation of net foreign assets (ΔNFA), the variation of the commodity terms of trade (ΔToT^{com}) and the variation of Balassa-Samuelson effect (ΔLBS). $\hat{c}$ represents the estimated threshold value, and $\hat{\gamma}$ is the estimated slope parameter of the transition function.
Significant coefficient at 1% (***), 5% (**) or 10% (*).

commodity terms of trade (ToT^{com}) as a transition variable. Indeed, in the literature, there are many different views and there is no consensus regarding the main factors impacting exchange rates. Moreover, there are many views regarding the transition variables of the relationship between real commodity price indices and REER. Indeed, beyond the empirical results found in the previous sections we propose testing a second transition variable of commodity terms of trade. The impact on REER can be linked to different explanatory factors, as well as to different transition variables.

This second test is important for the interpretation of our results and their robustness. Indeed, previous studies have evidenced that the commodity terms of trade are the preponderant factor in the determination of the real exchange rate of the commodity-exporting countries (Chen and Rogoff, 2003; Cashin et al., 2004). Therefore, as the wealth of commodity-exporting countries largely depends on commodity exports, and as commodity prices are subject to huge fluctuations, the commodity terms of trade are a relevant determinant of their real exchange rates. The contribution of this test is to check, beyond the financial integration level, whether the trade channel can also be a major factor when studying the relationship between real commodity prices and the REER. Indeed, in the previous literature, the introduction of commodity terms of trade as a transition variable was tested mainly in the case of the oil sector.

The terms of trade are defined as the ratio of the prices of a country's exports relative to the prices of its imports. Consequently, for commodity-exporting countries, the terms of trade are often approximated as the ratio of the prices of the three main commodities exported by a country, deflated by the manufacture unit value of industrialized countries. Because primary commodities dominate the exports of commodity-exporting countries, fluctuations in world commodity prices have the potential to explain a large share of movements in their terms of trade. Therefore, as the wealth of commodity-exporting countries largely depends on commodity exports, and as commodity prices are subject to huge fluctuations, the commodity terms of trade are a relevant determinant of their real exchange rates.

To examine this matter, as in the previous section, we test the PSTR specification for the whole sample and our four panels: energy, metals, food and beverages, and raw materials. Our aim is to capture whether the transmission of volatility of the real commodity price indices on the REER will be greater in periods of low or high volatility of the commodity terms of trade (approximated by the absolute value of the terms of trade variations). As usual, we start by conducting the linearity test against the PSTR alternative. As expected, the null hypothesis of linearity is rejected in favour of the PSTR model with two regimes. This finding highlights that real commodity price volatility impacts the real exchange rate differently, depending on the stability of the commodity terms of trade (low versus high volatility).[16] Table 7 displays the PSTR estimation results.

First, we can discern that the transition occurs in different ways for the panels. The estimated value of the threshold ($\hat{c}$) is high for the food and beverages, energy and metals panels compared to the raw materials panel. The first regime includes periods of low volatility of the commodity terms of trade, and the second regime consequently contains the periods when a country is subject to high volatility in its commodity terms of trade. The results show, for the whole sample, that the response of the REER to the real commodity price index volatilities is different between the two regimes. The relationship between the two variables is negative but goes down when the threshold value reaches 0.09. Considering our four panels, we can observe that the volatility of the real commodity price index is a significant and negative determinant of the variations in REER during the first regime (except for the metals panel). Indeed, when the commodity terms of trade are stable – lower volatility – an increase in the volatility of the real price index results in a depreciation in REER. On the other hand, in the second regime, for periods when the volatility of the terms of trade is medium to high, the estimated coefficient of volatility of the price index is statistically significant, but the impact is reduced compared to the first regime.

Focusing our attention on the fundamentals variable, we find some common results with our previous PSTR specification (Table 3). The NFA position is negatively signed, from which we can deduce that positive variations in the NFA position will appreciate the REER. The Balassa-Samuelson effect is correctly signed (positive) and significant. However, variations in the commodity terms of trade are not a significant determinant of variations in REER, except for the energy panel.

To sum up, it is evident that, globally, the volatility of the real commodity price index appears to be a significant determinant of variations in REER using the commodity terms of trade as another kind of transition channel. Furthermore, similarly to our first PSTR specification, that is, with financial integration as the transition variable, we find that the NFA is a main fundamental variable, which plays a significant role as a determinant of variations in REER. These results therefore support our previous finding, which is that, in the short term, when the NFA position improves, there is a resulting depreciation in REER.

Globally, these robustness tests confirm the non-linear relationship between the volatility of real commodity price indices and REER variations, and this relationship can be transmitted through many different channels (financial, trade). However, it appears that our findings highlight a clear behaviour when considering financial integration as a transition variable. However, the results are mixed when considering the commodity terms of trade as a transition variable. Indeed, for some panels the impact is not significant (food and beverages, only for regime 2; metals and raw materials panels). Therefore, our findings provide evidence of the growing relevance of the financial channel due to the growth in financialization of the commodity markets.

