Commodity price shocks and macroeconomic dynamics

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20 May 2022

Abstract

We analyse the transmission mechanism of commodity price shocks in emerging economies. Using a panel vector autoregression, we find that the shock leads to 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 transmission mechanism can be understood using a dynamic stochastic general equilibrium model of a small commodity-exporting open economy with nominal as well as search and matching frictions. We find that the conduct of monetary policy is key to both the variables' dynamics as well as to the magnitude of Dutch disease effects.

JEL classifications: E31, E32, E44, E52, E61, F42, O11

Keywords: Commodity prices, emerging markets, inflation, monetary policy, search and matching, unemployment, Dutch disease, DSGE modelling.

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, 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 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 (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 three 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

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[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.

empirical results where the parameters are chosen 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, 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]

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. The bulk of the existing literature on commodity prices and emerging economies has relied on real models. Key exceptions are Chang (2014), Hevia and Nicolini (2014), Arango Thomas et al. (2015) and Drechsel et al. (2019), but these papers rely on calibrated models to analyse optimal monetary policy. Our model provides a potential rationale for understanding how the commodity price shock affects the dynamics of both inflation and unemployment as well as the role of monetary policy in potentially ameliorating or exacerbating the symptoms of the Dutch disease.

The model suggests that despite the increase in both GDP and inflation following the commodity price shock, the monetary policy response is initially muted. Indeed, upon impact the interest rate falls 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

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[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.

critical determinant for the magnitude of any Dutch disease symptoms.

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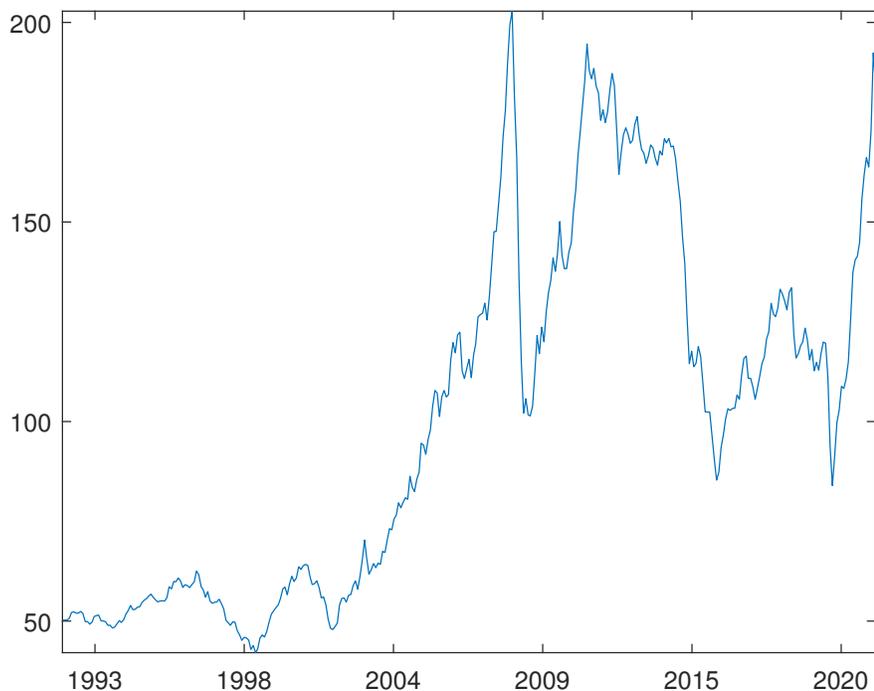
Raw commodity price series, 2016 = 100. Source: IMF primary commodity prices website.

2   Commodity price shocks: time series evidence

Our dataset consists of quarterly series for Brazil, Chile and South Africa from $2001Q3$ to $2015Q3$. Commodities represent the majority of merchandise exports for these three economies while they can still be regarded as having a negligible impact on world commodity prices, enabling identification of the shock.[3] 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 (T-bills) and a trade-weighted commodity price index expressed in dollars compiled by the IMF.[4]

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[3]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.

[4]See IMF.

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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 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).

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 three 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.

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.

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. As a result, we

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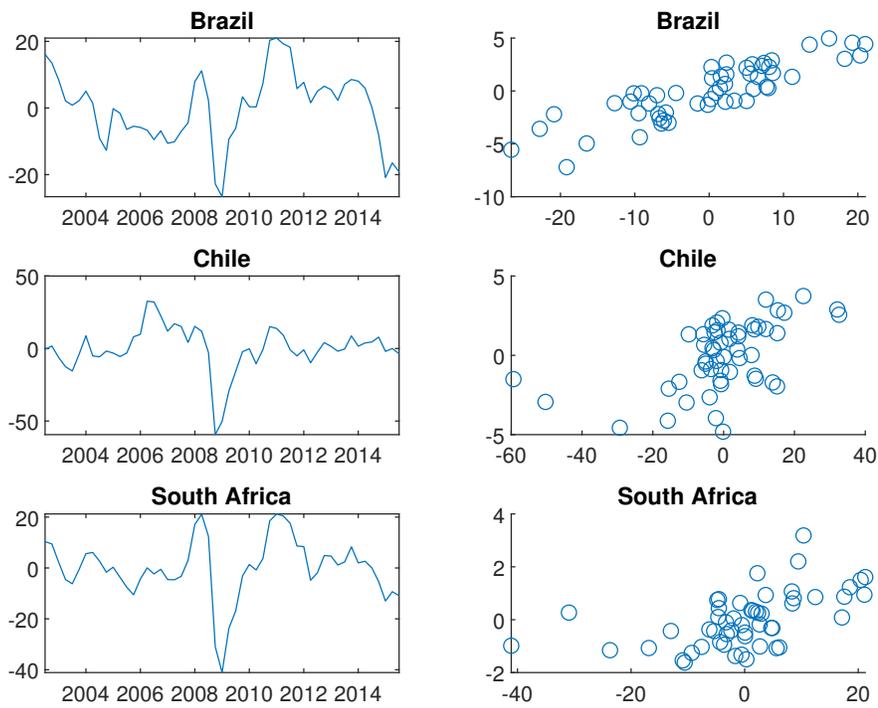
The figures on the left panel show commodity prices. The scatter plots on the right display commodity prices (horizontal axis) and output (vertical axis). All variables are in deviations from a quadratic trend.

order the commodity price first in the SVAR above and use a Cholesky decomposition to identify the commodity price shock, implying that country-specific shocks cannot affect commodity prices contemporaneously by assumption.[5] Moreover, we model prices for these goods as an AR(p) process so that all the elements on the first rows of $A(L)$ bar the first entries are set to zero.

