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Commodity exports, financial frictions, and international spillovers[☆]

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ABSTRACT

This paper offers a solution to the international co-movement puzzle found in open-economy macroeconomic models. We develop a small open economy (SOE) dynamic stochastic general equilibrium (DSGE) model describing three endogenous channels that capture spillovers from the world to a commodity exporter: a world commodity price channel, a domestic commodity supply channel, and a financial channel. We estimate our model with Bayesian methods on two commodity-exporting SOEs, namely Canada and South Africa. In addition to explaining international business cycle synchronization, the new model attributes an important fraction of business cycle fluctuations to foreign shocks in the SOEs.

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1. Introduction

Estimated closed-economy DSGE models can quantitatively match observed macroeconomic fluctuations (e.g. Christiano et al., 2005 and Smets and Wouters, 2007). The same is not true of open-economy models. These models have particular difficulty in explaining the synchronization of international business cycles and the importance of foreign shocks in driving macroeconomic fluctuations in SOEs (Schmitt-Grohe, 1998 and Justiniano and Preston, 2010, henceforth JP). In an influential paper, JP show that the workhorse New-Keynesian model of Gali and Monacelli (2005) implies that US shocks only play a marginal role in macroeconomic fluctuations in Canada and thus fails to explain the synchronization of business cycles between these two economies.[3] These findings are counter-intuitive given the large degree of trade and financial linkages between the two countries and not consistent with the empirical evidence presented in their paper.[4]

In this paper, we build a SOE model that explains the synchronization of international business cycles and the importance of foreign shocks in driving macroeconomic fluctuations in commodity-exporting SOEs. Commodity exports play an important role in many economies. For instance, more than half of the world countries are commodity-dependent, in the sense that over 60 percent of their total merchandise exports are composed of commodities (UNCTAD, 2019). Moreover, many advanced and emerging economies that are not classified as commodity-dependent still rely on commodities for a substantial share of their exports, and our results apply to these economies as well.

Our model consists of two blocks: a domestic block representing a commodity-exporting SOE and a foreign block capturing its relation with the rest of the world. We augment the standard SOE-DSGE framework with three transmission channels: a world commodity price channel, a domestic commodity supply channel, and a financial channel. Shocks originating from the foreign economy endogenously transmit to the commodity exporter through these channels. They can be summarized as follows. First, both domestic and foreign economies produce primary commodities used as inputs in the final good sector. Commodity prices are endogenously determined in the global market based on world supply and demand for commodities. Second, the domestic supply of commodities is endogenous. Production and exports thus respond to fluctuations in world commodity prices. Third, we introduce a set of financial frictions. We assume that a fraction of households is financially constrained and behaves as hand-to-mouth consumers, linking consumption to their labor incomes (Mankiw, 2000). Moreover, we introduce domestic and foreign banks who extend credit to entrepreneurs. Domestic banks charge a premium over the risk-free rate as a function of domestic entrepreneurs' debt to collateral ratio, where collateral consists of a claim on entrepreneurs' capital stock. Foreign banks operate in domestic and foreign markets and transmit external financing conditions to the domestic economy.

How do foreign shocks spill over to the domestic economy? In our framework, a positive demand shock in the foreign economy stimulates the demand for commodities used as inputs in the production process, which implies a rise in world commodity prices. The magnitude of the response of commodity prices depends on the elasticity of substitution between commodities and other productive inputs (such as labor and capital). The lower the elasticity, the harder it is for foreign firms to substitute commodities with other productive inputs, and the stronger the increase in world commodity prices. In turn, the increase in commodity prices generates a boom in the domestic economy through higher commodity export volumes, which has a positive impact on GDP. This impact on GDP depends on the size of the domestic commodity sector and on the price-elasticity of commodity supply. The higher the price-elasticity, the stronger the increase in commodity export volumes. To produce commodities, firms combine labor, capital and land. As the supply of land is fixed, firms' ability to extend production in response to higher prices depends on their ability to substitute land with other productive inputs.

Financial frictions amply the effect of foreign demand shocks on GDP. Indeed, the increase in domestic commodity supply is accompanied by an increase in demand for labor, which raises hand-to-mouth households' labor income and consumption. In addition, foreign banks respond to the improved global economic conditions by lowering the spread on credit to domestic entrepreneurs. Moreover, entrepreneurs' income and the value of their collateral increase with higher commodity prices, which lowers their debt to collateral ratios, and accounts for another drop in their borrowing costs at domestic banks. Looser financing conditions end up stimulating investment in the primary and final good sectors, as well as entrepreneurs' consumption. These increases in consumption and investment combined with the increase in commodity export volumes generate a significant response of domestic GDP to foreign demand shocks.

We then confront our model with the data. We estimate our model with Bayesian methods on two commodity-exporting SOEs that stand at different stages of economic development: Canada and South Africa. Therefore, our results can be extended to a large set of emerging and advanced commodity-exporting and commodity-dependent economies. We use US data (as well as a world aggregate as a robustness check) to identify a broad range of foreign shocks: aggregate demand, aggregate supply, credit supply, monetary policy, and commodity supply shocks.

The estimation shows that, in contrast to most other SOE models, our model reproduces a significant degree of business cycle synchronization and attribute an important fraction of business cycle fluctuations in the domestic economy to foreign shocks. By

[3] In other estimated New Keynesian models, Adolfson et al. (2005, 2007), Christiano et al. (2011) and Steinbach et al. (2009) find that foreign shocks play a small role in the euro area, Sweden and South Africa, respectively. Two-country models also have difficulty in explaining business cycle synchronization: see for e.g. de Walque et al. (2017) for a model applied to the US and the euro area. In a calibration exercise, Schmitt-Grohe (1998) shows that standard SOE real business cycle models are unable to explain the transmission of US output shocks to Canada.

[4] Several studies analyze the spillovers of country specific and common shocks with structural vector autoregressive (SVAR) and structural factor models (Canova and Marrinan, 1998; Stock and Watson, 2005; Kose et al., 2008; Dewachter et al., 2012; IMF, 2013; Ciccarelli et al., 2016; Ha et al., 2020). For instance, IMF (2013) analyses a sample of 63 advanced and emerging economies and finds that US shocks spill over to other countries through trade and financial linkages.

shutting down our three transmission channels one at a time in sequence, we find that the world commodity price channel, the domestic commodity supply channel, and the financial channel all contribute to foreign shocks' spillovers to South African and Canada (although the domestic commodity supply channel is a bit weaker in Canada due to a lower estimated price-elasticity). When shutting down all these three channels, we find that foreign shocks are not important drivers of business cycle fluctuations in South Africa and Canada, which highlight their importance to solve the international comovement puzzle.

Our results support the view that commodity prices are an important driver of economic fluctuations in commodity-exporting SOEs (e.g. Mendoza, 1995; and Kose, 2002). Recently, there has been a growing number of empirical studies endorsing (e.g. Fernández et al., 2017 and Shousha, 2016) or challenging this view (e.g. Schmitt-Grohé and Uribe, 2018; Aguirre, 2011; Lubik and Teo, 2005; and Broda, 2004). Our paper contributes to this debate by proposing a new structural framework that models the interactions between the commodity sector and other sectors in the domestic and foreign blocks.

Existing SOE models such as Adolfson et al. (2007) and JP do not explicitly model the foreign economy as we do in this paper. Instead, these studies use a recursive VAR or a small-scale closed-economy model for the foreign economy. In this paper, we build a fully-fledged SOE model where the domestic and foreign economies differ in their size and in their degree of dependence on the commodity sector.[5] The fact that the foreign economy uses commodities produced by the SOE is a key feature that opens the world commodity price and the domestic commodity supply channels, which generate international spillovers and business cycle synchronization. In addition, we highlight the specific roles of financial frictions in both economies in amplifying the effect of foreign shocks.

When commodity prices are introduced in existing SOE-DSGE studies, they are assumed to be exogenous. We depart from this literature and allow commodity prices to be driven both by demand and supply forces originating from the foreign block of our model, which echoes the SVAR literature on oil prices (e.g. Kilian, 2009, Baumeister and Peersman, 2013a, Baumeister and Peersman, 2013b and Caldara et al., 2019). In this respect, our paper also relates to Bergholt et al. (2019). While they study the interaction between the oil and other productive sectors in the Norwegian economy, we focus on the interactions between the commodity and financial markets and their impact on business cycle synchronization. We show that endogenous commodity prices help in generating international comovement.

A number of papers also introduced a commodity sector in SOE models (with exogenous commodity price shocks) either modeled as an exogenously given endowment (Medina and Soto, 2007, Medina and Soto, 2016, Malakhovskaya and Minabutdinov, 2014, Drygalla, 2017 and Jääskelä and Nimark, 2011) or with a Cobb–Douglas production function (Dib, 2008, Schmitt-Grohé and Uribe, 2018, Rees et al., 2016 and Allegret and Benkhodja, 2015). We differ from these papers by using a CES production function to control for the price-elasticity of commodity supply in the SOE, and by documenting its effect on the contribution of foreign shocks.[6]

In this paper, commodity prices also interact with a financial amplification channel. Our paper thus relates to Shousha (2016), Fernández et al. (2018) and Drechsel and Tenreyro (2018) that extend the debt elastic foreign interest rate seen in Schmitt-Grohe and Uribe (2003) with an (ad hoc) commodity price component. We differ from these papers by also considering financial exclusion and contagion originating from foreign banks, and we explicitly model the financial frictions behind our financial amplification channel. In spirit, our foreign banks are similar to Kollmann (2013), Ueda (2012) and Alpanda and Aysun (2014)'s global banks as they operate in the domestic and foreign economies.[7] Finally, other studies have also used DSGE models to study business cycle synchronization through trade in intermediate inputs (see for e.g. Eyquem and Kamber, 2014, Bergholt and Sveen, 2014 and Bergholt, 2015). We also consider trade in intermediate inputs, but our focus is on trade in primary commodities and financial frictions.

The rest of the paper is arranged as follows. Section 2 motivates our paper. Section 3 presents the model. Section 4 discusses the calibration and estimation strategy. Section 5 shows how foreign shocks propagate to the SOE through the commodity and financial channels in a calibrated version of the model. Section 6 demonstrates that our estimated model offers a solution to the international co-movement puzzle for small open commodity exporters. The last section concludes.

2. Empirical motivation

2.1. The composition of merchandise exports

Commodities play an important role in the economic decisions of households, firms and the governments in many advanced and developing countries. For instance, commodities are key inputs in the production of final and industrial goods. The commodity sector is a major source of income in many countries. Fig. 1 reports average shares of commodity and non-commodity merchandise exports in South African and Canadian GDP and establishes that commodity exports play a significant role in driving economic activity in these economies. In appendix A, we show that this is also the case in other emerging and advanced economies, and that commodities sometimes play an even larger role. We therefore believe our country choice is both representative and conservative as to the impact of the commodity channels. The next section presents an in-depth SVAR analysis where we focus on Canada and South Africa.

[5] Another strand of literature developed fully-fledged two country models (Lubik and Schorfheide, 2006, Jacob and Peersman, 2013, de Walque et al., 2017). The two countries considered are often symmetric in structure, although they may differ in their size (Bergin, 2006).

[6] Murchison and Rennison (2006) and Dorich et al. (2013) also use a CES production function, but do not focus on its implication for the supply price-elasticity or for the contribution of foreign shocks.

[7] Miyamoto and Nguyen (2017a) employ a simple SOE-RBC model with a complex shock structure and apply it to a panel of developed and developing countries to establish the importance of global shocks and financial frictions. In contrast, we build a fully-fledged model to interpret the results.

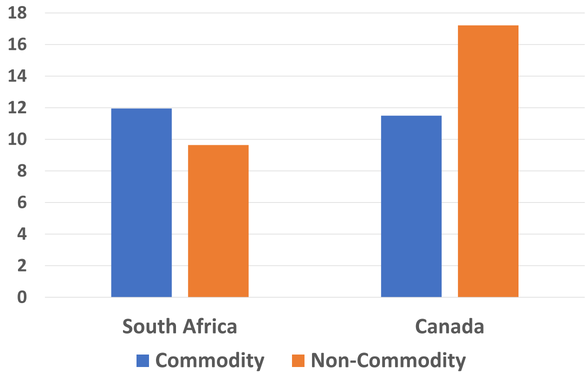

Fig. 1. Shares of commodity and non-commodity merchandise exports (% GDP). Note: Average over 1995–2017 period.
Source: UNCTAD (2019).

