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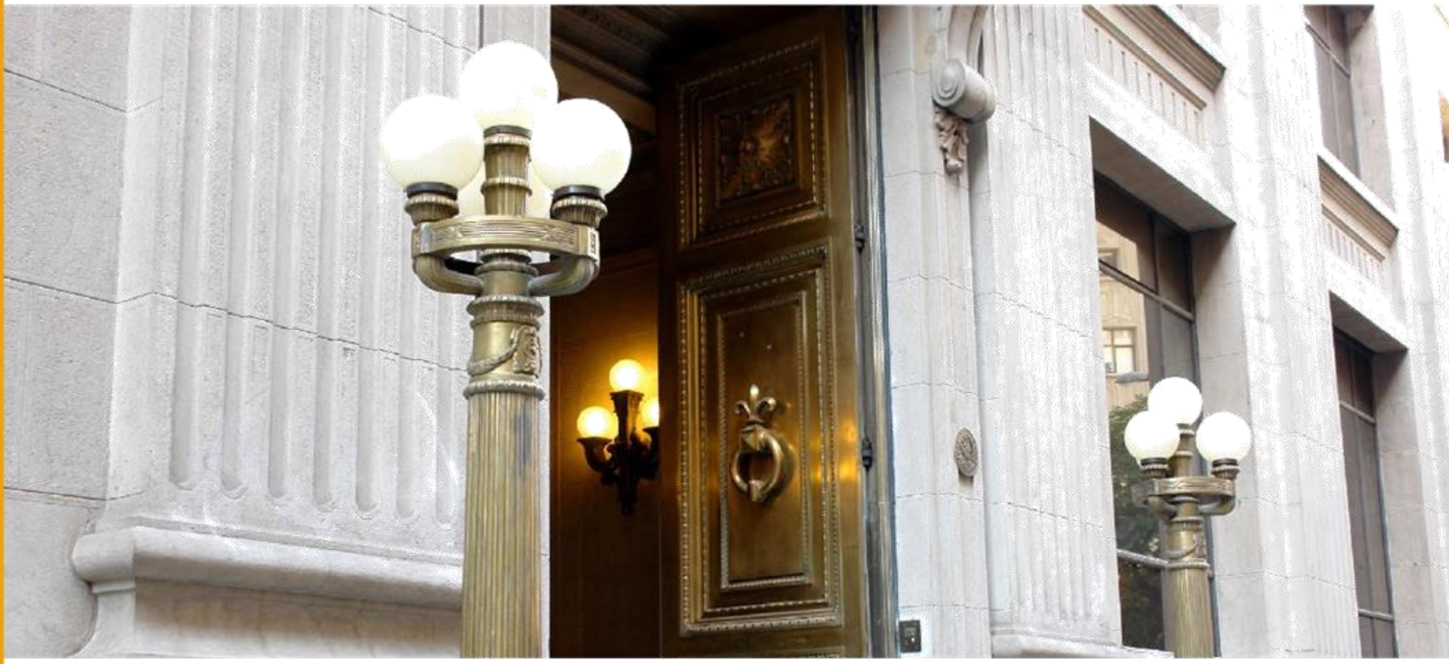

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Domestic Linkages and the Transmission of Commodity Price Shocks

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Abstract

This paper studies the role of input-output (IO) linkages in the transmission of commodity price fluctuations. Empirically, the positive correlation between commodity prices and GDP decreases in the degree of IO linkages. In a model of a commodity-exporting economy where international markets set the commodity price, IO linkages reduce the demand for inputs by the commodity sector, dampening the level of income of the country after a positive commodity price shock. In a calibrated version of the model, the elasticity of GDP to commodity prices would be at least 7% higher if the commodity sector had been 10% less connected.

Resumen

Este artículo estudia el rol de enlaces productivos derivados de la matriz de insumo-producto (input-output linkages) en la transmisión de shocks de precios de materias primas (commodities). Empíricamente existe una correlación positiva entre fluctuaciones en precios de materias primas y el PIB, la cual decrece en el nivel de conexiones productivas del sector de materias primas con el resto de la economía. En un modelo para una economía pequeña y abierta que toma como dado el precio de commodities, enlaces más intensos reducen la demanda por factores productivos por parte del sector de materias primas, lo que amortigua el incremento en ingreso luego de un shock positivo. En una versión calibrada del modelo, la elasticidad del PIB con respecto al precio de materias primas sería un 7% mayor si el sector estuviese un 10% más conectado.

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1 Introduction

Terms of trade and commodity price fluctuations are critical driving forces in emerging economies.[1] Two main characteristics help to explain these aggregate results. First, commodities represent more than half of the export basket of emerging countries. Therefore, fluctuations in commodity prices and terms of trade are significantly correlated. At the same time, the commodity sector is relevant for its relative size in the economy; hence, it is *central*.[2] Second, these economies are small relative to the rest of the world, so the foreign demand for those goods plays a significant role in the determination of prices, i.e., for emerging economies, commodity prices are exogenous. In the light of the boom and bust cycle in commodity prices experienced in the 2000s decade, the trade war between China and the U.S. during 2018, and the recent Covid-19 pandemics, there is a renewed interest in the role of fluctuations in commodity prices in emerging economies. However, beyond the consensus about their aggregate importance, the macroeconomic consequences of those fluctuations and their transmission channels are still a matter of discussion.

This paper contributes to the literature by studying the role of domestic input-output (IO) linkages in the transmission of commodity price shocks to GDP. First, using a panel of commodity-exporting emerging economies, this paper documents a positive correlation between fluctuations in commodity prices and GDP, in line with previous literature. We then interact commodity prices with measures of production linkages between the commodity sector and the rest of the economy. The main empirical finding of this paper is that such interaction is negative. In other words, stronger linkages between the commodity sector and the mainland economy dampen the effect of commodity prices. This result is robust to control for unobserved factors, different treatments of the data, and alternative definitions

[1]While Mendoza (1995) and Kose (2002) find that at least 30% of the variance of output is explained by terms of trade shocks, Fernandez et al. (2017) and Fernandez et al. (2018) show that commodity price shocks explain close to 50% of this variance.

[2]On average, the commodity sector represents 39% of aggregate GDP and 68% of total exports. In terms of connections with other sectors within the economy, on average, downstream linkages (i.e., the fraction of commodity output coming from materials of other domestic industries) are 29%, while upstream linkages (i.e., the fraction of commodity output sold as materials to other domestic sectors, weighted by their relative size) are 33%.

of variables.

To rationalize this result, we build a theoretical model for a commodity-exporting economy with three main ingredients. First, we assume that the country is a small open economy, implying a limited role for supply forces in determining commodity prices. This assumption is motivated by the vast empirical literature establishing that commodity prices are demand-driven (Kilian, 2009; Kilian and Hicks, 2012; Stuermer, 2018; Jacks and Stuermer, 2020). The implication is that, conditional on a level of foreign demand for commodities, their price is exogenously set for the exporting country. Second, on the production side of the model, we assume a multisector economy with production linkages. Every industry in the economy corresponds to a representative firm that produces a differentiated good and has access to technology with decreasing returns. Each firm operates by demanding labor, imported goods, and domestic materials and acts competitively (both in the market for inputs and in the market for output). Finally, we assume that the linkages described by the IO matrix are technologically given and fixed, This implies that after any shock the relative importance of each sector, either as a customer or as a supplier of others, does not change.

To provide intuition, we start the analysis with a simplified closed-form model with two sectors.[3] In terms of the mechanism, the model operates as follows. An increase in foreign demand translates into an increase in the commodity price, more sectoral production, and a boost in demand for factors and the equilibrium wage. This shock represents a positive income effect implying an increment in GDP. Once we consider production linkages of the commodity sector, other forces play a role. With the increase in the commodity price, the marginal cost of downstream sectors (i.e., those who demand commodity for production) increases. By perfect competition, their equilibrium price raises, which increases the marginal cost of production of the commodity sector. However, because the foreign demand fixes the commodity price, the only way to keep its marginal cost sufficiently low (i.e., equal to its price) is by decreasing its demand for inputs, including labor. Therefore, in an economy in which the commodity sector has stronger production linkages with other industries, a positive commodity price shock increases GDP, but less than for an economy with an isolated commodity sector. We refer to this lower impact of commodity price shocks as the dampening effect of IO linkages.

[3]This is the limiting case of constant returns to scale.

Then we show that these results are broadly general. In particular, the dampening effect of IO linkages is present in an economy with (i) an arbitrary number of sectors, (ii) an arbitrary IO structure, and (iii) different labor supply schedules, given by alternative preferences for the representative household. Moreover, we provide exact conditions for the dampening effect to operate, which, as we argue, are broadly satisfied for almost any calibration of the model.

To illustrate the quantitative implications of domestic linkages, we study counterfactual economies characterized by different degrees of connections between the commodity sector and the rest of the economy. For implementation, we simulate a change in the usage of materials and a replacement with a proportional variation on imports.[4] The idea behind those alternative scenarios is not only to capture the quantitative importance of the IO mechanism but, for example, to replicate in a reduced form the effect of the Covid-19 pandemics. Relative to a baseline exercise where all linkages between sectors are operative, the elasticity of GDP to commodity prices is 7 to 10% higher if we reduce the degree of links by 10% (either as a customer or as a supplier). Conversely, if we increase such linkages by 10%, such elasticity is 3 to 7% lower than in the baseline economy. We also investigate how critical parameters in the model (such as the Frisch elasticity and the price elasticity of foreign demand) interact with IO linkages, showing that variations in the response of labor supply play a key role. Moreover, in additional robustness exercises, we show that those results are highly nonlinear and asymmetric in the degree of changes in linkages.

Relation to the Literature This paper is related to two main strands of literature. First, it relates to studies evaluating the impact of terms of trade and commodity price shocks in small open economies. Starting with the seminal contributions of Mendoza (1995), and Kose (2002), different papers have evaluated alternative channels to understand the transmission of these kinds of shocks.[5]

[4]As the theoretical analysis shows, these results are invariant to changes in other inputs, such as labor.

[5]Some examples are the role of fiscal policy (Pieschacon, 2012; Céspedes and Velasco, 2014; Medina and Soto, 2016), monetary policy (Catão and Chang, 2015), prudential policies (Garcia-Cicco and Kawamura, 2015), exchange regimes (Broda, 2004; Edwards and Levy Yeyati, 2005; Céspedes and Velasco, 2012), trade imbalances (Kohn et al., 2018), and the financial implications of commodity price fluctuations (Shousha, 2016; Alberola and Benigno, 2017; Drechsel and Tenreyro, 2018).

Most related to our paper is the literature considering the possibility that the commodity sector demands factors from the non-commodity economy. For example, Bergholt and Hoghaug Larsen (2016) studies a medium-scale New Keynesian model adapted for Norway, where the oil-supply sector produces using labor, capital, and intermediate inputs. Those intermediates are a composite of manufactures and services. Something similar occurs in Fornero et al. (2016) for the case of Chile, in which the copper industry demands non-mining output to produce investment goods. Finally, Caputo and Irarrazaval (2017) study a real business cycle model that considers a composite of tradable and non-tradable goods as a productive factor of the copper industry in Chile. All these papers assume that the commodity sector exports its entire output abroad. Our contribution to this literature is twofold. First, we consider the dual role of the commodity sector for the transmission of shocks (customer and supplier). Since previous papers do not take into account the supplier role of the commodity sector, they do not consider the direct effect that commodity prices have over marginal cost and prices of other sectors, beyond the general equilibrium effects of wages or the user cost of capital. We show that the role as a supplier is both qualitatively and quantitatively significant. Second, while the papers cited before only mention that the commodity sector buys inputs from the rest of the economy, they do not explore the importance of IO linkages for the transmission or amplification of shocks, neither theoretically nor empirically. Relative to these papers, we provide empirical evidence about the importance of domestic IO linkages for the transmission of commodity price shocks. To the best of our knowledge, this is the first paper that presents evidence about a dampening effect of linkages by focusing on the case of commodity price shocks in small open economies. We explore the theoretical reasoning behind this phenomenon.