The estimated impulse responses of the panel SVAR to a one standard deviation increase in commodity prices are shown in Figure 3 with the solid black lines, along with the 80% confidence bands, as in Drechsel and Tenreyro (2018).

Figure 3: Responses to commodity price shock
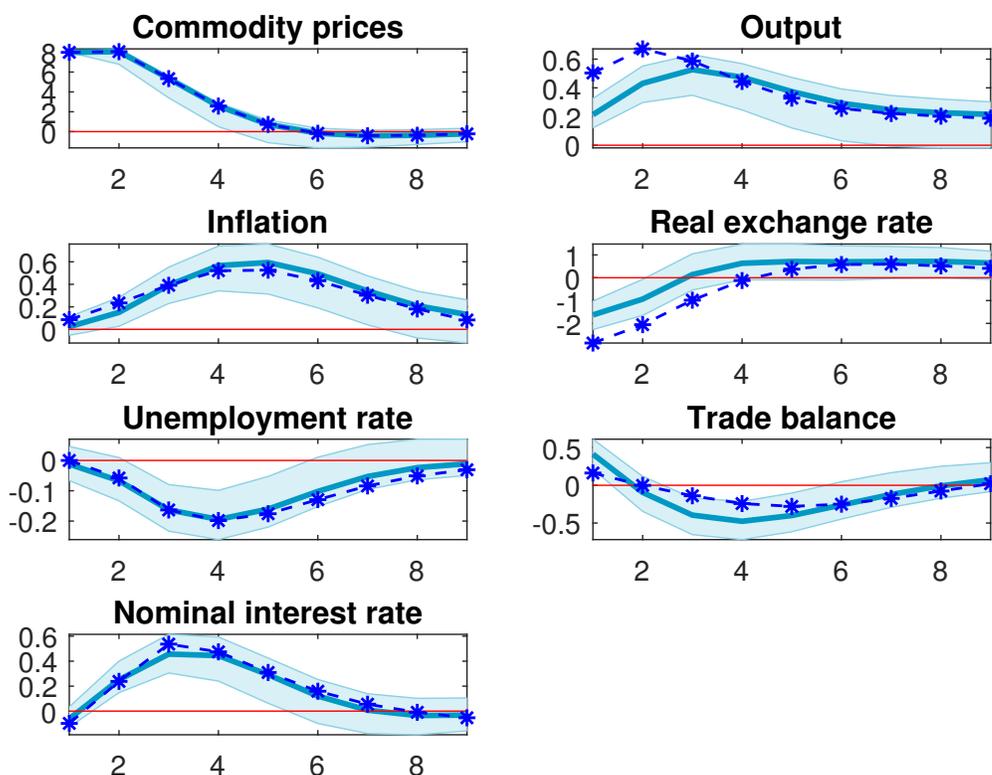
Note: The black solid line represents the estimated response to a one standard deviation commodity price shock along with the 80% blue confidence band from 5,000 bootstraps. The blue dashed lines correspond to the IRFs implied by the DSGE model matched to the panel SVAR.

Upon impact, commodity prices rise by almost 8% and return to trend after six 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 are 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 0.18 percentage points while in our sample the decline reaches 0.25 points.

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.

Lastly, we performed two 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 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 Figure 11, the baseline VAR is robust to these modifications.

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

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

$$n_t = \int_0^1 n_{1,t}(i)di + \int_0^1 n_{2,t}(i)di = n_{1,t} + n_{2,t} \tag{3}$$
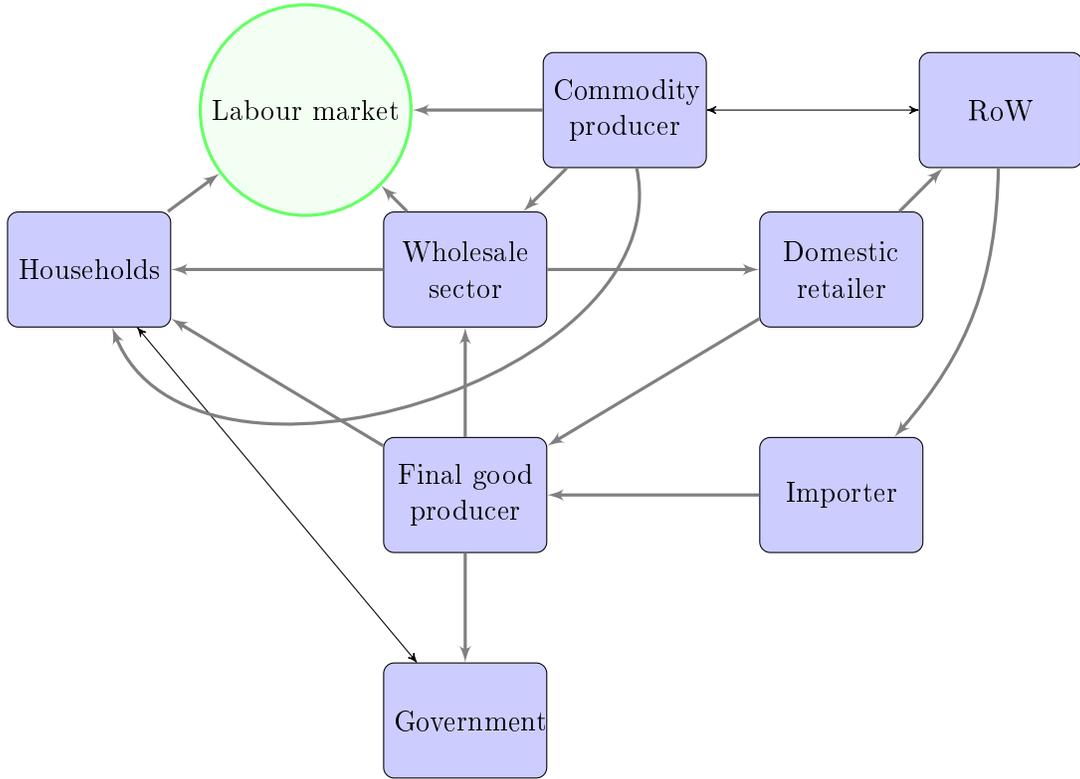
Figure 4: Main elements of the DSGE model (RoW = rest of the world).

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 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 vacancies, v_t and

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$\bar{m}$ 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.

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

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

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 Merz (1995), Andolfatto (1996) 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, $i_{s,t}$ and $k_{s,t}$, respectively.

Analogously to Lama and Medina (2012), García-Cicco et al. (2015) 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 capital stock, $k_t = k_{1,t} + k_{2,t}$, and rents it out to firms, for which it is paid $r_{s,t}^k$. 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.