2.2. Empirical findings with SVAR model

We employ Bayesian SVAR models to present the dynamic effects of foreign shocks in commodity exporters. In the benchmark analysis, the US represents our foreign economy.[8] For the home economy, we focus on either Canada or South Africa. We employ a combination of a normal-inverted Wishart prior and a Minnesota type prior and assume that Canadian and South African variables have no impact on the US block, because they are SOEs.

We identify foreign aggregate demand, productivity, and commodity supply shocks with sign restrictions following the methodology proposed by Uhlig (2005). Here, we focus on foreign aggregate demand shocks because they are identified based on the positive comovement between prices and GDP in the foreign economy only. The foreign spread, interest rate, commodity prices, and all domestic variables are left unrestricted. Moreover, aggregate demand shocks are good candidates to explain the synchronization of international business cycles (e.g., Andrle et al., 2017) and turn out to play an important role in our DSGE analysis. We show the impact of productivity and commodity supply shocks in the appendices A and B.

Fig. 2 reports the impulse response to global aggregate demand shocks. Following a contraction in global aggregate demand, world commodity prices depress as the result of a decline in world demand for commodities. Moreover, this adverse shock generates an increase in US spreads. How do South Africa and Canada respond to this shock? A contraction in world aggregate demand implies a contraction in commodity supply, consumption, investment and employment in Canada and South Africa. Moreover, spreads increase. As a result, real activity contracts in South Africa and Canada. Therefore, world aggregate demand shocks are good candidates to explain the synchronization between commodity exporters and the US.

These results echo a well-developed literature on international business cycle. JP review this literature and perform an empirical analysis with a SVAR model that illustrates the importance of US shocks in driving macroeconomic fluctuations in Canada. These findings were also supported by other studies (e.g., Klyuev, 2008; Miyamoto and Nguyen, 2017b). In South Africa, shocks originating from major economies such as the US, Europe, and China also play a crucial role (e.g., Kabundi, 2009; Çakir and Kabundi, 2013; Waal and van Eyden, 2016; Houssa et al., 2013, 2015 in SVAR or structural factor models). In what follows, we build a SOE-DSGE model that is capable to account for these empirical regularities.

3. A model with commodities and financial frictions

The model comprises two blocks, each describing the structure of one type of economy: a block for a small open commodity exporter (domestic); and a block for the rest of the world (foreign) which can be interpreted as the global economy. The foreign block is modeled as an approximately closed economy that builds on the work of Smets and Wouters (2007), henceforth denoted as SW. The domestic block is an extension of the SOE-DSGE model proposed by Adolfson et al. (2007), henceforth denoted as ALLV.[9]

We extend the models of SW and ALLV in three dimensions that open three transmission channels of foreign shocks: a world commodity price channel, a domestic commodity supply channel, and a financial channel (see Fig. 3 for a visual representation of these channels).

First, both domestic and foreign economies produce primary commodities (and secondary goods) that are traded. Commodity prices are endogenously determined in the global market through the confrontation of foreign supply and demand. The domestic

[8] The results are qualitatively similar with an alternative measure of the foreign economy defined by an aggregate OECD and BRIIC (Brazil, Russia, India, Indonesia, and China); see appendices A and B available at https://researchportal.unamur.be/fr/publications/appendix-to-houssa-mohimont-otrok-2022.

[9] For simplicity, we do not consider taxes on labor and capital or nominal and real trends. As such, the model already extends the work of JP with capital (and investment adjustment costs), public consumption, and an incomplete exchange rate passthrough to export prices in the SOE (in addition to import price rigidities already present in JP). We further extend these works with the commodity and financial channels described in this section.

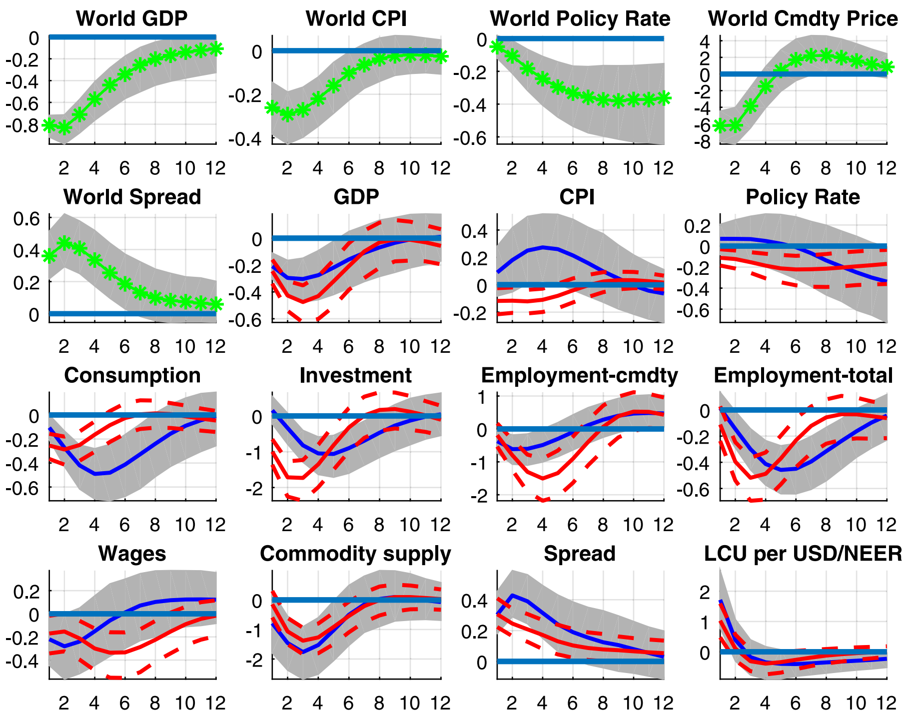

Fig. 2. SVAR - World aggregate demand shocks in South Africa and Canada.
Note: The green line indicates the median IRF for the world. The blue and red lines indicate the median IRF in South Africa and Canada, respectively. The shaded areas and areas defined by the red dashed lines report the 68% credible intervals. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

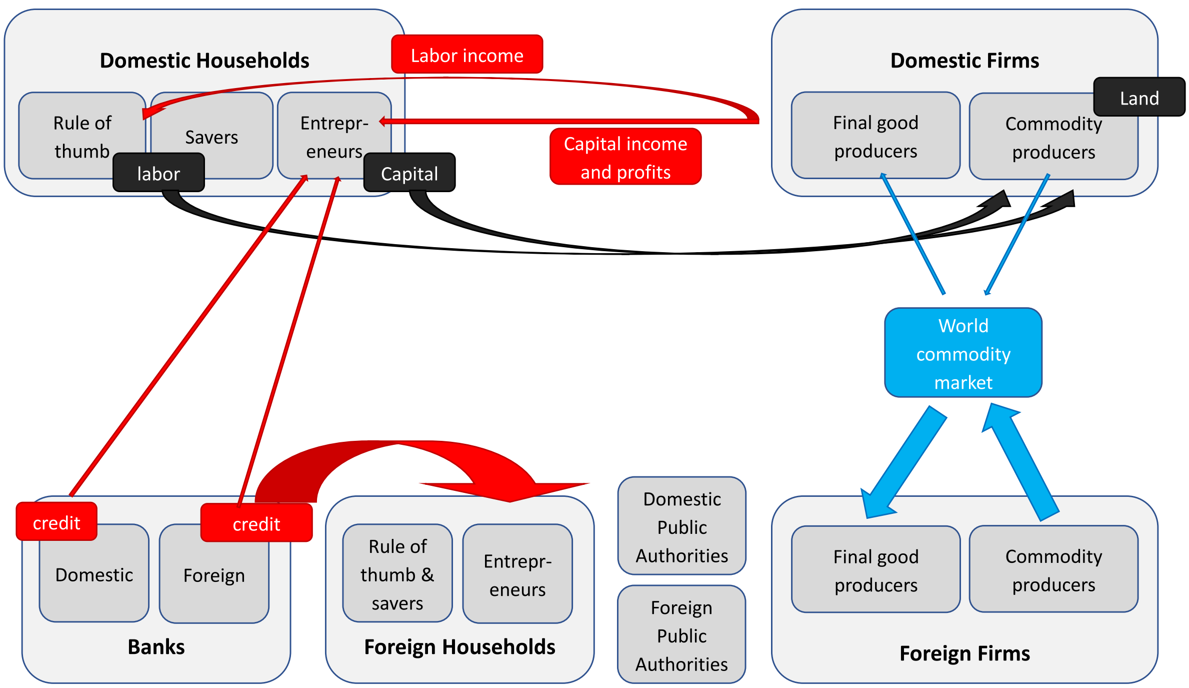

Fig. 3. Graphical representation of the model.

economy has no impact on world commodity prices given the SOE assumption.[10] Second, domestic supply of commodities is endogenous. Production thus responds to fluctuations in world commodity prices. Third, we introduce a set of financial frictions. We distinguish three categories of households to capture key differences among savers, entrepreneurs, and financially constrained (rule-of-thumb) households. Moreover, we introduce a financial sector comprising domestic and foreign banks. Foreign banks are global players operating in the domestic and foreign markets that transmit international financing conditions to the domestic economy.

The following sections describe our model in detail. The first-order conditions, its steady state and observation equations are presented in appendices C, D and E.

3.1. Households

The domestic economy is populated by three types of households: savers, entrepreneurs and rule-of-thumb consumers. Any households j derive utility from a consumption basket $C_{j,t}$:

$$C_{j,t} = \left[(1-\omega_c)^{1/\eta_d}(C^d_{j,t})^{(\eta_d-1)/\eta_d} + \left(\omega_c\right)^{1/\eta_d}(C^m_{j,t})^{(\eta_d-1)/\eta_d}\right]^{\eta_d/(\eta_d-1)}, \tag{1}$$

where $C^d_{j,t}$ and $C^m_{j,t}$ denote consumption of domestic and imported goods, respectively. ω_c is the (steady-state) share of imports in consumption and η_d is the elasticity of substitution between domestic and foreign consumption goods.

3.1.1. Savers

Household optimization problem There is a continuum of savers of mass ω_s indexed by $j \in (0, \omega_s)$. The representative saver maximizes the inter-temporal utility by choosing his or her consumption level, labor effort, and domestic as well as foreign financial asset holdings. The jth household's preferences are given by

$$\mathrm{E}^j_0 \sum_{t=0}^{\infty} \beta^t_S \left[\frac{\left(C_{j,t} - \mathbf{b}C^s_{t-1}\right)^{1-\sigma_c}}{1-\sigma_c} - A_{h,p}\frac{(h^p_{j,t})^{1+\sigma_h}}{1+\sigma_h} - A_{h,f}\frac{(h^f_{j,t})^{1+\sigma_h}}{1+\sigma_h}\right], \tag{2}$$

where E is the expectation operator and C^s_{t-1} is the previous period average level of consumption within the savers' group. $h^p_{j,t}$ and $h^f_{j,t}$ denote work effort in the primary and secondary sectors. The parameters σ_c and σ_h denote the inverse of the inter-temporal elasticity of substitution for consumption and the inverse of the elasticity of work effort, respectively. $A_{h,p}$ and $A_{h,f}$ are the relative importance of labor in the utility, $\mathbf{b}$ is the external habit parameter and β_S is the discount factor of savers.

Budget constraint For any given period t, savers face the same budget constraint which is given, in nominal terms, by

$$\begin{aligned} &B_{j,t+1} + S_t B^*_{j,t+1} + P^c_t C_{j,t} = TR^s_t + SCS_{j,t} \\ &+ W^p_{j,t} h^p_{j,t} + W^f_{j,t} h^f_{j,t} + \varepsilon_{b,t-1} R_{t-1} B_{j,t} + \varepsilon_{b,t-1} R^*_{t-1} \Phi(A_{t-1}, \tilde{\phi}_{t-1}) S_t B^*_{j,t} \end{aligned} \tag{3}$$

where the subscript j indicators denote the household's choice variables, whereas the upper-case variables, without the subscript, are the economy-wide aggregates. B_t denotes the value of nominal domestic assets, S_t is the nominal exchange rate defined as the amount of local currency per unit of foreign currency and B^*_t is the value of foreign assets (expressed in foreign currency). TR^s_t denotes lump-sum transfers from the government, $SCS_{j,t}$ is the household's net cash income from participating in state-contingent securities at time t.[11] P^c_t is the consumer price index and W^p_t (W^f_t) represents the wage rate in the primary (secondary) sector. R_t and R^*_t are gross domestic and foreign policy rates determined by the domestic and foreign central banks, respectively. The exogenous process $\varepsilon_{b,t}$ creates a wedge between the monetary policy rate and the return on assets held by savers (e.g. SW).