Second, this paper applies the insights from the literature on the propagation of shocks in production networks for closed economies (Foerster et al., 2011; Acemoglu et al., 2012, 2016; Atalay, 2017) to a small open economy context. In particular, we construct a similar model to the one presented in the seminal contribution of Long and Plosser (1983), with three main differences. First, our model considers an open economy adapted to a commodity-exporting country. Second, the previous literature focuses on the transmission of technology shocks (aggregate and sectoral) through IO linkages, while our paper studies how IO linkages permeate commodity price shocks. We show that these shocks spread both downstream and upstream, which is different from the case of Acemoglu et al. (2016), in which demand shocks go only upstream (to input-supplying industries), while supply shocks go only downstream (to customer industries). Also, assuming perfect competition as other papers do, we show that IO linkages dampen commodity price shocks.

Section 2 describes the data used in the paper and presents motivating evidence about the importance of domestic linkages in the transmission of commodity price shocks, showing the dampening effect of linkages. Section 3 rationalizes this evidence by presenting the theoretical model. Section 4 explores the mechanisms behind the dampening effect of IO linkages for commodity prices. Section 5 provides numerical examples and counterfactual exercises to analyze the impact of IO linkages over the elasticity of GDP to commodity price shocks. Finally, section 6 concludes.

2 Empirical Evidence

This section documents the importance of input-output (IO) linkages of the commodity sector for the transmission of commodity price shocks. First, we describe the empirical setting to analyze the relationship between business cycle fluctuations and domestic IO linkages. Then we present the data used in the analysis and the main empirical results. For future references, we define the commodity sector as an aggregate of agriculture, fishing, and mining and quarrying industries.

2.1 Setting

Commodity price shocks generally matter for business cycles because the sector is relatively large. In this sense, the commodity sector is central for the aggregate economy. However, this view ignores other channels by which commodity price shocks can affect the economy.

This paper tries to fill this gap by offering an alternative transmission mechanism: IO linkages. Those linkages imply that after a positive commodity price shock, there is an increase in demand for the sectoral output of the mainland economy (i.e., all sectors but commodity), which has effects on aggregate activity and prices. This paper aims to study the impact of commodity prices on the real GDP of small open economies and how the IO linkages shape those responses. To investigate this, we estimate variants of the following reduced form equation

$$y_{it} = \beta p_{it-1} + \gamma^d (p_{it-1} \times \text{Down}_i) + \gamma^u (p_{it-1} \times \text{Up}_i) + \zeta (p_{it-1} \times \text{Size}_i) + \theta X_{it-1} + \nu_{i,t}, \quad (1)$$

where y_{it} is a measure of real GDP of country i in year t, p_{it} is a measure of the commodity price relevant for country i, and $\nu_{i,t}$ is the error term. The variable Size measures the degree of openness of the economy and the centrality of the sector. As we will see below, controlling for those features is key for understanding the interaction between linkages and commodity prices. Vector X_{it} includes aggregate macroeconomic controls, and country and time fixed effects. To avoid any potential concern about endogeneity, we use all regressors lagged one period. To make the data stationary, we consider the log-deviation of each variable relative to a quadratic trend. Later on, we show that the qualitative insights remain if we consider other alternatives.

Linkages. The key element under study is the relevance of IO linkages between the commodity sector and the rest of the economy. Following Acemoglu et al. (2012), those links are captured in reduced form by the terms Down_i and Up_i in (1)–downstream and upstream measures of connections. The downstream measure captures the importance of the commodity sector as a *customer* of other industries. It is the value of materials produced by other domestic sectors as a fraction of commodity revenue. On the other hand, the upstream measure captures the importance of the commodity sector as a *supplier* for other industries. This measure is also known as the weighted outdegree or degree of the sector.

Let $\text{Sales}_{i,j\to co}$, $\text{Sales}_{i,co\to j}$ and $\text{Sales}_{i,co}$ denote sales from industry j to the commodity sector (co), sales from the commodity sector to industry j, and total sales of the commodity sector in country i, respectively. Then the downstream and upstream measures are constructed as

$$\text{Down}_i = \frac{\sum_{j\neq co}^{n} \text{Sales}_{i,j\to co}}{\text{Sales}_{i,co}} \quad \text{and} \quad \text{Up}_i = \sum_{j\neq co}^{n} \frac{\text{Sales}_{i,co\to j}}{\text{Sales}_{i,j}}.$$

There are three elements to emphasize in the computation of these measures. First, in the data, the fraction of sales within a sector is not negligible across countries: on average, sales within the commodity sector represent 14% percent of its output. Since we want to capture the pure relation between commodity and other sectors, we do not consider these within-commodity sector sales, so we impose the condition $j \neq co$ in the expressions above. Second, both downstream and upstream measures capture technological relations between sectors. Therefore, we consider a fixed measure for these two variables at the country level. The support for this assumption is that the relations inherited in IO tables are stable over time, even though both the numerator and the denominator are changing.[6] Third, the focus of the paper is on the aggregate effect of commodity price shocks over GDP and how production linkages between the commodity sector and the rest of the economy shape those responses. In this regard, we consider the previously described downstream and upstream measures as proxies for connections between the commodity sector and the rest of the economy.[7]

Controls. The vector X_{it} includes several controls for the relationship between commodity prices and GDP. First, it includes the log of GDP per capita to capture the level of development of each country, working as a proxy for the quality of institutions that could affect GDP. Following Broda (2004) and Edwards and Levy Yeyati (2005), it also includes a measure of the exchange rate regime on each country to control for the differential effect of management in exchange rates and how this isolates the economy from foreign shocks.[8] Finally, it considers domestic inflation (measured as year-over-year changes in domestic CPI) and the cyclical component of the bilateral exchange rate relative to the US dollar to control for other covariates that might affect the business cycle of these small open economies. Additionally, we include country and time fixed effects to control for unobserved characteristics that could

[6]Qualitative results are robust to time-varying measures.

[7]The downstream and upstream measures are proxies for the different roles that the commodity sector may have (either as a customer or as a supplier). They help to test how deviations of the assumption of (i) a commodity sector using just primary factors (or an endowment commodity sector) and (ii) a commodity sector that fully exports its output, shape aggregate responses to commodity price fluctuations.

[8]We experiment with additional variables such as fiscal cyclicality (to control for institutional responses to the windfall behind commodity price shocks). While not reported, these controls do not change the main qualitative insights of the paper.

affect GDP. In particular, country fixed effects capture, among other things, macroeconomic policies, country-level aggregate volatility, country size and population, and the level of income. On the other hand, time fixed effects capture, among other things, common shocks across countries beyond the effect of commodity prices.

Selection Criteria. We construct a yearly panel of 34 emerging economies for the period 1990-2015, following the definition of a "commodity-dependent developing country" in UNCTAD (2016). This corresponds to countries in which the share of commodity exports to total merchandise exports is above 60 percent. Following Schmitt-Grohe and Uribe (2018), we include countries that satisfy two criteria. First, it must have an average level of GDP per capita below 25,000 dollars during the period. Second, it must have information about real GDP and the main covariates for the whole sample period to avoid short-run panels that could bias the estimation. The countries selected mostly specialize in energy and mineral commodities, such as oil or copper. Appendix A.1 presents a detailed description of the data sources and selection criteria. Appendix A.2 presents the list of countries and descriptive statistics.

2.2 Results

The results of the estimation of equation (1) are reported in Table 1. Commodity prices are standardized, so the coefficients are interpreted as the effect of one standard deviation above the mean. Column (1) shows the result of running the regression between GDP and the commodity price without further controls. As expected, the unconditional effect of commodity prices over GDP is both economically and statistically significant: an increase in one standard deviation in the commodity price (close to 20 percent) implies an increase of 1.5 percent in GDP, which is close to one third of the variation in this latter variable.

Column (2) interacts commodity prices and the degree of linkages of the sector and the rest of the economy, without further controls. Both coefficients are negative, implying that stronger linkages dampen the impact of commodity price fluctuations over GDP. However, neither coefficients are statistically significant. Once we control for a measure of exports size in column (3), which in this case corresponds to net commodity exports over GDP, the interactive terms gain statistic power.[9] The interpretation of this result is that production linkages of the commodity sector are a relevant transmission, source conditional on the relative size of the sector. Quantitatively, a one standard deviation increase in commodity prices increments output in 1.2 standard deviations in the average economy. However, in countries in which the downstream and upstream linkages are 10% above the mean, the impact of the shock is only 0.25 standard deviations.

The rest of the columns sequentially include controls to the baseline regression to analyze the robustness of the results. Column (4) includes macroeconomic controls (the log-level of GDP per capita, inflation, the cyclical component of the nominal exchange rate, and the exchange rate regime itself). Both interactions remain stable after we control for business cycle features of the economy. In columns (5) and (6), we include country and year fixed effects to control for unobservable country-specific heterogeneity and common time-series (such as the global financial cycle). The results show that all coefficients remain stable, both in magnitude and statistical significance.

Robustness. To further explore the robustness of these results, in the appendix, we analyze two additional exercises. Table A.2 presents the results of running equation (1) using alternative commodity price indexes. In particular, while the baseline results presented in Table 1 use a commodity index that weights each product by their relative average importance in commodity exports, we include three alternative indexes: (i) one that weights individual prices by using the time-varying importance of each commodity good in commodity exports; (ii) one using fixed weights denoting the importance of each commodity good in GDP; and (iii) an index using time-varying weights as relative importance over GDP. Our results show that the dampening effect of commodity linkages remains significant to different commodity price indexes.

Table A.3 analyzes the role of different detrending schemes. In particular, it compares the baseline result (which uses a quadratic detrending method) to the Hodrick-Prescott (HP) filter (with a smoothing parameter $\lambda = 100$) and the filter proposed by Hamilton (2018).

[9]Results are similar if we control for aggregate net exports or the relative size of the commodity sector over GDP.

Results from this exercise show that both effects, Down and Up, remain qualitatively negative, but only the former is statistically significant. The fact that emerging markets export most of their commodity output supports this outcome. Therefore, even though important, it seems that the commodity sector as a supplier is second-order relative to its role as a customer for the transmission of commodity price shocks.

Table 1. The Effect of Commodity Prices and Commodity Linkages over GDP

	(1)	(2)	(3)	(4)	(5)	(6)
Commodity price$_{it-1}$	1.47	1.52	1.24	1.12	0.89	1.02
	(0.34)	(0.26)	(0.26)	(0.26)	(0.27)	(0.46)
Commodity price$_{it-1}\times$ Down$_i$		-3.14	-7.88	-7.55	-6.93	-6.30
		(3.20)	(3.26)	(3.03)	(2.72)	(2.54)
Commodity price$_{it-1}\times$ Up$_i$		-1.40	-2.06	-2.26	-2.32	-2.13
		(0.97)	(0.96)	(0.92)	(0.91)	(0.75)
Observations	850	850	583	548	548	548
Adj R-squared	0.09	0.09	0.11	0.16	0.17	0.23
Exports size	No	No	Yes	Yes	Yes	Yes
Controls	No	No	No	Yes	Yes	Yes
Country FE	No	No	No	No	Yes	Yes
Year FE	No	No	No	No	No	Yes

Notes: This table reports the results of estimating (1). The variable commodity price is standardized. All control variables are lagged one period. Robust standard errors clustered at the country level in parentheses. See the main text and Appendix A for details about variables' definitions.

