Journal of Economic Dynamics & Control 151 (2023) 104654

Contents lists available at ScienceDirect

Journal of Economic Dynamics & Control

journal homepage: www.elsevier.com/locate/jedc

Commodity price shocks, labour market dynamics and monetary policy in small open economies☆

Ruthira Naraidoo[a], Juan Paez-Farrell[b,*]

[a] University of Pretoria, South Africa
[b] University of Sheffield, United Kingdom

ARTICLE INFO

Article history:
Received 23 May 2022
Revised 31 March 2023
Accepted 11 April 2023
Available online 13 April 2023

JEL classification:
E31
E32
E44
E52
E61
F42
O11

Keywords:
Commodity prices
Emerging markets
Inflation
Monetary policy
Search and matching
Unemployment
Dutch disease
DSGE modelling
Bayesian impulse response matching

ABSTRACT

We analyse the transmission mechanism of commodity price shocks in inflation targeting emerging economies. Using a panel vector autoregression, we find that for a commodity exporter, the shock causes a real exchange rate appreciation, increases in output, inflation, the nominal interest rate and the trade balance, and a fall in the unemployment rate. The mechanism underlying the dynamics driving the VAR can be understood using a dynamic stochastic general equilibrium model. Search and matching frictions in the labour market and the conduct of monetary policy are key for the model to match the data.

1. Introduction

For many small open economies, especially emerging and developing ones, commodities constitute an important component of total exports. According to UNCTAD (2019), two thirds of developing countries count as commodity-dependent (CD), whereby commodities account for more than 60 percent of their merchandise exports. At the same time, individual commodity exporters typically account for a small proportion of the world market for these goods so that they effectively

☆ We are grateful to the British Academy for financial support through the Newton Mobility Grant (No. NMGR1180417). We would like to thank two anonymous referees, the Co-Editor, Juan Francisco Rubio-Ramírez, Vito Polito, Christoph Thoenissen as well as participants at AMEF 2022 (Thessaloniki) and SES 2022 (Glasgow) for many useful comments.

* Corresponding author.
E-mail addresses: ruthira.naraidoo@up.ac.za (R. Naraidoo), j.paez-farrell@sheffield.ac.uk (J. Paez-Farrell).

https://doi.org/10.1016/j.jedc.2023.104654
0165-1889/

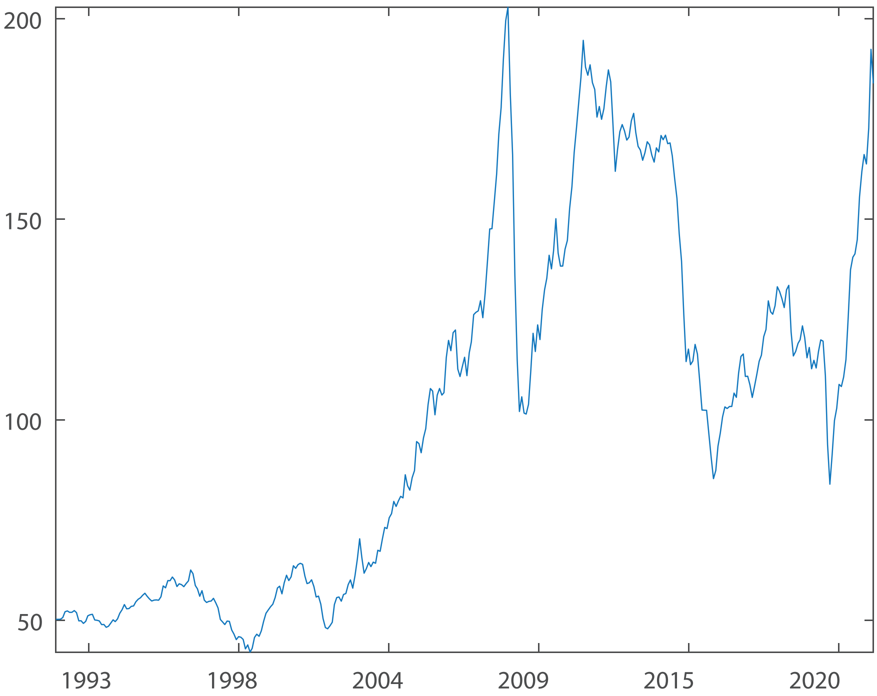

Fig. 1. All commodity price index. Raw commodity price series, 2016 = 100. Source: IMF primary commodity prices website.

act as price takers. Given that commodity prices are notoriously highly volatile they are often regarded as key drivers of business cycles for commodity exporters, as noted by Agénor and Montiel (2008, pp. 15–16).

Figure 1 shows the dramatic movements in the all-commodity price index, as calculated by the IMF, which rose almost five-fold in under ten years (1990–2008). The majority of the literature on small open emerging market economies has focused on the role of exogenous terms of trade shocks – see Mendoza (1995) and Schmitt-Grohé and Uribe (2018), for example. However, doing so combines the effects of commodity price shocks with events in the non-commodity tradable sector even though each implies different macroeconomic dynamics. Moreover, relying on terms of trade shocks imposes symmetric effects of changes in import and export prices, which may be inappropriate (Di Pace et al., 2020). More recently, Kohn et al. (2021) estimate a model to show that the empirical observation of greater business cycle volatility in emerging markets relative to those in developed economies can be explained by the reliance of the former on exporting commodities. Lastly, Fernández et al. (2018) show that commodity price fluctuations are important determinants of output volatility in emerging economies.[1]

This paper contributes to the growing literature that seeks to understand the effects of commodity price shocks in commodity-exporting economies. We focus on emerging markets and key to our analysis is a consideration of labour market and monetary policy dynamics. To this end, we estimate a panel vector autoregression (PVAR) model using data for four inflation targeting countries and find that an increase in commodity prices leads to rising output, interest rates and inflation, a real exchange rate appreciation, a trade surplus and a decrease in unemployment. We develop a small open economy dynamic stochastic general equilibrium (DSGE) model to shed light on the mechanism driving our empirical results where the parameters are estimated using Bayesian methods so that implied impulse responses are matched to those obtained from the PVAR.

In order to understand the dynamic responses following a commodity price shock, the model includes search and matching frictions in the labour market à la Diamond (1982); Mortensen (1982) and Pissarides (1985); nominal rigidities and an interest rate premium that is affected by commodity prices. We find that the combination of these features enables the model to match the estimated impulse responses. The increase in commodity prices leads to a real exchange rate appreciation and a boom in the commodity-producing sector, with this greater wealth resulting in a rise in domestic expenditure. At the same time, as the home tradable good becomes more expensive, output and employment in this sector contract, exhibiting the effects of a Dutch disease.[2]

[1] On this last point, Ben Zeev et al. (2017) provide evidence supporting the role of news about commodity price shocks as sources of business cycles.

[2] As in García-Cicco and Kawamura (2015), we refer to the Dutch disease as the contraction in the domestic non-commodity tradable sector following the increase in income generated by the commodity sector. However, we do not rely on a non-tradable sector for the presence of this mechanism: a re-allocation of resources towards the commodity producing sector is sufficient to generate this effect.

By embedding search and matching frictions in the labour market into a small open economy New Keynesian model, our paper sheds new light on the role of monetary policy in shaping the macroeconomic responses to commodity price shocks in countries that export these goods.

There are two main approaches in seeking to understand the macroeconomic effects of commodity price shocks in commodity dependent economies. The first one relies on time series methods, such as structural vector autoregressions (SVARs), which attempt to estimate effects of commodity price shocks through short/long-run or sign identification restrictions. For economies that produce commodities with prices set in world markets, which facilitate the identification of the shock, SVARs provide a valuable insights.

Although the majority of the literature using time series methods to estimate the effects of commodity price (or terms of trade) shocks has focused on commodity importing countries, there is now a growing body of work considering the impacts on commodity dependent economies. Fornero et al. (2014) estimate separate SVARs for six countries while Schmitt-Grohé and Uribe (2018) do so with 38, albeit with annual data. Roch (2019) and Bodenstein et al. (2018) use panel SVARs to quantify the impact of commodity price shocks, using 22 and 3 countries, respectively. In contrast, Drechsel et al. (2019) and García-Cicco and Kawamura (2015) rely on a single country (Argentina and Chile, respectively) when estimating the SVAR. Of the above, all bar Fornero et al. (2014) include only real variables in their estimation. Camacho and Pérez-Quirós (2014) examine the effects of commodity price shocks on economic growth in the seven largest Latin American economies using Markov switching impulse response functions.

The second approach relies on theoretical models that shed light on the underlying mechanisms and enable counterfactual analysis. Using dynamic stochastic general equilibrium (DSGE) models, Mendoza (1991) and Mendoza (1995) analyse the impact of terms of trade shocks in small open economies, showing that roughly half of the variation in aggregate output in a sample of the G7 and 23 developing economies can be attributed to terms of trade shocks. Kose (2002) uses a similar framework, finding that terms of trade shocks can explain almost all of the variance in output in small open developing economies. In contrast, Schmitt-Grohé and Uribe (2018) estimate the structural parameters in a three-sector open economy model, concluding that terms of trade shocks explain less than 10% of variations in aggregate activity. There is a growing literature on the macroeconomic effects of commodity price shocks, such as Drechsel et al. (2019); Fernández et al. (2018) and García-Cicco and Kawamura (2015). The former, along with Shousha (2016) include in their models a role for commodity prices to directly affect interest rate risk premia, complementing the findings in Neumeyer and Perri (2005); Uribe and Yue (2006) and García-Cicco et al. (2010) regarding the role of countercyclical interest rate movements as key drives of business cycles in emerging markets.

The bulk of the existing literature on commodity prices and emerging economies has relied on real models and or fiscal policy.[3] More recent work has included nominal features, such as Arango Thomas et al. (2015); Chang (2014); Hevia and Nicolini (2014) and Drechsel et al. (2019), but these papers rely on calibrated models to analyse optimal monetary policy, rather than attempting to match the data. Related work closest to this paper is that by Bodenstein et al. (2018); Fornero et al. (2014); Guerra-Salas et al. (2021); Medina and Soto (2016) and Rees et al. (2016). The first three develop DSGE models that aim to capture the time series evidence on the effects of commodity price shocks provided by vector autoregressions (VARs). However, Fornero et al. (2014) do not consider unemployment and the model in Bodenstein et al. (2018) is purely real, while Medina and Naudon (2011) rely on a parameterised version of their model. Although the latter carry out an exercise similar to that of the present paper, their model is unable to replicate the decrease in unemployment following the commodity price shocks that they obtain from the VAR. Both Guerra-Salas et al. (2021) and Rees et al. (2016) develop a New Keynesian model with a commodity sector that is then estimated with Bayesian methods. However, while the former includes search and matching frictions, the commodity sector is modelled as an endowment and they do not discuss the effects of commodity price shocks. In contrast, Rees et al. (2016) do endogenise commodity output but as given the labour market structure they assume, they cannot consider the dynamics of unemployment. Our model also builds on Christiano et al. (2011) who develop a New Keynesian model with financial as well as search and matching frictions that is estimated on Swedish data, finding a very small role for labour supply shocks in explaining GDP, unlike the model estimated on similar data in Adolfson et al. (2007).[4] In Christiano et al. (2011) the model with financial and employment frictions provides the best forecasting performance relative to the alternatives but more importantly, as they argue, it is the richer model's ability to better describe the driving forces of the economy that adds value.

In this paper we develop a theoretical model that matches the responses of unemployment and inflation, among other key macroeconomic variables, to our empirical results. We build on previous findings in the literature to highlight that a model with interacting labour market search and matching frictions, New Keynesian features and monetary policy are key to understanding the transmission mechanism of commodity price shocks in commodity-dependent economies. One benefit of using the results provided by VARs to guide the development of the model is the avoidance of pre-emptively imposing specific conclusions.[5]

[3] See Agénor (2016), Fernández et al. (2018); Ojeda-Joya et al. (2016); Pieschacón (2012) and Drechsel et al. (2019), among others.

[4] Many estimated New Keynesian models with standard labour market specifications assign an important role to labour supply shocks, such as Smets and Wouters (2003) but this possesses the unappealing feature that such shocks are hard to interpret.

[5] For example, estimating models with strong Ricardian features will inevitably lead to small fiscal multipliers even if this is not supported by the VAR evidence, as in Ilori et al. (2022).

Table 1
Summary of related literature on effects of 10% shocks to commodity prices.

Panel A: Time series evidence						
Author	GDP	π	*rer*	*ue*	*nx*	*R*
Bodenstein et al. (2018)	0.32		−1.8	−0.21	0.6	
Drechsel and Tenreyro (2018)	1.5				−0.94	
Fornero et al. (2014)	0.3	0.15	−3.2			1
Schmitt-Grohé and Uribe (2018)	0.36		−1.6		0.5	
Roch (2019)	4		−10		4	
García-Cicco and Kawamura (2015)			−1.3			
This paper	0.62	0.23	−1.9	−0.15	0.34	0.21
Model evidence						
	GDP	π	*rer*	*ue*	*nx*	*R*
García-Cicco and Kawamura (2015)	1.96		−0.3			
Bodenstein et al. (2018)	0.2		−1.2	−0.12	0.4	
Drechsel and Tenreyro (2018)	1.9				−0.9	
Fornero et al. (2014)	0.6	0.0	−0.6			0
García-Cicco and Kirchner (2015)	0.3	−0.1	−1		1	0
Medina and Naudon (2011)				−5.9		
Hevia and Nicolini (2014)	2.2		−15			
This paper	0.59	0.15	−2.3	−0.1	0.16	0.14

Panel C: Quantifying the Dutch disease				
Measure	This paper	MN	HN	LM
n_1	−0.59	−0.35	−9.4	−1.4

Peak responses (approximate values). For Panels A and B: π is inflation; *rer* is the real exchange rate; *ue* is the unemployment rate; *nx* is net exports and *R* is the nominal interest rate. For Panel C: MN denotes Medina and Naudon (2011); HN is Hevia and Nicolini (2014) and LM is Lama and Medina (2012). The impulse in Schmitt-Grohé and Uribe (2018) is the terms of trade. For Panel C: n_1 denotes employment in the domestic non-commodity sector.

The model we present suggests that despite the increase in both GDP and inflation following the commodity price shock, the monetary policy response is initially muted. Indeed, the interest rate responds to the shock with a lag and it is this factor that limits the contraction in the home tradable good. Thus we find that the response of monetary policy is key for understanding the macroeconomic dynamics caused by commodity price shocks and that the neglect of monetary factors omits important channels. Our robustness checks confirm these conclusions by considering which features of the model are key elements of the transmission mechanism, finding that the rule followed by the central bank is a critical determinant for the magnitude of any Dutch disease symptoms. Table 1 provides a summary on the time series evidence and model-based results most closely related to the focus of this paper.[6] The work of Pieschacón (2012) is closely related to ours in that she analyses the transmission mechanism of oil price shocks in both Mexico and Norway by developing a DSGE model that can match the responses from a VAR. However, her paper focuses on the role of fiscal policy and excludes a role for monetary variables.