Country risk premium In Eq. (3), the function $\Phi(A_t, \tilde{\phi}_t) = \exp(-\tilde{\phi}_A(A_t) + \tilde{\phi}_t)$ captures the country risk premium function of the real aggregate net foreign asset position $A_t \equiv \frac{S_t B^*_{t+1}}{P_t}$ and a time-varying shock to the risk premium $\tilde{\phi}_t$.[12]

Wage-setting Wages are sticky as in Erceg et al. (2000). Every household (except entrepreneurs) is a monopoly supplier of a differentiated labor service in the primary and secondary sectors and has a probability $(1-\xi_w)$ of being allowed to re-optimize its wage rates $W^p_{j,t}$ and $W^f_{j,t}$. Those that cannot re-optimize their wages follow a partial indexation rules described by $W^p_{j,t+1} = \left(\pi^c_t\right)^{\kappa_w} W^p_{j,t}$ and $W^f_{j,t+1} = \left(\pi^c_t\right)^{\kappa_w} W^f_{j,t}$, where κ_w determines the degree of wage-indexation to past consumer price inflation ($\pi^c_t = \frac{P^c_t}{P^c_{t-1}}$). The wage Philips curves are standard and thus presented in appendix C.

Foreign savers Foreign savers face a similar optimization problem. However, the closed-economy assumption implies that they only consume foreign goods and only accumulate foreign bonds.

[10] This assumption is discussed in appendix H.

[11] Household can insure against any type of idiosyncratic risk through the purchase of the appropriate portfolio of state-contingent securities. This standard assumption ensures that the representative agent assumption holds. The government balances its budget with lump-sum transfers.

[12] It induces stationarity of the model. See Schmitt-Grohe and Uribe (2003).

3.1.2. Rule-of-thumb households

There is a continuum of rule-of-thumb households of mass $1-\omega_s$ indexed by $j \in (\omega_s, 1)$. They mimic savers in setting their wages and consume their entire labor income in every period (e.g. Mankiw, 2000).[13] Their budget constraint is given by

$$P_t^c C_{j,t} = W_{j,t}^p h_{j,t}^p + W_{j,t}^f h_{j,t}^f \ . \tag{4}$$

Hours worked by each category of households are perfect substitutes: the aggregate labor effort in the primary (secondary) sector available to the economy is simply given by the sum of hours worked by savers and rule-of-thumb households in that sector.

Foreign rule-of-thumb households Foreign Rule-of-thumb households are similar but spend their entire labor income on foreign consumption goods.

3.1.3. Entrepreneurs

Optimization problem There is a continuum of entrepreneurs of mass 1, indexed by $j \in (0,1)$, which attain utility from consumption. Their inter-temporal utility is given by

$$\mathrm{E}_0^j \sum_{t=0}^{\infty} \beta_E^t \left[\frac{\left(C_{j,t} - \mathbf{b} C_{t-1}^e\right)^{1-\sigma_c}}{1-\sigma_c} \right], \tag{5}$$

where C_{t-1}^e is the past average consumption level of entrepreneurs and $\beta_E < \beta_S$ ensures that entrepreneurs are more impatient than savers. Entrepreneurs consume, invest in physical capital, borrow in domestic-currency assets (from the bank), and manage firms.

Investment and capital accumulation Capital and investment are assumed to be sector-specific. The investment (I^q) in each sector $q \in (p, f)$ -p for primary sector and f for secondary sector- is given by a CES aggregate of domestic ($I_t^{d,q}$) and imported investment goods ($I_t^{m,q}$) in each sector

$$I_t^q = \left[(1-\omega_i)^{1/\eta_d} (I_t^{d,q})^{(\eta_d-1)/\eta_d} + \left(\omega_i\right)^{1/\eta_d} (I_t^{m,q})^{(\eta_d-1)/\eta_d} \right]^{\eta_d/(\eta_d-1)}, \tag{6}$$

where ω_i is the steady-state share of imports in investment and η_d is the elasticity of substitution between domestic and imported investment goods.

The capital accumulation rule is subject to investment adjustment costs and follows

$$K_{t+1}^q = (1-\delta) K_t^q + \Upsilon_t (1 - \tilde{S}(I_t^q / I_{t-1}^q)) I_t^q \ , \tag{7}$$

where δ is the depreciation rate and Υ_t is a stationary investment-specific technology shock common to both sectors. The adjustment cost function follows (Christiano et al., 2005) and is defined by $\tilde{S}(I_t/I_{t-1}) = \phi_i \left\{ exp\left(\frac{I_t}{I_{t-1}} - 1\right) + exp\left(-\frac{I_t}{I_{t-1}} + 1\right) - 2 \right\}$.

Budget constraint Entrepreneurs maximize their utility (5) under the constraint

$$P_t^c C_{j,t} + P_t^i \left(I_{j,t}^p + I_{j,t}^f \right) + \varepsilon_{b,t-1} R_{t-1}^L B_{j,t}^e = \Pi_{t,j} + B_{j,t+1}^e + SCS_{j,t}^e \ , \tag{8}$$

with

$$\Pi_{t,j} = P_t Y_{j,t}^f + S_t P_t^{*p} Y_{j,t}^p - \left(W_t^p H_{j,t}^p + W_t^f H_{j,t}^f + P_t^{m,n} N_{j,t}^m \right). \tag{9}$$

In Eq. (8), the term P_t^i represents the price of the investment good. Entrepreneurs are charged a lending rate R_{t-1}^L (discussed in the financial sector section below) on credit B_t^e carried over from the previous period. The term $SCS_{j,t}^e$ represents net income from state-contingent securities. The exogenous process $\varepsilon_{b,t}$ creates a wedge between the lending rate and cost of entrepreneurs liabilities.[14]

In Eq. (9), entrepreneurs' profits $\Pi_{t,j}$ depend on sales and production costs. The first term represents the income from sales of final goods. The second term represents the income from primary commodity exports. The final term in parenthesis captures their wage bill ($W_t^p H_{j,t}^p + W_t^f H_{j,t}^f$) and expenditure on imported inputs ($P_t^{m,n} N_{j,t}^m$).

Foreign entrepreneurs Foreign entrepreneurs face a similar optimization problem. Because commodity supply is exogenous in the foreign economy, they only invest in final capital goods and pay wages to foreign households working in the final good sector. Because the foreign economy is closed, they sell all their production in the foreign market and do not purchase inputs abroad.

3.2. Firms

There are two categories of goods in this model: primary commodity and secondary goods.

[13] Hand-to-mouth households have been introduced in DSGE models applied to both emerging (Medina and Soto, 2007; and Céspedes et al., 2013) and advanced economies (e.g. Coenen and Straub, 2005, Erceg et al., 2006, López-Salido and Vallés, 2007, and Kaplan et al., 2018).

[14] More details on our wedge shock in appendix G.

3.2.1. Commodity sector

The primary commodity is produced under perfect competition in the two blocks of the model.

Domestic commodity producers Firms combine capital K_t^p, labor H_t^p and land L_t^p to produce a commodity input Y_t^p with a CES technology

$$Y_t^p = Y_0^p \left[\alpha_p \left(\frac{\varepsilon_{p,t} K_t^p}{K_0^p} \right)^{\frac{\sigma_p - 1}{\sigma_p}} + \beta_p \left(\frac{\varepsilon_{p,t} L_t^p}{L_0^p} \right)^{\frac{\sigma_p - 1}{\sigma_p}} + (1 - \alpha_p - \beta_p) \left(\frac{\varepsilon_{hp,t} H_t^p}{H_0^p} \right)^{\frac{\sigma_p - 1}{\sigma_p}} \right]^{\frac{\sigma_p}{\sigma_p - 1}}. \tag{10}$$

Land is a fixed production factor ($L_t^p = L_0^p$). Throughout the paper, production functions are written in their normalized form (e.g., Temple, 2012; Cantore and Levine, 2012) and any variable X_0 with the subscript 0 is a normalizing constants. Thus, α_p and β_p are income shares of capital and land in the primary sector, respectively. σ_p is the elasticity of substitution between production factors in the primary sector. The exogenous process $\varepsilon_{hp,t}$ is a labor-augmenting productivity shock specific to the primary sector. $\varepsilon_{p,t}$ is a capital and land-augmenting productivity shock.[15]

The domestic commodity supply is entirely exported abroad and responds to world commodity prices. This domestic commodity supply channel is an important mechanism through which foreign shocks affect the domestic economy. Endogenous domestic commodity production has also been used in the literature, but our framework is distinctive in the use of a CES production function with land. Kose (2002) also introduced land to capture its role in the production process and to reduce the volatility of commodity supply by introducing decreasing returns to scale in the other (non-fixed) production factors. While the share of land reduces the price-elasticity of commodity supply, this may not be enough. When we calibrate the land, capital, and labor shares to plausible values (as detailed in Section 4), the price-elasticity of commodity supply remains relatively high with a Cobb–Douglas production function. In contrast, a CES production function better controls the price elasticity of commodity supply with the elasticity of substitution between production factors σ_p (more details in Section 5 and appendix C).[16]

Foreign commodity producers The world commodity price P_t^{*p} is determined endogenously through the confrontation of foreign supply (Y_t^{pS*}) and demand (Y_t^{pD*}) for commodities. Foreign commodity supply is modeled as an exogenous AR(1) process

$$Y_t^{pS*} = (1 - \delta_p^*) Y_{t-1}^{pS*} + \delta_p^* Y^{pS*} + \epsilon_{p,t}^*, \tag{11}$$

where Y^{pS*} is the steady-state value of foreign commodity production and $\epsilon_{p,t}^*$ is the foreign commodity supply shock which is assumed to be an IID process (more details on this shock in appendix G). The foreign demand for commodity is determined by the foreign secondary goods sector where it serves as an input (see the following section).

3.2.2. Secondary sector

The structure of the secondary sector can be arranged in three steps: (i) production of an undifferentiated secondary good, (ii) its differentiation with brand-naming technology and finally (iii) its aggregation into consumption or investment good. Step one is performed by a secondary good producer. Steps two and three depend on intermediate and final distributors operating in the domestic, import and export markets, which introduce (Calvo, 1983) price stickiness.

Domestic secondary goods producers The secondary good is produced under perfect competition. Firms use capital K^f, purchase foreign inputs N^m and hire labor H^f to produce undifferentiated secondary goods denoted by Y^f. Two steps are involved. First, firms combine labor and capital to produce a domestic input using a standard Cobb–Douglas technology

$$N_t^d = N_0^d \left(\frac{K_t^f}{K_0} \right)^{\alpha} \left(\frac{\varepsilon_{h,t} H_t^f}{H_0} \right)^{(1-\alpha)}, \tag{12}$$

where $\varepsilon_{h,t}$ represents a labor-augmenting technology shock specific to the secondary sectors.

In the second step, secondary producers combine domestically-produced inputs with imported inputs to create the secondary good using the following CES function:

$$Y_t^f = Y_0^f \left[\omega_n \left(\frac{N_t^m}{N_0^m} \right)^{\frac{\sigma_n - 1}{\sigma_n}} + (1 - \omega_n) \left(\frac{N_t^d}{N_0^d} \right)^{\frac{\sigma_n - 1}{\sigma_n}} \right]^{\frac{\sigma_n}{\sigma_n - 1}}, \tag{13}$$

where σ_n is the elasticity of substitution between domestic and foreign inputs (Burstein et al., 2008). Note at this stage that the foreign input is an aggregate basket of commodities and secondary goods (more details in the importing distributors section below). Commodities are thus used as production inputs in both the domestic and foreign economies.

[15] More details on our capital and land-augmenting productivity shock in appendix G.

[16] The use of land in the production function has not been limited to the literature studying commodity markets. An important example is the literature on financial frictions, that has introduced land in the final good production function with Cobb–Douglas technology (e.g., Liu et al., 2013).