3 Baseline Model

This section studies a model for a small open economy that produces a commodity good whose price is determined by foreign demand in international markets. This modeling assumption is based on abundant empirical evidence indicating that fluctuations in global demand primarily drive commodity price booms and busts (Kilian and Zhou, 2018).[10]

The economy is populated by a representative household that supplies labor and consumes. On the production side, the economy is composed of N sectors that produce differentiated goods using the labor supplied by the household, imported goods, and domestic materials from other sectors in the economy. These sectoral goods are demanded either for production purposes by other sectors or by final aggregators that combine them to get the consumption good and an exportable good. This model builds on the RBC literature (Mendoza, 1995; Schmitt-Grohe and Uribe, 2018) by including a multi-sector production side and domestic input-output (IO) linkages at the sectoral level, in the spirit of Long and Plosser (1983).[11] To put the main theoretical contribution of the paper in perspective, we consider a static environment in which there is no debt or capital.

3.1 Households

The representative household chooses consumption and labor to maximize its utility

$$U(C, L) = \frac{1}{1-\sigma}\left(C - \vartheta\frac{L^{1+\xi}}{1+\xi}\right)^{1-\sigma}, \tag{2}$$

subject to the budget constraint, $wL + D = P^c C$.

In terms of notation, C represents consumption, which has price P^c and L is the household's labor supply which the productive sectors of the economy will demand at a wage rate w. There is only one labor market, and labor is perfectly mobile across sectors. The term, $D = \sum_{j=1}^{N} D_j$ collects all sectoral profits in the economy.[12]

The maximization problem of the household gives the following labor supply and consumption schedules

$$L = \left(\frac{1}{\vartheta}\frac{w}{P^c}\right)^{1/\xi} \tag{3}$$

[10] See also Kilian (2009), Kilian and Hicks (2012), Stuermer (2018) and Jacks and Stuermer (2020).

[11] Other papers with a similar theoretical framework for a closed economy are Acemoglu et al. (2016), Foerster et al. (2011) and Atalay (2017).

[12] As is well known, the GHH preferences considered here imply that the labor supply does not exhibit income effects. Alternative separable preferences generate similar results. See Appendix B.2.2 for discussion.

$$C = \frac{w}{P^c}L + \frac{D}{P^c}. \tag{4}$$

3.2 Productive Sectors

There are N sectors in the economy that produce differentiated goods. These sectors are indexed by j, in which $j = 1$ corresponds to the commodity sector. We assume that all industries have access to a Cobb-Douglas technology of the form

$$Y_j = \delta_j Z_j^{\phi_j} \left(L_j^{\alpha_j} V_j^{\theta_j} \prod_{i=1}^{N} M_{ij}^{\gamma_{ij}} \right)^{\phi_j},$$

where δ_j is a constant term. In every sector, Z_j denotes the level of productivity. Each representative firm demands labor L_j from the household, intermediate goods from other sectors M_{ij} and a composite imported good V_j which is the numeraire of the economy. The sub-index (ij) denotes goods produced by industry i demanded by industry j. The parameter $\gamma_{ij} \in \mathbf{\Gamma}$ captures the intensity in these productive linkages, where $\mathbf{\Gamma}$ is the IO table of the economy.[13] Note that this specification takes into account the whole nature of IO linkages and not a single composite intermediate good.

We assume perfect competition and decreasing returns to scale in all sectors, so $\phi_j \in (0, 1)$ for each j. The previous assumptions imply that every sector takes prices as given, both in the market for inputs and where they sell their products and obtain rents from production. Conditional on their technologies, these sectors maximize profits by choosing the optimal demands for labor, intermediates, and imports. We also assume $\alpha_j + \theta_j + \sum_{i=1}^{n} \gamma_{ij} = 1$.

The first-order conditions for profit maximization are

$$L_j = \frac{\alpha_j \phi_j P_j Y_j}{w} \tag{5}$$

$$V_j = \theta_j \phi_j P_j Y_j \tag{6}$$

$$M_{ij} = \frac{\gamma_{ij} \phi_j P_j Y_j}{P_i}. \tag{7}$$

Combining (5)-(7) with the production function, we get an expression for the pricing rule equal to marginal cost given by perfect competition

[13] For convenience, define $\widetilde{\mathbf{\Gamma}}$ as the IO table of the economy for the mainland economy (i.e., excluding the commodity sector). This component will be relevant for the analysis below.

$$P_j = \frac{1}{Z_j}\left(w^{\alpha_j}\prod_{i=1}^{N} P_i^{\gamma_{ij}}\right) Y_j^{\widetilde{\phi}_j}, \tag{8}$$

where $\widetilde{\phi}_j \equiv \frac{1-\phi_j}{\phi_j}$. Note that in the limiting case of constant returns to scale, $\phi_j = 1$ so $\widetilde{\phi}_j = 0$ and the sectoral price does not depend on the output level. Otherwise, there is a positive relationship between the two variables.

3.3 Final Goods and Foreign Demand for Commodity

Final Goods. There are two final goods in the economy: consumption and exports. The domestic household consumes the former, while the latter is sold abroad. Each good is produced by a representative competitive firm that combines inputs from sectoral producers. In particular, the production function of each aggregator is

$$C = \delta_c \prod_{j=1}^{N} A_{c,j}^{\mu_j}, \qquad X = \delta_x \prod_{j=2}^{N} A_{x,j}^{\eta_j},$$

where δ_c and δ_x are constants and $\sum_{j=1}^{N}\mu_j = \sum_{j=2}^{N}\eta_j = 1$. Note that, while the production of the consumption good requires commodity for production, the output generated by exports does not. This captures the notion that the exportable good corresponds to all other exports but commodity (e.g. manufactures and services). The first order conditions for profit maximization are

$$A_{c,j} = \frac{\mu_j P^c C}{P_j} \tag{9}$$

$$A_{x,j} = \frac{\eta_j P^x X}{P_j}, \tag{10}$$

with

$$P^c = \prod_{j=1}^{N} P_j^{\mu_j} \tag{11}$$

$$P^x = \prod_{j=2}^{N} P_j^{\eta_j}. \tag{12}$$

Foreign Demand for Commodity. We assume that the small open economy faces the following foreign (inverse) demand for commodity goods

$$P_1 = \exp(\nu) A_{x,1}^{-1/\varepsilon}, \tag{13}$$

where P_1 is the commodity price, $A_{x,1}$ is the quantity exported to the rest of the world, $\varepsilon > 0$ is the price elasticity of foreign demand, and ν is an exogenous shifter. As mentioned before, if foreign demand shocks drive commodity price fluctuations, changes in activity abroad set the quantity of commodities exported goods by the small open economy $A_{x,1}$, and are mapped into fluctuations in prices.

3.4 Market Clearing and Gross Domestic Product

Market Clearing. Two markets must clear each period to close the model. First, labor supply must equal total labor demanded by all sectors

$$L = \sum_{j=1}^{N} L_j. \tag{14}$$

The second condition is the market-clearing for every sector j[14]

$$Y_j = A_{c,j} + A_{x,j} + \sum_{i=1}^{N} M_{ji}. \tag{15}$$

Gross Domestic Product. The object of interest in this paper is GDP, corresponding to the sum of real sectoral value-added; i.e., the value of production net of imports and intermediate inputs from the N sectors in the economy

$$\text{GDP} = \sum_{j=1}^{N} \text{VA}_j = \sum_{j=1}^{N} \left(P_j Y_j - V_j - \sum_{i=1}^{N} P_i M_{ji} \right).$$

[14]Note that, by combining the market clearing conditions of the economy, as well as the budget constraint of the representative household (which is also an equilibrium condition of the model), we obtain the trade balance condition given by $P^x X + P_1 A_{x,1} = \sum_{j=1}^{N} V_j$. Such equation is redundant by Walras' law and the assumption of financial autarky.

The previous definition has a counterpart that follows from the income approach of national accounts. In this model, the sources of income are labor and profits. Therefore, GDP is equivalent to

$$\text{GDP} = wL + D. \tag{16}$$

In (16), GDP is in units of the importable foreign good, which is in line with the measure used in the empirical section. On the other hand, given the static nature of the model, we do not consider alternative possibilities such as chained-value GDP, Paasche GDP deflators, or double-deflation methods because all take into account the dynamics of prices and quantities to calculate real GDP.

3.5 Equilibrium

Given sectoral productivities Z_j and the foreign demand for commodities, an equilibrium of this economy consists of a set of aggregate allocations $\{C, L, D, X\}$, a set of sectoral allocations for $j = 1, \ldots, N$, $\{L_j, V_j, M_{ij}, D_j, Y_j, A_{c,j}, A_{x,j}\}$ and prices $\{w, P_j, P^c, P^x\}$ such that (i) given prices, the household's allocation solves the household's problem; (ii) given prices, the allocation of producers in each sector j solves each producers' problem; (iii) given prices, the allocations for aggregate goods solves the final goods' problems; and (iv) markets clear.

4 Theoretical Results

This section uses the model to study how domestic linkages shape the response of GDP after a commodity price shock. Note that in the presence of decreasing returns, the model has no closed-form solution. To provide insights about the IO mechanism, we assume that every sector has constant returns to scale ($\phi_j = 1$), implying (i) that marginal costs do not depend on the level of sectoral output; and (ii) the only source of income, hence GDP, is labor. Later on, we extend our results by considering decreasing returns in every sector.

To build intuition, we start with a simplified version of the model, with (i) only two sectors in the economy and (ii) only sales between but not within sectors (i.e., diagonal elements in the IO matrix are zero, $\gamma_{ii} = 0$). Then, we extend these results to an arbitrary N-sector economy. The critical assumption is that domestic materials are replaced with importable goods. Therefore, any change in $\boldsymbol{\gamma}_{j1}$, $\boldsymbol{\gamma}_{1j}$ or γ_{11} is compensated with variations in imports, so changes in $\boldsymbol{\theta}$. Later on, we discuss this assumption in more detail.

4.1 The Elasticity of GDP to Commodity Prices

4.1.1 Two-sector Economy

Consider the model presented in section 3, but assuming only two sectors: commodity and a composite sector for the mainland economy (or rest-of-the-economy sector). For consistency in notation, we index the commodity sector as $j = 1$ and the composite mainland sector as $j = 2$. This assumption reduces the heterogeneity in the production side of the economy to the minimum level necessary to understand the forces at play. We also assume that there are no sales within a sector (i.e., $\gamma_{11} = \gamma_{22} = 0$), so production linkages are characterized only by sales between sectors (given by parameters $\gamma_{12} > 0$ and $\gamma_{21} > 0$). Therefore, the IO matrix of the economy is 2×2 with zero diagonal terms. For simplicity, in this example, we ignore productivity and consider fluctuations in foreign demand for commodities as the only driver of the model.

Commodity Price. The commodity price P_1 is pinned-down by the foreign demand of the economy. In particular, given a level of foreign activity and the demand for domestic commodity goods $A_{x,1}$, the price for the commodity is set by (13). Such behavior captures the notion that the economy is small relative to the rest of the world, so it takes the price of this exportable good as given.

Domestic Prices. Given the commodity price P_1, and assuming constant returns to scale, the expression for marginal costs (8) sets the price of the mainland good P_2, and the wage w

$$\alpha_1 \log w = \log P_1 - \gamma_{21} \log P_2 \tag{17}$$

$$\log P_2 = \alpha_2 \log w + \gamma_{12} \log P_1. \tag{18}$$

These expressions are the supply equations of the commodity sector and the composite mainland sector, respectively. The only difference between the two is the intensity of labor usage (α) and materials from the other sector (γ). The fundamental element to consider is that the commodity price P_1 is determined in global markets; i.e., it is taken as given for the small open economy. Therefore, the first equation pins down wages in terms of the commodity price.