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 $w_{s,t}$. 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 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 and $b_t^* = B_t^*/P_t^*$

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

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) that for commodity-exporting countries, interest rate premia are strongly affected by commodity prices, denoted by $p_{2,t}$. The quantitative importance of this channel is determined by the elasticity parameter $\xi_{p,2}$ and as we show below, it plays an important role in enabling the model to match the data.

We allow the degree of adjustment costs to be sector-specific so that the capital accumulation equation for each sector s is given by

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

where

$$S_{s,t} = \frac{\phi_s}{2} \left(\frac{i_{s,t}}{i_{s,t-1}} - 1 \right)^2 \tag{12}$$

Using λ_t to denote the Lagrange multiplier on the household's budget constraint, the first order conditions for the representative household are then given by

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

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

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

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

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

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

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.[6]

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

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

This implies that the employment accumulation equation can be written as

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

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

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

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

while in the commodity sector the analogous equation is given by

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

where $p_t^s = P_t^s/P_t$ is the price of the good in sector s relative to the final good, $w_{s,t} = W_t/P_t$ is the real wage, r_t^k the rental rate of capital and $\beta\frac{\lambda_{t+1}}{\lambda_t}$ the firm's stochastic discount factor. It is worth noting that for all firms, the costs of hiring a worker are proportional to the aggregate hiring rate, as in Di Pace and Hertweck (2019). 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

$$\kappa x_t = p_{s,t} mpn_{s,t} - w_{s,t} + \beta E_t \frac{\lambda_{t+1}}{\lambda_t}\frac{\partial F_{s,t+1}(i)}{\partial n_{s,t}(i)} \tag{21}$$

Where $mpn_{s,t}$ 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.

Making use of the envelope theorem and combining with the expression above we obtain

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

thus the optimality condition in both sectors is the same and the hiring rate is a function of the discounted stream of earnings, including savings on adjustment costs.

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

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

and free entry into the labour market implies the no-arbitrage condition

$$J_{s,t} = \kappa x_t \tag{23}$$

Thus, the net marginal value of employment is the same across firms and sectors.

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

$$\gamma J_t = (1 - \gamma) \mathcal{W}_t \tag{24}$$

where $\mathcal{W}_t$ represents the value of a job to a worker, which given the assumptions above is the same across sectors, and is given by

$$\mathcal{W}_t = w_t - b + \beta E_t \frac{\lambda_{t+1}}{\lambda_t} (1 - \rho - s_{t+1}) \mathcal{W}_{t+1} \tag{25}$$

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.

Combining (23) and (24)-(25) we obtain an expression for the evolution of real wages

$$w_t = (1 - \gamma) b + \gamma p_{w,t} mpn_{1,t} + \beta \gamma E_t \frac{\lambda_{t+1}}{\lambda_t} s_{t+1} \kappa x_{t+1} \tag{26}$$

Just as in Ravenna and Walsh (2008), albeit with hiring rather than search costs, absent frictions in the labour market $(\kappa = 0)$, then $s_t = (1 - \gamma)b + \gamma p_{w,t} mpn_{1,t}$, 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

$$y_{2,t} = A_{2,t} k_{2,t-1}^{\alpha_2} n_{2,t}^{1-\alpha_2} \tag{27}$$

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

$$r_{2,t}^k = p_{2,t} \alpha_2 \frac{y_{2,t}}{k_{2,t-1}} \tag{28}$$

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

$$y_{2,t} = y_{21,t} + y_{2,t}^x \tag{29}$$

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3.5 Domestic wholesaler

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

$$y_{1,t} = A_{1,t} k_{1,t-1}^{\alpha_1} n_{1,t}^{\gamma_1} y_{21,t}^{\beta_1} \tag{30}$$

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, equation (19) and subject to its labour accumulation equation

$$n_{2,t}(i) = (1 - \rho) n_{2,t-1}(i) + x_{2,t}(i) n_{2,t-1}(i) \tag{31}$$

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

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

Where $y_{h,t}^d$ represents the aggregate demand for the domestic retail good. All firms that are able to do so choose the same price, $\tilde{P}_{h,t}$, which is associated with the following optimality condition

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

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

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

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and we assume that the demand for exports is given by

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

where y_t^* denotes world output.

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

$$\int_0^1 y_{h,t}(i)di = y_t^w = \Delta_{h,t} y_{h,t}$$ (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

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

The Dixit-Stiglitz price aggregate then follows

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

The log-linear approximations to equation (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[7]

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

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

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

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

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

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

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

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

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

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[7]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.

while the process for price dispersion is given by

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

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

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

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

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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

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_r} \left[\left(\frac{\Pi_t}{\Pi}\right)^{\phi_\pi} \left(\frac{1 + u_t}{1 + u_{t-1}}\right)^{-\phi_u} \left(\frac{p_{2,t}^*}{p_2^*}\right)^{\phi_p}\right]^{(1-\rho_r)} \tag{46}$$

This rule embodies interest rate inertia, measured by $0 \leq \rho_r < 1$, with the strength of the response to inflation is given by ϕ_π. We model monetary policy as reacting to changes in the unemployment rate, resembling the rules analysed by Orphanides and Williams (2007) and which have the benefit of being robust to mismeasurements in the natural rate of unemployment. 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

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

where the interest rate on foreign bonds, $\tilde{R}_t^*$, is given by equation (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

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

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 1.

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 with 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 mean of the government spending-output ratio G/Y is set to match its average share across the three countries during our sample period and we adopt the same approach for the share of merchandise exports in GDP, which then helps us determine the relative size of the commodity sector, $\frac{y_2}{y_w}$. The employment shares in each sector are similar to those in Drechsel and Tenreyro (2018) and we choose conventional values for