Foreign secondary good producers Two steps are involved in the production of foreign secondary goods (similarly to Bodenstein et al., 2011). First, foreign firms combine capital K_t^* and labor H_t^* to produce foreign intermediate goods using a standard Cobb–Douglas technology

$$N_t^* = N_0^* \left(\frac{K_t^*}{K_0^*}\right)^{\alpha^*} \left(\frac{\epsilon_{h,t}^* H_t^*}{H_0^*}\right)^{(1-\alpha^*)}, \tag{14}$$

where $\epsilon_{h,t}^*$ is a labor efficiency shock. In the second step, foreign firms combine intermediate goods with commodities using a CES function to obtain secondary foreign goods

$$Y_t^* = Y_0^* \left[\beta^* \left(\frac{Y_t^{pD*}}{Y_0^{pD*}}\right)^{\frac{\sigma_p^*-1}{\sigma_p^*}} + (1-\beta^*) \left(\frac{N_t^*}{N_0^*}\right)^{\frac{\sigma_p^*-1}{\sigma_p^*}}\right]^{\frac{\sigma_p^*}{\sigma_p^*-1}}, \tag{15}$$

where β^* is the (income) share of commodity in foreign secondary goods sector and σ_p^* is the elasticity of substitution between commodity and foreign intermediate goods. Eq. (15) shows how foreign (supply, demand, credit, and monetary policy) shocks are transmitted to world commodity prices. A boom in the foreign economy causes an increase in commodity demand which eventually raises commodity prices. The elasticity σ_p^* is a key parameter that determines the strength of commodity price responses to changes in foreign demand for commodities (more details in Section 5.1 and appendix C).

Domestic and foreign distributors Domestic (foreign) distributors introduce (Calvo, 1983) price stickiness to the domestic (foreign) final good price P_t (P_t^*). Details are presented in appendix C.

Importing and exporting distributors Importing and exporting distributors introduce incomplete exchange rate passthrough to import and export prices (ALLV) with one difference described below. In the domestic economy, distributors also import foreign inputs that consist in a Leontief basket of commodities and intermediate goods:

$$N_t^m = \min\left(\frac{N_t^{m,f}}{1-\omega_p}, \frac{N_t^{m,p}}{\omega_p}\right). \tag{16}$$

This allows both imported commodities $N_t^{m,p}$ and intermediate products $N_t^{m,f}$ to enter the domestic production function (13) via imported inputs N_t^m sold at price $P_t^{m,n}$.

Finally, foreign demand for the final domestic good follows ALLV and is defined by

$$X_t^f = \left(\frac{P_t^x}{P_t^*}\right)^{-\eta_f} Y_t^*, \tag{17}$$

where P_t^x is the export price (denominated in export market currency), P_t^* is the price of the foreign good in foreign currency and Y_t^* is foreign GDP (capturing foreign demand). The coefficient η_f is the foreign elasticity of substitution between foreign and domestic goods.

3.3. Financial sector

There are two types of banks: domestic and foreign. Domestic banks operate in the domestic market. Foreign banks are global players operating in the domestic and foreign markets. Entrepreneurs take loans denominated in domestic currency at aggregate rate R_t^L given by

$$R_t^L = (1-\omega_b) R_t^{L,d} + \omega_b R_t^{L,f}, \tag{18}$$

where ω_b is the share of foreign banks operating in the domestic economy. $R_t^{L,d}$ and $R_t^{L,f}$ are the lending rates charged by domestic and foreign banks to domestic borrowers, respectively. We assume that entrepreneurs borrow a fixed share ω_b of their credit needs from foreign banks and they cannot take advantage of arbitrage opportunities. We define these lending rates below.

Domestic financial market Domestic banks collect deposits from savers and have access to the central bank to finance any liquidity shortages. The deposit rate is equal to the central bank rate R_t. We assume the existence of an agency problem between banks and borrowers (presented and compared to Bernanke et al., 1999 in appendix C). The domestic bank determines the domestic lending rate $R_t^{L,d}$ and charges a premium over the deposit rate to finance monitoring costs by setting

$$R_t^{L,d} = \phi_{fc} \left(\frac{B_t^e}{V_t}\right)^{\phi_{nw}} \varepsilon_{R_L,t} R_t, \tag{19}$$

where B_t^e is the entrepreneur nominal debt and V_t is its collateral such that $\frac{B_t^e}{V_t}$ represents leverage. Therefore, ϕ_{nw} is the elasticity of the domestic bank's spread to domestic entrepreneurs' leverage. ϕ_{fc} captures fixed lending cost (allowing us to calibrate the spread at steady state). $\varepsilon_{R_L,t}$ is a pure domestic credit supply shocks.[17] We define collateral as a claim on entrepreneurs' capital stock

$$V_t = P_t^{k,p} K_t^p + P_t^{k,f} K_t^f \ , \tag{20}$$

where $P_t^{k,p}$ and $P_t^{k,f}$ are the price of physical capital in the primary and secondary sectors.

Foreign financial market Foreign banks face an identical agency problem. They set the foreign currency rate $R_t^{L,*}$ when lending to foreign entrepreneurs:

$$R_t^{L,*} = \phi_{fc}^* \left(\frac{B_t^*}{V_t^*} \right)^{\phi_{nw}^*} \varepsilon_{R_L,t}^* R_t^* \tag{21}$$

where B_t^{e*} is the foreign entrepreneur nominal debt and $\varepsilon_{R_L,t}^*$ is a pure foreign credit supply shock. V_t^* is the value of collateral defined as $V_t^* = P_t^{k*} K_t^*$ where K_t^* is capital in the foreign economy and P_t^{k*} is its price.

Foreign banks also set a domestic currency lending rate. We assume that foreign banks do not discriminate between domestic and foreign borrowers, that foreign entrepreneurs have access to domestic currency credit at the foreign banks, and that domestic entrepreneurs are too small to have an impact on the profits of foreign banks. Foreign banks thus set a single rate $R_t^{L,f}$ for lending in domestic currency to both domestic and foreign entrepreneurs:

$$R_t^{L,f} = \phi_{fc}^* \left(\frac{B_t^*}{V_t^*} \right)^{\phi_{nw}^*} \varepsilon_{R_L,t}^* R_t \ . \tag{22}$$

In Eqs. (21) and (22), ϕ_{nw}^* is the elasticity of the foreign bank's spread to foreign entrepreneurs' leverage. Foreign banks therefore introduce contagion from developments in the global market into the domestic economy through the interest rate $R_t^{L,f}$ they charge in the domestic economy.[18]

3.4. Public authorities

The public sector consists of a central bank and a fiscal authority.

Central bank The monetary authority is assumed to follow a simple Taylor-type rule

$$R_t = \rho_r R_{t-1} + \left(1-\rho_r\right) \left(\bar{R} + \tau_\pi \left(\pi_t^c - 1\right) + \tau_{\Delta y} \left(\frac{Y_t}{Y_{t-1}} - 1 \right) + \tau_{\Delta s} \left(\frac{S_t}{S_{t-1}} - 1 \right) \right) + \varepsilon_{R,t}, \tag{23}$$

where ρ_r is the interest rate smoothing parameter, $\bar{R}$ is the level of the gross risk free rate at steady state, τ_π is the response to current consumer price inflation, $\tau_{\Delta y}$ to (real) GDP growth and $\tau_{\Delta s}$ to the change in exchange rate. The exogenous process $\varepsilon_{R,t}$ is a monetary policy shock. The foreign central bank follows a similar rule (but does not respond to the exchange rate by the closed-economy assumption).

Government The government follows a simple spending rule

$$G_t = \rho_g G_{t-1} + (1-\rho_g)\bar{G} + \varepsilon_{g,t}\bar{G}, \tag{24}$$

where $\bar{G}$ is the steady-state value of government spending and $\varepsilon_{g,t}$ is a government spending shock. We assume that government consumption is composed of domestic goods only. The government balances its budget with lump-sum transfers. The foreign government follows a similar rule.

3.5. Closing market conditions

In equilibrium, the domestic goods market, the loan market and the foreign bond market have to clear. The aggregate resource constraint on the use of domestic goods is:

$$C_t^d + I_t^d + G_t + X_t^f \leq Y_t^f. \tag{25}$$

The loan market clears when the demand for liquidity from firms and entrepreneurs equals the supply of liquidity including savers' deposits and monetary injections by the central bank. Since the central bank liquidity supply is perfectly inelastic at its policy rate, clearing is guaranteed.

The foreign asset market clears when the positions of the exporting and importing firms equal the households' choice of foreign bond holdings. Foreign assets evolve according to:

$$S_t B_{t+1}^* = R_{t-1}^* \Phi\left(a_{t-1}, \tilde{\phi}_{t-1}^a\right) S_t B_t^* + S_t P_t^x X_t^f + S_t P_t^{*p} X_t^p - P_t^m \left(C_t^m + I_t^m\right) - P_t^{m,n} N_t^m. \tag{26}$$

Finally, the aggregate resource constraint in the foreign economy implies that total final output is used for private and public consumption and investment. The supply of commodities in the foreign economy is equal to the demand for commodities by foreign firms in the secondary sector.

[17] In spirit, the pure credit supply shock identification is similar to Helbling et al. (2011) and Meeks (2012): it is an increase in the credit spread unrelated to borrowers' risk. Note that it differs from the wedge shock $\varepsilon_{b,t}$ that we interpret as an aggregate demand shock.

[18] Our assumptions thus fit the idea that foreign banks can act as shock's absorbers when an economy is hit by domestic shocks (e.g. de Haas and van Lelyveld, 2010) and as a transmission channel for global shocks (e.g. de Haas and van Lelyveld, 2014 and Cetorelli and Goldberg, 2011).

3.6. Structural shocks

Table 5 summarizes the Gaussian structural shocks analyzed in the model. We define two broad categories of shocks: domestic and foreign shocks. Domestic and foreign shocks are disturbances that are unambiguously identified from domestic and foreign origins, respectively. Country risk premium shocks do not fit in one of these categories as they could be explained by a change in domestic country risk (beyond what is captured by the net foreign asset position) or by a change in foreign risk aversion towards the SOE leading to a revision of the price of exchange rate risks. Note, however, that these shocks have no impact on foreign variables. To ease the exposition of some results, domestic and foreign shocks are classified into five groups: aggregate demand shocks (AD), aggregate supply shocks (AS), monetary policy shocks (MP), credit supply shocks (Cred), and commodity supply shocks (Com).

When describing the transmission mechanisms of foreign shocks to the domestic economy in our calibrated model, we focus on foreign wedge shocks. This type of shocks is the most important foreign source of business cycle fluctuations in this paper (based on our estimation results), and aggregate demand shocks are promising candidates to explain business cycle synchronization (see for example Andrle et al., 2017).

4. Calibration and estimation strategy

This section presents our calibration and estimation strategy.

4.1. Calibrated parameters and priors

Here, we discuss the calibration and priors of important parameters that directly relate to our three main transmission channels (standard parameters are discussed in appendix I). Calibrated parameters and prior distributions are displayed in Tables 6 and 7, respectively.

Some parameters are estimated. In Section 6, the estimated mode is used to quantify the importance of foreign shocks and the role of commodity and financial channels in Canada and South Africa. In Section 5, we describe the transmission mechanisms of foreign shocks in a fully calibrated model. In this latter case, we simply calibrate these parameters to their prior mean.

Financial channel The mass of rule-of-thumb households is calibrated to $1/3$ ($\omega_s = 2/3$). This proportion is consistent with the data: Kaplan et al. (2014) show that hand-to-mouth households represent more than 30% of the population in the US and Canada. For South Africa, this calibration is probably very conservative, but consistent with the fact that only 64% of households have an account at any financial institution (World Bank financial inclusion database, average over three waves of data in 2011, 2014 and 2017). The mass of entrepreneurs is set to 1 as in Gerali et al. (2010). The discount factor is set to 0.99 for savers (β_S) and matches the average interest rate spread for entrepreneurs (β_E). The private non-financial sector credit to GDP ratio is calibrated based on BIS data.

The prior means for the financial accelerator in the domestic (ϕ_{nw}) and foreign (ϕ^*_{nw}) economies are set to 0.05 following Bernanke et al. (1999). This value is very close to the estimate in Christensen and Dib (2008) for the US. Our choice for the prior mean of the share of foreign banks in domestic credit (ω_b) follows Claessens and Horen (2014). They estimate the share of foreign banks' assets among total bank assets to 22% for South Africa and 41% for Canada. In the calibrated version of the model, we however set this value to 0.5 to give an equal weight to domestic and foreign financing conditions.

Domestic commodity supply channel The commodity exports-to-GDP ratio is set to 12% in Canada and South Africa based on UNCTAD trade data. It implies that commodities represent about 36% and 44% of total exports in these economies. The land share β_p is then calibrated to fit the average primary sector to total employment ratio (5 and 7% in Canada and South Africa, respectively).[19] In the calibrated version of the model, we set the commodity exports-to-GDP and primary sector to total employment ratios to 12 and 6%, respectively.