What happens after a positive foreign demand shock that increases the price of commodities? First, it boosts the demand for factors by the commodity sector, given the increase in its revenue, putting upward pressures over the equilibrium wage. The implication is a rise in the cost of production in the rest of the economy because other sectors demand labor and commodities to produce ($\gamma_{12} > 0$). Perfect competition translates into a higher price in the rest of the economy, P_2. IO linkages have a feedback effect on the pricing equation of the commodity sector because it demands products from the rest of the economy to produce commodities ($\gamma_{21} > 0$). The critical point is that international markets set the commodity's price. Hence, the only margin of adjustment that satisfies the pricing equation given by perfect competition and the small open economy assumption is to change the equilibrium wage. We can see the latter point more clearly in the supply equation of the commodity sector (17), in which P_1 is given and P_2 is increasing by the direct effect of the commodity price shock.

Because the commodity sector cannot react to the increase in its cost of production by adjusting its price, the only way to compensate is by reducing the quantity of factors demanded (labor and materials) to the point in which the cost of production is again equal to the price of the good. The second-round effect of the shock is that it will reduce the mainland sector's price and the equilibrium wage relative to the initial scenario.

In equilibrium, the price in mainland sectors and the wage are a function of the commodity price

$$\log w = \left(\frac{1-\gamma_{21}\gamma_{12}}{\alpha_1+\alpha_2\gamma_{21}}\right)\log P_1$$
$$\log P_2 = \left(\frac{\alpha_2+\alpha_1\gamma_{12}}{\alpha_1+\alpha_2\gamma_{21}}\right)\log P_1,$$

where the previous expression comes from solving for w and P_2 using equations (17) and

(18). There are two points to notice from the previous expression. First, linkages (γ_{12} and γ_{21}) unambiguously dampens the effect of commodity prices over wages, while the effect over the price in the mainland sector depends on the relative strength of those linkages and the demand for labor. Second, the dampening effect of linkages over wages holds even if only one of the margins in which the commodity sector operates (either as a customer or as a supplier) is active.

We then obtain the consumption price. Note that we need such expression because labor income, hence GDP, is a function of wages and the price of consumption. Using (11) we get

$$\log P^c = \mu_1 \log P_1 + \mu_2 \log P_2 = \left(\frac{\alpha_1(\mu_1 + \mu_2\gamma_{12}) + \alpha_2(\mu_2 + \mu_1\gamma_{21})}{\alpha_1 + \alpha_2\gamma_{21}} \right) \log P_1.$$

Changes in the commodity price positively affect the price of consumption, but the effect of linkages is ambiguous and depends on (i) the relative usage of labor by each sector and (ii) how much sectoral output demands the final consumption aggregator (μ).

Labor supply and GDP. Using the expression for GDP given by (16), with constant returns to scale in production, we have $\log \mathrm{GDP} = \log w + \log L$. Also, from (3), labor supply adopts the form $\log L = (\log w - \log P^c - \log \vartheta)/\xi$. By replacing the expressions for wages and the price of consumption, we can obtain the elasticity of GDP with respect to the commodity price

$$\frac{\partial \log \mathrm{GDP}}{\partial \log P_1} = \frac{(\xi+1)(1-\gamma_{21}\gamma_{12}) - \alpha_1(\mu_1 + \mu_2\gamma_{12}) - \alpha_2(\mu_2 + \mu_1\gamma_{21})}{\xi(\alpha_1 + \alpha_2\gamma_{21})}. \tag{19}$$

From this expression, linkages between the commodity sector and the rest of the economy dampen the effect of commodity price shocks. Such dampening effect of IO linkages is because the labor supply and, therefore GDP, is increasing in wage and decreasing in the price of consumption. As we saw before, IO linkages diminish (amplify) the impact of commodity price shocks in the former (latter).

An important point to highlight is that a positive commodity price shock stimulates the economy and positively impacts prices and wages. The main contribution of this paper is to show that IO linkages between the commodity sector and the rest of the economy dampen the magnitude of these positive effects.

4.1.2 Multisector Economy

As the following proposition shows, the previous result can be generalized to a N-sector economy with an arbitrary IO structure.

Proposition 1. *The elasticity of GDP to commodity prices in a $N \times N$ economy with arbitrary IO linkages, constant returns to scale, and GHH preferences is given by*

$$\psi_{GHH} \equiv \frac{\partial \log \mathrm{GDP}}{\partial \log P_1} = \frac{1}{\xi} \left\{ (\xi + 1)\Omega_p - \mu_1 - \boldsymbol{\mu}' \widetilde{\mathbf{H}} (\boldsymbol{\alpha} \Omega_p + \boldsymbol{\gamma_{1j}}) \right\}, \tag{20}$$

where ξ is the inverse of the Frisch elasticity, $\widetilde{\mathbf{H}}^{-1} \equiv (\mathbf{I}_{N-1} - \widetilde{\boldsymbol{\Gamma}}')^{-1}$ is the transpose of the Leontief inverse in the mainland economy (i.e., all sectors but commodity) and $\Omega_p \equiv \left(\frac{1 - \gamma_{11} - \boldsymbol{\gamma_{j1}}' \widetilde{\mathbf{H}} \boldsymbol{\gamma_{1j}}}{\alpha_1 + \boldsymbol{\gamma_{j1}}' \widetilde{\mathbf{H}} \boldsymbol{\alpha}} \right)$ is the elasticity of the equilibrium wage to commodity prices.

Proof. See Appendix B.2.1. □

As in the two-sector economy, the elasticity of GDP depends on the Frisch elasticity, labor share in production, sectoral shares in consumption, and the IO matrix. The main difference relative to the simple case comes from the presence of the Leontief inverse matrix, which captures all the sectoral interactions once we control for the intensity of the commodity sector either as customer or supplier (given by vectors $\boldsymbol{\gamma}_{j1}$ and $\boldsymbol{\gamma}_{1j}$). All in all, note that as in the 2×2 version, linkages between the commodity sector and the rest of the economy unambiguously decrease the elasticity of GDP to commodity prices, dampening the effects of those shocks through parameters $\boldsymbol{\gamma}_{j1}$ and $\boldsymbol{\gamma}_{1j}$.

This result is more general and does not depend on the assumption of GHH preferences. In particular, Appendix B.2.2 shows that (i) the elasticity of GDP to commodity prices has a similar structure in comparison to (20) under separable preferences, and (ii) whenever this elasticity is positive under GHH preferences, then it will be larger than under separable preferences.

4.2 The Dampening Effect of Domestic Linkages

This section illustrates the dampening effect of domestic linkages between the commodity sector and the rest of the economy. To clarify the exposition, we rely on the limiting case when we completely remove those linkages. This is, when either there is no downstream effect (when $\boldsymbol{\gamma}_{j1} \to \mathbf{0}_{(N-1)\times 1}$) or no upstream effect (when $\boldsymbol{\gamma}_{1j} \to \mathbf{0}_{(N-1)\times 1}$) of the commodity sector.

The following proposition, which is the main theoretical contribution of the paper, shows that under general conditions about the model's parameters, there is a dampening effect of domestic linkages to fluctuations in commodity prices over GDP.

Proposition 2. *Suppose $\xi + 1 \geq \boldsymbol{\mu}'\widetilde{\mathbf{H}}\boldsymbol{\alpha}$ and denote $\psi_{GHH}^{No\ Up}$ and $\psi_{GHH}^{No\ Down}$ as the elasticity of GDP to commodity prices when the commodity sector acts only as customer (no upstream effect) and only as supplier (no downstream effect), respectively. Then, $\psi_{GHH}^{No\ Up} \geq \psi_{GHH}$ and $\psi_{GHH}^{No\ Down} \geq \psi_{GHH}$. Under additional parametric conditions, $\psi_{GHH}^{No\ Down} \geq \psi_{GHH}^{No\ Up}$.*

Proof. See Appendix B.2.3. □

Proposition 2 states that whenever we remove production linkages between the commodity sector and the rest of the economy (either downstream or upstream linkages), the response of GDP to commodity price fluctuations is higher than in the case when those links are active. This result formalizes the primary intuition of the simple example presented in section 4.1.1.

4.3 Discussion

This section discusses five points regarding the previous results. First, throughout the analysis, it is assumed that the margin of adjustment once we remove production linkages, is through changes in importable goods. In other words, once we remove links between the commodity sector and the rest of the economy (either as a customer or as a supplier), those goods are replaced by foreign varieties summarized by the aggregate importable good. The idea embedded in this assumption is that commodities are physical goods (e.g., oil and minerals) that only can be replaced with goods of similar characteristics, so the natural margin of adjustment is through imports/exports once we analyze a structural change in the production network of the economy. Something similar happens when the commodity sector no longer demands domestic goods but varieties from abroad. Note, however, that even in the alternative case in which we replace commodities with labor, the same dampening effect operates. This can be seen in (20) by noting the negative relationship between the elasticity of GDP to commodity prices ψ_{GHH} and the expenditure shares in labor α_1 and $\boldsymbol{\alpha}$ through the impact of commodity price in the equilibrium wage, Ω_p. This later idea applies, for example, in the case of replacing domestic with foreign services, which are more labor-intensive than physical materials.

Second, the analysis considers as given the structure of the foreign demand for commodity goods (13). In particular, given a level of foreign demand $A_{x,1}$, this equation pins down the commodity price for the small open economy. The critical elements in this structure are the elasticity of demand ε, measuring the sensitivity of the quantity demanded to changes in the price, and the demand shifter ν, measuring the level of the commodity price. Most literature analyzing commodity price shocks in small open economies assumes that the demand is infinitely elastic to price changes, so $\varepsilon \to \infty$. As we will see in the next section, both parameters play an important quantitative role in the determination of the elasticity of GDP to such prices.

Third, note that labor supply elasticity $(1/\xi)$ plays a critical role in the effect. Even though its impact depends on other structural features of the model (see equation 20), from Proposition 2 we can see that a minimum level for this parameter is required for the dampening effect to operate. Note, however, that the necessary condition stated in the proposition is satisfied by almost any calibration of the model, implying that such requirement is not very demanding. Later on, we study the sensitivity of the results to changes in this parameter.[15]

Fourth, note that sectoral output and the labor market equilibrium play no role in the solution of the model for the particular examples developed in this section. Given the static nature of the model and the assumption of constant returns to scale, only labor income, hence wages and prices, are necessary to solve for GDP. This result does not hold in the

[15] Given the properties of the IO matrix of the mainland economy, the Leontief inverse $\widetilde{\mathbf{H}}$ is characterized only by non-negative elements. On the other hand, the vectors $\boldsymbol{\mu}$ and $\boldsymbol{\alpha}$ are composed only by elements in the $(0, 1)$ space. Therefore, the expression $\boldsymbol{\mu}'\widetilde{\mathbf{H}}\boldsymbol{\alpha}$ is a weighted average of values between zero and one, so the whole expression is a number below one. (In the data, we have $\boldsymbol{\mu}'\widetilde{\mathbf{H}}\boldsymbol{\alpha} = 0.53$ for the average country in the sample.) All these elements imply that the necessary condition for the inverse of the Frisch elasticity is that should be larger than a negative number, which holds by definition and is way above the typical values used in the literature for this parameter. (See for example Mendoza (1991) for a classical reference for models of small open economies, and the review in Chetty et al. (2013).)

general model presented in section 3. The complete solution of the model requires knowing the quantities produced, and for this purpose, the labor market equilibrium condition given by equation (14) is crucial (see Appendix B.1).

Finally, note that the dampening effect of domestic linkages does not depend on the specific assumption of GHH preferences. As shown in Appendix B.2.3, the same conditions of Proposition 2 are sufficient for the dampening effect of linkages when we consider separable preferences of the form $U = \frac{C^{1-\sigma}-1}{1-\sigma} - \vartheta \frac{L^{1+\xi}}{1+\xi}$. Moreover, that section shows that the elasticity of GDP is higher with GHH than with separable preferences.