2. Commodity price shocks: time series evidence

Our dataset consists of quarterly series from 2001Q3 to 2019Q4 for four inflation targeting emerging economies: Brazil, Chile, Mexico and South Africa. Commodities represent the majority of merchandise exports for these four economies while they can still be regarded as having a negligible impact on world commodity prices, enabling identification of the shock.[7] For each country we include seven variables: real GDP per capita, the annual rate of CPI inflation, the real broad effective exchange rate, the unemployment rate, net exports as a proportion of GDP, the nominal interest rate (policy rate) and a trade-weighted, country-specific, export commodity price index expressed in dollars compiled by the IMF.[8]

We obtained the GDP series from the OECD's Main Economic Indicators (MEI) while the population series originate from the World Bank. The inflation rate, the unemployment rate and net exports originate from the MEI. The source for the real exchange rate series is the Bank for International Settlements. For Brazil and South Africa we use the Treasury bill as the

[6] Although as discussed above Medina and Naudon (2011) estimate a VAR to measure the impact of a commodity price shock, they do not report the size of the shock so their results are therefore not presented in the table.

[7] Lack of data availability prevented us from including additional countries and variables as well as from extending the sample. In addition, Ben Zeev et al. (2017) also limit the number of countries they consider given the different output dynamics of some countries and the fact that for some Asian economies cannot be regarded as price takers in commodity markets.

[8] See IMF.

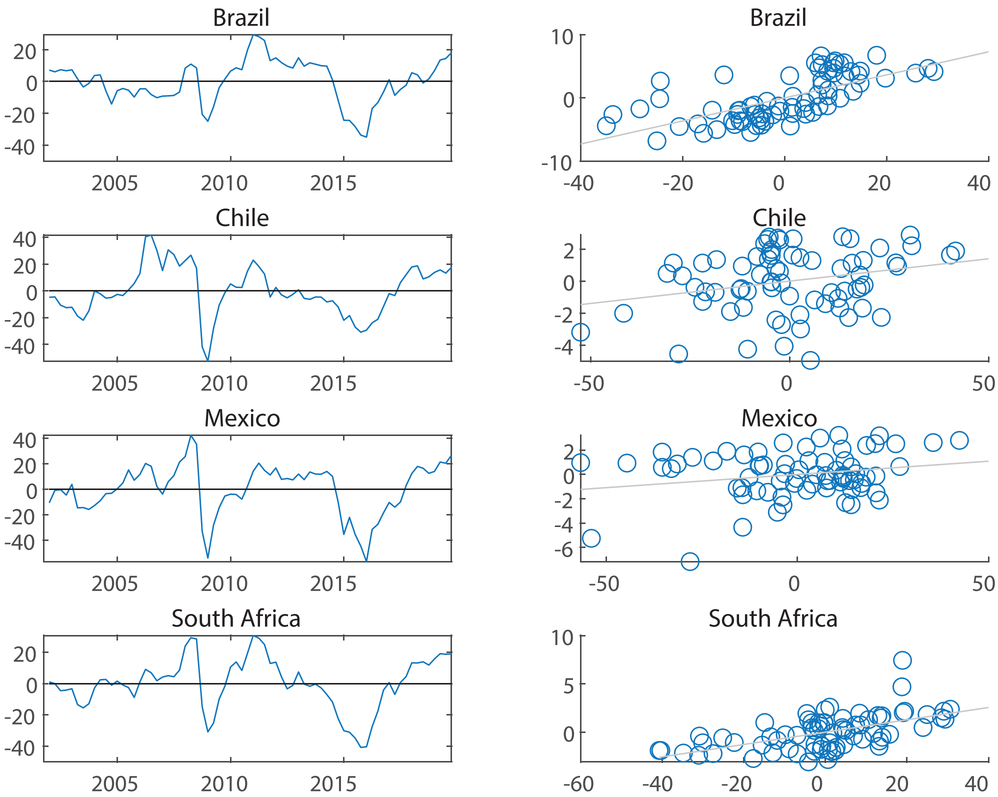

Fig. 2. Commodity prices and output. The figures on the left panel show commodity prices. The scatter plots on the right display commodity prices (horizontal axis) and output (vertical axis). All variables are in deviations from a quadratic trend.

measure of the nominal interest rate, obtained from the IMF's International Financial Statistics while for Chile we employ the 90-day interbank rate, from the MEI. Lastly, the proportions of commodity exports out of total merchandise exports can be found in UNCTAD (2019). A summary of the data definitions is provided in Table 6.

All the data, apart from population and commodity prices, were retrieved from the FRED. Commodity prices, output and the real exchange rate are transformed into logs while we remove a quadratic trend from all the series.

Figure 2 presents some data on commodity prices and output, both in percentage deviations from a quadratic trend. The left subplots show the time series of commodity prices, where the high volatilities of the series for all four countries are evident. Moreover, as can be seen in the right subplots, commodity prices are strongly procyclical, which suggests their potentially important role as a source of business cycles.

One key benefit of studying the impact of export commodity price shocks lies in identification. With the prices of these goods being set in world markets, standard time series techniques can be used to identify the impact of the shock in a manner less controversial than fiscal or monetary policy shocks, for example.

To determine the effects of commodity price shocks on the macroeconomy our empirical model is the following reduced form panel vector autoregression model (PVAR)

$$y_{i,t} = \nu_i + A(L)y_{i,t-1} + \varepsilon_{i,t} \tag{1}$$

where $A(L)$ denotes a polynomial in the lag operator L. The residual ε_t is a zero-mean, serially uncorrelated vector with variance-covariance matrix Σ_ε and ν_i represents the country fixed effect. Therefore, as in Ravn et al. (2012) and Bodenstein et al. (2018), we assume that the heterogeneity across countries is constant. We estimate a PVAR rather than individual country-VARs as the former provides substantially greater efficiency and power. Country-specific VARs would suffer from very low degrees of freedom and just as importantly, the identified effects of the commodity price shocks are similar across the individual countries considered in our sample, justifying the approach.[9]

We set the lag length to 2 as suggested by the Schwarz and Hannan-Quinn information criteria. For the countries in our sample commodity prices can be taken as set in world markets. Therefore, we order the commodity price first in the SVAR

[9] We also considered Colombia and Peru but their responses were too dissimilar to merit inclusion.

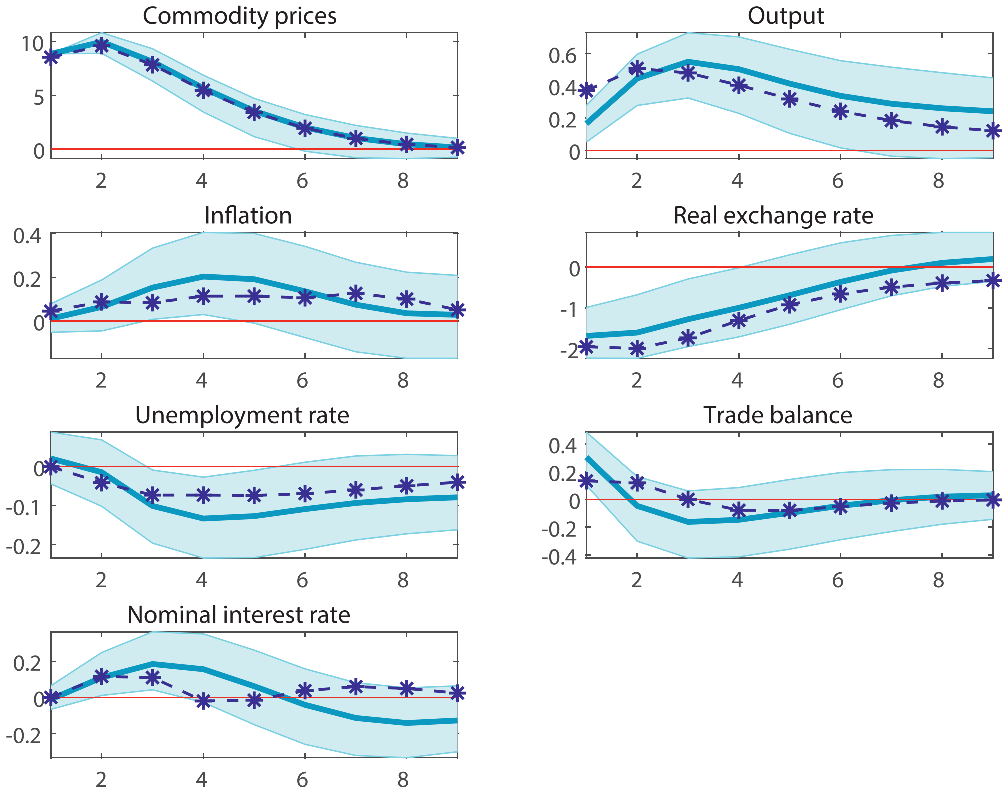

Fig. 3. Responses to commodity price shock. *Note:* The blue solid line represents the estimated response to a one standard deviation commodity price shock along with the 95% blue confidence band from 5000 bootstraps. The blue dashed lines correspond to the IRFs implied by the DSGE model matched to the panel SVAR. Inflation is expressed at an annual rate and a real exchange rate decline represents an appreciation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

above and set all the elements on the first rows of $A(L)$ bar the first entries to zero, implying that we model the series for commodity prices as an exogenous AR(p) process.[10]

The estimated impulse responses of the panel SVAR to a one standard deviation increase in commodity prices are shown in Fig. 3 with the solid black lines, along with the 95% confidence bands. Upon impact, commodity prices rise by almost 9% and return to trend after eight quarters. The effects of the shock are expansionary and initially export-driven: output and net exports increase while the unemployment rate falls. At the same time, although the real exchange rate exhibits a large appreciation, the inflation rate increases, as does the nominal interest rate, albeit after an initial (non-significant) contraction. Qualitatively, the behaviour of the real variables as estimated in the VAR is consistent with those in Bodenstein et al. (2018); García-Cicco and Kawamura (2015) and Schmitt-Grohé and Uribe (2018) (with terms of trade shocks), but in contrast to Drechsel and Tenreyro (2018) for Argentina, who find that increases in commodity prices lead to a trade balance deterioration. The sizes of the responses are substantial, as a 10% increase in commodity prices implies a GDP impact of over 0.6%, much larger than the mean effect estimated by Schmitt-Grohé and Uribe (2018), 0.36%, for an equivalent terms of trade shock. Likewise, Bodenstein et al. (2018) estimate the same-sized shock to reduce unemployment by approximately 0.2 percentage points while in our sample the decline reaches 0.15 points. While the muted response of unemployment may seem surprising, it reflects the fact that the shock only has a direct impact on the commodity sector, which typically makes a small proportion of overall employment. Panel A of Table 1 provides a summary of recent findings on the related literature, where it is evident that most of the emphasis has been on real variables but excluding the labour market.

In terms of the dynamics, except for the real exchange rate, the peak responses of the other variables occur after a lag and return to zero after a substantial delay, suggesting non-trivial endogenous propagation mechanisms. In particular, the peak responses of output and the nominal interest rate occur after three quarters and that of the inflation takes place in the fifth quarter. To assess the overall importance of commodity prices as a source of business cycles, Table 4 shows the share of the variance accounted for by commodity price shocks.

Lastly, we performed several further checks to assess the robustness of our results. First, we included the interest rate spread between Moody's seasoned Baa corporate bond yield and the Federal funds rate. As suggested by Akinci (2013) and

[10] As we do not attempt to identify the remaining shocks to the system, the ordering of the other variables is irrelevant.

Schmitt-Grohé and Uribe (2018), this represents a better measure of world interest rates for emerging markets. In addition, we also estimated the VAR by allowing for a break in the unconditional mean in 2005Q1 for the Chilean commodity price index, as found in García-Cicco and Kawamura (2015). As can be seen in Fig. 10, the baseline VAR is robust to these modifications. As a final check, we estimated the VAR using sign restrictions as in Uhlig (2005) but the responses, shown in Fig. 11, were very imprecisely estimated although they encompass our benchmark results.[11]

3. A dynamic stochastic general equilibrium model

We now present a dynamic stochastic general equilibrium (DSGE) model with the aim of accounting for the empirical evidence presented above. Given our interest in including the dynamics of both inflation and output, we consider a New Keynesian small open economy model with a commodity sector and with search and matching frictions in the labour market. The objective is to develop a tractable model that can account for the transmission mechanism of commodity price shocks in emerging market economies.

The model consists of seven domestic agents: households, commodity and wholesale good producers, domestic retailers, importers, final good producers and the government. The first three interact directly in the labour market. Following Ravenna and Walsh (2008), we place the labour market frictions in the wholesale and commodity sectors, where prices are flexible, while sticky prices are present in the retail and import sectors, which do not employ labour.

The commodity good is either exported or used as an input in the production of the wholesale good. The wholesale good is then sold to the domestic retailer who bundles it into a differentiated good. This is then either exported or used for the production of the final good. Importers carry out a similar action so that differentiated imported goods also enter the production of the final good. This final good is then used for consumption, investment and government purchases. The latter are financed via lump-sum taxes and bonds, with the central bank implementing monetary policy via a simple interest rate rule.

Figure 4 summarises the main elements and interactions of the model.

3.1. Labour market

Household members that are employed supply their labour to either commodity producers or to domestic wholesale firms, both of which sell their output in perfectly competitive markets and pay the same wage. Those that are unemployed search for a job in an aggregate labour market.

Every period t, a firm i that uses labour posts vacancies $v_{j,t}(i)$ in order to recruit new workers, where $j = \{1, 2\}$ denotes the domestic wholesale and commodity sectors, respectively. Aggregate vacancies and employment are given by

$$v_t = \int_0^1 v_{1,t}(i)di + \int_0^1 v_{2,t}(i)di = v_{1,t} + v_{2,t} \tag{2}$$

$$n_t = \int_0^1 n_{1,t}(i)di + \int_0^1 n_{2,t}(i)di = n_{1,t} + n_{2,t} \tag{3}$$

As in Gertler et al. (2008), we assume that unemployed workers who find a match begin employment within the period so that the pool of unemployed workers searching for a job, u_t, is the difference between the total labour force, normalised to one, and the number of employed workers at the end of period $t-1$, n_{t-1}:

$$u_t = 1 - n_{1,t-1} - n_{2,t-1} \tag{4}$$

The number of matches (newly employed workers), m_t, is a function of aggregate vacancies (v_t) and searching workers

$$m_t = \bar{m} u_t^{\sigma} v_t^{1-\sigma} \tag{5}$$

where σ denotes the elasticity of the matching function with respect to aggregate unemployment, u_t and $\bar{m}$ represents the efficiency of the matching process.

The probability that a searching worker will find a job is given by

$$s_t = \frac{m_t}{u_t} \tag{6}$$

While the probability that a firm will fill its vacancy is represented by

$$q_t = \frac{m_t}{v_t} \tag{7}$$

Following Bodenstein et al. (2018) and Di Pace and Hertweck (2019), we assume that searching workers are randomly matched with a hiring firm in either sector. Therefore, the probabilities above are functions of aggregate quantities so that both firms and workers will take them as exogenous.

[11] Given the nature of the shock, our benchmark identification scheme seems more appropriate and as Wolf (2022) points out, there may be some linear combination of the other shocks that satisfy the restrictions.