The elasticity of substitution between production factors in the domestic primary sector production function (σ_p) has a determining impact on the domestic commodity supply price-elasticity. The literature generally supports a low elasticity. We therefore set the prior mean of σ_p to 1/3. Combined with the introduction of a fixed production factor (land), this value of σ_p produces a reasonably low commodity supply price-elasticity (of about 0.14 with the baseline calibration) that lies inside the range of value reported in the literature review of Caldara et al. (2016) on oil supply price-elasticity.[20]

World commodity price channel We calibrate the commodity income share in final goods production (β^*) to 0.08 and commodity supply adjusts to meet this target. The mean of the prior governing the foreign commodity demand elasticity of substitution (σ^*_d) is set to 0.13 following the literature review in Caldara et al. (2016) on oil demand elasticity.

[19] For Canada, this value is obtained using the sum of employees' compensation in Agriculture, hunting and forestry (ISIC4_A) and mining and quarrying (ISIC4_B) divided by the total compensation of employees (ISIC4_TOTAL) from OECD. For South Africa, this value corresponds to the mining sector's share in total non-agricultural employment as reported by the South African Chamber of Mines.

[20] We compute this short-run commodity supply elasticity based on the IRFs to a foreign commodity supply shock. We divide the response of domestic commodity output on impact by the response of real commodity prices expressed in domestic currency (in deviation from steady state).

4.2. Bayesian estimation and data

When we estimate the model, we use Bayesian methods (e.g. DeJong et al., 2000; Otrok, 2001; Schorfheide, 2000; and Adjemian et al., 2011). We estimate the model in two steps. First, foreign parameters are estimated using only foreign data. Second, domestic parameters are estimated on the full dataset, calibrating foreign parameters at their mode values estimated in the first step. This strategy ensures that foreign parameters remain identical when estimating the model on different SOEs, which simplifies the exposition of the results and allows to compare the two SOEs. Table 7 reports the mode of all estimated parameters (for Canada, South Africa and the US) used to produce our results in Section 6. More details on the estimation and robustness checks are provided in the appendices E, F, and G.[21]

We estimate the model using quarterly data on 11 domestic and 9 foreign variables over the period 1994Q1 to 2019Q4. We sequentially use South African and Canadian data for the domestic economy, and US data for the foreign economy. The start date has been selected to avoid the apartheid period in South Africa (which was characterized by instability and relatively low trade and financial linkages with the rest of the world). The following domestic and foreign variables are used: GDP, consumption, investment, hours worked, consumer price indexes, wages, risk-free rate (we use the shadow rate of Wu and Xia, 2016 for the US), and corporate spread. In addition, we include the nominal exchange rate and a world commodity price. Specifically for the domestic economy, we also include commodity exports and employment in the commodity sector.

Due to data availability issue, we build a South African spread proxy using the predicted values obtained from regressing an emerging market spread index on South African variables. Moreover, South African commodity exports are proxied by sales in the mining sector (about 70% is exported). Again for South Africa, we use labor compensation instead of wages and we use employment instead of hours worked. We thus introduce an ad-hoc equation linking employment to hours with a labor-hoarding parameter as in ALLV. Also note that we allow for calibrated measurement errors for all variables.

5. Transmission mechanisms of foreign demand shocks

How does the model reproduce business cycle synchronization, and how do foreign shocks transmit to the domestic economy? To answer these questions, we describe the impact of a favorable foreign aggregate demand shock on the domestic economy, with different calibrations of the model that are meant to sequentially open or close our three main transmission channels. The calibration always ensures that the domestic and foreign economies are identical in economic structure, except for their relative size and share of the commodity sector (the domestic economy is a net exporter of commodities). We proceed in two steps. First, we describe how foreign shocks generate spillovers to the domestic economy through the endogenous world commodity price and domestic commodity supply channels. Second, we show how financial frictions can amplify the impact of foreign shocks and lead to a stronger business cycle synchronization. We also provide a more theoretical discussion of the commodity channels based on a simplified version of our model presented in appendix C.[22]

5.1. Commodity channels

In this section, we investigate how foreign shocks transmit through the world commodity price and domestic commodity supply channels. To focus on these channels, we abstract from financial frictions. For this purpose, we simply calibrate the share of rule-of-thumb households and entrepreneurs to zero and assume that patient households manage the stock of capital. The question we address here is: can we generate foreign spillovers in a model with trade in commodities used as production inputs?

To some extent, we can. Fig. 4 shows the IRFs of foreign and domestic variables to foreign wedge shocks when the world commodity price and the domestic commodity supply channels are open or closed. When we close the world commodity price channel, we assume that real world commodity prices are constant and Eq. (11) becomes $P_t^{*p} = P_t^*$. To close the domestic commodity supply channel, we set the elasticity of substitution between production factors in the primary sector (σ_p) to zero. In this case, the domestic commodity supply is exogenous and its price-elasticity is zero. When both commodity channels are open (in grey), foreign aggregate demand shocks spill over to the domestic economy. When one or both commodity channels are closed, the aggregate foreign demand shock has a very small impact on domestic GDP. This result is consistent with the international co-movement puzzle found in standard open-economy macroeconomic models.

How does the combination of an endogenous world commodity price channel with an endogenous domestic commodity supply channel generate business cycle synchronization? In our model, an increase in foreign aggregate demand stimulates demand for commodities used in the production process. When commodity prices are endogenously determined through the confrontation of foreign supply and demand for commodities, equilibrium on the commodity market must be reached with an increase in commodity prices. We refer to this response of commodity price to a non-commodity shocks as the world commodity price channel. In a

21 We discuss the identification of parameters related to our main transmission channels, an alternative strategy to identify foreign shocks, and a joint estimation of domestic and foreign parameters with MCMC methods accounting for parameter uncertainty. Further robustness exercises are also presented in the working paper version of this article (see Houssa et al., 2019), such as different strategies to identify foreign and SOE shocks, a sub-period analysis, different calibrations for the elasticity of substitution between domestic and foreign goods and the share of rule-of-thumb households, estimations with or without endogenous priors (Christiano et al., 2011), and different proxies to measure South African commodity exports and spread.

22 It is not so straightforward to express the financial channel with a few equations. We thus rely on IRFs in this section and present a more theoretical discussion in appendix C.

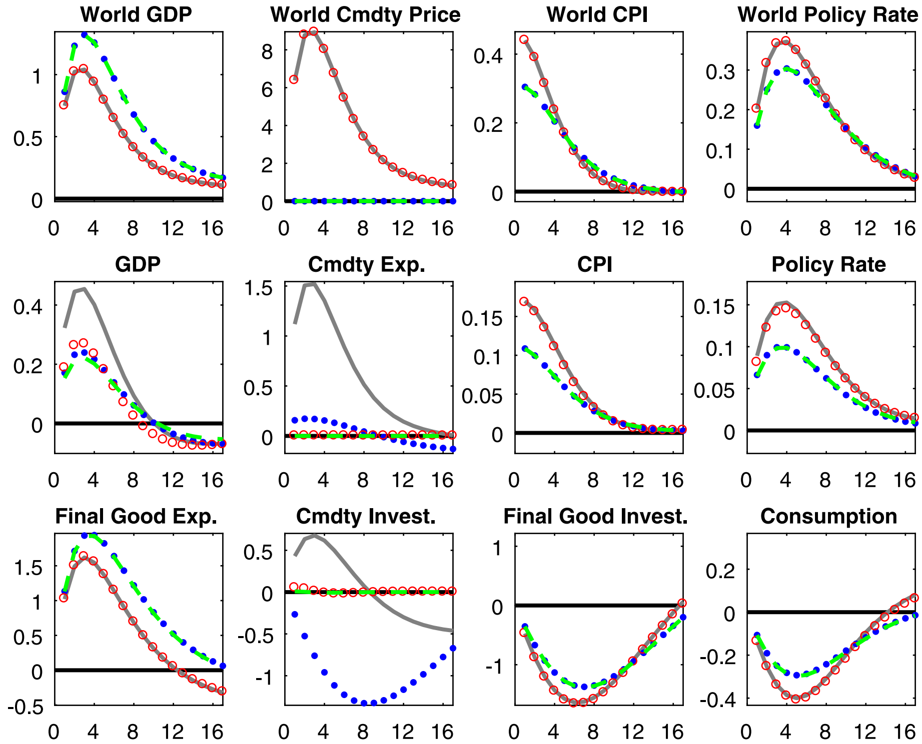

Fig. 4. IRFs - Foreign aggregate demand shocks and commodity channels.
Note: Variables expressed in percentage deviation from steady state. Inflation and interest rates annualized. Horizon in quarters. The financial channel is closed.
Grey: Open world commodity price channel, open domestic commodity supply channel.
Red: Open world commodity price channel, closed domestic commodity supply channel.
Blue: Closed world commodity price channel, open domestic commodity supply channel.
Green: Closed world commodity price channel, closed domestic commodity supply channel. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

simplified version of our model that is useful to build more intuition on this channel, we show that the path of real world commodity prices ($\hat{\gamma}_t^{p*}$) expressed in percentage deviation from steady state follows the world GDP ($\hat{Y}_t^*$):

$$\hat{\gamma}_t^{p*} = \frac{1}{\sigma_p^*}\hat{Y}_t^* \ . \tag{27}$$

Eq. (27) shows that the magnitude of the increase in commodity prices depends on the elasticity of substitution between commodities and other productive inputs (labor and physical capital).[23] The lower the elasticity, the harder it is for foreign firms to substitute commodities with other productive inputs, and the stronger the increase in world commodity prices. When we calibrate the elasticity of substitution between commodities and other productive inputs (σ_p^*) to 1 (instead of 0.13 in the baseline calibration), the response of commodity prices becomes more muted, and the model generates a weaker synchronicity between GDP in the domestic and foreign economies (see Fig. 5).

When an endogenous commodity supply is introduced to the domestic block of the model, an increase in world commodity prices causes an increase in domestic commodity exports and GDP. The response of domestic commodity supply to the changes in world commodity prices is our domestic commodity supply channel. In a simplified version of our model, we obtain commodity supply in the SOE as a function of commodity prices:

$$\hat{Y}_t^p = \frac{\sigma_p\left(1-\alpha_p-\beta_p\right)}{\alpha_p+\beta_p}\hat{\gamma}_t^{p*} \ , \tag{28}$$

where the term $\frac{\sigma_p(1-\alpha_p-\beta_p)}{\alpha_p+\beta_p}$ is the price-elasticity of commodity supply. It is decreasing in the share of capital (α_p) and land (β_p) which are a fixed production factor constraining firms' ability to adjust commodity supply (we assume that capital is also fixed to obtain Eq. (28)). It is increasing in the elasticity of substitution between labor, land and capital (σ_p). The higher this elasticity, the easier it is for firms to substitute these fixed production factors with labor in the primary sector. In the limit case where the elasticity

[23] We present our simplifying assumptions in appendix C where we also show the equivalent to Eqs. (27) and (28) for our baseline model.

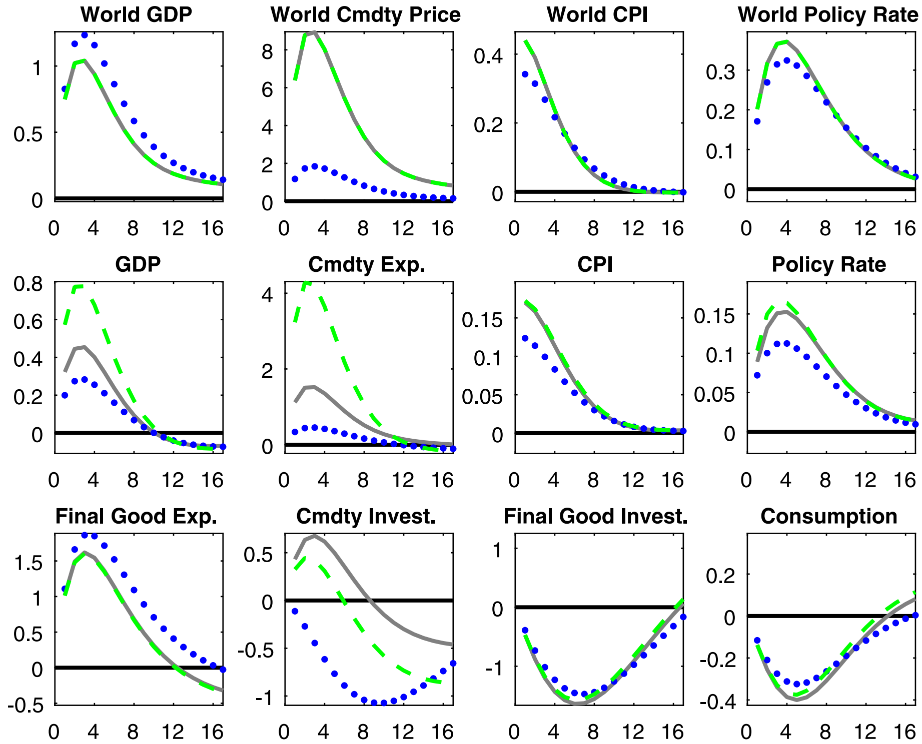

Fig. 5. IRFs - Foreign elasticity of commodity demand and domestic elasticity of commodity supply.
Note: Variables expressed in percentage deviation from steady state. Inflation and interest rates annualized. Horizon in quarters. The financial channel is closed.
Grey: Baseline elasticities in the domestic and foreign economies ($\sigma_p = 0.33$ and $\sigma_p^* = 0.13$).
Green: Increased commodity supply elasticity in the SOE ($\sigma_p = 1$ and $\sigma_p^* = 0.13$).
Blue: Increased commodity demand elasticity in the foreign economy ($\sigma_p = 0.33$ and $\sigma_p^* = 1$). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

of substitution between productive factors (σ_p) is calibrated to zero (instead of 0.33 in the baseline), the domestic commodity supply does not respond to changes in commodity prices, and the model generates a weaker synchronicity between GDP in the domestic and foreign economies.