5 Numerical Examples

While the previous section studied the theoretical nature of the dampening effect of domestic linkages, this section analyzes the quantitative importance of the mechanism. Using a calibrated version of the model, we show how the elasticity of GDP to commodity prices changes with different levels of linkages and how this depends on some deep model parameters. Moreover, we also show that these results are asymmetric, nonlinear, and translate into changes in GDP's first and second moments.

Calibration. The model is calibrated for the average economy using data for the 34 countries of the empirical section and 21 sectors (see Appendix A.2 for details). The parameters associated with the production function are calibrated using data from the EORA database for each country-sector-year and aggregated to generate values for an average emerging economy. Those parameters correspond to vectors $\boldsymbol{\alpha}$, $\boldsymbol{\theta}$, $\boldsymbol{\Gamma}$ and $\boldsymbol{\phi}$ describing the sectoral expenditure share in labor, imports, domestic materials and the degree of decreasing returns of every sector, respectively. To calibrate the parameters for final goods given by $\boldsymbol{\mu}$ and $\boldsymbol{\eta}$ (consumption and exports, respectively), we rely on a similar strategy and dataset. The (inverse of the) Frisch elasticity and the shifter and elasticity of foreign demand are $\xi = 1$, $\nu = 0.22$, and $\varepsilon = 1$, respectively. They imply a relative size of the commodity sector above 50%. In what follows, we compute the elasticity of GDP to commodity prices by computing the response of the former after a slight exogenous shift in the foreign demand for commodity goods (ν).

Dampening Effect under Baseline Calibration. Panel A of Table 2 presents the elasticity of GDP to commodity prices (ψ) for an average emerging economy. The first column presents the elasticity in the baseline scenario in which all linkages are active. Columns (2) and (3) solve a counterfactual model with a 10% decrease of downstream (column 2) and upstream (column 3) linkages of the commodity sector. In line with the theoretical analysis of section 4, a decrease in the level of linkages of the commodity sector implies a higher elasticity of GDP to commodity prices. In particular, a 10% decrease in the demand for domestic materials by the commodity sector (column 2) generates an elasticity of 3.55, which is higher than in the baseline scenario (3.30). With a decrease in the supply of materials by the commodity sector (column 3), such elasticity is 3.41.

Asymmetries. Are increases in linkages equal to decreases? Columns (4) and (5) analyze the opposite case in which there is a 10% increase in the degree of linkages. Consistent with the theoretical analysis, the elasticity of GDP decreases to 3.08 and 3.20 when there is a more robust demand (in column 4) and supply (in column 5) of the commodity sector, reflecting the dampening effect of domestic linkages. In comparison with columns (2) and (3), notice that the magnitude of variations in the elasticity is lower, implying that we observe more pronounced variations in the sensitivity of GDP to commodity prices when there are decreases in linkages rather than increases.

Changes in Elasticities. How sensitive are the previous results to changes in key parameters of the model? In particular, how strong is the dampening effect of domestic linkages when there are changes in the (inverse) of the Frisch elasticity and the elasticity of foreign demand for commodities? To answer these questions, panels B and C of Table 2 study the same counterfactual exercises but under different values for those elasticities. In particular, panel B studies the case proposed by Mendoza (1991) and Schmitt-Grohe and Uribe (2018) in which the Frisch elasticity is 1.455, implying a value of $\xi = 0.69$. Similarly, panel C studies a case with a large foreign demand elasticity, with a value of $\varepsilon = 10$, which is closer to the assumption of perfectly elastic demand for commodity goods.

There are two points to highlight when comparing these results to panel A. First, all qualitative messages of panel A hold for panels B and C: decreases in domestic linkages amplify the elasticity of GDP to commodity prices (columns 2 and 3), while increases reduce such sensitivity (columns 4 and 5). Second, for the baseline model and every counterfactual in linkages, the elasticity of GDP when we reduce the (inverse) of the Frisch elasticity (panel B) is higher than in the baseline case (panel A). Therefore, the economy becomes more responsive when the labor supply reacts by more. At the same time, domestic GDP becomes less responsive when we augment the elasticity of foreign demand (panel C). The reason is that the elasticity is computed given a level of foreign demand. An alternative case where we allow such quantity to change would produce a different result.

Table 2. Elasticity of GDP to Commodity Prices–Counterfactuals

	Baseline	10% decrease		10% increase	
		Down	Up	Down	Up
	(1)	(2)	(3)	(4)	(5)
Panel A: Baseline calibration ($\xi = 1$ and $\varepsilon = 1$)					
ψ	3.30	3.55	3.41	3.08	3.20
Panel B: Alternative Frisch Elasticity ($\xi = 0.69$)					
ψ	3.42	3.68	3.54	3.19	3.32
Panel C: Alternative Foreign Demand Elasticity ($\varepsilon = 10$)					
ψ	3.27	3.49	3.37	3.06	3.17

Notes: This table presents counterfactual results about the elasticity of GDP to commodity prices (ψ) for different degrees of production linkages of the commodity sector. Column (1) shows the elasticity for the baseline calibration. Columns (2) and (3) show a 10% decrease in the degree of demand and supply of materials by the commodity sector, respectively. Columns (4) and (5) show a 10% increase in the degree of demand and supply of materials by the commodity sector by the commodity sector, respectively.

Nonlinearities. Table 2 shows that the effect of changes in production linkages are asymmetric in the direction of those changes. How important is the magnitude of those changes to understand variations in the elasticity of GDP? Table C.1 repeats the exercise but comparing with stronger changes in linkages of 50 and 100%. The main observation from this table is that results are highly nonlinear in the magnitude of changes. For example, with a 50% decrease in linkages in the baseline calibration of panel A (see columns 6 and 7 in the table), the elasticity of GDP should have been 4.55 and 3.85 in downstream and upstream linkages, respectively. However, the observed magnitudes are 4.69 and 3.87. On the other hand, increases in linkages generate variations in GDP that are lower relative to a linear case. Again, analyzing the baseline calibration of panel A (see columns 8 and 9 in the table), we observe elasticities of 2.37 and 2.81 for increases in downstream and upstream linkages. Under linear variations, those changes should have been 2.20 and 2.80, respectively.

Two remarks are in order. First, stronger linkages variations (100%) greatly exacerbate the previous observations (columns 10-13). Second, note that these results are qualitatively similar for alternative calibrations of the Frisch elasticity and the price elasticity of foreign demand, as shown in panels B and C of Table C.1. Therefore, the asymmetries in variations of production linkages are highly nonlinear in the magnitude of those variations.

From Elasticities to Moments. All the previous analysis focuses on how IO linkages affect the elasticity of GDP to commodity prices. However, such changes should also affect GDP's first and second moments. In particular, it should be the case that increases in linkages reduce (i) the response of GDP to commodity price fluctuations and (ii) its volatility.

To verify that this is the case, appendix C.2 presents counterfactual results for the level and volatility of GDP. In particular, Table C.2 shows the effect of IO linkages over the level of GDP, and Figure C.1 shows the impact over its standard deviation in simulated economies. As can be noticed, all the qualitative results about the dampening effect of IO linkages hold: increments in the degree of linkages reduce the sensitivity of GDP to commodity prices and the level of output and its volatility.

6 Conclusion

This paper analyzes the role of domestic IO linkages as a transmission mechanism of commodity price shocks in emerging economies. Focused on the effect over GDP, we document that economies with more connected commodity sectors experience lower fluctuations from commodity price shocks. Therefore, linkages between the commodity sector and the rest of the economy dampen the effect of such shocks. To rationalize this fact, we build a static real business cycle model for a small open economy that produces commodities, takes the foreign demand for commodities as given, and has IO linkages in production. In the model, an increase in the commodity price represents a windfall and an increase in the marginal cost of the commodity sector's customers. Because they also act as suppliers of the commodity sector, this has second-round effects on the production cost of the latter. However, because the economy takes the commodity price as given, the only way to keep marginal cost sufficiently low is by decreasing the demand for inputs. Therefore, the impact over GDP is lower than in a model without linkages. The model's predictions are verified under counterfactual exercises, showing a decreasing elasticity of GDP to commodity prices in the intensity of linkages, which translates into lower output volatility. We conclude that taking productive linkages of a small open economy into account is crucial to understanding commodity price shocks' impact on business cycles.

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A Empirical Appendix

A.1 Data Sources

Macroeconomic Data and Controls. We obtain data of real GDP per capita, aggregate GDP, CPI, and nominal exchange rates from the World Bank's World Development Indicators (WDI) database. The intensity of commodity exports comes from the UN's Comtrade Database. From this dataset, we obtain total exports and exports of different commodity products to mimic the basket of goods characterizing the commodity price index described below. We classify as commodity products those coming from the same set of goods defined by the commodity price index to be consistent with the definitions for commodity prices in each country (see details below). Finally, for the exchange rate regime, we use the recently developed database by Ilzetzki et al. (2019) which summarizes de facto exchange rate arrangements. we combine their coarse classification codes to construct a dummy variable that takes a value equal to zero if a country-year pair has a peg exchange rate arrangement and one otherwise (floating exchange rate).[16]

Commodity Prices. Because the exporting structure is heterogeneous for this group of countries, it could be misleading to consider just one commodity price to run the analysis.[17] In our approach, we use the International Monetary Fund (IMF) database constructed by Gruss and Kebhaj (2019). They build a single commodity price index for 182 economies for 1962-2018 at monthly and yearly frequencies. They use 45 commodity prices, broadly classified into agricultural raw materials, energy, food and beverages, and metals, and aggregate them using different possible weights. In our baseline exercise, we use the index version that

[16]In concrete, pegs are defined by any following classification: no separate legal tender, pre-announced pegs or crawling pegs, and de facto crawling pegs. Likewise, floating regimes are defined by any of the following: pre-announced or de facto crawling bands, moving bands, managed floating or freely floating regimes.

[17]Recently, Fernandez et al. (2017) argue that only one foreign price, such as terms of trade, explains a small fraction of the variance in domestic output (less than 10 percent). Even though we consider a model with one price only, this summarizes the importance of individual commodity prices in a better way. This observation has been confirmed recently by Fernandez et al. (2018), which finds that the median share of the forecast error variance decomposition of GDP in Brazil, Chile, Colombia, and Peru is 50%.

aggregates individual prices using fixed weights over the 1962-2018 period, corresponding to the average of commodity export shares over total exports. As we will show later, our results are robust to aggregate with time-varying weights. Real commodity prices correspond to the commodity price in US dollars divided by the IMF's unit value index for manufactured export.

Input-output Data. A key element in the analysis corresponds to IO tables to measure the downstream and upstream connections of the commodity sector with the rest of the domestic economy. Unfortunately, most databases that construct such information for different countries do not consider emerging economies: only developed economies and the "rest of the world" aggregate. Such an approach is followed by, for example, of the OECD Input-Output tables (IOTs) and the World Input-Output Database (WIOD) (Timmer et al., 2015). One alternative would be to rely on country-level information about IO tables. However, in general, domestic statistical agencies and central banks do not have this data in many of the countries considered in the paper. Also, when the data is available, the comparison across countries is difficult given different sectoral classifications. To overcome these issues, we use the Multi-region Input-Output table (MRIO) EORA 26 database (Lenzen et al., 2013). This database provides a complete world IO table for 190 countries, using a harmonized 26-sector classification for the period 1990-2015. The main source of information for constructing this database is the National Accounts Main Aggregates and Official Data by the United Nations. Therefore, the EORA database is constructed consistently by aggregating series at the country and world levels. Note that the data availability of this dataset restricts the time-series dimension of the full dataset to the 1990-2015 period. Importantly, because of the heterogeneity in the goods composing the commodity price index and consistency, we define the commodity sector as the sum of agriculture, fishing, mining, and quarrying. We consider that technological reasons are behind the formation of production linkages. Therefore, we use the average IO matrix in the 1990-2015 period for each country to compute the downstream and upstream measures.