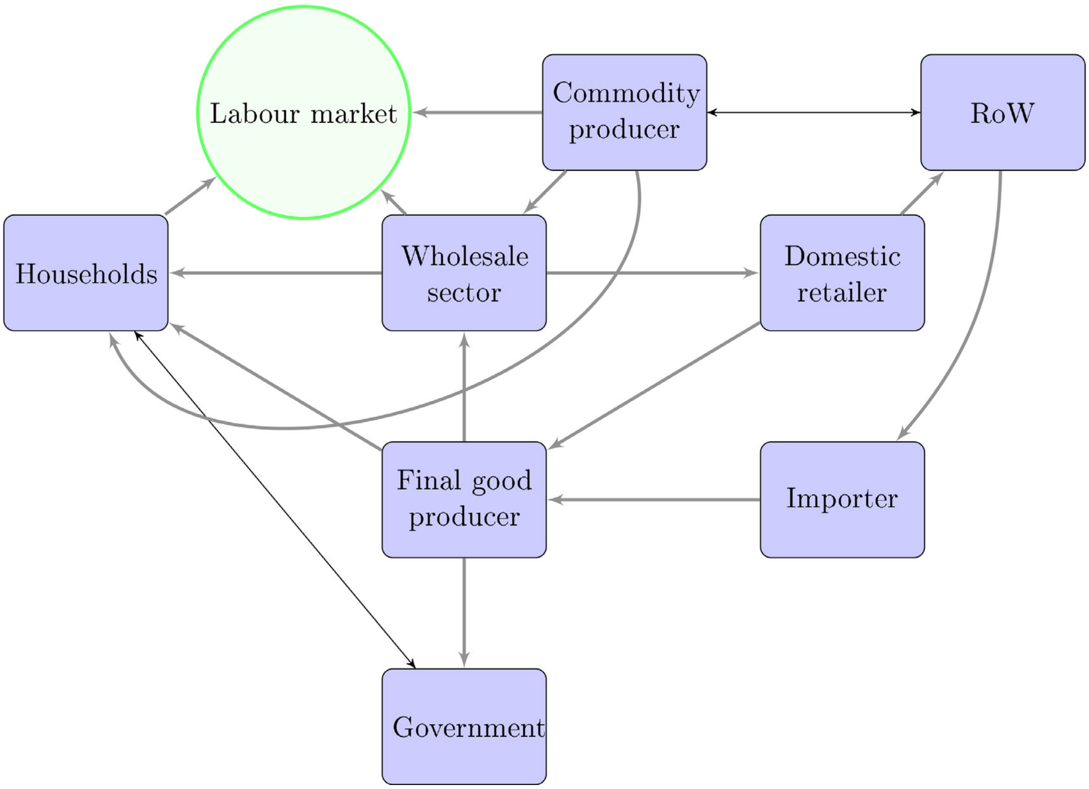

Fig. 4. Main elements of the DSGE model (RoW = rest of the world).

Each period, a fraction ρ of the existing jobs break up and workers who lose their job in period t are not allowed to search until the following period. This follows Gertler et al. (2008) and implies that fluctuations in unemployment are due to cyclical variations in hiring, rather than being caused by separations. Consequently, the evolution of employment is given by

$$n_{1,t} + n_{2,t} = (1-\rho)(n_{1,t-1} + n_{2,t-1}) + m_t \tag{8}$$

In addition, it will be useful to define the hiring rate, x_t, as the ratio of matches to the existing workforce

$$x_t = \frac{m_t}{n_{t-1}} \tag{9}$$

3.2. Households

Each representative household consists of a continuum of individuals of measure one, whose members are either employed by commodity or wholesale good sectors, or search in the labour market. As in Andolfatto (1996); Merz (1995) and Di Pace and Hertweck (2019), we assume that all household members insure each other against idiosyncratic income risk from unemployment.

Conditional on n_t, the proportion in employment, the household maximises its utility function by its choices of consumption, c_t, government (foreign) bond holdings, B_t (B_t^*) as well as investment and the stock of physical capital in each sector, $i_{j,t}$ and $k_{j,t}$, respectively.

Analogously to García-Cicco et al. (2015); Lama and Medina (2012) and García-Cicco et al. (2017), lifetime utility is given by

$$E_t \sum_{s=0}^{\infty} \beta^s U(c_{t+s})$$

with

$$U(c_t) = \log(c_t - hc_{t-1})$$

so that h represents the degree of habit formation in the consumption of the final good, c_t. The household owns the sector-specific capital stock, $k_t = k_{1,t} + k_{2,t}$ and this is rented out to firms, for which it is paid $r^k_{j,t}$. It also receives lump-sum profits, D_t, from its ownership of the firms and obtains wage income from employment in either sector. In addition, the domestic and foreign one–period bonds pay interest of R_t and $\tilde{R}_t^*$, respectively, with the former also being the monetary policy instrument.

The household's budget constraint is given by

$$c_t + i_{1,t} + i_{2,t} + \frac{B_t}{P_t R_t} + \frac{e_t B_t^*}{\tilde{R}_t^* P_t} = w_{1,t} n_{1,t} + w_{2,t} n_{2,t} + (1 - n_{1,t} - n_{2,t}) b$$
$$+ r_{1,t}^k k_{1,t-1} + r_{2,t}^k k_{2,t-1} + D_t + \frac{B_{t-1}}{P_t} + \frac{e_t B_{t-1}^*}{P_t} - T_t$$

where P_t is the price level of the final good, used as the numeraire, e_t is the nominal exchange rate (an increase represents a depreciation) and real wages are represented by $w_{j,t}$. T_t represents lump-sum taxes levied by the government to finance its expenditure and the unemployment benefits, net of seigniorage revenue, while b represents the flow value from unemployment, including unemployment benefits. The interest rate on foreign bonds (B_t^*) equals the world interest rate, R_t^* plus a debt-elastic risk premium term, similar to that used by Drechsel and Tenreyro (2018), where rer_t denotes the real exchange rate, defined as $rer_t = \tilde{e}_t P_t^* / P_t$, where e_t is the nominal exchange rate, and $b_t^* = B_t^* / P_t^*$

$$\tilde{R}_t^* = R_t^* e^{-\chi \, rer_{t-1} \frac{b_{t-1}^*}{\bar{gdp}}} \left(\frac{p_{2,t}}{\bar{p}_2} \right)^{\xi_{p,2}} \tag{10}$$

As in Justiniano and Preston (2010), the premium is an increasing function of the economy's level of debt as a proportion of steady state GDP, where variables without a time subscript denote steady state values. This ratio is taken as exogenous by the household and as discussed by Schmitt-Grohé and Uribe (2003), it ensures stationarity in our small open economy model with incomplete markets.

The second component of the risk premium above is based on the finding by Drechsel and Tenreyro (2018) and Shousha (2016) that for commodity-exporting countries, interest rate premia are strongly affected by commodity prices, denoted by $p_{2,t}$. Given its frequent use in the literarure, see Houssa et al. (2022), for example, this feature is initially included in the model but in Section 4 below we assess its empirical contribution towards matching the data.

We allow the degree of investment adjustment costs to be sector-specific so that the capital accumulation equation for each sector $j \in \{1, 2\}$ is given by

$$k_{j,t} = (1-\delta) k_{j,t-1} + \left(1 - \Phi_j \left(\frac{i_{j,t}}{i_{j,t-1}} \right) \right) i_{j,t} \tag{11}$$

where

$$\Phi_{j,t} = \frac{\phi_j}{2} \left(\frac{i_{j,t}}{i_{j,t-1}} - 1 \right)^2 \tag{12}$$

The household maximises its utility subject to the budget constraint and the low of motion for capital. Using λ_t to denote the Lagrange multiplier on the household's budget constraint, the first order conditions are given by

$$\lambda_t = \frac{1}{c_t - h c_{t-1}} - \beta E_t \frac{h}{c_{t+1} - h c_t} \tag{13}$$

$$\lambda_t = \beta E_t \frac{R_t \lambda_{t+1}}{\Pi_{t+1}} \tag{14}$$

$$q_{j,t}^k (1 - \Phi_{j,t}) = q_{j,t}^k \phi_j \left(\frac{i_{j,t}}{i_{j,t-1}} - 1 \right) \left(\frac{i_{j,t}}{i_{j,t-1}} \right) - \beta E_t \frac{\lambda_{t+1}}{\lambda_t} q_{j,t+1}^k \phi_j \left(\frac{i_{j,t+1}}{i_{j,t}} - 1 \right) \left(\frac{i_{j,t+1}}{i_{j,t}} \right)^2 + 1 \tag{15}$$

$$q_{j,t}^k = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \left(r_{j,t+1}^k + (1-\delta) q_{j,t+1}^k \right) \tag{16}$$

$$\lambda_t = \beta E_t \lambda_{t+1} \left[\frac{rer_{t+1} \tilde{R}_t^*}{rer_t \Pi_{t+1}^*} \right] \tag{17}$$

where $q_{j,t}^k$ is the value of installed capital (in consumption units) in sector j.

3.3. Hiring firms

As in Ravenna and Walsh (2008) and Gertler et al. (2008), we separate the hiring from the pricing decision. Firms in both the commodity and domestic wholesale good sectors operate in a perfectly competitive environment with capital being fully mobile across both firms and sectors. In addition, there is a competitive rental market in capital, with the consequence, as in Gertler et al. (2008), that firms operate under constant returns to scale. Moreover, as in Gertler et al. (2008) and Di Pace and

Hertweck (2019), we assume that firms are subject to hiring, rather than searching, costs and that these are proportional to the aggregate hiring rate.[12]

The hiring rate of firm i in sector j is given by

$$x_{j,t}(i) = \frac{q_t v_{j,t}(i)}{n_{j,t-1}(i)}$$

This implies that the employment accumulation equation can be written as

$$n_{j,t}(i) = (1-\rho)n_{j,t-1}(i) + x_{j,t}(i)n_{j,t-1}(i) \tag{18}$$

Domestic wholesale firms use commodities as a production input, $y_{21,t}$, so that the value of the firm in this sector is given by

$$F_{1,t}(i) = p_{1,t}y_{1,t}(i) - w_{1,t}n_{1,t}(i) - \frac{1}{2}\kappa x_{1,t}^2(i)n_{1,t-1}(i) - p_{2,t}y_{21,t} - r_{1,t}^k k_{1,t}(i) + \beta E_t \frac{\lambda_{t+1}}{\lambda_t}F_{1,t+1}(i) \tag{19}$$

while in the commodity sector the analogous equation is given by

$$F_{2,t}(i) = p_{2,t}y_{2,t}(i) - w_{2,t}n_{2,t}(i) - \frac{1}{2}\kappa x_{2,t}^2(i)n_{2,t-1}(i) - r_{2,t}^k k_{2,t}(i) + \beta E_t \frac{\lambda_{t+1}}{\lambda_t}F_{2,t+1}(i) \tag{20}$$

where $p_{j,t} = P_{j,t}/P_t$ is the price of the good in sector s relative to the final good, $w_{j,t} = W_{j,t}/P_t$ is the real wage, $r_{j,t}^k$ the rental rate of capital and $\beta\frac{\lambda_{t+1}}{\lambda_t}$ the firm's stochastic discount factor. We follow Gertler et al. (2008) in assuming that quadratic costs of hiring at the firm level.[13] The only substantive difference in the descriptions of the two sectors lies in the fact that the wholesale good producer uses the commodity good as production input.

The optimal hiring rate in either sector implies

$$\kappa x_{j,t} = p_{j,t}mpn_{j,t} - w_{j,t} + \beta E_t \frac{\lambda_{t+1}}{\lambda_t}\left[(1-\rho)\kappa x_{j,t+1}(i) + \frac{1}{2}\kappa x_{j,t+1}^2(i)\right] \tag{21}$$

where $mpn_{j,t}$ is the marginal product of labour in sector s and given the assumptions regarding the production technology as well as the perfect mobility of factors within a sector, is the same across firms within a given sector.

Making use of the envelope theorem we have

$$\frac{\partial F_{j,t}}{\partial n_{j,t-1}} = \kappa x_{j,t}(i)\big(1-\rho + x_{j,t}(i)\big) - \frac{1}{2}\kappa x_{j,t}^2(i)$$

Combining this equation with (21) we obtain

$$\kappa x_{j,t}(i) = p_{j,t}mpn_{j,t} - w_{j,t} + \beta E_t \frac{\lambda_{t+1}}{\lambda_t}\left[(1-\rho)\kappa x_{j,t+1}(i) + \frac{1}{2}\kappa x_{j,t+1}^2(i)\right] \tag{22}$$

thus the hiring rate is a function of the discounted stream of earnings, including savings on adjustment costs.

If we define $J_{j,t}(i)$ as the value to the firm of an additional worker, after hiring costs are sunk, we have

$$J_{j,t}(i) = p_{j,t}mpn_{j,t} - w_{j,t} + \beta E_t \frac{\lambda_{t+1}}{\lambda_t}\frac{\partial F_{j,t+1}(i)}{\partial n_{j,t}(i)} \tag{23}$$

Again, using (21) we obtain the no-arbitrage condition

$$J_{j,t} = \kappa x_{j,t} \tag{24}$$

Thus, the net marginal value of employment is the same across firms within a sector.

3.3.1. Wage determination

We assume that wages across both sectors are set in Nash bargaining with the worker's share being denoted by γ and is equal across sectors. As real wages are renegotiated every period, and neither the worker nor the firm controls the price level, bargaining in terms of the real or the nominal wage yield identical outcomes. The surplus-sharing condition is then

$$\gamma J_{j,t} = (1-\gamma)\mathcal{W}_{j,t} \tag{25}$$

where $\mathcal{W}_{j,t}$ represents the value of a job in sector j to a worker. In the Appendix we show that $\mathcal{W}_t$ is given by

$$\mathcal{W}_{j,t} = w_{j,t} - b + \beta E_t \frac{\lambda_{t+1}}{\lambda_t}\left[(1-\rho)\mathcal{W}_{j,t+1} - \Sigma_{l=\{1,2\}}s_{l,t+1}\mathcal{W}_{l,t+1}\right] \tag{26}$$

[12] These costs are homogeneous with the final goods.

[13] In an earlier version of this paper we assumed that the costs of hiring a worker were proportional to the aggregate hiring rate, as in Di Pace and Hertweck (2019). However, this formulation resulted in a poorer empirical performance and is therefore not considered further. We thank a referee for suggesting this modification.

This equation shows that when an unemployed worker finds a job the household obtains a net increase in income and in addition benefits from the continuation value of employment at the same firm, net of the opportunity cost of searching for a job and finding another employer.

As shown in the appendix, by combining (24) and (25), (26) we obtain an expression for the evolution of real wages

$$w_{j,t} = \gamma p_{j,t} mpn_{j,t} + (1-\gamma)b + \gamma E_t \beta \frac{\lambda_{t+1}}{\lambda_t}\left[\frac{1}{2}\kappa x_{j,t+1}^2 + \kappa \sum_{l=\{1,2\}} s_{l,t+1} x_{l,t+1}\right] \tag{27}$$

Just as in Ravenna and Walsh (2008), albeit with hiring rather than search costs, absent frictions in the labour market ($\kappa = 0$), then $w_t = (1-\gamma)b + \gamma p_{s,t} mpn_{s,t}$, since firms would only have to pay workers a wage equal to the latter's outside opportunity. By contrast, with $\kappa > 0$, the match behaves more like an asset, raising the wage.