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Table 1: 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 decision	$\kappa x_t = (p_{st} mpn_{s,t} - w_t) + \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \left(\frac{\kappa}{2} x_{t+1}^2 + \kappa x_{t+1}(1 - \rho) \right)$	[x]
Commodity price process	$\ln(p_{2,t}^*/p_2) = 1.01 \ln(p_{2,t-1}^*/p_2) - 0.35 \ln(p_{2,t-2}^*/p_2) + \varepsilon_{p_{2t}^*}$	[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	$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_r} \left[\left(\frac{\Pi_t}{\Pi} \right)^{\phi_\pi} \left(\frac{1 + u_t}{1 + u_{t-1}} \right)^{-\phi_u} \left(\frac{p_{2,t}^*}{p_2} \right)^{\phi_{p2}} \right]^{1-\rho_r}$	[xiv]
Net foreign asset position	$\frac{b_t^*}{R_t^*} = \frac{b_{t-1}^*}{\Pi_t^*} + \frac{p_{h,t}}{rer_t} y_{x,t} - y_{f,t} + \frac{p_{2,t}}{rer_t} y_{2x,t}$	[xv]
Domestic firm's output (hf)	$y_{h,t} = \frac{y_{w,t}}{\Delta_{h,t}}$	[xvi]
Domestic price level	$\Pi_{h,t}^{1-\varepsilon} = (1 - \omega)(\tilde{p}_{h,t} \Pi_{h,t})^{1-\varepsilon} + \omega \Pi_{h,t-1}^{\zeta(1-\varepsilon)}$	[xvii]
Domestic good MPN	$mpn_{1,t} = \gamma_1 \frac{y_{1,t}}{n_{1,t}}$	[xviii]
FOC investment	$q_{s,t}^k (1 - SS_{s,t}) = q_{s,t}^k \phi_s \left(\frac{i_{s,t}}{i_{s,t-1}} - 1 \right) \left(\frac{i_{s,t}}{i_{s,t-1}} \right) - \beta E_t \frac{\lambda_{t+1}}{\lambda_t} q_{s,t+1}^k \phi_s \left(\frac{i_{s,t+1}}{i_{s,t}} - 1 \right) \left(\frac{i_{s,t+1}}{i_{s,t}} \right)^2 + 1$	[xix]
Capital accumulation	$k_{s,t} = (1 - SS_{s,t}) i_{s,t} + (1 - \delta) k_{s,t-1}$	[xx]
Inv. adjustment costs	$SS_{s,t} = \left(\frac{\phi_s}{2} \right) \left(\frac{i_{s,t}}{i_{s,t-1}} - 1 \right)^2$	[xxi]
FOC capital	$q_{s,t}^k = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \left(r_{s,t+1}^k + 1 - \delta \right) q_{s,t+1}^k$	[xxii]
Rental rate of capital	$r_{s,t}^k = p_{s,t} \alpha_s \frac{y_{s,t}}{k_{s,t-1}}$	[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	$\Pi_{f,t}^{1-\varepsilon} = (1 - \omega_f)(\tilde{p}_{f,t} \Pi_{f,t})^{1-\varepsilon} + \omega_f \Pi_{f,t-1}^{\zeta_f(1-\varepsilon)}$	[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	$y_{d,t} = \alpha_d (p_{h,t})^{-\nu} Z_t$	[xxxiii]
Demand imported good	$y_{f,t} = (1 - \alpha_d)(p_{h,t})^{-\nu} Z_t$	[xxxiv]
Deviation LOP	$rer_t = \psi_{f,t} p_{f,t}$	[xxxv]
Uses of final good	$Z_t = c_t + i_t + G_t + \left(\frac{\kappa}{2} \right) x_t^2 (n_{1,t-1} + n_{2,t-1})$	[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]
Wage equation	$w_t = \gamma p_{s,t} mpn_{j,t} + (1 - \gamma) b + \gamma \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \kappa x_{t+1} s_{t+1}$	[xlii]

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

$\varepsilon, \varepsilon_f$ and the depreciation rate δ.[8]

We set the ratio of (non-commodity) merchandise exports to GDP to 6.5%, which represents the average for Brazil, Chile and South Africa in UNCTAD (2019).The ratio of commodity to wholesale output is calibrated so that the share of commodities in total exports is close to 60%. 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 Obstfeld and Rogoff (2000) note, high estimates of substitution elasticities are often found in microeconomic data.

Our econometric methodology for the remaining structural parameters 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 García-Cicco and Kawamura (2015), Bodenstein et al. (2018) and Ilori et al. (2022).[9] These parameters are stacked in the vector Θ^e and are estimated by minimising the weighted distance between the empirical impulse responses estimated in Section 2 above, denoted by IR, and the impulse functions implied by the model, denoted $IR^m(\Theta^c, \Theta^e)$

$$\hat{\Theta}^e = argmin_{\Theta^e} \left[IR - IR^m(\Theta^c, \Theta^e)\right]' \Omega^{-1} \left[IR - IR^m(\Theta^c, \Theta^e)\right] \tag{51}$$

The weighting matrix Ω is obtained from the diagonal elements of the variance-covariance matrix of the estimated impulse response functions, Σ_{IR^e}. The objective (51) therefore places more weight on the impulse responses that are more precisely estimated, that is, those with narrower error bands. 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.

4.1   Performance of the model

The dashed and starred lines in Figure (3) show the IRFs implied by the DSGE model when the parameters are chosen to minimise the objective in (51) and are reported in the bottom panel of

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[8]As is well known, to a first order approximation ε plays no role in the solution of the model.
[9]The model is linearised around a zero (net) inflation steady state.

Table 2.

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 output and real exchange rate responses in the initial periods after the shock but otherwise lie within the estimated error bands.

To model attributes the delayed dynamics of the impulse responses to several sources of endogenous persistence. The job separation rate and the degree of consumption habits are estimated at 0.12 and 0.66, respectively. Moreover, both the domestic retail and import sectors display a high degree of indexation to past inflation.

The interest rate premium elasticity, at 0.15 indicates the limited ability of financial markets for risk-sharing. At the same time, the sensitivity of the interest rate spread to commodity prices, $\xi_{p,2}$, is estimated at a relatively large value of -0.19, which is almost identical to the value obtained by Drechsel and Tenreyro (2018).

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 several mechanisms that are simultaneously interacting. The shock results in a positive wealth effect; it directly lowers the interest spread; it induces a more expansionary monetary policy via $\phi_{p,2}$ and it raises the costs for domestic producers given that commodities enter the production function.

The first three 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 cause inflation to increase in response to the shock; absent these, the real exchange rate appreciation caused by the commodity price increase generally results in a decrease in inflation, as will be shown below.