A.2 Descriptive Statistics

Selected Countries. The list of selected countries is as follows: Algeria, Angola, (Kingdom of) Bahrain, Bolivia, Burkina Faso, Cameroon, Chad, Chile, Colombia, Democratic Republic of Congo, Republic of Congo, Gabon, Ghana, Guinea, Iran, Jamaica, Lao People's Democratic Republic, Mali, Mozambique, Namibia, Niger, Nigeria, Oman, Papua New Guinea, Peru, Saudi Arabia, Sierra Leone, Sudan, Suriname, Tanzania, Togo, Trinidad and Tobago, Republic of Yemen and Zambia.

Sectoral Classification. The EORA database considers the 26 following sectors: (i) Agriculture; (ii) Fishing; (iii) Mining and Quarrying; (iv) Food & Beverages; (v) Textiles and Wearing Apparel; (vi) Wood and Paper; (vii) Petroleum, Chemical and Non-Metallic Mineral Products; (viii) Metal Products; (ix) Electrical and Machinery; (x) Transport Equipment; (xi) Other Manufacturing; (xii) Recycling; (xiii) Electricity, Gas and Water; (xiv) Construction; (xv) Maintenance and Repair; (xvi) Wholesale Trade; (xvii) Retail Trade; (xviii) Hotels and Restaurants; (xix) Transport; (xx) Post and Telecommunications; (xxi) Financial Intermediation and Business Activities; (xxii) Public Administration; (xxiii) Education, Health and Other Services; (xxiv) Private Households; (xxv) Others; (xxvi) Re-export & Re-import. For this paper we consider a single commodity sector composed by the aggregation of sectors (i)–(iii), and remove as part of sectors in the rest of the economy sectors (xxiv)–(xxvi).

Descriptive Statistics. Table A.1 presents descriptive statistics for selected variables in the sample. Panel A presents GDP and the commodity price in log deviations with respect to a quadratic trend. All variables, except for GDP, are expressed in deviations with respect to the sample average. To avoid the influence of outliers, we remove observations at the bottom one and top 99 percent.

As panel A shows, there is a large degree of variation in the business cycle's level and volatility in emerging economies, with a great deal of dispersion in GDP. Something similar happens for the relevant commodity price for each country. Note also that the commodity price variability is more than four times larger than the variability of GDP. The previous observation implies that one crucial source of income in emerging economies (commodity prices) experiences a great deal of variation, which induces significant volatility swings in aggregate income.

Panel b presents descriptive statistics for the linkages between the commodity sector and the rest of the economy. Recall from section 2.1 that the variable Down captures the importance of the commodity sector as a customer of other industries, while the variable Up captures its importance as a supplier.

Table A.1. Descriptive Statistics

	Mean	Median	Std. Dev.	Min	Max
Panel A: GDP and commodity price					
GDP	0.08	-0.23	4.65	-9.74	12.14
Commodity price	0.00	-0.17	19.82	-57.62	47.83
Panel B: Commodity linkages					
Down	0.00	-0.03	0.16	-0.23	0.37
Up	0.00	-0.03	0.32	-0.45	0.79

Notes: Panel A shows descriptives for GDP and commodity price (variables expressed in percentage log-deviations with respect to a quadratic trend). Panel B shows descriptives for linkages between the commodity sector and the rest of the economy. The commodity price index is computed by weighting different commodity products over total commodity exports. All variables, except GDP, expressed in deviations with respect to the sample average.

A.3 Additional Empirical Results

Table A.2 compares baseline results with those using alternative commodity price indexes. Table A.3 compares baseline results for different commodity price indexes and filtering schemes. As we can see, even though some results lose statistical significance (especially the coefficient for variable Up when we filter the data using either HP or Hamilton (2018)'s filter), all the qualitative insights about the dampening effect of domestic commodity linkages remain.

TABLE A.2. The Effect of Commodity Prices and Commodity Linkages over GDP–Alternative Commodity Price Indexes

	Panel A: Weighting by commodity over exports				Panel B: Weighting by commodity over GDP			
	Fixed weights		Rolling weights		Fixed weights		Rolling weights	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Commodity price$_{it-1}$	0.89	1.02	0.97	1.37	1.65	1.71	1.68	1.88
	(0.27)	(0.46)	(0.27)	(0.49)	(0.41)	(0.55)	(0.34)	(0.45)
Commodity price$_{it-1}\times$ Down$_i$	-1.11	-1.01	-1.05	-0.96	-1.28	-1.14	-1.11	-1.05
	(0.44)	(0.40)	(0.40)	(0.35)	(0.55)	(0.51)	(0.47)	(0.42)
Commodity price$_{it-1}\times$ Up$_i$	-0.74	-0.68	-0.66	-0.57	-0.88	-0.80	-0.62	-0.47
	(0.29)	(0.24)	(0.28)	(0.23)	(0.31)	(0.26)	(0.26)	(0.23)
Observations	548	548	548	548	548	548	548	548
Adj R-squared	0.17	0.23	0.17	0.25	0.18	0.25	0.17	0.24
Exports size	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	Yes	No	Yes	No	Yes	No	Yes

NOTES: This table reports the results of estimating (1). The variable commodity price is standardized. Panel A shows results using a commodity price index weighting each product over total commodity exports. Panel B shows results using a commodity price index weighting each product over GDP. Columns denoted by "Fixed weights" and "Rolling weights" use data from 1962-2018. All control variables are lagged one period. Robust standard errors clustered at the country level in parentheses. See the main text and Appendix A for details about variables' definitions.

TABLE A.3. The Effect of Commodity Prices and Commodity Linkages over GDP–Alternative Commodity Price Indexes and Filters

	Panel A: Quadratic detrending				Panel B: HP Filter				Panel C: Hamilton's Filter			
	Fixed weights		Rolling weights		Fixed weights		Rolling weights		Fixed weights		Rolling weights	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Commodity price$_{it-1}$	0.89	1.02	0.97	1.37	0.44	0.36*	0.52	0.61	0.96	0.85*	1.09	1.05
	(0.27)	(0.46)	(0.27)	(0.49)	(0.14)	(0.20)	(0.14)	(0.18)	(0.27)	(0.43)	(0.28)	(0.41)
Commodity price$_{it-1}\times$ Down$_i$	-1.11	-1.01	-1.05	-0.96	-0.44	-0.38	-0.56	-0.50	-0.57	-0.59	-0.60	-0.60
	(0.44)	(0.40)	(0.40)	(0.35)	(0.19)	(0.18)	(0.20)	(0.19)	(0.27)	(0.25)	(0.28)	(0.25)
Commodity price$_{it-1}\times$ Up$_i$	-0.74	-0.68	-0.66	-0.57	-0.03	-0.04	-0.03	-0.03	-0.14	-0.20	0.03	-0.03
	(0.29)	(0.24)	(0.28)	(0.23)	(0.15)	(0.12)	(0.15)	(0.13)	(0.27)	(0.25)	(0.24)	(0.23)
Observations	548	548	548	548	548	548	548	548	533	533	533	533
Adj R-squared	0.17	0.23	0.17	0.25	0.07	0.17	0.08	0.19	0.09	0.15	0.10	0.16
Exports size	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes

NOTES: This table reports the results of estimating (1). The variable commodity price is standardized. Panel A shows results using data filtered with a quadratic trend. Panel B shows results using data filtered using Hodrick-Prescott with smoothing parameter $\lambda = 100$. Panel C shows results using data filtered by the proposed by Hamilton (2018). Columns denoted by "Fixed weights" and "Rolling weights" use data from 1962-2018. All control variables are lagged one period. Robust standard errors clustered at the country level in parentheses. See the main text and Appendix A for details about variables' definitions.

B Theoretical Appendix

This appendix describes the solution of the complete model presented in section 3 and proofs of results presented in section 4.

B.1 Model Characterization

Note that the model cannot be solved analytically under decreasing returns to scale ($\phi_j < 1$). In what follows, we present the basic steps to solve for the economy's equilibrium numerically.

1. Set values for fundamentals of the economy. In particular, for productivities, the level of foreign commodity demand ($A_{x,1}$) and the demand shifter ν. Given those values, (13) pins-down a value for the commodity price.

2. Guess values for Y_j for each $j = 1, \dots, N$.

3. From (8), for $j = 1$ get

$$\alpha_1 \log w = \log Z_1 + (1 - \gamma_{11}) \log P_1 - \boldsymbol{\gamma_{j1}}' \log \widetilde{\mathbf{P}} - \widetilde{\phi}_1 \log Y_1, \qquad \text{(B.1)}$$

where $\boldsymbol{\gamma_{j1}} = [\gamma_{2,1}, \dots, \gamma_{N,1}]'$, $\widetilde{\mathbf{P}} = [P_2, \dots, P_N]'$ and $\widetilde{\phi}_j \equiv \frac{1-\phi_j}{\phi_j}$.

Using (8) for $j = 2, \dots, N$ get

$$\underbrace{\begin{bmatrix} 1-\gamma_{22} & -\gamma_{32} & \dots & -\gamma_{N2} \\ -\gamma_{23} & 1-\gamma_{22} & \dots & -\gamma_{N3} \\ \vdots & \vdots & \ddots & \vdots \\ -\gamma_{2N} & -\gamma_{3N} & \dots & 1-\gamma_{NN} \end{bmatrix}}_{\widetilde{\mathbf{H}}^{-1} \equiv (\mathbf{I}_{N-1} - \widetilde{\mathbf{\Gamma}}')^{-1}} \begin{bmatrix} \log P_2 \\ \log P_3 \\ \vdots \\ \log P_N \end{bmatrix} = - \begin{bmatrix} \log Z_2 \\ \log Z_3 \\ \vdots \\ \log Z_N \end{bmatrix} + \begin{bmatrix} \alpha_2 \\ \alpha_3 \\ \vdots \\ \alpha_N \end{bmatrix} \log w$$

$$+ \begin{bmatrix} \gamma_{12} \\ \gamma_{13} \\ \vdots \\ \gamma_{1N} \end{bmatrix} \log P_1 + \begin{bmatrix} \widetilde{\phi}_2 \\ \widetilde{\phi}_3 \\ \vdots \\ \widetilde{\phi}_N \end{bmatrix} \begin{bmatrix} \log Y_2 \\ \log Y_3 \\ \vdots \\ \log Y_N \end{bmatrix},$$

which can be written in matrix form as

$$\log \widetilde{\mathbf{P}} = \widetilde{\mathbf{H}}(-\log \widetilde{\mathbf{Z}} + \boldsymbol{\alpha} \log w + \boldsymbol{\gamma_{1j}} \log P_1 + \widetilde{\boldsymbol{\phi}} \odot \log \widetilde{\mathbf{Y}}), \tag{B.2}$$

where $\odot$ denotes the Hadamard (entrywise) product. Combining (B.1) and (B.2), solve for the equilibrium wage and sectoral prices

$$\log w = \Psi_z + \Omega_p \log P_1 + \Psi_y \widetilde{\boldsymbol{\phi}} \log \widetilde{\mathbf{Y}} + \Omega_y \log Y_1 \tag{B.3}$$

$$\log \widetilde{\mathbf{P}} = \widetilde{\mathbf{H}} \left[(\boldsymbol{\alpha} \Psi_z - \log \widetilde{\mathbf{Z}}) + (\boldsymbol{\alpha} \Omega_p + \boldsymbol{\gamma_{1j}}) \log P_1 + (\boldsymbol{\alpha} \Psi_y + \mathbf{I}_{N-1}) \widetilde{\boldsymbol{\phi}} \log \widetilde{\mathbf{Y}} + \boldsymbol{\alpha} \Omega_y \log Y_1 \right], \tag{B.4}$$

with

$$\Psi_z = \left(\frac{\log Z_1 + \boldsymbol{\gamma_{j1}}' \widetilde{\mathbf{H}} \log \widetilde{\mathbf{Z}}}{\alpha_1 + \boldsymbol{\gamma_{j1}}' \widetilde{\mathbf{H}} \boldsymbol{\alpha}} \right), \qquad \Omega_p = \left(\frac{1 - \gamma_{11} - \boldsymbol{\gamma_{j1}}' \widetilde{\mathbf{H}} \boldsymbol{\gamma_{1j}}}{\alpha_1 + \boldsymbol{\gamma_{j1}}' \widetilde{\mathbf{H}} \boldsymbol{\alpha}} \right)$$

$$\Psi_y = \left(\frac{-\boldsymbol{\gamma_{j1}}' \widetilde{\mathbf{H}}}{\alpha_1 + \boldsymbol{\gamma_{j1}}' \widetilde{\mathbf{H}} \boldsymbol{\alpha}} \right), \qquad \Omega_y = \left(\frac{-\widetilde{\phi}_1}{\alpha_1 + \boldsymbol{\gamma_{j1}}' \widetilde{\mathbf{H}} \boldsymbol{\alpha}} \right).$$