3.4. Commodity producers

Apart from the hiring decision, commodity producers rent capital from households, with the commodity price being set in world markets. Their production function is given by

$$y_{2,t} = A_{2,t} k_{2,t-1}^{\alpha_2} n_{2,t}^{1-\alpha_2} \tag{28}$$

where $A_{2,t}$ is an exogenous technology shock. In maximising the value of the firm, given by (20), the first order condition for capital is given by

$$r_{2,t}^k = p_{2,t}\alpha_2 \frac{y_{2,t}}{k_{2,t-1}} \tag{29}$$

Given our assumption of a Cobb–Douglas production function and perfect capital mobility within the sector, all the capital-output ratio is the same for all commodity-producing firms. Commodity output can be sold to domestic wholesale firms ($y_{21,t}$) who use it as an input or it can be exported abroad ($y_{2,t}^x$)

$$y_{2,t} = y_{21,t} + y_{2,t}^x \tag{30}$$

3.5. Domestic wholesaler

Wholesale firms use labour and capital to produce a homogeneous good where the production function is given by

$$y_{1,t} = A_{1,t} k_{1,t-1}^{\alpha_1} n_{1,t}^{\gamma_1} y_{21,t}^{\beta_1} \tag{31}$$

where $\alpha_1 + \beta_1 + \gamma_1 = 1$. The resulting first order conditions for $k_{1,t-1}$ and $y_{21,t}$ in order to maximise the value of the firm, Eq. (19) and subject to its labour accumulation Eq. (18) are given by

$$r_{1,t}^k = p_{1,t}\alpha_1 \frac{y_{1,t}}{k_{1,t-1}} \tag{32}$$

and

$$p_{2,t} = p_{1,t}(1-\alpha_1)\frac{y_{1,t}}{y_{21,t}} \tag{33}$$

As with the commodity sector, all firms choose the same capital-output ratio.

3.6. Domestic retailers

We assume the existence of a continuum of monopolistically competitive firms that produce differentiated goods, $y_{h,t}(j)$, and are subject to sticky prices à la Calvo (1983). Each retailer purchases the domestic wholesale output and converts it into a retail good, with the firm's nominal marginal cost given by

$$MC_{h,t} = P_{1,t}$$

Each period a retailer is able to adjust its price with probability $1-\omega$ while the remaining firms set prices according to the following indexation rule

$$P_{h,t}(i) = P_{h,t-1}(i)\Pi_{h,t-1}^{\zeta_h}$$

where $\Pi_{h,t}$ is the gross inflation rate in the (home) retail sector and ζ_h denotes the degree of indexation to past inflation. A firm re-optimising in period t will choose the price of its good that maximises the current market value of its profits at the given price. It therefore sets $P_{h,t}(i)$ to maximise

$$E_t \sum_{s=0}^{\infty} (\beta\omega)^s \frac{\lambda_{t+s}}{\lambda_t} y_{h,t+s}\left[P_{h,t}(i)\left(\frac{P_{h,t+s}}{P_{h,t-1}}\right)^{\zeta_h} - P_{h,t+s} mc_{h,t+s}\right]$$

where $mc_{h,t+s} = \frac{p_{1,t+s}}{p_{h,t+s}}$ is the retailer's real marginal cost and the demand for the its output is given by

$$y_{h,t+s}(i) = y^d_{h,t+s}(i) = \left[\frac{\tilde{P}_{h,t}(i)}{P_{h,t+s}} \left(\frac{P_{h,t+s-1}}{P_{h,t-1}} \right)^{\zeta_h} \right]^{-\varepsilon} y^d_{h,t+s}$$

where $y^d_{h,t}$ represents the aggregate demand for the domestic retail good. As for importers, the individual demands for $y_{h,t}(i)$ ($y_{f,t}(i)$ come from Dixit–Stiglitz aggregators with substitution elasticities across varieties of ε (ε_f). All firms that are able to do so choose the same price, $\tilde{P}_{h,t}$, which is associated with the following optimality condition

$$\left(\frac{\varepsilon - 1}{\varepsilon} \right) \tilde{P}_{h,t} = \frac{\sum (\beta\omega)^s \frac{\lambda_{t+s}}{\lambda_t} y_{h,t+s} P^{1+\varepsilon}_{h,t+s} \left(\frac{P_{h,t+s-1}}{P_{h,t-1}} \right)^{-\zeta\varepsilon} mc_{h,t+s}}{\sum (\beta\omega)^s \frac{\lambda_{t+s}}{\lambda_t} y_{h,t+s} P^{\varepsilon}_{h,t+s} \left(\frac{P_{h,t+s-1}}{P_{h,t-1}} \right)^{\zeta(1-\varepsilon)}} \tag{34}$$

The home retail good can be used either for domestic uses (consumption, investment and government spending), denoted by $y_{d,t}$, or for export ($y_{x,t}$):

$$y_{h,t} = y_{d,t} + y_{x,t} \tag{35}$$

and we assume that the demand for exports is given by

$$y_{x,t} = \alpha_x \left(\frac{p_{h,t}}{rer_t} \right)^{-\zeta_x} y^*_t \tag{36}$$

where y^*_t denotes world output.

The aggregate resource constraint for the retail good can then be written as

$$\int_0^1 y_{h,t}(i) di = y^w_t = \Delta_{h,t} y_{h,t} \tag{37}$$

with $\Delta_{h,t} \equiv \int_0^1 \left(\frac{P_{h,t}(i)}{P_{h,t}} \right)^{-\varepsilon} di$ representing the degree of price dispersion in the retail sector, given by

$$\Delta_{h,t} = (1-\omega) \tilde{p}^{-\varepsilon}_{h,t} + \omega \Pi^{\varepsilon}_{h,t} \Pi^{-\varepsilon\zeta_h}_{h,t-1} \Delta_{h,t-1} \tag{38}$$

The Dixit–Stiglitz price aggregate then follows

$$1 = (1-\omega) \left(\frac{\tilde{P}_{h,t}}{P_{h,t}} \right)^{1-\varepsilon} + \omega \Pi^{\varepsilon-1}_{h,t} \Pi^{\zeta(1-\varepsilon)}_{h,t-1} \tag{39}$$

The log-linear approximations to Eqs. (34)–(39) can be combined to obtain the New Keynesian Phillips curve for the domestic retail inflation rate.

3.7. Importers

We follow the set-up in Monacelli (2005) and Justiniano and Preston (2010) by allowing for imperfect exchange rate pass-through. There is a continuum of firms importing foreign differentiated goods for which the law of one price holds at the docks. We assume that importers are monopolistically competitive so that there may be short-run deviations from the law of one price.

Importers are subject to Calvo pricing with parameter ω_f and for firms unable to re-optimise their degree of indexation to past inflation is given by ζ_f. Each firm faces the following demand curve[14]

$$y_{f,t+s}(i) = \left(\frac{P_{f,t}(i)}{P_{f,t+s}} \left(\frac{P_{f,t+s-1}}{P_{f,t-1}} \right)^{\zeta_f} \right)^{-\varepsilon_f} y_{f,t+s}$$

The importer's problem is to maximise the expected present discounted value of profits, given by

$$E_t \sum_{s=0}^{\infty} \left(\beta\omega_f\right)^s \frac{\lambda_{t+s}}{\lambda_t} y_{f,t+s}(i) \left[P_{f,t}(i) \left(\frac{P_{f,t+s-1}}{P_{f,t-1}} \right)^{\zeta_f} - e_{t+s} P^*_{f,t+s} \right]$$

where e_t denotes the nominal exchange rate. Given our small open economy assumption, $P^*_t = P^*_{f,t}$, so that we can re-write the expression above as

$$E_t \sum_{s=0}^{\infty} \left(\beta\omega_f\right)^s \frac{\lambda_{t+s}}{\lambda_t} y_{f,t+s}(i) \left[P_{f,t}(i) \left(\frac{P_{f,t+s-1}}{P_{f,t-1}} \right)^{\zeta_f} - P_{f,t+s} mc_{f,t+s} \right]$$

[14] In solving the model we set $\varepsilon_f = \varepsilon$ as this parameter has no effect on the model's dynamics when solving at first order.

where the real marginal cost faced by the importer is given by

$$mc_{f,t+s} = rer_t / p_{f,t} \tag{40}$$

and represents the law of one price gap. All firms able to re-set their price then choose

$$\tilde{P}_{f,t}(i) = \left(\frac{\varepsilon}{\varepsilon - 1}\right) \frac{\sum (\beta\omega)^s \frac{\lambda_{t+s}}{\lambda_t} y_{f,t+s} P_{f,t+s}^{1+\varepsilon_f} \left(\frac{P_{f,t+s-1}}{P_{f,t-1}}\right)^{-\varepsilon_f \zeta_f} mc_{f,t+s}}{\sum (\beta\omega)^s \frac{\lambda_{t+s}}{\lambda_t} y_{f,t+s} P_{f,t+s}^{\varepsilon_f} \left(\frac{P_{f,t+s-1}}{P_{f,t-1}}\right)^{(1-\varepsilon_f)\zeta_f}}$$

As with the domestic retailers, the evolution of the aggregate Dixit–Stiglitz price index in the imported sector follows

$$1 = \left(1 - \omega_f\right) \left(\frac{\tilde{P}_{f,t}}{P_{f,t}}\right)^{1-\varepsilon_f} + \omega_f \Pi_{f,t}^{\varepsilon_f - 1} \Pi_{f,t-1}^{\zeta_f (1-\varepsilon_f)} \tag{41}$$

while the process for price dispersion is given by

$$\Delta_{f,t} = \left(1 - \omega_f\right) \tilde{p}_{f,t}^{-\varepsilon_f} + \omega_f \Pi_{f,t}^{\varepsilon_f} \Pi_{f,t-1}^{-\varepsilon_g \zeta_f} \Delta_{f,t-1} \tag{42}$$

3.8. Final good producers

There is a perfectly competitive representative firm that combines the domestic retail and imported goods to produce a final good, Z_t, using the CES technology

$$Z_t = \left[\alpha_d^{\frac{1}{\nu}} y_{d,t}^{\frac{\nu-1}{\nu}} + (1-\alpha_d)^{\frac{1}{\nu}} y_{f,t}^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}}$$

where $\nu > 0$ represents the elasticity of substitution between domestic and foreign goods, while $\alpha_d > 0$ is the share of domestic goods in the aggregate bundle, which is the same across all expenditure components (consumption, investment and government spending) and measures home bias.

The price index of the final good, P_t is chosen to be the numeraire so that it can be written as

$$1 = \alpha_d p_{h,t}^{1-\nu} + (1-\alpha_d) p_{f,t}^{1-\nu} \tag{43}$$

Given the production function above, the final good producer chooses $y_{d,t}$ and $y_{f,t}$ to maximise

$$P_t Z_t - P_{h,t} y_{d,t} - P_{f,t} y_{f,t}$$

the resulting first order conditions are

$$y_{d,t} = \left(\frac{P_{h,t}}{P_t}\right)^{-\nu} Z_t \tag{44}$$

$$y_{f,t} = \left(\frac{P_{f,t}}{P_t}\right)^{-\nu} Z_t \tag{45}$$

3.9. Government

The government budget constraint is given by

$$T_t + \frac{B_t}{P_t R_t} - \frac{B_{t-1}}{P_t} = G_t + (1 - n_t) b$$

We assume that G_t is a constant fraction $\bar{g}$ of steady state output and that the monetary authority follows an interest rate rule given by

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_r} \left[\left(\frac{\Pi_{t-1}}{\Pi}\right)^{\phi_\pi} \left(\frac{gdp_{t-1}}{gdp_{t-2}}\right)^{\phi_y} \left(\frac{p_{2,t-1}}{p_2}\right)^{\phi_{p_2}}\right]^{(1-\rho_r)} \tag{46}$$

This rule embodies interest rate inertia, measured by $0 \le \rho_r < 1$, with the strength of the response to inflation is given by ϕ_π. We model monetary policy as reacting to cyclical output. In addition, the interest rate also reacts to commodity price movements. The motivation for such a rule is primarily empirical as alternative formulations, such as inflation-forecast rules or including the exchange rate, are unable to match the dynamics of the estimated VAR.

3.10. Commodity prices

Commodity prices are set in world markets so that the domestic producer takes them as given. We calibrate $p_{2,t}$ as an AR(2) process using the coefficients in the estimated SVAR above. Consequently, we have

$$\frac{p_{2,t}^*}{p_2} = \frac{p_{2,t-1}^*}{p_2^*}^{\rho_{2,1}} \frac{p_{2,t-2}^*}{p_2^*}^{\rho_{2,2}} e^{\varepsilon_{p_{2,t}^*}} \tag{47}$$

with $\varepsilon_{p_{2,t}^*} \sim \mathcal{N}(0, \sigma_{p_2^*})$.

The relative domestic price is therefore given by

$$p_{2,t} = rer_t p_{2,t}^* \tag{48}$$

3.11. Aggregation and market clearing

The trade balance is given by

$$\frac{b_t^*}{\tilde{R}_t^*} = \frac{b_{t-1}^*}{\Pi_t^*} + \frac{p_{h,t}}{rer_t} y_{x,t} - M_t + \frac{p_{2,t}}{rer_t} y_{2,t}^x \tag{49}$$

where the interest rate on foreign bonds, $\tilde{R}_t^*$, is given by Eq. (10) and M_t represents total imports

$$M_t = \int y_{f,t}(i)di = \Delta_{f,t} y_{f,t}$$

gdp_t is then defined by

$$gdp_t = p_{h,t} y_{h,t} + rer_t p_{2,t}^* y_{2x,t} \tag{50}$$

Aggregate capital and investment are simply the sums of their sectoral components

$$i_t = i_{1,t} + i_{2,t} \tag{51}$$

$$k_t = k_{1,t} + k_{2,t} \tag{52}$$

with

$$k_{j,t} = \int k_t(i)di$$

Lastly, the final good can be used for expenditure on consumption, investment, government purchases and hiring costs.

$$Z_t = c_t + i_t + G_t + \frac{1}{2}\kappa \left(x_{1,t}^2 n_{1,t-1} + x_{2,t}^2 n_{2,t-1} \right) \tag{53}$$

where

$$x_{j,t} n_{j,t-1} = \int x_{j,t}(i) n_{j,t-1}(i) di$$

Given our small open economy assumption, foreign variables (output, inflation and interest rates) are assumed to follow an exogenous process and given our focus on the impact of commodity price shocks, it is not necessary to provide an explicit representation. A summary of the model's equilibrium conditions is given in Table 5.

4. Reconciling the model with the VAR

We now seek to estimate and evaluate our model. We partition the parameters into two groups, the first of which is calibrated and stacked in the vector Θ^c. Commodity prices are modelled as an AR (2) process using the values obtained from the estimated SVAR. We parameterise β to imply an annual real interest rate of around 6.2%, consistent with Fernández et al. (2018) and García-Cicco and Kawamura (2015), while the value for the elasticity of the matching function with respect to unemployment, σ, follows Gertler et al. (2008). The following ratios are set to match the average of their empirical counterparts during our sample period: the government spending-output ratio, G/gdp; the shares of employment in either sector and the share of (non-commodity) merchandise exports to GDP, Y^x/gdp.[15] We choose conventional values for ε, ε_f and the depreciation rate δ.[16]

The model performs best when a high value is assigned to ν, ζ_x and β_1, the elasticities of trade, foreign demand and commodities in wholesale output, respectively. Similar difficulties were encountered by Adolfson et al. (2007), although as

[15] See UNCTAD (2019).

[16] As is well known, to a first order approximation ε plays no role in the solution of the model.

Table 2
Calibrated parameters.