Table 2: Model parameters

| Parameter	Description	Value	
	Calibrated parameters		
β	Discount factor	0.9927	
σ	Elasticity matches with respect to unemployment	0.5	
n_1	Steady state employment in wholesale sector	0.71	
n_2	Steady state employment in commodity sector	0.19	
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	9	
$\frac{Y^x}{gdp}$	Merchandise exports to GDP ratio	0.065	
$\frac{y_2}{y_w}$	Commodity to wholesale sector output ratio	0.25	
$\frac{G}{Y}$	Government spending to GDP ratio	0.17	
$\rho_{p_{2,1}}$	AR(1) coefficient on commodity prices	1.0094	
$\rho_{p_{2,2}}$	AR(2) coefficient on commodity prices	-0.35	
$\bar{m}$	Matching function efficiency (implied)	0.88	
b/w	Replacement ratio (as proportion of real wage)	0.15	
κ	Hiring costs (implied)	4019	
γ_1	Output elasticity of labour in wholesale sector (implied)	0.28	
α_1	Output elasticity of capital in wholesale sector (implied)	0.57	
α_x	Export function parameter (implied)	70.9	
α_d	Home bias parameter (implied)	0.84	
α_2	Output elasticity of capital in commodity sector	0.7	
ζ_x	Foreign elasticity of demand for domestic good	9	
β_1	Commodity weight in wholesale production	0.15	
	Estimated parameters		s.e.
h	Degree of habits	0.66	(0.08)
ρ	Job separation rate	0.12	(0.00)
γ	Household's bargaining weight	0.35	(0.01)
ω	Calvo parameter (home good)	0.88	(0.00)
ω_f	Calvo parameter (imported good)	0.95	(0.00)
ζ	Degree of indexation (home good)	0.77	(0.00)
ζ_f	Degree of indexation (imported good)	0.90	(0.02)
ϕ_1	Investment adjustment costs in wholesale sector	3.29	(0.07)
ϕ_2	Investment adjustment costs in commodity sector	0.17	(0.00)
χ	Interest rate premium elasticity	0.15	(0.01)
$\xi_{p,2}$	Risk premium elasticity to commodity prices	-0.19	(0.00)
ϕ_π	Interest rate rule (inflation)	1.05	(0.01)
ϕ_u	Interest rate rule (unemployment)	0.58	(0.01)
ϕ_{p_2}	Interest rate rule (commodity price)	-0.015	(0.00)
ρ_r	Interest rate smoothing	0.09	(0.01)

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 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. 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.

To gain some intuition regarding the impulse responses implied by the model, as well as to understand why each of the features described above are necessary for matching the data, we can consider the effects of altering some of the key parameters whilst maintaining all others unchanged from their estimated values.

Consider first the consequences of setting $\xi_{p,2}$ to zero, whereby there is no direct reduction on the interest rate spread from an increase in commodity prices. The results are shown in Figures 5 and 6, which again highlight how ignoring this channel results in an economic expansion much larger than that estimated in the SVAR. With $\xi_{p,2} = 0$, the commodity price shock leads to sharper increase in the nominal interest rate and a modest real exchange rate depreciation. Although the increase in the domestic demand for the home good is smaller, the real exchange rate depreciation leads to a large increase in the exports of these goods, to the extent that resources are re-allocated to this sector and away from the production of commodities. Being the larger component of GDP, the expansion in the domestic tradable good causes a sharp increase (decrease) in GDP (the unemployment rate), while the real exchange rate depreciation amplifies the inflationary impact of the shock.

Next, we turn to monetary policy. In the model we allow for a direct effect of commodity prices on the interest rate rule via $\phi_{p,2}$ and the effects of switching this channel off are shown in Figures 7 and 8. With $\phi_{p,2} = 0$ the commodity price shock results in very pronounced symptoms of the

Figure 5: Shock to commodity prices for different values of $\xi_{p,2}$
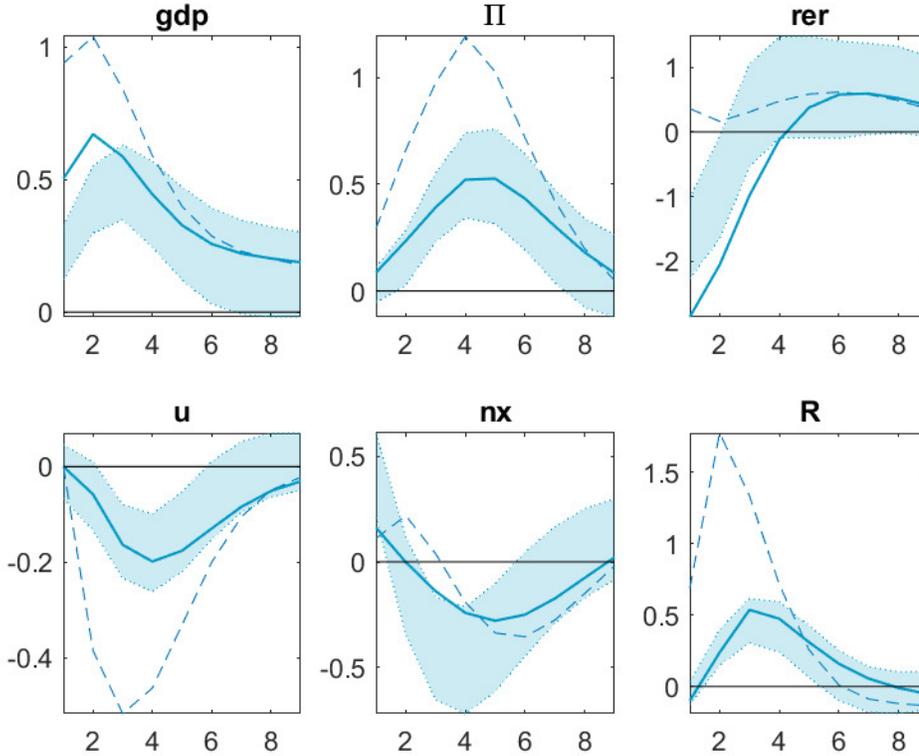

Note: The simulation takes the calibrated and estimated parameters from Table 2 (solid line), while the dashed line shows impulse responses with $\xi_{p,2} = 0$. $\xi_{p,2}$ represents the sensitivity of the interest rate spread to commodity prices. Π denotes the gross inflation rate, rer the real exchange rate, u the unemployment rate, nx the trade balance-GDP ratio and R is the nominal interest rate.

Dutch disease. Despite the increase in domestic expenditure from the greater wealth accruing to households, the larger real exchange rate appreciation amplifies the re-allocation of resources from the domestic wholesale to the commodity sector, with the consequence that unemployment rises while inflation falls. As a result, 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 the tradable sector and hence on unemployment.[10] One consequence of having monetary policy

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[10]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.