4. Recover the price for final goods from (11) and (12)

$$\log P^c = \sum_{j=1}^{N} \mu_j \log P_j = \mu_1 \log P_1 + \boldsymbol{\mu}' \log \widetilde{\mathbf{P}} \tag{B.5}$$

$$\log P^x = \sum_{j=2}^{N} \eta_j \log P_j = \boldsymbol{\eta}' \log \widetilde{\mathbf{P}}. \tag{B.6}$$

5. Get aggregate labor supply from (3) as

$$\log L = \frac{1}{\xi} (\log w - \log P^c - \log \vartheta). \tag{B.7}$$

Recover also sectoral and aggregate profits

$$D_j = P_j Y_j - w L_j - V_j - \sum_{i=1}^{N} P_i M_{ij} \tag{B.8}$$

$$D = \sum_{j=1}^{N} D_j. \tag{B.9}$$

6. Compute aggregate consumption from (4) as $C = \frac{W}{P^c}L + \frac{D}{P^c}$ and the demands for each sector by the consumption aggregator $A_{c,j}$ from (9).

7. Use the sectoral market clearing condition (15) and the sectoral demand for the exportable goods' aggregator (10) to get

$$\mathbf{Y} = \widehat{\mathbf{H}}\left(\widetilde{\mathbf{A}}_{\mathbf{c}} + \widetilde{\boldsymbol{\eta}}X\right), \tag{B.10}$$

where $\widetilde{\mathbf{A}}_{\mathbf{c}} = \mathbf{A}_{\mathbf{c}} + \widetilde{\mathbf{x}}$, with $\mathbf{A}_{\mathbf{c}} = [A_{c,1}, \ldots, A_{c,N}]'$ being the demand for the consumption good for every sector, $\widetilde{\mathbf{x}}$ is a $N \times 1$-dimensional zero vector, except the first element which is $A_{x,1}$, and $\widetilde{\boldsymbol{\eta}} = [0, \widetilde{\eta}_2, \ldots, \widetilde{\eta}_N]'$ with $\widetilde{\eta}_j \equiv \eta_j \frac{P^x}{P_j}$ and $\widehat{\mathbf{H}} = (\mathbf{I}_N - \widehat{\mathbf{\Gamma}})^{-1}$ with $\widehat{\mathbf{\Gamma}}$ having as representative element $\widetilde{\gamma}_{ij} \equiv \gamma_{ij}\phi_j \frac{P_j}{P_i}$. This is

$$\widehat{\mathbf{\Gamma}} = \begin{bmatrix} \gamma_{11}\phi_1 & \gamma_{12}\phi_2\frac{P_2}{P_1} & \ldots & \gamma_{1N}\phi_N\frac{P_N}{P_1} \\ \gamma_{21}\phi_1\frac{P_1}{P_2} & \gamma_{22}\phi_2 & \ldots & \gamma_{2N}\phi_N\frac{P_N}{P_1} \\ \vdots & \vdots & \ddots & \vdots \\ \gamma_{N1}\phi_1\frac{P_1}{P_N} & \gamma_{N2}\phi_2\frac{P_2}{P_N} & \ldots & \gamma_{NN}\phi_N \end{bmatrix}.$$

On the other hand, using the labor market clearing condition (14) and the sectoral demands for labor (5) we have

$$L = \sum_{j=1}^{N} L_j = \sum_{j=1}^{N} \frac{\alpha_j\phi_j P_j Y_j}{w} = \sum_{j=1}^{N} \widetilde{\alpha}_j Y_j = \widetilde{\boldsymbol{\alpha}}'\mathbf{Y}, \tag{B.11}$$

where $\widetilde{\boldsymbol{\alpha}} = [\widetilde{\alpha}_1, \ldots, \widetilde{\alpha}_N]'$ and $\widetilde{\alpha}_j \equiv \alpha_j\phi_j\frac{P_j}{w}$.

Replacing (B.10) in (B.11) recover an expression for exports

$$X = \frac{L - \widetilde{\boldsymbol{\alpha}}'\widehat{\mathbf{H}}\widetilde{\mathbf{A}}_{\mathbf{c}}}{\widetilde{\boldsymbol{\alpha}}\widehat{\mathbf{H}}\widetilde{\boldsymbol{\eta}}}. \tag{B.12}$$

8. Replace (B.12) in (B.10) to get a model-implied value for output. Use this expression as residual to solve for the guessed values of sectoral output Y_j.

B.2 Proofs

B.2.1 Proof of Proposition 1

Proof. Note that there are no sectoral profits under constant returns to scale and perfect competition. Therefore, GDP corresponds only to the labor income of the economy, GDP $= wL$. From the GHH assumption, we have that labor supply equals $L = (w/\vartheta P^c)^{1/\xi}$. Therefore, we need to characterize the equilibrium value of wage and consumption price. The second implication of constant returns to scale is that the parameters $\widetilde{\phi}_j = 0$ for every j, so marginal costs and prices do not depend on the quantity produced. This implies that (B.3) and (B.4) adopt the form

$$\begin{aligned}
\log w &= \Psi_z + \Omega_p \log P_1 \\
\log \widetilde{\mathbf{P}} &= \widetilde{\mathbf{H}} \left[(\boldsymbol{\alpha}\Phi_z - \log \widetilde{\mathbf{Z}}) + (\boldsymbol{\alpha}\Omega_p + \boldsymbol{\gamma_{1j}}) \log P_1 \right].
\end{aligned}$$

The price of consumption given in (B.5) adopts the form

$$\log P^c = \boldsymbol{\mu}'\widetilde{\mathbf{H}}(\boldsymbol{\alpha}\Phi_z - \log \widetilde{\mathbf{Z}}) + \left[\mu_1 + \boldsymbol{\mu}'\widetilde{\mathbf{H}}(\boldsymbol{\alpha}\Omega_p + \boldsymbol{\gamma_{1j}}) \right] \log P_1.$$

Taking logs in the expression of GDP and using the labor supply equation we have $\log \text{GDP} = \left(\frac{\xi+1}{\xi}\right) \log w - \frac{1}{\xi} \log P^c - \frac{1}{\xi} \log \vartheta$. Replacing for wage and the price of consumption, we get the following expression for GDP, which depends on sectoral productivity and the commodity price

$$\begin{aligned}
\frac{\partial \log \text{GDP}}{\partial \log P_1} = & \underbrace{\frac{1}{\xi} \left\{ (\xi+1)\Psi_z - \boldsymbol{\mu}'\widetilde{\mathbf{H}}(\boldsymbol{\alpha}\Phi_z - \log \widetilde{\mathbf{Z}}) - \log \vartheta \right\}}_{\text{Constant terms + productivity}} \\
& + \underbrace{\frac{1}{\xi} \left\{ (\xi+1)\Omega_p - \mu_1 - \boldsymbol{\mu}'\widetilde{\mathbf{H}}(\boldsymbol{\alpha}\Omega_p + \boldsymbol{\gamma_{1j}}) \right\}}_{\text{Elasticity of GDP to commodity price}} \log P_1,
\end{aligned}$$

with $\Psi_z = \left(\frac{\log Z_1 + \boldsymbol{\gamma_{j1}}'\widetilde{\mathbf{H}} \log \widetilde{\mathbf{Z}}}{\alpha_1 + \boldsymbol{\gamma_{j1}}'\widetilde{\mathbf{H}}\boldsymbol{\alpha}} \right)$ and $\Omega_p = \left(\frac{1 - \gamma_{11} - \boldsymbol{\gamma_{j1}}'\widetilde{\mathbf{H}}\boldsymbol{\gamma_{1j}}}{\alpha_1 + \boldsymbol{\gamma_{j1}}'\widetilde{\mathbf{H}}\boldsymbol{\alpha}} \right)$ as before. Taken the partial derivative of GDP with respect to the commodity price, we obtain the same expression as in the main text. □

B.2.2 Elasticity of GDP to Commodity Prices with Separable Preferences

The following proposition presents the elasticity of GDP with respect to commodity prices for the case of separable preferences.

Proposition 3. *The elasticity of GDP to commodity prices in a $N \times N$ economy with arbitrary IO linkages, constant returns to scale, and separable preferences is given by*

$$\psi_S \equiv \frac{\partial \log \text{GDP}}{\partial \log P_1} = \frac{1}{\sigma + \xi} \left\{ (\xi + 1)\Omega_p - (1 - \sigma) \left[\mu_1 + \boldsymbol{\mu}' \widetilde{\mathbf{H}} (\boldsymbol{\alpha} \Omega_p + \boldsymbol{\gamma}_{\mathbf{1j}}) \right] \right\}, \tag{B.13}$$

where the definition of each element is the same as in Proposition 1.

Proof. Given separable preferences of the form $U = \frac{C^{1-\sigma}-1}{1-\sigma} - \vartheta \frac{L^{1+\xi}}{1+\xi}$, the labor supply schedule takes the form $L = \left(\frac{1}{\vartheta} \left(\frac{w}{P^c} \right)^{1-\sigma} \right)^{\frac{1}{\sigma+\xi}}$. Note that this change in preferences does not alter either the definition of GDP as labor income, nor the equilibrium wage/prices in the economy. Thus, the same values for equilibrium values shown in Proposition 1 hold. Taking logs to the expression of GDP we get

$$\log \text{GDP} = \frac{\xi + 1}{\sigma + \xi} \log w - \frac{1 - \sigma}{\sigma + \xi} \log P^c - \frac{1}{\sigma + \xi} \log \vartheta.$$

Replacing the equilibrium values for wages and the price of consumption (presented in the proof of Proposition 1), and taking the partial derivative with respect to $\log P_1$

$$\psi_S \equiv \frac{\partial \log \text{GDP}}{\partial \log P_1} = \frac{1}{\sigma + \xi} \left\{ (\xi + 1)\Omega_p - (1 - \sigma) \left[\mu_1 + \boldsymbol{\mu}' \widetilde{\mathbf{H}} (\boldsymbol{\alpha} \Omega_p + \boldsymbol{\gamma}_{\mathbf{1j}}) \right] \right\},$$

which completes the proof. □

The following corollary compares the elasticity of GDP with respect to commodity prices for GHH and separable preferences.