6. Conclusion

This paper studies the relationship between the real commodity price indices and the real effective exchange rates of 42 commodity-exporting economies between 1980 and 2016. The main objective of this study is to investigate the potential asymmetric

[16] The results of the linearity tests are available upon request from the authors.

effects of the level of financial integration of commodity-exporting countries on the relationship between real commodity price indices and the REER. Indeed, as a result of the growing financialization of the commodities, the asymmetric effect of the volatility of the real commodity price indices on the real effective exchange rates of commodity-exporting countries appears to be coherent.

With this in mind, we subdivided our 42 countries into 4 panels, according to the main type of commodity exported, in order to account for potential heterogeneity between panels. We then used a PSTR model in order to consider the potential non-linear effects of the volatility of the real price indices on the real effective exchange rate variations of commodity-exporting countries. Our results are significant and show that the short-term dynamics of commodity-exporting countries' real exchange rates are affected by the volatility of their respective real commodity price index. Specifically, based on the PSTR specification, with financial integration as the transition variable, we find that for the energy, raw materials and food and beverages groups, the volatility of the real price index is a significant driver of variations in REER. On the contrary, the results are less robust for the metals panel. Furthermore, for the energy, raw materials and food and beverages groups, we find a common pattern in the estimated coefficients. Indeed, according to our study, for the periods when a country is poorly integrated financially, the increase in volatility of the real price index results in a depreciation in REER. On the contrary, based on our results, in the second regime, when a country is better integrated financially, the estimated coefficients of the price indices tend to be closer to 0. Consequently, when a country is better integrated financially, the volatility of the real price index has a limited impact on variations in REER, leading to a possible stabilization of its domestic currency against its trading partners. The noticeable change in the relationship between the volatility of the real commodity price index and variations in REER could be explained by the wealth of commodity-exporting countries originating from their commodity exports. Therefore, when a country is poorly integrated financially, the volatility of the real commodity price index is experienced as uncertainty and risk. The uncertainty provoked by the fluctuation in prices leads to an amplification of the transition of the volatility of the price index to the REER. On the contrary, when a country is better integrated financially, a fluctuation in the real price index will be less noteworthy for its real exchange rates, as it will be able to take measures to restrain its impact. Furthermore, our findings highlight the post-2000 financialization growth of commodities, particularly in the case of the energy sector. This result is evidenced by the literature and highlights the increasing financialization of the energy sector for the post-2000 years. We also test another PSTR specification, including commodity terms of trade as a transition variable. The results support our assumption that the volatility of commodity terms of trade is a significant transmission channel in the relationship between the volatility of the real commodity price indices and the REER variations, specifically in the case of food and beverages, and energy panels.

To sum up, our results highlight the importance of the financialization channel, when analysing the impact of real commodity price fluctuations on the REER of commodity-exporting countries. However, one should not focus on the level of financial integration of a country alone when analysing the relationship between real commodity prices and the REER. Indeed, we provide evidence that, in periods of high volatility of the commodity terms of trade, the volatility of the real price index becomes an important driver of variations in REER for some panels. While this research focuses on commodity-exporting countries, the aim of further research should be to capture the role played by the financialization of commodity markets in the spread of volatility of commodity prices on the REER of commodity-importing countries.

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Appendix

Tables A.1–A.3.

Table A.1
List of countries.[a]

Country	Commodity group	Country	Commodity group
Algeria	Energy	**Mozambique**	Raw materials
Argentina	Food & beverages	**Nigeria**	Energy
Australia	Energy	**Niger**	Metals
Bahrain	Energy	**Norway**	Energy
Bolivia	Metals	**Oman**	Energy
Brazil	Metals	**Papua New Guinea**	Metals
Canada	Raw materials	**Paraguay**	Food & beverages
Chile	Metals	**Peru**	Metals
Colombia	Food & beverages	**Philippines**	Food & beverages
Honduras	Food & beverages	**Saudi Arabia**	Energy
India	Food & beverages	**Senegal**	Raw materials
Indonesia	Energy	**South Africa**	Metals
Iran	Energy	**Thailand**	Food & beverages
Ivory Coast	Food & beverages	**Togo**	Raw materials

(continued on next page)

Table A.1 (*continued*)

Country	Commodity group	Country	Commodity group
Kenya	Food & beverages	**Tunisia**	Raw materials
Kuwait	Energy	**Turkey**	Raw materials
Malawi	Raw materials	**Uganda**	Food & beverages
Malaysia	Food & beverages	**United Arab Emirates**	Energy
Mali	Raw materials	**Uruguay**	Food & beverages
Mexico	Energy	**Venezuela**	Energy
Morocco	Raw materials	**Zambia**	Metals

[a] Due to the lack of available data or extensive periods of war, which would have had for effect to distort the results, we decided to discard and remove some countries such as Syria, Libya, Central African Republic, Burundi, Nigeria, etc., from the initial list of 52 countries of Cashin et al. (2004).

Table A.2
Main commodity exports and share of primary commodities in total exports.