Figure 6: Shock to commodity prices for different values of $\xi_{p,2}$
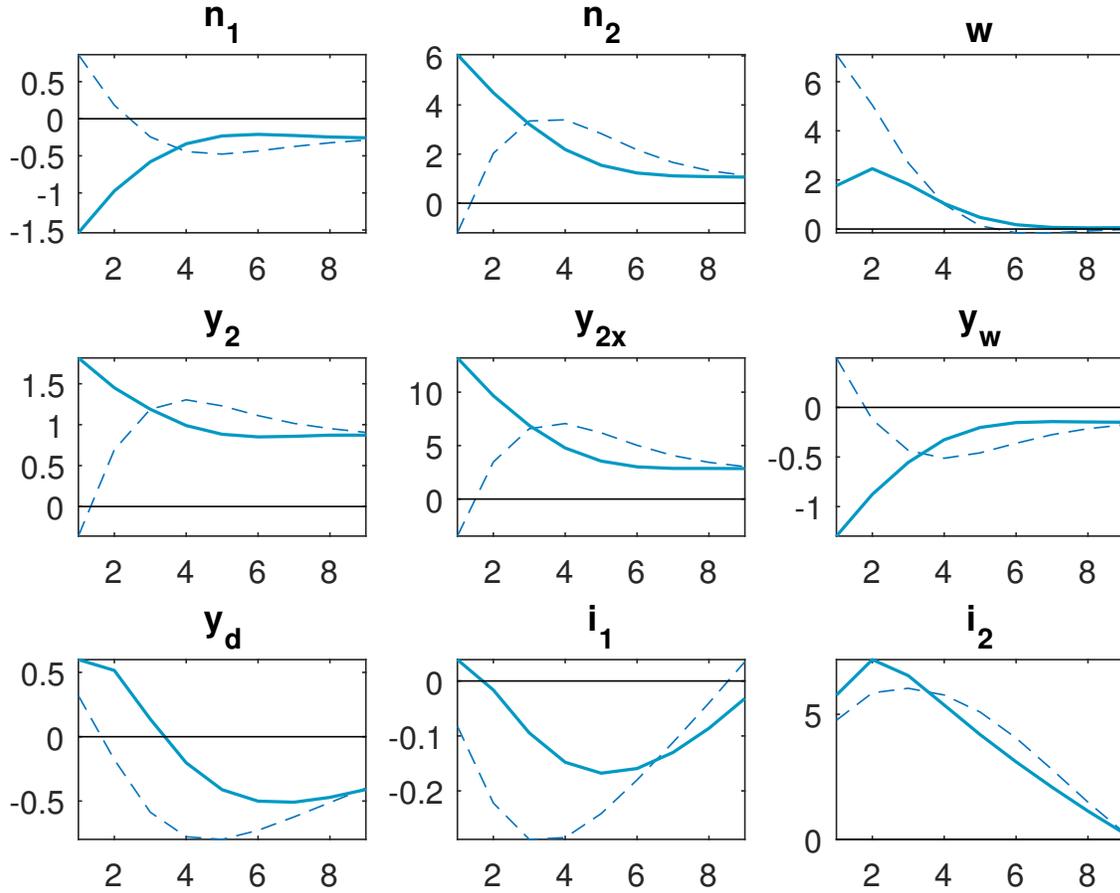
See notes to Figure 5. The subscript 1 (2) denotes the home tradable (commodity) sector. Commodity exports are y_{2x}, y_w is domestic tradable output and y_d is domestic expenditure on the home tradable good.

react directly to commodity prices is that by limiting the real exchange rate appreciation, the overall effect on inflation is positive and the expansionary effects on GDP are much larger. With $\phi_{p,2} = 0$ the model would have been unable to replicate this feature in the data.[11]

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

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[11]It should be noted that although the estimated value of $\phi_{p,2}$ is very small, the effects are non-trivial given the large standard deviation of the commodity price shock.

Figure 7: Shock to commodity prices for different values of $\phi_{p,2}$
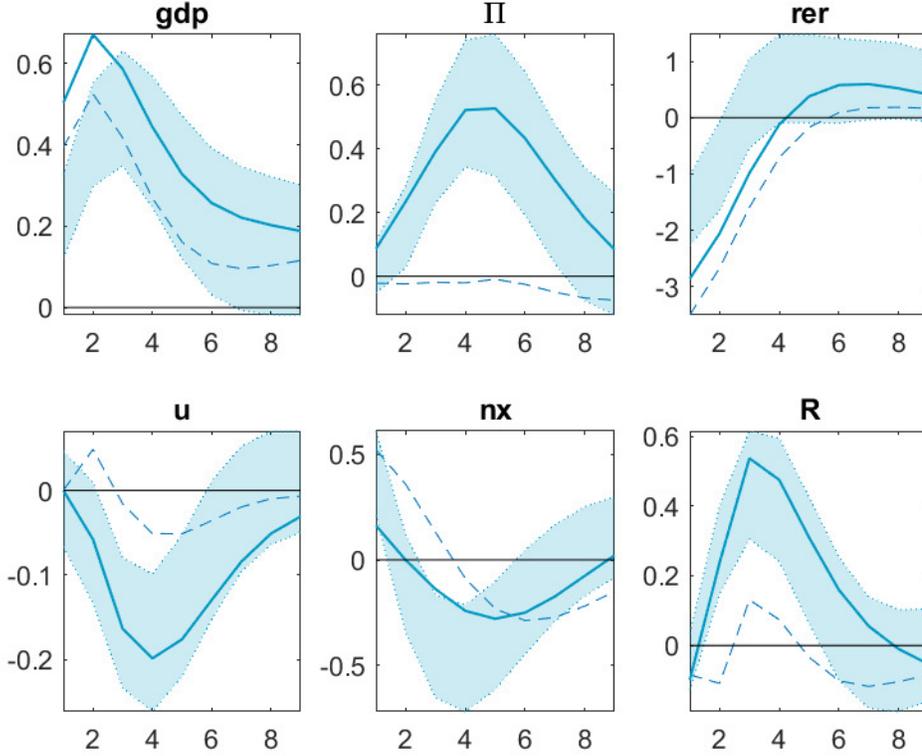
Note: The simulation takes the calibrated and estimated parameters from Table 2 (solid line), while the dashed line shows impulse responses with $\phi_{p,2} = 0$. $\phi_{p,2}$ represents the coefficient on commodity prices in the interest rate rule.

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{0.7} \left[\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{1.5} \left(\frac{gdp_t}{gdp}\right)^{0.125}\right]^{0.3} \tag{52}$$

In this case, the responses of both GDP and inflation are quantitatively much smaller, to the extent that the latter falls. Moreover, compared to the benchmark model where commodity prices enter the policy rule, the real exchange rate appreciates even more. This produces a larger contraction in the domestic tradable sector so that overall unemployment rises. Modifying the coefficients in the reaction function above would not alter the conclusion that such a Taylor-type rule is unable to match the estimated impulse responses to a commodity price shock.[12]

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[12]An interesting feature of this analysis is that the commodity price shock produces an overall much smaller increase