Combining Eqs. (27) and (28), we express the international spillovers operating through the world commodity price and domestic commodity supply channels as:

$$\hat{Y}_t = \varpi_p \frac{\sigma_p \left(1 - \alpha_p - \beta_p\right)}{\alpha_p + \beta_p} \frac{1}{\sigma_p^*} \hat{Y}_t^* \ . \tag{29}$$

These spillovers are stronger in SOEs with a larger share of the commodity sector in GDP (when ϖ_p is high) and a bigger price-elasticity of commodity supply (when σ_p is high or α_p and β_p are small). They are also stronger when the elasticity of world commodity prices to world GDP is higher (when σ_p^* is small).

Finally, one might ask if and how our simplified model can generate more pronounced business cycle synchronization. In fact, it can easily generate a stronger GDP response in the domestic economy, but at the cost of an unrealistically high commodity supply price-elasticity in the domestic economy. In the baseline, we calibrated the elasticity of substitution between land and other productive inputs in the domestic primary sector to 1/3, which generates a sizable but plausible elasticity of the domestic commodity supply (0.16 when α_p and β_p are calibrated to match a realistic labor income share). In contrast, the literature (e.g. Dib, 2008, Schmitt-Grohé and Uribe, 2018, Rees et al., 2016 and Allegret and Benkhodja, 2015) has largely used Cobb–Douglas production functions when endogenizing commodity supply, which is equivalent to imposing an elasticity of substitution between land and other productive inputs of one. When we follow this literature and calibrate this parameter to one, the response of domestic commodity exports and GDP are much larger, as shown in Fig. 5. However, this calibration implies an elasticity of commodity supply in the domestic economy that is close to 0.5, which lies outside the range of plausible values reported in Caldara et al. (2016). Moreover, the decline in consumption and investment is at odd with the empirical evidence presented in Section 2.2.[24]

[24] The monetary policy response to the increase in CPI (due to an increase in foreign demand for domestic good and from higher commodity prices used in the production process) causes a decline in consumption and investment in the final good sector.

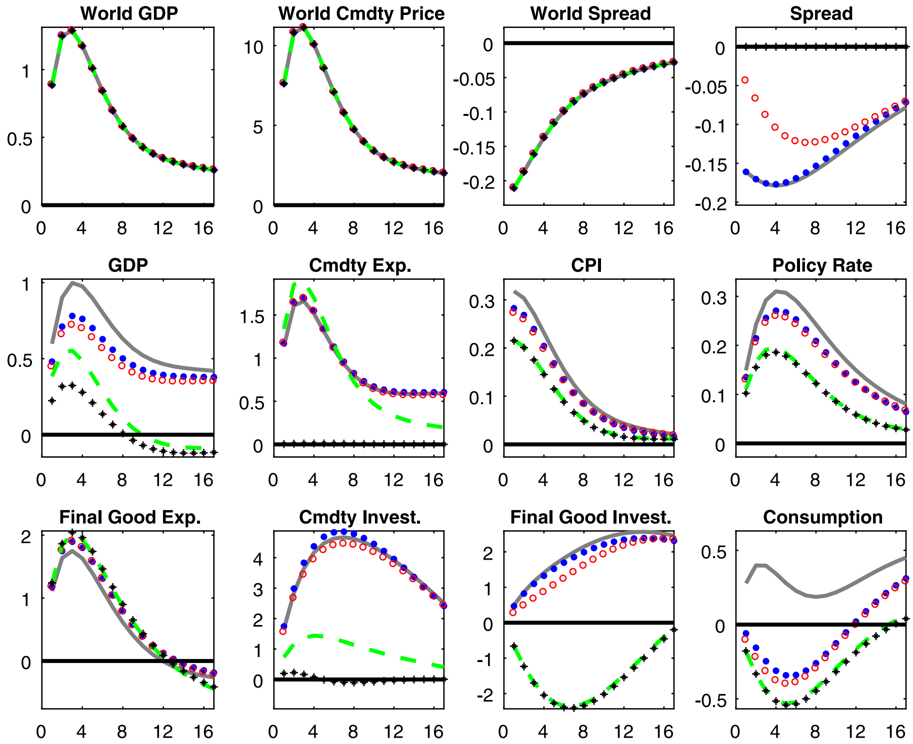

Fig. 6. IRFs - Foreign aggregate demand shocks and the financial channel.
Note: Variables expressed in percentage deviation from steady state. Inflation rates, interest rates and spreads annualized. Horizon in quarters.
Grey: Baseline with open financial and commodity supply channels in the SOE ($\sigma_p = 0.33$).
Blue: Semi-open financial channel in the SOE (domestic and foreign banks only, $\sigma_p = 0.33$).
Red: Semi-open financial channel in the SOE (domestic banks only, $\sigma_p = 0.33$).
Green: Closed financial channel in the SOE (no banks, no ROTHs, $\sigma_p = 0.33$).
Black: Closed financial and commodity supply channels in the SOE ($\sigma_p = 0$). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

5.2. Adding the financial channel

In this section, we first demonstrate that our model generates sizable international spillovers to a SOE when the commodity and financial channels are combined. Then, we describe how the financial channel amplifies the impact of foreign shocks. For that purpose, we decompose our financial channel intro three components attributed to domestic banks and entrepreneurs, foreign banks, and rule-of-thumb households, respectively.

When our commodity and financial channels are activated, Fig. 6 shows that positive foreign aggregate demand shocks generate substantial spillovers to the domestic economy. In the domestic and foreign economies, GDP expands and the spread declines. The magnitude of the response in these variables is similar between the domestic and foreign economies. Moreover, consumption, investment, and exports increase in the domestic economy. In contrast, when the financial channel is closed, the impact of foreign demand shocks on domestic GDP is weaker and consumption and investment fall. The financial channel thus amplifies the impact of foreign demand shocks in the SOE and leads to greater synchronization between domestic and foreign real variables.

How does the financial channel amplify the impact of a favorable foreign aggregate demand shocks? To answer this question, we start from the no financial friction case, and gradually add domestic banks and entrepreneurs, foreign banks, and rule-of-thumb households. To completely close the financial channel, we calibrate the share of rule-of-thumb households and entrepreneurs to zero and assume that patient households manage the stock of capital (as in Section 5.1).

Starting from the situation where the financial channel is closed, we first add domestic banks and entrepreneurs (while assuming that foreign banks lend at the risk-free rate to domestic entrepreneurs). The difference between the model with a closed financial channel and the model with domestic banks and entrepreneurs captures the role of domestic financing conditions in the transmission of a positive foreign demand shock. In the latter model, the spread charged by domestic banks gradually narrows over time as entrepreneurs benefit from higher incomes with higher commodity prices, which progressively reduces their debt to collateral ratios. This long-lasting drop in the spread encourages entrepreneurs to increase investment in the primary and secondary sectors, and to raise consumption (see Fig. 6).

Next, we introduce foreign banks (in addition to domestic banks) to evaluate the contribution of international financing conditions in the transmission of foreign demand shocks. The easing of international financing conditions causes a more pronounced

Table 1
Correlation between domestic and foreign variables.

South Africa	Corr(x,GDP*)		Corr(x,CP*)		Corr(x,x*)	
	Data	DSGE	Data	DSGE	Data	DSGE
GDP	0.37	0.40	0.60	0.45	0.37	0.40
Employment	0.22	0.44	0.38	0.48		
Consumption	0.41	0.22	0.51	0.25	0.34	0.21
Investment	0.14	0.16	0.21	0.19	0.18	0.19
Exports	0.53	0.46	0.36	0.44		
Imports	0.46	0.09	0.49	0.07		
Commodity exports	0.31	0.31	0.54	0.39		
Commodity empl.	−0.17	0.41	0.49	0.49		
CPI	−0.22	0.17	−0.13	0.18	0.15	0.45
Labor compensation	0.25	0.38	0.46	0.42		
Risk-free rate	0.34	0.01	−0.10	0.00	0.76	0.50
Spread	−0.28	−0.13	−0.48	−0.11	0.64	0.70
Exchange rate	0.02	−0.05	−0.17	−0.07		
Canada	Data	DSGE	Data	DSGE	Data	DSGE
GDP	0.78	0.50	0.41	0.54	0.78	0.50
Hours	0.75	0.53	0.45	0.57	0.75	0.53
Consumption	0.58	0.42	0.60	0.48	0.49	0.38
Investment	0.65	0.22	0.59	0.25	0.61	0.24
Exports	0.82	0.45	0.25	0.36		
Imports	0.78	0.15	0.65	0.14		
Commodity exports	0.65	0.21	0.38	0.27		
Commodity empl.	0.22	0.38	0.44	0.47		
CPI	0.06	0.17	0.43	0.17	0.62	0.52
Wage	0.18	0.12	0.05	0.11	0.58	0.26
Risk-free rate	0.48	0.00	0.17	−0.02	0.87	0.57
Spread	−0.70	−0.11	−0.39	−0.12	0.75	0.55
Exchange rate	0.00	−0.05	−0.32	−0.08		

Note: Risk-free rate and spread in levels; Exchange rate in Q/Q growth rate; all other variables in Y/Y growth rates. Stars stand for foreign variables. South Africa data in the upper panel and Canada in the lower panel. The second column displays the correlation between foreign GDP and domestic variables listed in the first column. The third column shows the correlation between world commodity prices and domestic variables. The fourth column shows domestic variables and their foreign counterparts (when appropriate).

drop in the spread in the short run. As a result, investment and consumption further expand. However, the contribution of international financing conditions is relatively modest compared to the contribution of domestic financing conditions. In the foreign block, the decline in the spread is strong but short-lived, as it is caused by a temporary increase in the value of capital used as collateral. In contrast, domestic financing conditions mostly improve through a more persistent decline in entrepreneur's debt.

Finally, we add rule-of-thumb households and end up with our full model. In this case, the impact of a positive foreign aggregate demand shocks on domestic consumption increases further. Indeed, as activity expands in the primary and final good sectors, labor incomes follow, which increases rule-of-thumb households' ability to purchase consumption goods. Together, the full set of financial frictions described above magnifies the impact of foreign aggregate demand shocks in the SOE.

6. Foreign shocks in Canada and South Africa

In this section, we demonstrate our estimated model's ability to explain the synchronization of international business cycles and to capture the contribution of foreign shocks in two small open commodity exporters: Canada and South Africa. First, we set all estimated parameters at their posterior's mode to estimate correlation coefficients between key domestic and foreign variables. Second, we present a variance decomposition. An historical decomposition that complements this analysis is also provided in appendix G. Third, we quantify the contribution of the world commodity price channel, the domestic commodity supply channel, and the financial channel in the transmission of foreign shocks. Here, we focus on the quantitative impact of these channels in the two SOEs driven by various domestic and foreign shocks, while Section 5 describes their underlying mechanisms in a calibrated model.

6.1. Synchronization of international business cycles

Table 1 shows that our model successfully reproduces some key correlations between the US-Canada and US-South Africa pairs. For example, our model fits the positive correlation between US variables and their South African counterparts for GDP (data: 0.37 vs DSGE: 0.40); consumption (0.34 vs 0.21); investment (0.18 vs 0.19); CPI (0.15 vs 0.45); interest rates (0.76 vs 0.50); and spreads (0.64 vs 0.70). It also fits the correlations between commodity prices and commodity exports (0.54 vs 0.39); commodity employment (0.49 vs 0.49); GDP (0.60 vs 0.45) and its different components.