Parameter	Description	Value
β	Discount factor	0.9927
σ	Elasticity matches with respect to unemployment	0.5
n	Steady state aggregate employment	0.9
n_1/n	Steady state employment share in wholesale sector	0.85
n_2/n	Steady state employment share in commodity sector	0.15
$\bar{q}$	Steady state vacancy filling rate	0.7
ε	Elasticity of substitution (domestic good)	11
ε_f	Elasticity of substitution (imported good)	11
δ	Depreciation rate	0.025
$\bar{\Pi}$	Steady state inflation	1
ν	Trade elasticity	4
$\frac{Y^x}{gdp}$	Merchandise exports to GDP ratio	0.065
$\frac{G}{Y}$	Government spending to GDP ratio	0.15
$\rho_{p_{2,1}}$	AR(1) coefficient on commodity prices	1.125
$\rho_{p_{2,2}}$	AR(2) coefficient on commodity prices	−0.35
$\bar{m}$	Matching function efficiency (implied)	0.79
b/w	Replacement ratio (as proportion of real wage)	0.4
κ	Hiring costs parameter (implied)	7
γ	Workers' share of total surplus(implied)	0.53
α_1	Output elasticity of capital in wholesale sector (implied)	0.37
γ_1	Output elasticity of labour in wholesale sector (implied)	0.53
α_x	Export function parameter (implied)	0.20
α_d	Home bias parameter (implied)	0.90
α_2	Output elasticity of capital in commodity sector	0.33
ζ_x	Foreign elasticity of demand for domestic good	6
β_1	Commodity weight in wholesale production	0.1
h	Degree of habits	0
Ψ	Weight on labour in utility function (implied)	1.35

Obstfeld and Rogoff (2000) note, high estimates of substitution elasticities are often found in microeconomic data. Similarly, the estimation tended to very low values of the job separation rate so this was fixed to 0.6, which is just slightly lower than that used by Kirchner and Tranamil (2016). For α_2, the elasticity of commodity output with respect to capital, we assign the value 0.33, which then pins down the rest of the model's parameters.[17] We set aggregate hiring costs in steady state to 1% of GDP, as in Gertler and Trigari (2009) and Blanchard and Galí (2010), which then implies a value of 7 for κ. These parameters are summarised in Table 2.

Our econometric methodology for the remaining structural parameters, stacked into the vector Θ, involves selecting these to minimise the distance between the impulse responses of the panel SVAR and those of the log-linear version of the DSGE model, as in Bodenstein et al. (2018); García-Cicco and Kawamura (2015) and Ilori et al. (2022).[18] However, unlike these authors, we follow Christiano et al. (2016) in using a Bayesian approach to impulse response matching. Let Θ be the vector of parameters to be estimated; $\hat{\psi}$ denote the vector of the estimated impulse responses and define the diagonal matrix containing the variances of the IRFs as V,

Then, the Bayesian posterior of Θ conditional on $\hat{\psi}$ and V is

$$f(\Theta \mid \hat{\psi}, V) = \frac{f(\hat{\psi} \mid \Theta, V)p(\Theta)}{f(\hat{\psi} \mid V)}$$

An important feature of the approach is that a larger weight is placed on the impulse responses that are more precisely estimated. We select the first nine periods following the commodity price shock. This is motivated by the fact that the impulse responses for the variables of interest cease to be significant after this horizon. We use a Markov Chain Monte Carlo algorithm to obtain the posterior distribution of the parameters.

Table 3 shows the priors along with the posterior mode and 95% probability intervals. We set a higher mean prior for investment adjustment costs in the commodity sector following Fornero et al. (2014), while the Calvo stickiness parameters as well as the degrees of indexation in both the domestic and imported good sectors are set at relatively low values. The prior for the interest rate premium elasticity (χ) lies between those obtained by Bodenstein et al. (2018) and Drechsel et al. (2019), while those for the parameters in the interest rate rule are fairly standard. We set a low value for ϕ_{p_2}, which could be interpreted as modest reaction towards stabilising sectoral outputs.

[17] The degree of habits is set to zero as it has no effects on the model dynamics for the observables that we consider.
[18] The model is linearised around a zero (net) inflation steady state.

Table 3
Estimated parameters.

Parameter	Description	Prior distribution $\mathcal{D}$, mean and std.	Posterior distribution Mode, [2.5–97.5%] M^*	Model with $\phi_{p_2} = \xi_{p,2} = 0$	Full model	Competitive labour market
ρ_r	Interest rate smoothing	Beta, 0.6, 0.05	0.60, [0.52, 0.71]	0.61, [0.51, 0.69]	0.59, [0.51, 0.70]	0.95, [0.86, 0.99]
ϕ_π	Interest rate rule (inflation)	Normal, 1.4, 0.1	1.37, [1.16, 1.58]	1.38, [1.17, 1.55]	1.41, [1, 16, 1.57]	1.71, [1.01, 2.29]
ϕ_y	Interest rate rule (output)	Normal, 0.125, 0.05	0.16, [0.07, 0.25]	0.13, [0.05, 0.23]	0.16, [0.07, 0.25]	0.08, [0.00, 0.17]
ϕ_{p_2}	Interest rate rule (commodity price)	Normal, −0.02, 0.01	−0.01 [−0.01, −0.0]	–	−0.01, [−0.01, −0.0]	−0.02, [−0.04, −0.0]
ζ	Degree of indexation (home good)	Beta, 0.55, 0.2	0.60, [0.14, 0.88]	0.47, [0.13, 0.88]	0.62, [0.15, 0.88]	0.47, [0.10, 0.84]
ζ_f	Degree of indexation (imported good)	Beta, 0.55, 0.2	0.46, [0.15, 0.87]	0.54, [0.23, 0.92]	0.68, [0.29, 0.95]	0.39, [0.09, 0.75]
ω	Calvo parameter (home good)	Beta, 0.55, 0.1	0.51, [0.38, 0.76]	0.52, [0.37, 0.74]	0.61, [0.39, 0.79]	0.60, [047, 0.82]
ω_f	Calvo parameter (imported good)	Beta, 0.55, 0.1	0.55, [0.38, 0.73]	0.59, [0.40, 0.74]	0.62, [0.42, 0.76]	0.84, [0.73, 0.90]
ϕ_1	Investment adjustment costs in wholesale sector	Gamma, 2, 0.5	1.70, [0.83, 2.75]	2.17, [1.24, 3.15]	1.42, [0.86, 2.81]	1.90, [0.80, 2.76]
ϕ_2	Investment adjustment costs in commodity sector	Gamma, 1.2, 0.5	0.27, [0.12, 0.77]	0.15, [0.10, 0.18]	0.29, [0.12, 1.08]	0.36, [0.17, 0.83]
χ	Interest rate premium elasticity	Normal, 1.6, 0.7	1.67, [0.77, 2.70]	1.49 [0.78, 2.79]	0.78, [0.13, 2.08]	2.48, [1.58, 3.33]
ξ_{p_2}	Risk premium elasticity to commodity prices	Normal, −0.15, 0.8	–	–	−0.04, [−0.1, −0.0]	–
ϕ	Inverse labour supply elasticity	Gamma, 2, 0.5	–	–	–	2.8, [2.01, 3.18]
	Log marginal likelihood (MCMC)		148.5451	146.9093	147.0864	94.66

Notes: The results are based on 500,000 draws from the posterior distribution using the Metropolis-Hastings algorithm and dropping the first 250,000 draws in order to achieve convergence. M^*, the preferred model, sets $\xi_{p_2} = 0$ so that the risk premium is not directly affected by commodity prices. The full model estimates both ϕ_{p_2} and $\xi_{p,2}$, while the competitive labour market model uses one observable less, the unemployment rate, in the estimation.

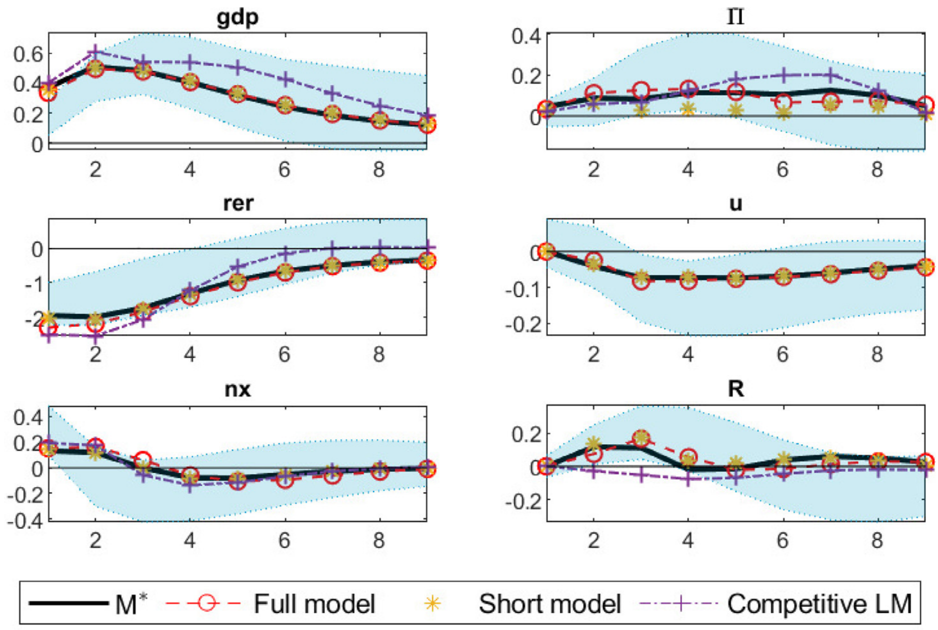

Fig. 5. Impulse responses to a commodity price shock. *Note:* The figure plots the impulse responses using the estimated parameters shown in Table 3. M^* includes commodity prices in the interest rate rule; 'Full Model' also includes commodity prices in the risk premium equation; 'Short Model' includes neither and 'Competitive Labour Market' estimates a version of the model without search and matching frictions. The shaded areas represent 95% confidence bands from the estimated VAR.

4.1. Performance of the model

Our objective is to provide an interpretation of the estimated impulse response functions with the aid of a DSGE model where we have used a Bayesian approach to estimate the model's parameters. In doing so, we consider the full model and present the results for three other variants: a version where commodity prices do not directly influence the risk premium ($\xi_{p_2} = 0$) nor the monetary policy rule ($\phi_{p_2} = 0$); one where the $\xi_{p_2} = 0$, and as further check, we also estimate the model assuming a competitive labour market. For this latter case, the period utility function becomes

$$U_t = \log\left(c_t - hc_{t-1}\right) - \Psi \frac{n_t^{1+\phi}}{1+\phi} \tag{54}$$

Which gives rise to the first order conditions

$$\Psi \frac{n_t^{\phi}}{\lambda_t} = p_{j,t} mpn_{j,t} \quad j \in \{1,\ 2\}$$

The results from estimating the different models are shown in Table 3 and the corresponding impulse responses are shown in Fig. 5. The first thing to note is that there is strong statistical evidence in support of the search and matching model (all three variants) over the competitive labour market (CL) model. The log marginal likelihood for M^* – which excludes the ξ_{p_2} so that the risk premium is not directly affected by commodity price shocks – is 148.5451. Integrating out unemployment in order to have the same set of observables as the CL model implies the result would be a log marginal likelihood no smaller than this number, which is 53.9 log points larger than the measure obtained from the CL model. It is noteworthy that despite the use of different models and observables, Christiano et al. (2016) and Guerra-Salas et al. (2021) also find strong support for the search and matching model. In our case, the CL model qualitatively matches the responses of the commodity price shock bar for the nominal interest, while also implying too strong a reaction of the real exchange rate.

Turning to the three models with search and matching frictions, the estimated parameters are not particularly dissimilar across models. Relative to the standard Taylor rule, the coefficient on output is slightly larger in all three versions. There is also a non-negligible degree of inflation persistence in the home and imported good sectors, measured by the indexation parameters ζ and ζ_f, which is over 0.4 across the different models. The Calvo stickiness parameters for these two sectors suggest that prices are adjusted on average around every two quarters, which is similar to the value obtained by Bils and Klenow (2004). It is also worth noting that Guerra-Salas et al. (2021) find that the estimated investment adjustment cost parameter is substantially lower when the model includes search and matching frictions in the labour market as opposed to the standard specification. They reason that the introduction of search and matching acts as substitute for frictions in capital. Our results do not indicate this, as the values of ϕ_1 and ϕ_2 do not differ substantially across models but it is worth noting that commodity output in Guerra-Salas et al. (2021) is modelled as an endowment.

The best performance is provided by the model where commodity prices enter the policy rule, M^*, as it results in a log marginal density that is 1.6 and 1.4 points larger than the model with fewer features ($\phi_{p_2} = \xi_{p_2} = 0$) and the model that also estimates ξ_{p_2}, respectively. As can be gleaned from Fig. 5, the former overstates the responses of net exports and understates that of inflation, whereas the full model leads to too strong a response of both net exports and the real exchange rate. In this regard, our results are consistent with those in Fernández et al. (2018), who conclude that the effect of commodity prices on interest spreads is quantitatively unimportant. Nonetheless, the preferred model produces a response of nominal interest rates slightly more muted than that estimated by the VAR and all models imply an excessive initial response of output.

In what follows, we restrict our discussion to model M^* as it is the one with the best relative empirical performance. Qualitatively, the model replicates the responses to a commodity price shock in the SVAR remarkably well and the implied IRFs are generally inside the estimated error bands. The model matches the key results that an increase in commodity prices leads to an increase in output, inflation, the trade balance and the nominal interest rate, while the real exchange rate appreciates and the unemployment rate falls. The model also provides a good account of the estimated dynamics, with many of the peak responses occurring after a lag. Quantitatively, the model slightly over-estimates the real exchange rate responses in the initial periods after the shock but otherwise lie within the estimated error bands.

The model attributes the delayed dynamics of the impulse responses to several sources of endogenous persistence. The degree of indexation in the domestic good sector is estimated at a fairly high value of 0.60 and the investment adjustment costs parameter in the wholesale sector implies a gradual response to the shock. In addition, although the monetary authority responds strongly to inflation, the backward-looking specification along with the interest rate smoothing parameter of 0.60 leads to a modest initial response of interest rates.

In order to understand the dynamics implied by the model in response to a shock to commodity prices, it is important to note that there are three key mechanisms that are simultaneously interacting. The shock results in a positive wealth effect; it induces a more expansionary monetary policy via ϕ_{p_2} but it also raises the costs for domestic producers given that commodities enter the production function.

The first two channels imply that the commodity price increase stimulates domestic expenditure and a re-allocation of resources from the home tradable good to the commodity sector. Moreover, the last two mechanisms are inflationary in response to the shock; absent these, the real exchange rate appreciation caused by the commodity price increase would be deflationary, as will be shown below.

5. Inspecting the mechanism

The model contains some features of a Dutch disease effect, in that the commodity price shock leads to an expansion in that sector at the expense of the domestic tradable good. Our theoretical and empirical results extend the work of Bodenstein et al. (2018); García-Cicco and Kawamura (2015) and Kohn et al. (2021) in that we are also able to assess the consequences for both inflation and nominal interest rates. Houssa et al. (2022) estimate a small open economy New Keynesian model with financial frictions on Canadian and South African data using Bayesian methods. Although they include endogenous production in the commodity sector, they do not consider unemployment in their analysis nor do they attempt to compare the implications of their model with those obtained from a VAR.

Moreover, we shed new light on the role of monetary policy in the transmission of the commodity price shock. The impulse leads to a positive wealth effect and to an increase in desired domestic expenditure while also leading to a sharp real exchange rate appreciation. As a result, although output and employment in the commodity sector expand, the reverse occurs in the domestic tradable good sector. Nonetheless, the expansionary effect of the former is sufficient to result in an increase in net exports, employment and GDP. One way of measuring the Dutch disease is to measure the peak contraction in employment in the domestic tradable sector, conditional on the commodity price shock. The results of this exercise, along with the implied measure obtained from other papers, are shown in Panel C in Table 1.[19]

A sharp increase in the international commodity price that raises $p_{2,t}mpn_{2,t}$ and lowers $p_{1,t}mpn_{1,t}$ thus increasing (decreasing) the profitability of the commodity (domestic good) sector.[20] As a consequence, this induces a sectoral allocation of employment (and investment) away from the domestic tradable good towards the commodity sector.