Figure 8: Shock to commodity prices for different values of $\phi_{p,2}$
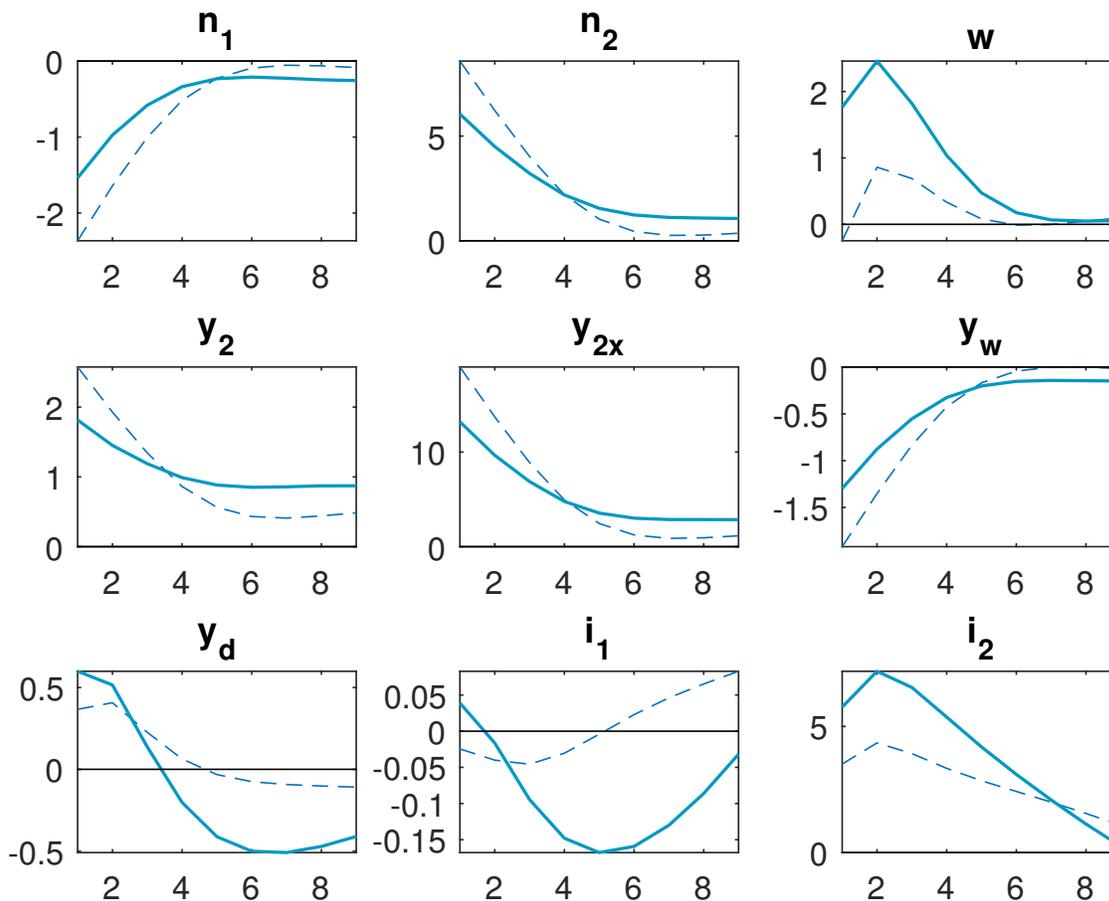
See notes to Figure 7. The subscript 1 (2) denotes the home tradable (commodity) sector.
Commodity exports are y_{2x}, y_w is domestic tradable output and y_d is domestic expenditure
on the home tradable good.

One key result that emerges from this part of the analysis is that monetary policy matters for
the dynamics, not only of inflation, but for the real variables. Moreover, the model suggests that
symptoms of the Dutch disease following commodity price shocks are dependent on the behaviour
of monetary policy. By directly responding to commodity price movements, the central bank is able
to substantially reduce the volatility in the wholesale sector, conditional on shocks to commodity
prices.[13] Therefore, models that rely solely on real variables, such as Bodenstein et al. (2018),

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in the nominal interest rate despite its formulation being more aggressive towards inflation and output. However, it
is this very hawkish response that produces more stable inflation and output, which then require a more moderate
increase in interest rates.

[13]Interestingly, Hevia and Nicolini (2014) suggest that in the presence of price frictions the Dutch disease reflects

Figure 9: Shock to commodity prices with Taylor rule
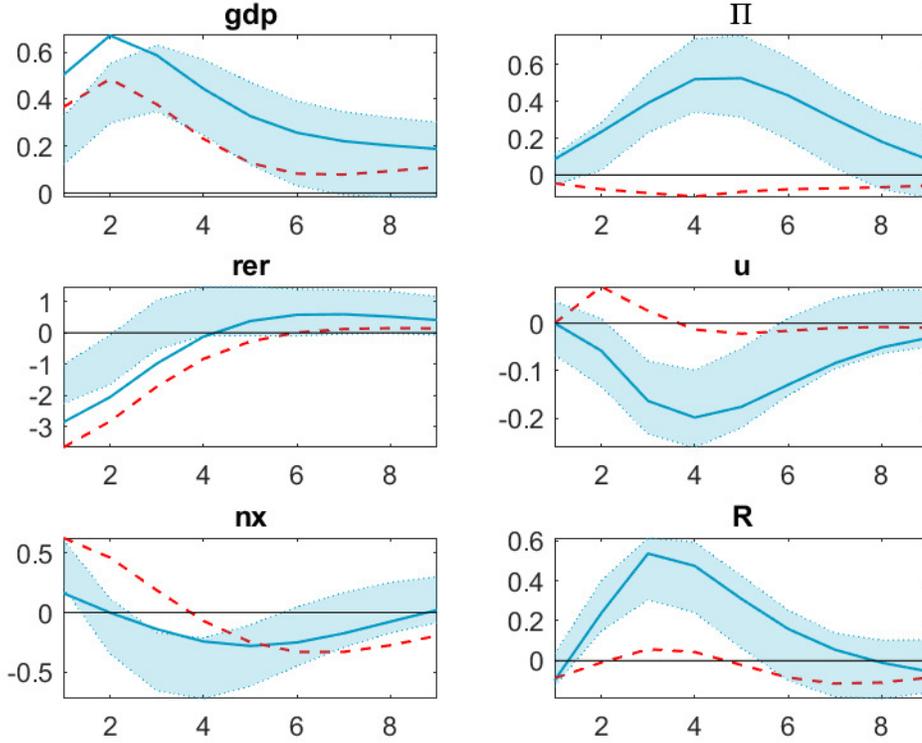
Note: The simulation takes the calibrated and estimated parameters from Table 2 (solid line), while the dashed line shows impulse responses with the interest rate rule $\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{0.7}\left[\left(\frac{\Pi_t}{\Pi}\right)^{1.5}\left(\frac{gdp_t}{gdp}\right)^{0.125}\right]^{0.3}$.

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 ($\phi_{p,2}$), 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

the optimal response to a relative price shock, rather than something that should be attenuated.