	Principal exports			Share in commodity exports (in %)		
Country	1	2	3	1	2	3
Argentina	Soy Meal	Wheat	Maize	18	13	11
Bolivia	Zinc	Tin	Gold	27	18	13
Brazil	Iron	Coffee	Aluminium	21	15	10
Canada	Softwood Sawn	Aluminium	Wheat	28	14	12
Chile	Copper	Fish	Fishmeal	70	9	6
Honduras	Coffee	Bananas	Shrimp	47	30	6
India	Rice	Shrimp	Soy Meal	18	15	12
Ivory Coast	Cocoa	Coffee	Cotton	65	14	6
Indonesia	Crude petroleum	Natural gas	Natural rubber	34	23	7
Kenya	Tea	Coffee	Fish	53	30	5
Malawi	Tobacco	Tea	Sugar	78	8	7
Malaysia	Palm oil	Natural rubber	Hardwood logs	44	15	15
Mali	Cotton	Gold		88	12	
Mauritania	Iron	Fish	Gold	65	34	1
Mexico	Crude petroleum	Copper	Coffee	72	5	5
Morocco	Phosphate rock	Fish	Lead	55	14	7
Mozambique	Cotton	Sugar	Maize	33	19	9
Niger	Uranium	Tobacco		96	3	
Norway	Crude petroleum	Natural Gas	Fish	67	13	8
Papua New Guinea	Copper	Gold	Palm Oil	23	23	20
Paraguay	Soybeans	Cotton	Soy Meal	44	26	9
Philippines	Coconut oil	Copper	Bananas	29	21	12
Peru	Copper	Fishmeal	Gold	28	19	15
Senegal	Phosphate rock	Groundnut Oil	Fish	29	29	16
South Africa	Gold	Coal	Iron	46	20	5
Thailand	Rice	Natural Rubber	Shrimp	26	24	23
Togo	Phosphate rock	Cotton	Coffee	44	40	9
Tunisia	Tobacco	Phosphate rock	Shrimp	23	21	20
Turkey	Tobacco	Wheat	Sugar	34	16	14
Uganda	Coffee	Fish	Gold	71	8	4
Uruguay	Beef	Rice	Fish	36	27	13
Zambia	Copper	Sugar		97	2	

Notes: Weights are calculated for the period 1991–2011. *Source*: Cashin et al. (2004), Table 1, pp. 246–247.

Table A.3
Descriptive statistics.

	$\Delta LREER$	ΔNFA	ΔToT^{com}	ΔLBS	$M2/GDP$	FDI/GDP	$Private\ credit/GDP$
				Metals panel			
Mean	0.7%	1.1%	2.2%	0.8%	29.2%	17.2%	19.3%
Median	−0.05%	0.4%	−1.2%	1.0%	27.9%	14.1%	12.6%
StDev	12.8%	53.1%	18.9%	4.7%	14.4%	13.1%	16.8%
Max	101.4%	386.7%	78.2%	12.7%	69.8%	60.7%	66.4%
Min	−48.7%	−422.2%	−46.6%	−20.6%	5.8%	0.8%	0.0%
				Food and beverages panel			
Mean	−0.006%	5.8%	1.1%	1.7%	39.3%	9.3%	18.9%
Median	0.5%	−0.02%	−0.1%	1.8%	30.7%	5.9%	14.2%
StDev	12.5%	60.4%	18.6%	4.5%	28.7%	8.5%	14.6%
Max	88.9%	496.5%	96.8%	14.6%	141.8%	45.4%	68.2%
Min	−69.5%	−441.8%	−54.0%	−11.7%	6.9%	0.3%	1.3%
				Raw materials panel			
Mean	−0.07%	5.5%	2.7%	1.3%	38.2%	14.8%	16.9%
Median	−0.3%	2.6%	−0.1%	1.5%	32.0%	9.6%	10.4%
StDev	9.8%	30.0%	25.7%	5.0%	19.4%	14.4%	14.6%
Max	42.4%	309.3%	350.0%	20.8%	86.3%	75.2%	73.7%
Min	−69.4%	−75.7%	−62.3%	−20.3%	10.5%	0.01%	1.4%
				Energy panel			
Mean	1.0%	5.6%	2.5%	0.6%	48.7%	49.2%	19.2%
Median	0.6%	2.3%	−0.006%	0.5%	45.4%	8.2%	15.4%
StDev	13.9%	65.1%	22.3%	7.0%	18.3%	11.8%	12.7%
Max	142.7%	432.2%	66.5%	65.8%	86.3%	49.2%	59.9%
Min	−93.4%	−377.7%	−52.7%	−27.2%	16.1%	0.01%	1.95%

Notes: StDev is the Standard Deviation. $\Delta LREER$ is the variation of the real effective exchange rate (expressed in logarithm), ΔNFA is the variation of the net foreign asset position (in percent of GDP), ΔToT^{com} is the variation of the commodity terms of trade, ΔLBS is the variation of the Balassa-Samuelson effect (expressed in logarithm), *M2/GDP* is the ratio of M2 to GDP, *FDI/GDP* is the ratio of foreign direct investment to GDP and private credit/GDP is the ratio of private credit to GDP.

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