In understanding the empirical performance of differerent features of the model as shown in Fig. 5 we estimated each model separately. However, in order to gain some intuition regarding the impulse responses implied by a specific model (M^*), as well as to understand why each of the features described above are necessary for matching the data, we consider the effects of altering one parameter whilst maintaining all others unchanged from their estimated values.

Monetary policy is directly affected by the presence of commodity prices in the interest rule, via ϕ_{p_2} and the effects of switching this channel off are shown in Figs. 6 and 7. Although the difference for many of the observables is negligible, with

[19] The magnitudes in the cited papers are approximate as these had to be calculated from the implied responses. This is also the reason we considered employment as opposed to output in the tradable sector given that few papers provide a quantitative measure of the latter.

[20] In an earlier version of this paper hiring costs were functions of aggregate hiring, which resulted in wage equalisation across sectors and implied $p_{1,t}mpn_{1,t} = p_{2,t}mpn_{2,t}$.

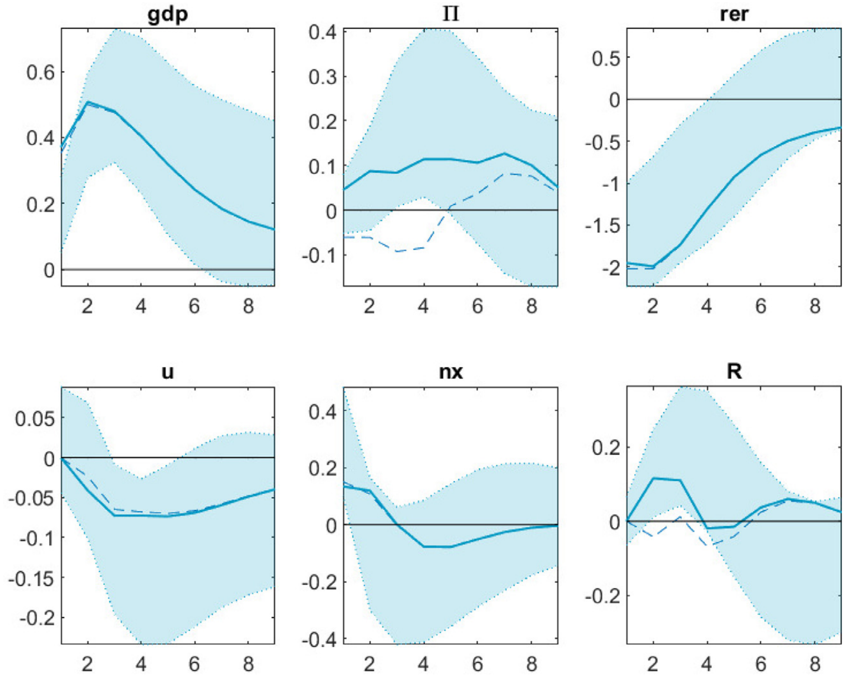

Fig. 6. Shock to commodity prices for different values of ϕ_{p_2}. *Note:* The simulation takes the calibrated and estimated parameters from Tables 2 and 3 (solid line), while the dashed line shows impulse responses with $\phi_{p_2} = 0$. This parameter represents the coefficient on commodity prices in the interest rate rule. The shaded areas represent 95% confidence bands from the estimated VAR.

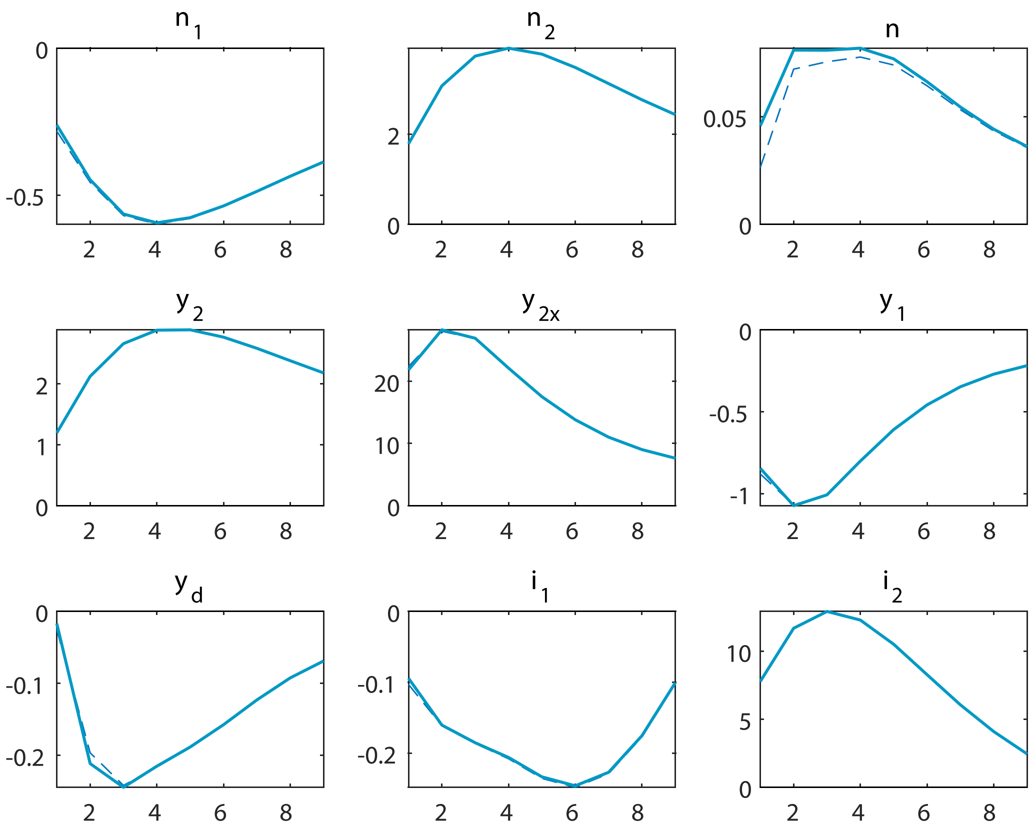

Fig. 7. Shock to commodity prices for different values of ϕ_{p_2}. See notes to Fig. 6. n_j and i_j represent employment and investment in sector j, respectively. w represents the real wage; y_j is output in commodity j for $j \in \{1, 2\}$. The subscript 1 (2) denotes the home tradable (commodity) sector. Commodity exports are y_{2x}, y_w is domestic tradable output and y_d is domestic expenditure on the home tradable good.

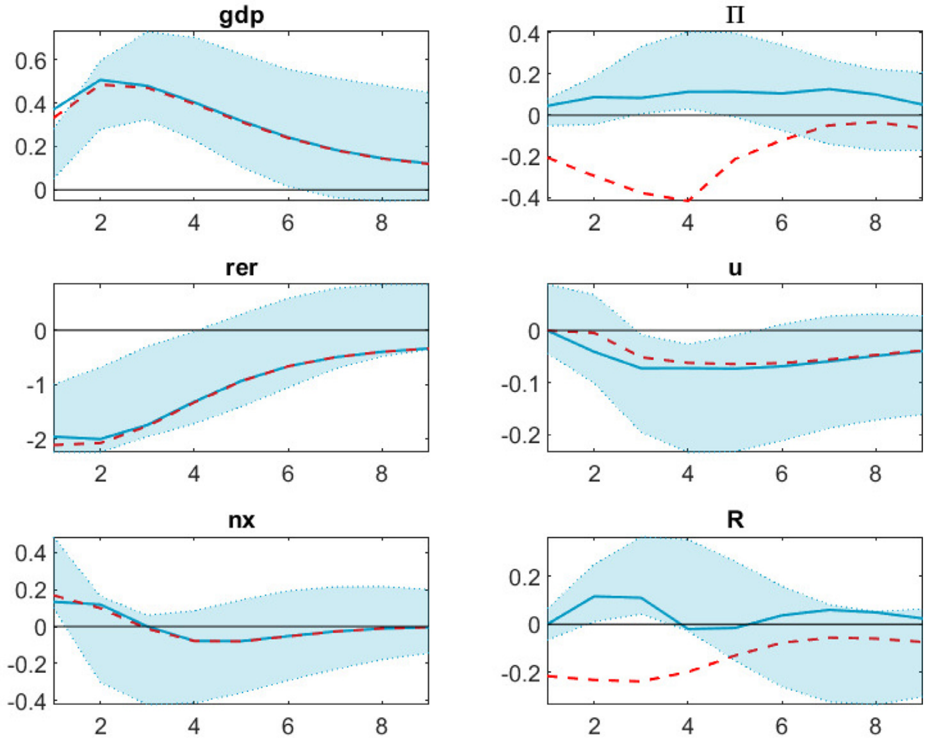

Fig. 8. Shock to commodity prices with Taylor rule. *Note:* The simulation takes the calibrated and estimated parameters from Tables 2 and 3 (solid line), while the dashed line shows impulse responses with the interest rate rule $\frac{R_t}{R} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{0.7}\left[\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{1.5}\left(\frac{gdp_t}{gdp}\right)^{0.125}\right]^{0.3}$. The shaded areas represent 95% confidence bands from the estimated VAR.

$\phi_{p_2} = 0$ the commodity price shock becomes deflationary and the interest rate falls. despite the small estimated value for this parameter, the size of the shock and its estimated dynamics imply that the increase in commodity prices is accompanied by expectations of a further increase in the following period.[21] This leads to a large wealth effect and the persistent reaction of both inflation and interest rates. Although quantitatively small, the presence of ϕ_{p_2} also implies in a slightly larger decline in unemployment as the contraction in the tradable good sector, where most of the employment is located, is now smaller. Therefore, the inclusion of $\phi_{p_2} < 0$ in the policy rule can be interpreted as attempts by the monetary authority to ameliorate the adverse impacts of commodity price shocks on tradable sector employment. Overall, despite being quantitatively small, the parameter ϕ_{p_2} has a strong influence on the model's dynamics. In this regard, Lama and Medina (2012) evaluates the welfare consequences of a Dutch disease episode using a New Keynesian model that is parameterised on Canadian data. Their inclusion of a learning by doing externality in the tradable sector provides a role for stabilising the exchange rate in response to the shock.

It is instructive to also compare the estimated model with one where monetary policy follows a Taylor-type rule. As a simple example, we assume that interest rates follow

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{0.8}\left[\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{1.5}\left(\frac{gdp_t}{gdp}\right)^{0.125}\right]^{0.2} \tag{55}$$

As shown in Figs. 8 and 9, this modification results ina larger contraction in inflation and a more muted response of the unemployment rate, while the trade surplus increases, driven by commodity exports. As the decrease in tradable employ-

[21] The reason for including commodity prices in the interest rate rule and not other variables, such as the real exchange rate is empirical. We experimented with different specifications but they all performed very poorly when attempting to match the estimated impulse response functions. Part of the reason lies in the fact that commodity prices are modelled as AR(2) process and exhibits a hump-shaped response to the shock.

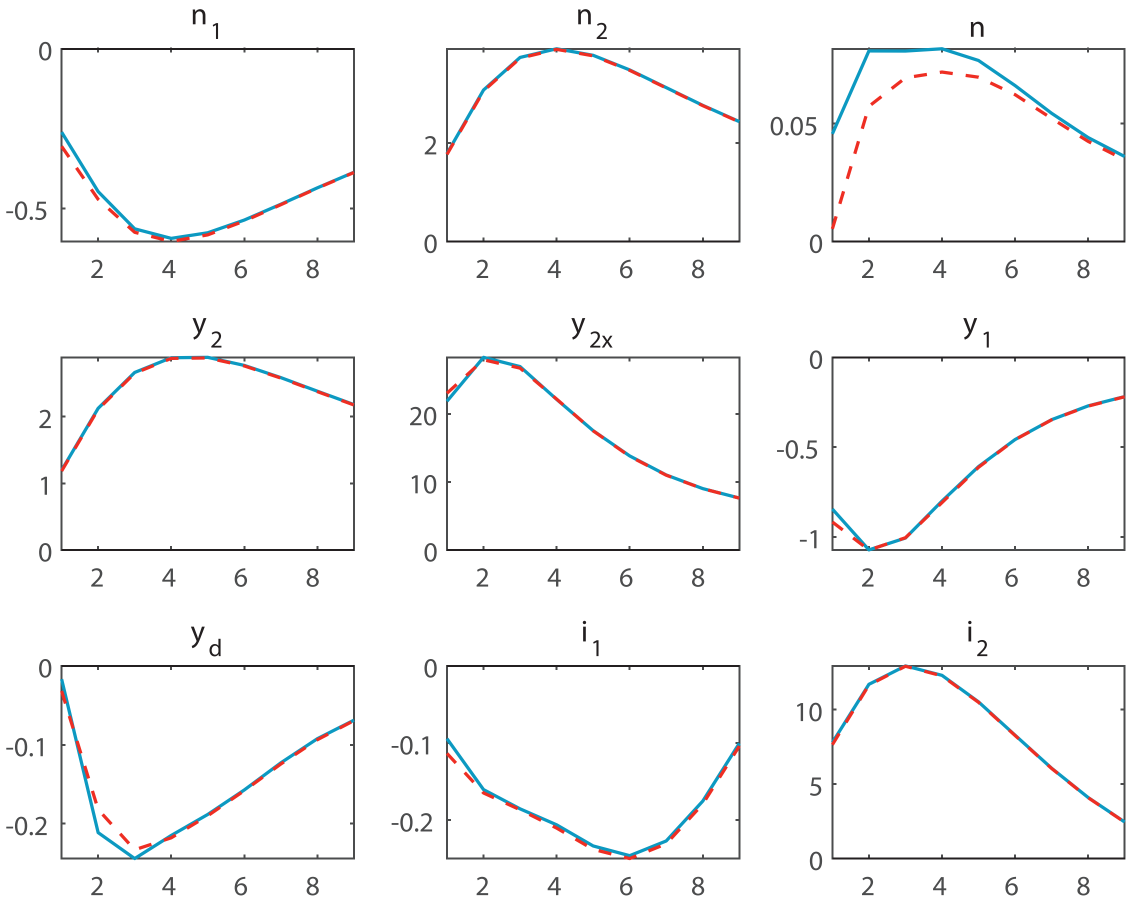

Fig. 9. Shock to commodity prices with Taylor rule. See notes to Fig. 8. n_j and i_j represent employment and investment in sector j, respectively. w represents the real wage; y_j is output in commodity j for $j \in \{1, 2\}$. The subscript 1 (2) denotes the home tradable (commodity) sector. Commodity exports are y_{2x}, y_w is domestic tradable output and y_d is domestic expenditure on the home tradable good.

ment is slightly more pronounced, the commodity price shock leads to a lower reduction in the unemployment rate whilst on impact, overall employment hardly responds.[22]

One key result that emerges from this part of the analysis is that while monetary policy matters for the dynamics of unemployment, whether a commodity price shock is inflationary is contingent on the policy rule. Moreover, the model suggests that symptoms of the Dutch disease following commodity price shocks are affected by the behaviour of monetary policy. By directly responding to commodity price movements, the central bank limits the volatility in the wholesale sector, conditional on shocks to commodity prices.[23] Therefore, models that rely solely on real variables, such as Bodenstein et al. (2018); García-Cicco and Kawamura (2015) and Drechsel and Tenreyro (2018), omit a potentially important channel through which commodity prices transmit in an economy.