Figure 10: Shock to commodity prices with Taylor rule
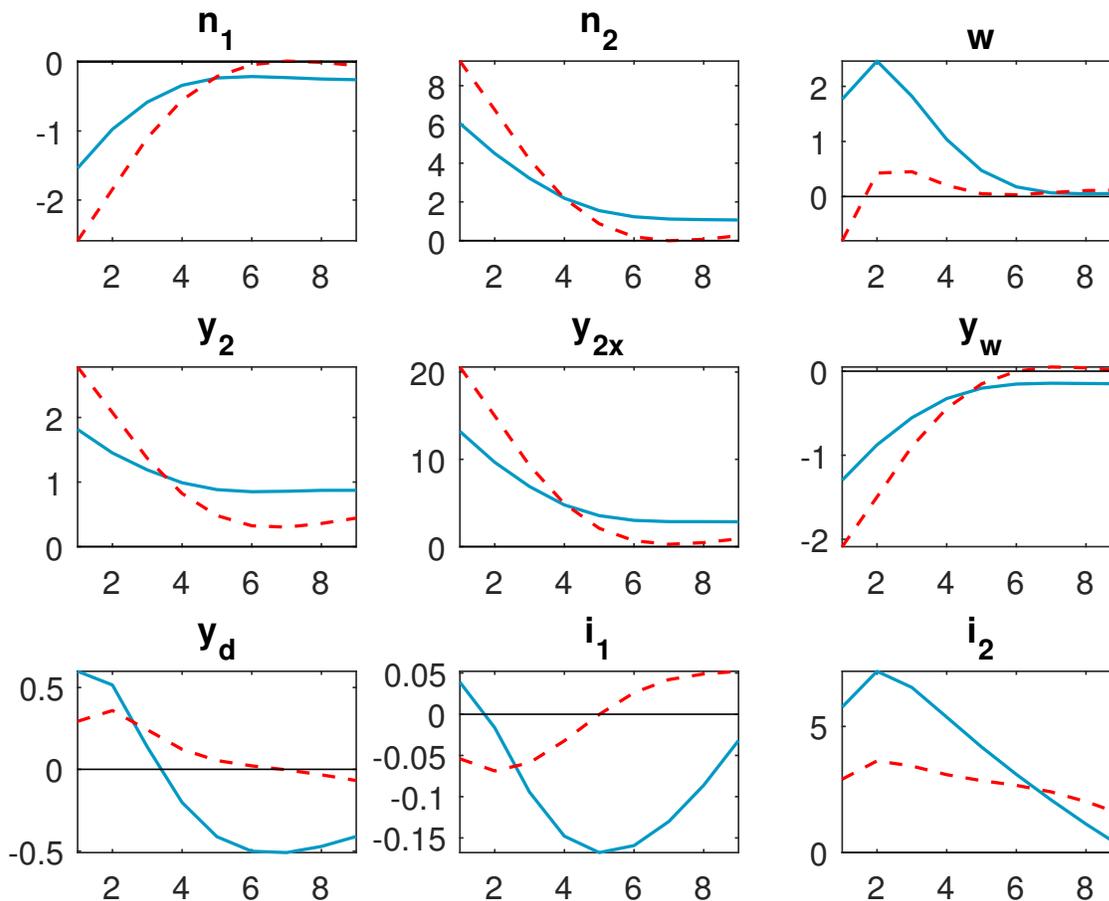
See notes to Figure 9. The subscript 1 (2) denotes the home tradable (commodity) sector. Commodity exports are y_{2x}, y_w is domestic tradable output and y_d is domestic expenditure on the home tradable good.

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.

6   Conclusion

In this paper we estimate as 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 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. We find that the sensitivity of the risk premium to commodity prices and the specific form of the monetary policy rule form important and essential elements 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, would otherwise lead to rises in the unemployment rate combined with a smaller increase in GDP.

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7 Appendix

Table 3: Data definitions and sources

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

GDP is per capita, with the population series obtained from the World Bank. The nominal interest rate is the Treasury Bill rate (from the IMF's International Financial Statistics) for Brazil and South Africa while for Chile we used the 90-day interbank rate, from MEI. We accessed the data via the FRED, except for the population and commodity price series.

Figure 11: SVAR impulse responses: robustness checks
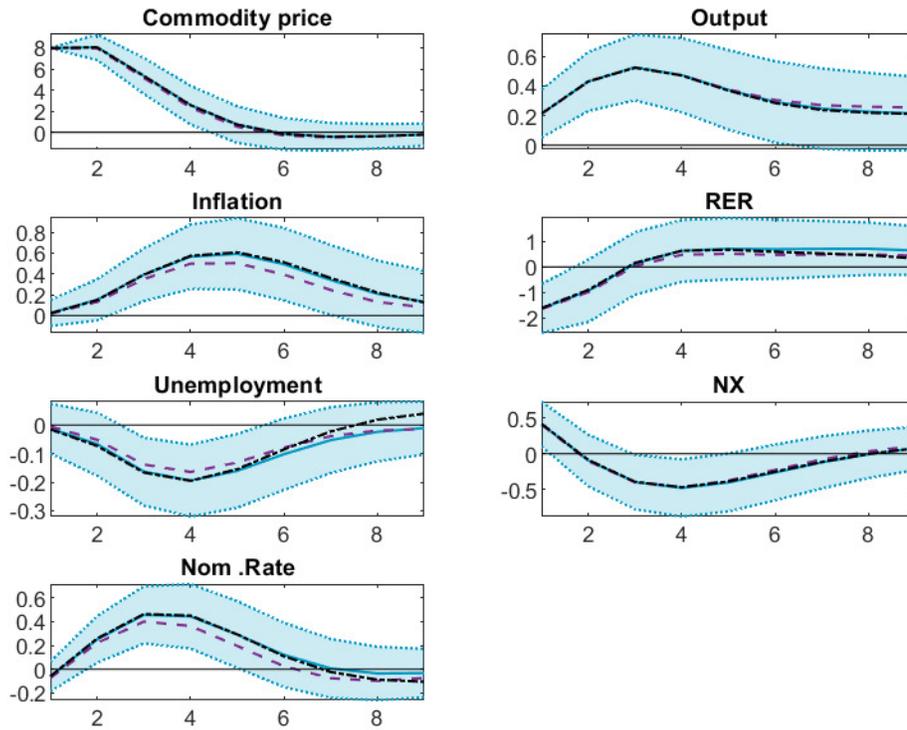
See notes to Figure 3. Estimated impulse responses to commodity price shock under different specifications: the solid line and confidence bands represent the benchmark model; the dashed line allows for a break in the unconditional mean in the commodity price for Chile; the dashed-dotted line are the estimates from a VAR that includes the interest rate spread.