Table 2
Foreign shocks contribution to foreign and domestic variables.

South Africa	AD*	AS*	MP*	Com*	Cred*	All*
GDP	13.80	3.42	2.68	2.13	4.51	26.54
Employment	17.36	2.40	3.44	2.09	5.91	31.20
Consumption	4.13	2.76	1.44	1.36	2.58	12.27
Investment	4.18	8.02	2.58	2.98	2.33	20.09
Exports	21.52	2.55	2.87	4.07	3.22	34.23
Imports	2.13	3.67	0.93	0.62	0.80	8.15
Commodity exports	7.49	4.68	1.55	4.15	1.18	19.05
Commodity Empl	16.89	8.54	3.95	5.20	2.89	37.47
CPI	19.71	4.19	2.48	2.89	3.50	32.77
Wage	10.81	2.76	2.43	1.80	3.80	21.60
Risk-free rate	21.74	7.71	2.43	4.36	3.19	39.43
Spread	17.46	6.55	3.35	5.58	26.61	59.55
Exchange rate	0.80	6.08	5.49	1.41	0.20	13.98
Canada	**AD***	**AS***	**MP***	**Com***	**Cred***	**All***
GDP	25.75	2.95	3.23	2.17	6.84	40.94
Employment	28.19	2.16	3.64	2.33	7.55	43.87
Consumption	13.31	5.72	3.93	4.29	5.70	32.95
Investment	5.24	8.44	3.32	3.64	3.45	24.09
Exports	28.44	5.98	1.06	5.35	4.30	45.13
Imports	2.51	5.64	1.74	0.94	1.81	12.64
Commodity exports	3.45	3.20	0.79	1.97	0.57	9.98
Commodity Empl	12.69	4.66	2.84	4.18	2.17	26.54
CPI	30.25	6.84	3.00	4.45	3.70	48.24
Wage	23.23	9.94	3.43	4.50	3.24	44.34
Risk-free rate	29.21	11.31	2.67	6.59	3.01	52.79
Spread	24.07	15.01	4.58	11.63	11.34	66.63
Exchange rate	0.71	11.00	12.57	1.84	0.14	26.26
United States	**AD***	**AS***	**MP***	**Com***	**Cred***	**All***
GDP	49.46	19.85	14.87	7.04	8.25	99.47
Consumption	48.86	22.61	14.77	4.97	8.35	99.56
Investment	48.62	20.72	18.53	5.96	5.76	99.59
Hours	42.32	20.82	9.30	8.87	17.71	99.02
CPI	57.51	9.33	21.90	3.31	7.64	99.69
Wage	21.71	65.88	8.56	0.90	2.38	99.43
Risk-free rate	78.55	2.51	4.78	4.60	7.93	98.37
Spread	9.57	12.10	2.75	5.63	69.20	99.25
(World) Commodity Price	40.56	15.65	12.12	24.37	6.77	99.47

Note: Risk-free rate and spread in levels; Exchange rate in Q/Q growth rate; all other variables in Y/Y growth rates. Stars stand for foreign shocks. See Table 5 for a description of the shocks' classification. The last column is the total contribution of all foreign shocks. South Africa data in the upper panel, Canada in the middle and US in the lower panel. Note that the sum of variances does not add up to 100 due to the inclusion of small calibrated measurement errors in the estimation.

We find similar correlations coefficients for Canada. In particular, the correlation between US and Canadian GDP is high at 0.5, although not as high as in the data (0.78). Compared to South Africa, non-commodity exports accounts for a larger share of GDP in Canada. Our model has a weaker ability to explain business cycle synchronization through trade in non-commodity goods, as in the case of conventional SOE models (see JP). Our model thus captures some transmission channels relevant to the Canadian economy (trade in commodities and financial frictions) but misses some others (such as trade in non-commodity goods or services). The fact that our model is better at fitting the correlations between commodity prices and Canadian commodity exports (0.38 vs 0.27), commodity employment (0.44 vs 0.47) and GDP (0.41 vs 0.54) than at fitting the correlation between US GDP and Canadian total exports (0.82 vs 0.45) also supports this interpretation.

6.2. The contribution of foreign shocks

Table 2 shows foreign shocks contribution to the variation of South African (upper panel), Canadian (middle panel) and US variables (lower panel). Foreign shocks are important drivers of economic fluctuations in South Africa and Canada. Together, they explain 27% and 36% of the fluctuations in South African and Canadian macroeconomic variables (on average) over the 1994 to 2019 period. They account for a large share of fluctuations in GDP (27% and 41%), the consumer price index (33% and 48%), the risk-free rate (39% and 53%) and the spread (60% and 67%). We report relatively smaller contributions to commodity exports (19% and 10%) and the nominal exchange rate (14% and 26%) which reflects the importance of UIP and commodity productivity shocks in driving these variables. The higher average variance decompositions in Canada can be attributed to smaller domestic shocks and to a larger exposure to trade in non-commodity goods. Going through specific foreign shocks, we can see that aggregate demand shocks play a dominant role in South Africa and Canada.

Table 3
Correlation between domestic and foreign variables and amplification channels.

South Africa	Baseline	No fin (1)	No CS (2)	Cst CP (3)	All (1,2,3)	Exo world CP	Data
Y*,Y	0.40	0.30	0.31	0.22	0.14	0.13	0.37
Y*,E	0.44	0.33	0.34	0.25	0.15	0.12	0.22
Y*,C	0.22	−0.06	0.18	0.08	−0.05	0.09	0.41
Y*,I	0.16	0.00	0.12	0.04	−0.03	−0.05	0.14
Y*,X	0.46	0.51	0.30	0.43	0.45	0.49	0.53
Y*,M	0.09	−0.11	0.02	0.08	−0.02	0.17	0.46
Y*,Yp	0.31	0.38	0.00	0.01	0.00	−0.07	0.31
Y*,WH	0.38	0.27	0.25	0.20	0.11	0.14	0.25
CP*,Y	0.45	0.34	0.32	0.21	0.13	0.23	0.60
CP*,E	0.48	0.35	0.35	0.22	0.13	0.27	0.38
CP*,C	0.25	−0.06	0.20	0.07	−0.06	0.10	0.51
CP*,I	0.19	0.00	0.13	0.03	−0.04	0.16	0.21
CP*,Yp	0.39	0.48	0.00	0.02	0.00	0.28	0.54
CP*,Ep	0.49	0.54	0.01	0.04	0.01	0.41	0.49
CP*,WH	0.42	0.30	0.26	0.18	0.09	0.19	0.46
CPI*,CPI	0.45	0.31	0.45	0.26	0.18	0.37	0.15
R*,R	0.50	0.31	0.50	0.34	0.21	0.48	0.76
Spr*,Spr	0.70	0.01	0.70	0.67	0.01	0.73	0.64
Canada	**Baseline**	**No fin (1)**	**No CS (2)**	**Cst CP (3)**	**All (1,2,3)**	**Exo world CP**	**Data**
Y*,Y	0.50	0.40	0.47	0.35	0.29	0.20	0.78
Y*,H	0.53	0.43	0.50	0.37	0.30	0.19	0.75
Y*,C	0.42	0.01	0.40	0.17	−0.08	0.12	0.58
Y*,I	0.22	0.01	0.18	0.05	−0.03	−0.09	0.65
Y*,X	0.45	0.49	0.40	0.61	0.62	0.68	0.82
Y*,M	0.15	−0.13	0.10	0.13	0.00	0.21	0.78
Y*,Yp	0.21	0.22	0.00	0.01	0.00	−0.06	0.65
Y*,W	0.12	0.09	0.11	0.08	0.05	0.11	0.18
CP*,Y	0.54	0.41	0.50	0.33	0.26	0.28	0.41
CP*,H	0.57	0.44	0.52	0.34	0.27	0.31	0.45
CP*,C	0.48	0.03	0.47	0.14	−0.10	0.25	0.60
CP*,I	0.25	0.00	0.20	0.05	−0.05	0.24	0.59
CP*,Yp	0.27	0.28	0.00	0.01	0.00	0.19	0.38
CP*,Ep	0.47	0.48	0.01	0.04	0.01	0.37	0.44
CP*,W	0.11	0.08	0.09	0.06	0.03	0.02	0.05
CPI*,CPI	0.52	0.42	0.52	0.35	0.29	0.46	0.62
R*,R	0.57	0.44	0.56	0.43	0.34	0.58	0.87
Spr*,Spr	0.55	0.01	0.55	0.45	0.01	0.57	0.75

Note: This table shows the correlation between domestic and foreign variables.
No fin (1) = Financial channel is closed in the SOE.
No CS (2) = Domestic commodity supply channel is closed ($\sigma_p = 0$).
Cst CP (3) = Commodity prices are constant (in dollar term) in the SOE. Note the foreign economy is left unchanged (commodity prices are still endogenous in the foreign economy). This closes the world commodity price channel from the point of view of the SOE while leaving the fluctuations in other foreign variables unchanged.
All (1,2,3) = No fin. + No CS + Cst CP in SOE.
Exo world CP = Commodity prices are exogenous in the domestic and foreign economies. In this case, we estimate an exogenous AR(1) process for commodity prices which replaces Eq. (11).

6.3. Transmission channels of foreign shocks

In this section, we investigate to which extent the world commodity prices channel, the domestic commodity supply channel, and the financial channel quantitatively affect business cycle synchronization (Table 3) and the contribution of foreign shocks (Table 4) in Canada and South Africa. To identify the role of each channel, we shut them down one at a time. Our four main results are as follows.

First, the financial and world commodity price channels strongly contribute to our model's ability to capture the role of foreign shocks in South Africa and Canada. In the model without financial frictions in the domestic economy, the contribution of foreign shocks to GDP declines in South Africa (from 27% to 14%) and in Canada (from 41% to 26%). In both countries, we also observe a large drop in the contribution of foreign shocks to consumption and investment. When we insulate the domestic economy from the world commodity price channel, we observe a big drop in the contribution of foreign shocks to GDP in South Africa (from 27% to 8%) and Canada (41 to 20%) which is explained by a much smaller contribution to commodity exports, consumption, and investment.[25]

[25] We assume that commodity prices are constant in the SOE (the SOE can buy and sell commodities at a constant price fixed at its steady state). The foreign economy is left unchanged (commodity prices fluctuate in the foreign economy). This experiment is similar to the one presented in Section 5 but allows to

Table 4
Foreign shocks contribution to domestic variables and amplification channels.

South Africa	Baseline	No fin (1)	No CS (2)	Cst CP (3)	All (1,2,3)	Exo world CP
GDP	26.54	13.93	16.99	7.54	3.11	13.88
Employment	31.20	15.90	19.82	9.52	2.97	17.13
Consumption	12.27	4.47	9.77	2.57	2.15	6.11
Investment	20.09	3.15	17.11	2.08	3.98	12.80
Exports	34.23	38.91	21.85	24.46	26.78	31.21
Imports	8.15	9.67	6.31	3.58	5.46	6.89
Commodity exports	19.05	24.95	0.00	0.24	0.00	10.05
Commodity Empl	37.47	42.85	0.00	0.80	0.00	29.27
CPI	32.77	15.59	32.50	11.55	5.41	29.95
Labor comp.	21.60	11.33	9.61	5.36	1.99	9.78
Risk-free rate	39.43	14.90	38.46	13.57	5.17	39.58
Spread	59.55	0.00	63.00	40.56	0.00	58.51
Exchange rate	13.98	10.32	11.45	3.03	3.28	5.82
Canada	**Baseline**	**No fin (1)**	**No CS (2)**	**Cst CP (3)**	**All (1,2,3)**	**Exo world CP**
GDP	40.94	25.77	36.98	19.76	13.21	25.06
Hours	43.87	27.38	39.73	20.88	12.90	26.80
Consumption	32.95	5.83	31.89	5.43	3.44	14.05
Investment	24.09	6.93	23.61	2.96	8.57	18.73
Exports	45.13	47.81	42.02	49.47	51.68	55.24
Imports	12.64	16.96	11.00	5.19	11.28	10.15
Commodity exports	9.98	9.34	0.00	0.10	0.00	5.48
Commodity Empl	26.54	27.65	0.00	0.46	0.00	18.38
CPI	48.24	33.44	47.19	22.04	16.17	45.83
Wage	44.34	24.99	40.26	13.01	7.13	37.15
Risk-free rate	52.79	36.94	50.69	22.26	17.65	52.18
Spread	66.63	0.00	68.06	24.67	0.00	62.96
Exchange rate	26.26	24.17	23.34	10.33	10.76	13.45

Note: This table shows the total contribution of foreign shocks to domestic variables.
No fin (1) = Financial channel is closed in the SOE.
No CS (2) = Domestic commodity supply channel is closed ($\sigma_p = 0$).
Cst CP (3) = Commodity prices are constant (in dollar term) in the SOE. Note the foreign economy is left unchanged (commodity prices are still endogenous in the foreign economy). This closes the world commodity price channel from the point of view of the SOE while leaving the fluctuations in other foreign variables unchanged.
All (1,2,3) = No fin + No CS + Cst CP in SOE.
Exo world CP = Commodity prices are exogenous in the domestic and foreign economies. In this case, we estimate an exogenous AR(1) process for commodity prices which replaces Eq. (11).