The analysis above highlights the important role that the real exchange rate plays in enabling the model to match the impulse responses. Factors that attenuate the real exchange rate appreciation, such as relatively high (low) values of β_1 (ϕ_{p_2}), produce stronger increases in inflation alongside reductions in the unemployment rate as well as limiting the jump in net exports.

To summarise, our theoretical model provides a rationale for the evidence presented in Section 2 regarding the macroeconomic effects of a shock to commodity prices. But in order to match the estimated impulse responses, the DSGE model requires all three of the mechanisms discussed above to be present.

[22] An interesting feature of this analysis is that the commodity price shock produces an overall decline in the nominal interest rate despite its formulation being more aggressive towards inflation and output. However, it is this more hawkish response that produces more stable inflation and output, which then requires a more moderate increase in interest rates.

[23] Interestingly, Hevia and Nicolini (2014) suggest that in the presence of price frictions the Dutch disease reflects the optimal response to a relative price shock, rather than something that should be attenuated.

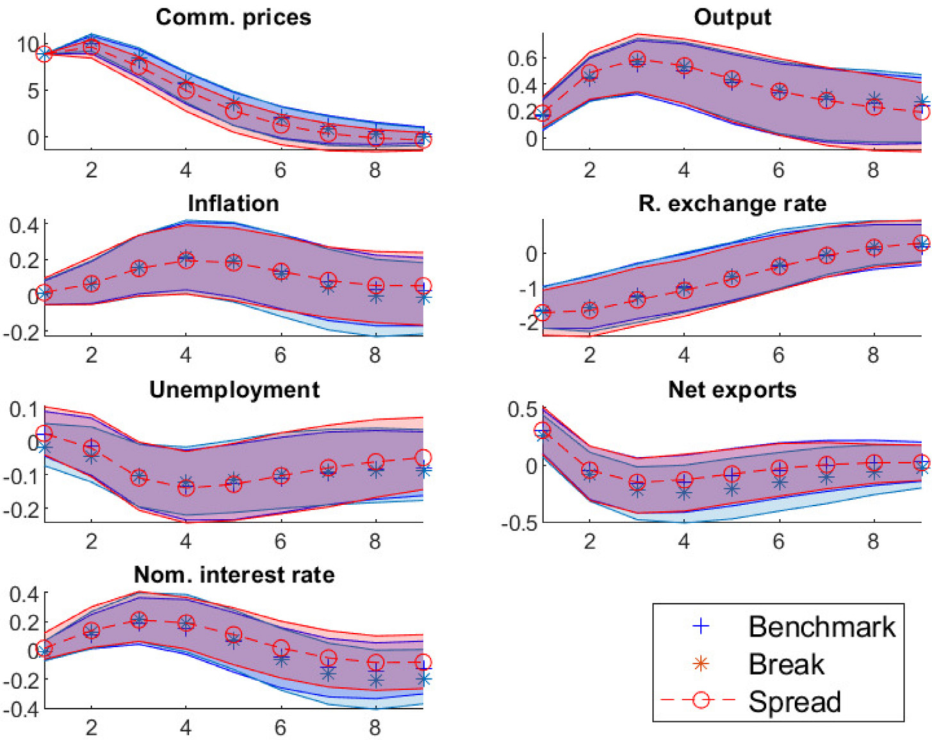

Fig. 10. SVAR impulse responses: robustness checks. See notes to Fig. 3. Estimated impulse responses to commodity price shock under different specifications: the line with the '+' sign and confidence bands represent the benchmark model; the line with asterisks allows for a break in the unconditional mean in the commodity price for Chile; the dashed-dotted line are the estimates from a VAR that includes the interest rate spread.

6. Conclusion

In this paper we estimate a structural panel vector autoregression to quantify the impacts of commodity price shocks in emerging small open economies. The shock is expansionary, with output, the trade balance and inflation all increasing while unemployment falls and the real exchange rate appreciates. The economy responds to the increase in commodity prices with a lag. To understand these dynamics we develop a New Keynesian small open economy DSGE model with search and matching frictions in addition to a commodity-producing sector. The model is then taken to the data by matching the impulse responses from the VAR with those from the model using Bayesian methods. We find that the specific form of the monetary policy rule is an important element of the transmission mechanism. The magnitude of Dutch disease effects, if present, is partly a policy choice. By directly responding to commodity prices, the central bank can limit the contraction to the domestic non-commodity sector which, by virtue of being larger, is a key determinant of the behaviour of unemployment.

Appendix A

A1. Value of employment to the household

Let $V_{j,t}(i)$ be value to the household of employment in sector j, in consumption goods. This equals the real wage plus the discounted expected continuation value of employment in addition to the expected value of unemployment if the match comes to an end

$$V_{j,t}(i) = w_{jt} + \Lambda_{t,t+1}\left[(1-\rho)V_{j,t+1} + \rho U_{t+1}\right]$$

Similarly, the value of unemployment is the current benefit plus the discounted expected value of finding a job in either sector as well as the continuation value of remaining unemployed in the next period

$$U_t = b + \Lambda_{t,t+1}[s_{1,t+1}V_{1,t+1} + s_{2,t+1}V_{2,t+1} + (1-s_{t+1})U_{t+1}]$$

where $s_{j,t}$ is the probability of a searching worker finding a job in sector j. As we assume that job searchers are randomly matched with vacancies from either sector and linear homogeneity in the matching function, $s_t = s_{1,t} + s_{2,t}$ and

$$s_t = \frac{m_t}{u_t} = s_t\left(\frac{v_{1,t} + v_{2,t}}{v_t}\right)$$

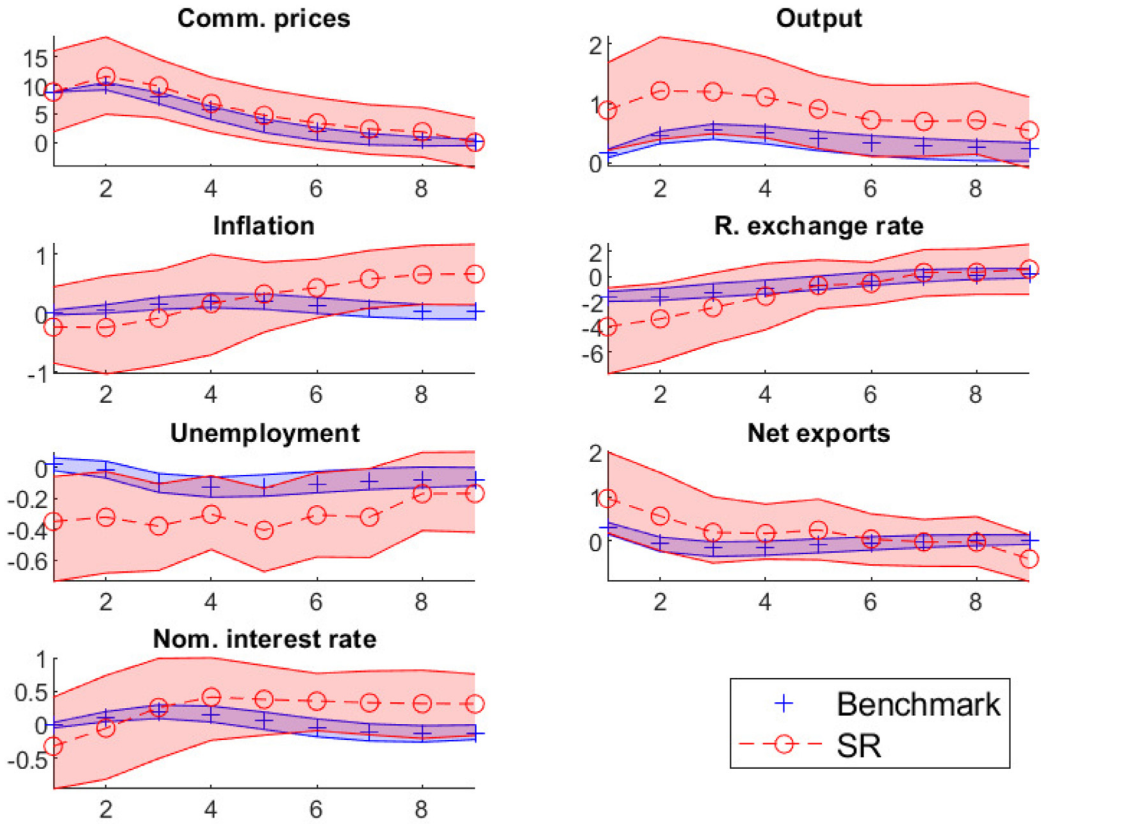

Fig. 11. SVAR impulse responses: further robustness checks. See notes to Fig. 3. Estimated impulse responses to commodity price shock under different specifications: the blue line and 95% confidence bands represent the benchmark model while those in red were obtained from estimating the VAR with sign restrictions. The imposed restrictions, lasting one period, are that the commodity price shock increases commodity prices, GDP and the trade balance, while reducing the unemployment rate and appreciating the real exchange rate. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The net worker surplus from employment in sector j is then

$$\mathcal{W}_{j,t} = V_{j,t} - U_t = w_{j,t} - b + \beta E_t \frac{\lambda_{t+1}}{\lambda_t}\left[(1-\rho)V_{j,t+1} - (1-\rho-s_{t+1})U_{t+1} - \sum_{l=1,2} s_{l,t+1}V_{l,t+1}\right]$$

$$\mathcal{W}_{j,t} = w_{j,t} - b + \beta E_t \frac{\lambda_{t+1}}{\lambda_t}\left[(1-\rho)\mathcal{W}_{j,t+1} - \sum_{l=1,2} s_{l,t+1}\mathcal{W}_{l,t+1}\right] \tag{56}$$

A2. Wage determination

Nash barganing implies that for sector j

$$\gamma J_{j,t} = (1-\gamma)\mathcal{W}_{j,t} \tag{57}$$

We also found that the value of employment is equal to the marginal cost of hiring

$$J_{j,t} = \kappa x_{j,t} \tag{58}$$

Combining (57) and (58)

$$\gamma\kappa x_{j,t} = (1-\gamma)\mathcal{W}_{j,t} \tag{59}$$

and using this in (56) we obtain

$$\gamma\kappa x_{j,t} = (1-\gamma)\big(w_{j,t} - b\big) + \gamma\beta E_t \frac{\lambda_{t+1}}{\lambda_t}\left[(1-\rho)\kappa x_{j,t+1} - \sum_{l=1,2} s_{l,t+1}\kappa x_{l,t+1}\right] \tag{60}$$

Replacing $\kappa x_{j,t}$ with the right hand side of (21) and simplifying yields the wage Eq. (27) presented in the main text.

Table 4
Contribution of commodity shocks to overall variance in the benchmark SVAR.

	Commodity prices	GDP	Inflation	Real exchange rate	Unemployment	Net exports	Nominal interest rate
Commodity price shocks	100	20.6	5	13.8	8	3.1	4.5

Note: shares expressed as percentages.

Table 5
Equilibrium conditions.

Description	Model equation	
Marginal utility c_t	$\lambda_t = \frac{\epsilon_t}{c_t - hc_{t-1}} - \beta E_t \frac{\epsilon_{t+1}}{c_{t+1} - hc_t}$	[i]
Consumption Euler equation	$\lambda_t = \beta E_t \left[\frac{\lambda_{t+1} R_t}{\Pi_{t+1}} \right]$	[ii]
Unemployment	$u_t = 1 - n_{1,t-1} - n_{2,t-1}$	[iii]
Matching function	$m_t = \bar{m} u_t^{\sigma} (v_{1,t} + v_{2,t})^{1-\sigma}$	[iv]
Job-filling probability	$q_t = \frac{m_t}{v_{1,t} + v_{2,t}}$	[v]
Job-finding probability	$s_t = \frac{m_t}{u_t}$	[vi]
Tightness	$\theta_t = \frac{v_{1,t} + v_{2,t}}{u_t}$	[vii]
Hiring rate	$x_t = \frac{m_t}{n_{t-1}}$	[viii]
Workforce	$n_{1,t} + n_{2,t} = (1-\rho)(n_{1,t-1} + n_{2,t-1}) + m_t$	[ix]
Firm's hiring decisions	$\kappa x_{j,t} = p_{j,t} mpn_{j,t} - w_{j,t} + \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \left[(1-\rho)\kappa x_{j,t+1}(i) + \frac{1}{2}\kappa x_{j,t+1}^2(i) \right]$	[x]
Commodity price process	$\ln\left(p_{2,t}^*/p_2\right) = 1.125 \ln\left(p_{2,t-1}^*/p_2\right) - 0.35 \ln\left(p_{2,t-2}^*/p_2\right) + \varepsilon_{p_{2t}^*}$	[xi]
Real marginal cost (domestic good)	$mc_{h,t} = \frac{p_{1,t}}{p_{h,t}}$	[xii]
gdp	$gdp_t = p_{h,t} y_{h,t} + rer_t p_{2,t}^* y_{2,t}^x$	[xiii]
Monetary policy	$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_r} \left[\left(\frac{\Pi_{t-1}}{\bar{\Pi}}\right)^{\phi_\pi} \left(\frac{gdp_{t-1}}{gdp_{t-2}}\right)^{\phi_y} \left(\frac{p_{2,t}}{p_2}\right)^{\phi_{p2}} \right]^{1-\rho_r}$	[xiv]
Net foreign asset position	$\frac{b^*}{\tilde{R}_t^*} = \frac{b_{t-1}^*}{\Pi_t^*} + \frac{p_{h,t}}{rer_t} y_{x,t} - y_{f,t} + \frac{p_{2,t}}{rer_t} y_{2x,t}$	[xv]
Domestic firm's output (hf)	$y_{h,t} = \frac{y_{w,t}}{\Delta_{h,t}}$	[xvi]
Domestic price level	$\Pi_{h,t}^{1-\varepsilon} = (1-\omega)\left(\tilde{p}_{h,t} \Pi_{h,t}\right)^{1-\varepsilon} + \omega \Pi_{h,t-1}^{\zeta(1-\varepsilon)}$	[xvii]
Wage equation	$w_{j,t} = \gamma p_{j,t} mpn_{j,t} + (1-\gamma) b + \gamma E_t \beta \frac{\lambda_{t+1}}{\lambda_t} \left[\frac{1}{2}\kappa x_{j,t+1}^2 + \kappa \sum_{l=\{1,2\}} s_{l,t+1} x_{l,t+1} \right]$	[xviii]
FOC investment	$q_{j,t}^k \left(1 - \Phi_{j,t}\right) = q_{j,t}^k \phi_j \left(\frac{i_{j,t}}{i_{j,t-1}} - 1\right)\left(\frac{i_{j,t}}{i_{j,t-1}}\right) - \beta E_t \frac{\lambda_{t+1}}{\lambda_t} q_{j,t+1}^k \phi_j \left(\frac{i_{j,t+1}}{i_{j,t}} - 1\right)\left(\frac{i_{j,t+1}}{i_{j,t}}\right)^2 + 1$	[xix]
Capital accumulation	$k_{j,t} = \left(1 - \Phi_{j,t}\right) i_{j,t} + (1-\delta) k_{j,t-1}$	[xx]
Inv. adjustment costs	$\Phi_{j,t} = \left(\frac{\phi_j}{2}\right)\left(\frac{i_{j,t}}{i_{j,t-1}} - 1\right)^2$	[xxi]
FOC capital	$q_{j,t}^k = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \left(r_{j,t+1}^k + 1 - \delta\right) q_{j,t+1}^k$	[xxii]
Rental rate of capital	$r_{j,t}^k = p_{j,t} \alpha_j \frac{y_{j,t}}{k_{j,t-1}}$	[xxiii]
Wholesale demand for commodities	$(1 - \alpha_1 - \gamma_1) p_{1,t} w_t \frac{y_t^w}{y_{21,t}} = p_{2,t}$	[xxiv]
RUIP	$\lambda_t = \beta E_t \lambda_{t+1} \left[rer_{t+1} \frac{\tilde{R}_t^*}{rer_t \Pi_{t+1}^*} \right]$	[xxv]
Uses of home good	$y_{h,t} = y_{d,t} + y_{x,t}$	[xxvi]
Demand for domestic exports	$y_{x,t} = \alpha_x \left(\frac{p_{h,t}}{rer_t}\right)^{-\zeta_x} y_t^*$	[xxvii]
Imported good price level	$\Pi_{f,t}^{1-\varepsilon} = \left(1 - \omega_f\right)\left(\tilde{p}_{f,t} \Pi_{f,t}\right)^{1-\varepsilon} + \omega_f \Pi_{f,t-1}^{\zeta_f(1-\varepsilon)}$	[xxviii]
Optimal re-set price ($j = \{h, f\}$)	$\left(\frac{\varepsilon-1}{\varepsilon}\right)\tilde{P}_{j,t} = \frac{\sum(\beta\omega)^i \frac{\lambda_{t+i}}{\lambda_t} Y_{h,t+i} P_{j,t+i}^{1+\varepsilon} A_{t,t+i}^{-\varepsilon} mc_{j,t+i}}{\sum(\beta\omega)^i \frac{\lambda_{t+i}}{\lambda_t} Y_{h,t+i} P_{j,t+i}^{\varepsilon} A_{t,t+i}^{1-\varepsilon}}$	[ixxx]
Domestic relative price	$\frac{p_{h,t}}{p_{h,t-1}} = \frac{\Pi_{h,t}}{\Pi_t}$	[xxx]
Imported good relative price	$\frac{p_{f,t}}{p_{f,t-1}} = \frac{\Pi_{f,t}}{\Pi_t}$	[xxxi]
CPI	$1 = \alpha_d p_{d,t}^{1-\nu} + (1-\alpha_d)\left(p_{t,}^f\right)^{1-\nu}$	[xxxii]
Demand domestic good	$y_{d,t} = \alpha_d \left(p_{h,t}\right)^{-\nu} Z_t$	[xxxiii]
Demand imported good	$y_{f,t} = (1-\alpha_d)\left(p_{h,t}\right)^{-\nu} Z_t$	[xxxiv]
Deviation LOP	$rer_t = \psi_{f,t} p_{f,t}$	[xxxv]
Uses of final good	$Z_t = c_t + i_t + G_t + \frac{1}{2}\kappa\left(x_{1,t}^2 n_{1,t-1} + x_{2,t}^2 n_{2,t-1}\right)$	[xxxvi]
Commodity production function	$y_{2,t} = A_{2,t} k_{2,t-1}^{\alpha_2} n_{2,t}^{1-\alpha_2}$	[xxxvii]
Marginal product of labour in commodity sector	$mpn_{2,t} = (1-\alpha_2) \frac{y_{2,t}}{n_{2,t}}$	[xxxviii]
Domestic commodity price	$p_{2,t} = rer_t p_{2,t}^*$	[xxxix]
Uses of commodity output	$y_{2,t} = y_{21,t} + y_{2,t}^x$	[xl]
Sectoral vacancies	$v_{2,t}(n_{1,t} - (1-\rho) n_{1,t-1}) = v_{1,t}(n_{2,t} - (1-\rho) n_{2,t-1})$	[xli]
Domestic good MPN	$mpn_{1,t} = \gamma_1 \frac{y_{1,t}}{n_{1,t}}$	[xlii]
Commodity sector MPN	$mpn_{2,t} = (1-\alpha_2) \frac{y_{2,t}}{n_{2,t}}$	[xliii]
Aggregate investment	$i_t = i_{1,t} + i_{2,t}$	[xliv]
Aggregate capital	$k_t = k_{1,t} + k_{2,t}$	[xlv]

Notes: $p_{h,t} = P_{h,t}/P_t$, $p_{f,t} = P_{f,t}/P_t$. Asterisks denote foreign variables and the j subscript represents the domestic wholesale (1) and commodity (2) sectors, respectively.

Table 6
Data definitions and sources.

Variables in VAR	Definition	Source
p_t^c	commodity export price	IMF (hyperlinked)
gdp_t	GDP	IMF's International Financial Statistics (IFS)
π_t	CPI inflation	IFS
u_t	Unemployment rate	IFS and national sources
nx_t	Trade balance-GDP ratio	IFS
rer_t	real exchange rate	Bank for International Settlements
R_t	Nominal interest rate	IFS

GDP is per capita, with the population series obtained from the World Bank. The nominal interest rate is the policy rate.

References

Adolfson, M., Laseen, S., Linde, J., Villani, M., 2007. Bayesian estimation of an open economy DSGE model with incomplete pass-through. J. Int. Econ. 72 (2), 481–511.
Agénor, P.R., 2016. Optimal fiscal management of commodity price shocks. J. Dev. Econ. 122 (C), 183–196.
Agénor, P.-R., Montiel, P.J., 2008. Development Macroeconomics, third ed. Princeton University Press.
Akinci, O., 2013. Global financial conditions, country spreads and macroeconomic fluctuations in emerging countries. J. Int. Econ. 91 (2), 358–371.
Andolfatto, D., 1996. Business cycles and labor-market search. Am. Econ. Rev. 86 (1), 112–132.
Arango Thomas, L.E., Chavarro, X., González, E., 2015. Commodity price shocks and inflation within an optimal monetary policy framework: the case of Colombia. Monetaria 0 (2), 203–249.
Ben Zeev, N., Pappa, E., Vicondoa, A., 2017. Emerging economies business cycles: the role of commodity terms of trade news. J. Int. Econ. 108 (C), 368–376.
Bils, M., Klenow, P.J., 2004. Some evidence on the importance of sticky prices. J. Polit. Econ. 112 (5), 947–985.
Blanchard, O., Galí, J., 2010. Labor markets and monetary policy: a new Keynesian model with unemployment. Am. Econ. J. 2 (2), 1–30.
Bodenstein, M., Kamber, G., Thoenissen, C., 2018. Commodity prices and labour market dynamics in small open economies. J. Int. Econ. 115 (C), 170–184.
Calvo, G.A., 1983. Staggered prices in a utility-maximizing framework. J. Monet. Econ. 12 (3), 383–398.
Camacho, M., Pérez-Quirós, G., 2014. Commodity prices and the business cycle in Latin America: living and dying by commodities? Emerg. Mark. Finance Trade 50 (2), 110–137.
Chang, R., 2014. Commodity price fluctuations and monetary policy in small open economies. In: Caputo, R., Chang, R. (Eds.), Commodity Prices and Macroeconomic Policy. Central Bank of Chile, pp. 19–50.
Christiano, L.J., Eichenbaum, M.S., Trabandt, M., 2016. Unemployment and business cycles. Econometrica 84 (4), 1523–1569.
Christiano, L.J., Trabandt, M., Walentin, K., 2011. Introducing financial frictions and unemployment into a small open economy model. J. Econ. Dyn. Control 35 (12), 1999–2041.
Di Pace, F., Hertweck, M., 2019. Labor market frictions, monetary policy, and durable goods. Rev. Econ. Dyn. 32, 274–304.
Di Pace, F., Juvenal, L., Petrella, I., 2020. Terms-of-Trade Shocks are Not All Alike. IMF Working Papers 2020/280. International Monetary Fund.
Diamond, P.A., 1982. Wage determination and efficiency in search equilibrium. Rev. Econ. Stud. 49 (2), 217–227.
Drechsel, T., McLeay, M., Tenreyro, S., 2019. Monetary policy for commodity booms and busts. CEPR Discussion Papers 14030, C.E.P.R. Discussion Papers.
Drechsel, T., Tenreyro, S., 2018. Commodity booms and busts in emerging economies. J. Int. Econ. 112 (C), 200–218.
Fernández, A., González, A., Rodríguez, D., 2018. Sharing a ride on the commodities roller coaster: common factors in business cycles of emerging economies. J. Int. Econ. 111 (C), 99–121.
Fornero, J., Kirchner, M., Yany, A., 2014. Commodity price fluctuations and monetary policy in small open economies. In: Caputo, R., Chang, R. (Eds.), Commodity Prices and Macroeconomic Policy. Central Bank of Chile, pp. 135–196.
García-Cicco, J., Kawamura, E., 2015. Dealing with the dutch disease: fiscal rules and macro-prudential policies. J. Int. Money Finance 55 (C), 205–239.
García-Cicco, J., Kirchner, M., 2015. Macroeconomic and financial interactions in Chile: An estimated DSGE approach.
García-Cicco, J., Kirchner, M., Carrillo, J., Rodríguez, D., Pérez, F., Gondo, R., Montoro, C., Chang, R., 2017. Financial and real shocks and the effectiveness of monetary and macroprudential policies in Latin American countries. BIS Working Papers 668, Bank for International Settlements.
García-Cicco, J., Kirchner, M., Justel, S., 2015. Domestic financial frictions and the transmission of foreign shocks in Chile. In: Raddatz, C., Saravia, D., Ventura, J. (Eds.), Global Liquidity, Spillovers to Emerging Markets and Policy Responses. In: Central Banking, Analysis, and Economic Policies Book Series, vol. 20. Central Bank of Chile, pp. 159–222.
García-Cicco, J., Pancrazi, R., Uribe, M., 2010. Real business cycles in emerging countries? Am. Econ. Rev. 100 (5), 2510–2531.
Gertler, M., Sala, L., Trigari, A., 2008. An estimated monetary DSGE model with unemployment and staggered nominal wage bargaining. J. Money, Credit Bank. 40 (8), 1713–1764.
Gertler, M., Trigari, A., 2009. Unemployment fluctuations with staggered Nash wage bargaining. J. Polit. Econ. 117 (1), 38–86.
Guerra-Salas, J., Kirchner, M., Tranamil, R., 2021. Search frictions and the business cycle in a small open economy DSGE model. Rev. Econ. Dyn. 39, 258–279.
Hevia, C., Nicolini, J.P., 2014. Monetary policy and Dutch disease: the case of price and wage rigidity. In: Caputo, R., Chang, R. (Eds.), Commodity Prices and Macroeconomic Policy. Central Bank of Chile, pp. 51–90.
Houssa, R., Mohimont, J., Otrok, C., 2022. Commodity Exports, Financial Frictions and International Spillovers. Federal Reserve Bank of Dallas. Globalization Institute Working Papers 419
Ilori, A.E., Paez-Farrell, J., Thoenissen, C., 2022. Fiscal policy shocks and international spillovers. Eur. Econ. Rev. 141, 103969.
Justiniano, A., Preston, B., 2010. Monetary policy and uncertainty in an empirical small open-economy model. J. Appl. Econom. 25 (1), 93–128.
Kirchner, M., Tranamil, R., 2016. Calvo Wages vs. Search Frictions: A Horse Race in a DSGE Model of a Small Open Economy. Central Bank of Chile. Working Papers Central Bank of Chile 778
Kohn, D., Leibovici, F., Tretvoll, H., 2021. Trade in commodities and business cycle volatility. Am. Econ. J. 13 (3), 173–208.
Kose, M.A., 2002. Explaining business cycles in small open economies: 'how much do world prices matter?'. J. Int. Econ. 56 (2), 299–327.
Lama, R., Medina, J.P., 2012. Is exchange rate stabilization an appropriate cure for the dutch disease? Int. J. Cent. Bank. 8 (1), 5–46.
Medina, J.P., Naudon, A., 2011. Labor Market Dyncamics in Chile: the Role of Terms of Trade Shocks. Central Bank of Chile. Working Papers Central Bank of Chile 637
Medina, J.P., Soto, C., 2016. Commodity prices and fiscal policy in a commodity exporting economy. Econ. Model. 59 (C), 335–351.
Mendoza, E.G., 1991. Real business cycles in a small open economy. Am. Econ. Rev. 81 (4), 797–818.
Mendoza, E.G., 1995. The terms of trade, the real exchange rate, and economic fluctuations. Int. Econ. Rev. 36 (1), 101–137.
Merz, M., 1995. Search in the labor market and the real business cycle. J. Monet. Econ. 36 (2), 269–300.
Monacelli, T., 2005. Monetary policy in a low pass-through environment. J. Money, Credit Bank. 37 (6), 1047–1066.
Mortensen, D.T., 1982. Property rights and efficiency in mating, racing, and related games. Am. Econ. Rev. 72 (5), 968–979.

Neumeyer, P.A., Perri, F., 2005. Business cycles in emerging economies: the role of interest rates. J. Monet. Econ. 52 (2), 345–380.
Obstfeld, M., Rogoff, K., 2000. The six major puzzles in international macroeconomics: is there a common cause? In: NBER Macroeconomics Annual 2000, Volume 15, NBER Chapters. National Bureau of Economic Research, Inc, pp. 339–412.
Ojeda-Joya, J.N., Parra-Polanía, J.A., Vargas, C.O., 2016. Fiscal rules as a response to commodity shocks: awelfare analysis of the Colombian scenario. Econ. Model. 52 (PB), 859–866.
Pieschacón, A., 2012. The value of fiscal discipline for oil-exporting countries. J. Monet. Econ. 59 (3), 250–268.
Pissarides, C.A., 1985. Short-run equilibrium dynamics of unemployment vacancies, and real wages. Am. Econ. Rev. 75 (4), 676–690.
Ravenna, F., Walsh, C.E., 2008. Vacancies, unemployment, and the Phillips curve. Eur. Econ. Rev. 52 (8), 1494–1521.
Ravn, M.O., Schmitt-Grohé, S., Uribe, M., 2012. Consumption, government spending, and the real exchange rate. J. Monet. Econ. 59 (3), 215–234.
Rees, D.M., Smith, P., Hall, J., 2016. A multi-sector model of the Australian economy. Econ. Rec. 92 (298), 374–408.
Roch, F., 2019. The adjustment to commodity price shocks. J. Appl. Econ. 22 (1), 437–467.
Schmitt-Grohé, S., Uribe, M., 2003. Closing small open economy models. J. Int. Econ. 61 (1), 163–185.
Schmitt-Grohé, S., Uribe, M., 2018. How important are terms of trade shocks? Int. Econ. Rev. 59 (1), 85–111.
Shousha, S., 2016. Macroeconomic effects of commodity booms and busts: the role of financial frictions. Unpublished Manuscript.
Smets, F., Wouters, R., 2003. An estimated dynamic stochastic general equilibrium model of the euro area. J. Eur. Econ. Assoc. 1 (5), 1123–1175.
Uhlig, H., 2005. What are the effects of monetary policy on output? Results from an agnostic identification procedure. J. Monet. Econ. 52 (2), 381–419.
UNCTAD, 2019. State of Commodity Dependence. Report. United Nations Conference on Trade and Development.
Uribe, M., Yue, V.Z., 2006. Country spreads and emerging countries: who drives whom? J. Int. Econ. 69 (1), 6–36.
Wolf, C.K., 2022. What can we learn from sign-restricted VARs? AEA Pap. Proc. 112, 471–475.