Second, the domestic commodity supply channel plays a large role in South Africa, but its importance to the Canadian economy is limited. The contribution of foreign shocks to South African GDP declines from 27 to 17% when commodity supply is exogenous in the domestic economy. Moreover, the correlation between domestic and foreign GDP growth rates decreases from 0.40 to 0.31. In contrast, the contribution of this channel is relatively modest in Canada, where the contribution of foreign shocks to GDP declines from 41 to 37%. The strength of the domestic commodity supply channel is directly related to the price-elasticity of commodity supply, and this elasticity is higher in South Africa (0.12) than in Canada (0.045). As shown in appendix G, the higher price-elasticity in South Africa is explained by two factors: a larger estimated factor substitutability (σ_p) and a larger labor income share ($1-\alpha-\beta_p$).

Third, when shutting down the financial, commodity price, and domestic commodity supply channels, the model is unable to capture the importance of foreign shocks. Our three channels are thus important contributions to generate international spillovers to small open commodity exporters.

Fourth, an endogenous world commodity price response to the global business cycle is key to replicating business cycle synchronization between small open commodity producers and the global economy. In our last experiment, we assume that commodity prices are fully exogenous to development in the foreign economy. We model commodity prices as an exogenous AR(1) process which replaces Eq. (11) in the foreign block of the model. Therefore, commodity prices do not respond to foreign demand shocks. In that case, we document a small reduction in the contribution of foreign shocks to domestic real variables such as GDP but the alternative model is capable to reproduce variance decompositions that are larger than in the constant commodity price scenario. However, exogenous commodity prices fails to produce business cycle synchronization. The correlation between US and South African GDP growth rates drops from 0.40 to 0.14. The correlation between US and Canadian GDP declines from 0.50 to 0.20. As described in appendix G, changes in commodity prices driven by commodity specific factors generate a negative comovement between the commodity exporter and the rest of the world and are thus unable to account for business cycle synchronization.

isolate the role of commodity prices fluctuations in the transmission of foreign shocks as the fluctuations in foreign demand for domestic final goods, foreign final good prices and foreign interest rates are left unchanged.

Table 5
Overview of structural shocks.

	Symbol	Process	Group	Description
Foreign shocks				
Wedge	$\varepsilon^*_{b,t}$	AR(1)	AD*	Wedge between the monetary policy rate and the return on households' assets and liabilities (affecting consumption and investment)
Investment-specific	Υ^*_t	AR(1)	AD*	Investment efficiency shock
Government demand	$\varepsilon^*_{g,t}$	AR(1)	AD*	Government consumption shock
Mark-up	$\lambda^*_{d,t}$	IID	AS*	Distributors markup shock
Wage-push	$\lambda^*_{w,t}$	IID	AS*	Wage markup shock
Productivity	$\varepsilon^*_{h,t}$	AR(1)	AS*	Aggregate labor-augmenting productivity shock
Monetary policy	$\varepsilon^*_{R,t}$	IID	MP*	Deviation from Taylor rule
Credit supply	$\varepsilon^*_{R_L,t}$	AR(1)	Cred*	External financing premium (spread) shock
Commodity supply	$\varepsilon^*_{p,t}$	IID	Com*	Exogenous shock to global commodity supply
UIP shock	$\tilde{\phi}_t$	AR(1)	UIP	Country risk premium shock (affecting UIP condition)
Domestic shocks				
Wedge	$\varepsilon_{b,t}$	AR(1)	AD	Wedge between the monetary policy rate and the return on households' assets and liabilities (affecting consumption and investment)
Investment-specific	Υ_t	AR(1)	AD	Investment efficiency shock (in primary and secondary sectors)
Government demand	$\varepsilon_{g,t}$	AR(1)	AD	Government consumption shock
Mark-up	$\lambda_{d,t}$	IID	AS	Domestic distributors markup shock
Wage-push	$\lambda_{w,t}$	IID	AS	Wage markup shock
Labor prod (final good)	$\varepsilon_{h,t}$	AR(1)	AS	Labor-augmenting productivity shocks in the secondary sectors
Monetary policy	$\varepsilon_{R,t}$	IID	MP	Deviation from Taylor rule
Credit supply	$\varepsilon_{R_L,t}$	AR(1)	Cred	External financing premium (spread) shock
Labor prod (cmdty)	$\varepsilon_{hp,t}$	AR(1)	Com	Labor-augmenting productivity shock in the primary sector
Land prod (cmdty)	$\varepsilon_{p,t}$	AR(1)	Com	Capital and land-augmenting productivity shock in the primary sector

Table 6
Calibrated Parameters.

	Description	Section 5	Canada	South Africa	United States
R	Mean (gross) risk-free rate	1.0101	1.0101	1.0101	1.0101
R^L	Mean (gross) lending rate	1.0151	1.0140	1.0205	1.0143
$\frac{b^e}{Y}$	Entrep loan to GDP ratio	1.0000	1.6962	0.6569	1.4551
δ	Capital depreciation rate	0.0200	0.0200	0.0200	0.0200
λ_d	Mark-up final good	1.1400	1.1400	1.1400	1.1400
λ_w	Mark-up labor market	1.1400	1.1400	1.1400	1.1400
$\frac{y^p}{y}$	Share of cmdty sector in GDP	0.1200	0.1206	0.1185	0.0800
ω_h	Share of cmdty sector in empl.	0.0600	0.0481	0.0729	
ω_c	Share of imports in consumption	0.1000	0.0978	0.0753	
ω_i	Share of imports in investment	0.5000	0.5833	0.4869	
ω_n	Share of foreign inputs in final good	0.1500	0.1645	0.1563	
ω_p	Share of cmdty in foreign inputs	0.4000	0.3696	0.4883	
$\frac{g}{y}$	Gov. consumption to GDP ratio	0.2000	0.2084	0.1956	0.1901
$\frac{i}{y}$	Investment to GDP ratio	0.2000	0.2184	0.1821	0.1703
σ_l	Labor suply elasticity	2.0000	2.0000	2.0000	2.0000
ϕ_a	Debt-elastic foreign interest rate	0.0001	0.0001	0.0001	

Note: Section 5: calibrated parameters values used in Section 5.
Canada: Values used when estimating the model on US and Canadian data in Section 6.
South Africa: Values used when estimating the model on US and South African data in Section 6.
United States: Values of foreign parameters in Section 6.

7. Conclusion

We build and estimate a DSGE model that explains business cycle synchronization and the importance of foreign shocks in commodity-exporting SOEs. Our model captures three important transmission channels of foreign shocks: a world commodity price channel, a domestic commodity supply channel, and a financial channel. In a calibrated version of the model, we detail the transmission mechanisms associated to these channels. We then confront our model to the data and demonstrate its ability to solve the international comovement puzzle. In our model, shocks originating in the foreign economy generate sizable endogenous spillovers to commodity-exporting SOEs. This is an important contribution to the literature which has so far struggled to explain the synchronization of international business cycles with endogenous propagation mechanisms.

Our framework could be used to quantify the impact of foreign shocks in different commodity-exporting SOEs. We estimate our model with Canadian and South African data, but the mechanisms developed in this paper could be applied to a broad set of commodity-exporting economies. In the working paper version of this article, we build an extended version of this model tailored to South Africa and demonstrate that its main transmission channels are relevant additions to large scale DSGE models used by policy

Table 7
Estimated Parameters.

Structural parameters		Prior			Posterior mode		
		Pr Mean	Pr Std	Pr shape	Canada	South Africa	United States
ξ_d	Calvo final good	0.750	0.100	BETA	0.874	0.758	0.788
ξ_m	Calvo final good impots	0.750	0.050	BETA	0.880	0.796	
$\xi_{m,n}$	Calvo inputs imports	0.750	0.050	BETA	0.770	0.807	
ξ_x	Calvo exports	0.750	0.050	BETA	0.659	0.796	
ξ_w	Calvo wages	0.750	0.100	BETA	0.771	0.801	0.919
κ_w	Indexation wages	0.500	0.100	BETA	0.432	0.402	0.556
ϕ_i	Inv. adj. cost	3.500	1.500	NORMAL	3.871	5.801	2.538
b	External habits	0.700	0.100	BETA	0.616	0.798	0.679
η_f	Exports price elast.	0.900	0.100	NORMAL	0.893	0.859	
η_d	Imports price elast.	0.900	0.100	NORMAL	0.894	0.922	
σ_c	Consumption subst. elast.	1.000	0.400	NORMAL	1.454	0.984	0.872
ρ_r	Int. rate smooth.	0.800	0.100	BETA	0.918	0.889	0.920
τ_π	CB inflation resp.	1.800	0.300	NORMAL	2.077	1.882	2.307
$\tau_{\Delta s}$	CB exchange rate resp.	0.125	0.025	NORMAL	0.119	0.133	
$\tau_{\Delta y}$	CB GDP growth resp.	0.300	0.100	NORMAL	0.415	0.373	0.460
σ_n	Dom.-Foreign input subst.	0.900	0.100	NORMAL	1.073	1.018	
σ_p	Factors subst. (cmdty)	0.330	0.100	BETA	0.147	0.210	
ω_b	Share of foreign banks	0.220	0.100	BETA	0.400	0.757	
ϕ_{nw}	Fin. accelerator	0.050	0.033	INV GAM.	0.030	0.025	0.031
σ_p^*	Foreign cmdty demand elast.	0.130	0.100	BETA			0.094
AR(1)							
ε_b	Wedge (aggregate demand)	0.800	0.100	BETA	0.896	0.947	0.914
Υ	Investment efficiency	0.800	0.100	BETA	0.713	0.784	0.740
ε_g	Government consumption	0.800	0.100	BETA	0.896	0.739	0.682
ε_h	Labor prod (final good)	0.800	0.100	BETA	0.952	0.980	0.949
ε_{RL}	Credit Supply	0.800	0.100	BETA	0.831	0.923	0.854
$\tilde{\phi}$	Country Risk Premium	0.800	0.100	BETA	0.886	0.878	
$\varepsilon_{h,p}$	Labor prod (cmdty)	0.800	0.100	BETA	0.963	0.888	
ε_p	Land/capital prod (cmdty)	0.800	0.100	BETA	0.949	0.846	
δ_p^*	Foreign cmdty supply	0.050	0.025	BETA			0.035
Std							
ε_b	Wedge (aggregate demand)	0.500	0.500	INV GAM.	0.264	0.301	0.209
Υ	Investment efficiency	0.500	0.500	INV GAM.	5.464	7.951	1.688
ε_g	Government consumption	0.500	0.500	INV GAM.	1.534	2.311	1.189
ε_h	Labor prod (final good)	0.500	0.500	INV GAM.	0.747	1.296	0.583
λ_d	Cost-Push (final good)	0.500	0.500	INV GAM.	0.457	0.858	0.362
λ_w	Wage-push	0.500	0.500	INV GAM.	0.727	1.067	0.817
ε_R	Monetary Policy	0.200	0.200	INV GAM.	0.129	0.181	0.128
ε_{RL}	Credit Supply	0.200	0.200	INV GAM.	0.294	0.304	0.211
$\tilde{\phi}$	Country Risk Premium	0.200	0.200	INV GAM.	0.381	0.806	
$\varepsilon_{h,p}$	Labor prod (cmdty)	0.500	0.500	INV GAM.	4.693	8.492	
ε_p	Land/capital prod (cmdty)	0.500	0.500	INV GAM.	2.073	3.479	
ε_p^*	Foreign cmdty supply	0.500	0.500	INV GAM.			1.188

institutions. Our model's ability to capture the impact of foreign shocks makes it an appropriate tool for the design of monetary and fiscal policies that could stabilize the domestic economy.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.euroecorev.2023.104465.

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