Corollary 1. *If the elasticity of GDP with respect to commodity prices is positive under GHH preferences ($\psi_{GHH} \geq 0$ in Equation 20), then such elasticity is larger than under separable preferences ($\psi_{GHH} \geq \psi_S$).*

Proof. Note that because $\xi \geq 0$, a necessary and sufficient condition for $\psi_{GHH} \geq 0$ is that $\Omega_p \geq \mu_1 + \boldsymbol{\mu}'\widetilde{\mathbf{H}}(\boldsymbol{\alpha}\Omega_p + \boldsymbol{\gamma_{1j}})$. Directly comparing ψ_{GHH} in equation (20) with ψ_S in equation (B.13), it follows that $\psi_{GHH} \geq \psi_S$ if and only if this condition is met. Note that in the particular case $\sigma = 0$, both elasticities coincide. □

The following corollary shows that under the same (sufficient but not necessary) conditions of Proposition 2, the dampening effect of domestic linkages also operates under separable preferences.

Corollary 2. *Consider the same conditions provided in Proposition 2 and denote $\psi_{S,-1j}$ and $\psi_{S,-j1}$ as the elasticity of GDP to commodity prices when the commodity sector acts only as customer (no upstream effect) and only as supplier (no downstream effect), respectively. Then, $\psi_{S,-1j} \geq \psi_S$ and $\psi_{S,-j1} \geq \psi_S$. Under additional parametric conditions, $\psi_{S,-j1} \geq \psi_{S,-1j}$.*

Proof. Recall that the expression for ψ_S is provided in (B.13). Following the same steps in the proof of Proposition 2, we have that (i) $\psi_{S,-1j} \geq \psi_S$ holds if $(\xi + 1 - (1-\sigma)\boldsymbol{\mu}'\widetilde{\mathbf{H}}\boldsymbol{\alpha})(\Omega_p^{\text{No Up}} - \Omega_p) + \boldsymbol{\mu}'\widetilde{\mathbf{H}}\boldsymbol{\gamma}_{1j} \geq 0$, and (ii) $\psi_{S,-j1} \geq \psi_S$ holds if $(\xi + 1 - (1-\sigma)\boldsymbol{\mu}'\widetilde{\mathbf{H}}\boldsymbol{\alpha})(\Omega_p^{\text{No Down}} - \Omega_p) \geq 0$. Note that the condition stated in Proposition 2, $\xi + 1 - \boldsymbol{\mu}'\widetilde{\mathbf{H}}\boldsymbol{\alpha} \geq 0$, here is only sufficient because $\sigma > 0$.

By comparing points (i) and (ii), note that $\psi_{S,-j1} \geq \psi_{S,-1j}$ holds if $(\xi + 1 - (1-\sigma)\boldsymbol{\mu}'\widetilde{\mathbf{H}}\boldsymbol{\alpha})(\Omega_p^{\text{No Down}} - \Omega_p^{\text{No Up}}) \geq (1-\sigma)\boldsymbol{\mu}'\widetilde{\mathbf{H}}\boldsymbol{\gamma}_{1j}$, which is analogous to the condition stated in the proof of Proposition 2. □

B.2.3 Proof of Proposition 2

The following lemma characterizes the impact of production linkages over the equilibrium wage, which, as we saw in the previous section, is a crucial element in determining GDP.

Lemma 1. *Denote $\Omega_p^{No\ Down}$ and $\Omega_p^{No\ Up}$ as the elasticity when removing the demand (downstream effect) and supply (upstream effect) of the commodity to other sectors, respectively, and recall from Proposition 1 that Ω_p is the elasticity of the equilibrium wage to the commodity price. Then, $\Omega_p < \Omega_p^{No\ Up} < \Omega_p^{No\ Down}$.*

Proof. Recall that the expression for the elasticity of wages to commodity prices takes the form $\Omega_p = \left(\frac{1-\gamma_{11}-\boldsymbol{\gamma_{j1}}'\widetilde{\mathbf{H}}\boldsymbol{\gamma_{1j}}}{\alpha_1+\boldsymbol{\gamma_{j1}}'\widetilde{\mathbf{H}}\boldsymbol{\alpha}}\right)$. Removing the role of the commodity sector as customer, $\Omega_p^{\text{No Down}}$, and supplier, $\Omega_p^{\text{No Up}}$, generates the counterfactual elasticities $\Omega_p^{\text{No Down}} = \frac{1}{\alpha_1}$ and $\Omega_p^{\text{No Up}} = \left(\frac{1}{\alpha_1+\boldsymbol{\gamma_{j1}}'\widetilde{\mathbf{H}}\boldsymbol{\alpha}}\right)$.

By direct comparison, first note that $\Omega_p < \Omega_p^{\text{No Up}}$ because $-(\gamma_{11} + \boldsymbol{\gamma_{j1}}'\widetilde{\mathbf{H}}\boldsymbol{\gamma_{1j}})(\alpha_1 + \boldsymbol{\gamma_{j1}}'\widetilde{\mathbf{H}}\boldsymbol{\alpha}) < 0$ holds. Such inequality is satisfied because all elements in the left-hand side are positive (entry-by-entry in the case of vectors and matrices).[18] In the same way, $\Omega_p^{\text{No Up}} < \Omega_p^{\text{No Down}}$ holds because $0 < \boldsymbol{\gamma_{j1}}'\widetilde{\mathbf{H}}\boldsymbol{\alpha}$ is satisfied by the same arguments as before. Therefore, $\Omega < \Omega_p^{\text{No Up}} < \Omega_p^{\text{No Down}}$, which concludes the proof. $\square$

This result describes a pecking order in the response of the equilibrium wage when considering different configurations in commodity linkages. In particular, when both margins exist (i.e., commodity sector as a customer and as a supplier of the rest of the economy), wages are lower than when the commodity sector only acts as a customer (no upstream effect). Conversely, the most potent response occurs when the commodity sector only acts as a supplier (no downstream effect). These results highlight the relative importance of downstream and upstream linkages of the commodity sector over wages.

With this result at hand, we are ready to prove Proposition 2.

Proof. From Proposition 1, recall that $\psi_{GHH} = \frac{1}{\xi}\left\{(\xi+1)\Omega_p - \mu_1 - \boldsymbol{\mu}'\widetilde{\mathbf{H}}(\boldsymbol{\alpha}\Omega_p + \boldsymbol{\gamma_{1j}})\right\}$. Define

$$\psi_{GHH}^{\text{No Up}} = \frac{1}{\xi}\left\{(\xi+1)\Omega_p^{\text{No Up}} - \mu_1 - \boldsymbol{\mu}'\widetilde{\mathbf{H}}\boldsymbol{\alpha}\Omega_p^{\text{No Up}}\right\} \tag{B.14}$$

$$\psi_{GHH}^{\text{No Down}} = \frac{1}{\xi}\left\{(\xi+1)\Omega_p^{\text{No Down}} - \mu_1 - \boldsymbol{\mu}'\widetilde{\mathbf{H}}(\boldsymbol{\alpha}\Omega_p^{\text{No Down}} + \boldsymbol{\gamma_{1j}})\right\} \tag{B.15}$$

as the counterfactual elasticities when the commodity sector only acts as customer (i.e., no upstream effect) and supplier (i.e., no downstream effect), respectively. Comparing (B.14) with (20), $\psi_{GHH}^{\text{No Up}} \geq \psi_{GHH}$ holds if $(\xi+1-\boldsymbol{\mu}'\widetilde{\mathbf{H}}\boldsymbol{\alpha})(\Omega_p^{\text{No Up}} - \Omega_p) + \boldsymbol{\mu}'\widetilde{\mathbf{H}}\boldsymbol{\gamma}_{1j} \geq 0$. On the other hand, comparing (B.15) with (20), $\psi_{GHH}^{\text{No Down}} \geq \psi_{GHH}$ holds if $(\xi+1-\boldsymbol{\mu}'\widetilde{\mathbf{H}}\boldsymbol{\alpha})(\Omega_p^{\text{No Down}} - \Omega_p) \geq$

[18] Note that the Leontief inverse of the mainland economy $\widetilde{\mathbf{H}}$ always exists and is element-wise nonnegative because the IO matrix is nonnegative with a spectral radius that is strictly less than 1. See Carvalho and Tahbaz-Salehi (2019) for details.

0. Note that both conditions are met because (i) the term $\xi + 1 - \boldsymbol{\mu}'\widetilde{\mathbf{H}}\boldsymbol{\alpha} \geq 0$ by assumption, and (ii) by Lemma 1 and the arguments provided therein.

Additionally, by comparing (B.14) with (B.15), note that $\psi_{GHH}^{\text{No Down}} \geq {}_{GHH}^{\text{No Up}}$ holds if $(\xi + 1 - \boldsymbol{\mu}'\widetilde{\mathbf{H}}\boldsymbol{\alpha})(\Omega_p^{\text{No Down}} - \Omega_p^{\text{No Up}}) \geq \boldsymbol{\mu}'\widetilde{\mathbf{H}}\boldsymbol{\gamma}_{1j}$. This is, if the latter condition holds, then the elasticity of GDP is larger when we remove the downstream effect of the commodity sector. $\square$

C Quantitative Analysis

C.1 Nonlinear Effects of IO Linkages

Table C.1 replicates the results presented in Table 2 about the quantitative variation in GDP after changes in the intensity of linkages between the commodity sector and the rest of the economy. Besides the baseline degree of variations (10%), it also considers changes of 50 and 100% in linkages.

Table C.1. GDP under Counterfactual Calibrations of the Model–Different Intensities of Changes

	Baseline	10% decrease		10% increase		50% decrease		50% increase		100% decrease		100% increase	
		Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Panel A: Baseline calibration ($\xi = 1$ and $\varepsilon = 1$)													
ψ	3.30	3.55	3.41	3.08	3.20	4.69	3.87	2.37	2.81	6.73	4.77	1.75	2.39
Panel B: Alternative Frisch Elasticity ($\xi = 0.69$)													
ψ	3.42	3.68	3.54	3.19	3.32	4.85	4.02	2.45	2.91	6.90	4.98	1.81	2.47
Panel C: Alternative Foreign Demand Elasticity ($\varepsilon = 10$)													
ψ	3.27	3.49	3.37	3.06	3.17	4.59	3.84	2.37	2.80	6.30	4.75	1.76	2.39

Notes: This table presents counterfactual results about the elasticity of GDP to commodity prices (ψ) for different degrees of production linkages of the commodity sector. Column (1) shows the elasticity for the baseline calibration. Columns (2) and (3) show a 10% decrease in the degree of demand and supply of materials by the commodity sector, respectively. Columns (4) and (5) show a 10% increase in the degree of demand and supply of materials by the commodity sector by the commodity sector, respectively. Columns (6)-(9) and (10)-(13) repeat the exercise for changes of 50% and 100% in linkages, respectively.

C.2 Moments of GDP

C.2.1 Level of GDP

Table C.2. Level of GDP–Counterfactuals

	Baseline	10% decrease		10% increase	
		Down	Up	Down	Up
	(1)	(2)	(3)	(4)	(5)
Panel A: Baseline calibration ($\xi = 1$ and $\varepsilon = 1$)					
GDP	2.55	2.59	2.64	2.51	2.46
%Δ relative to baseline		1.74	3.73	-1.56	-3.46
Panel B: Alternative Frisch Elasticity ($\xi = 0.69$)					
GDP	2.58	2.62	2.68	2.53	2.48
%Δ relative to baseline		1.84	3.92	-1.65	-3.63
Panel C: Alternative Foreign Demand Elasticity ($\varepsilon = 10$)					
GDP	3.38	3.51	3.54	3.26	3.23
%Δ relative to baseline		3.81	4.67	-3.36	-4.30

Notes: This table presents counterfactual results about the level of GDP to commodity prices for different degrees of production linkages of the commodity sector. Column (1) shows the elasticity for the baseline calibration. Columns (2) and (3) presents a 10% decrease in the degree of demand and supply of materials by the commodity sector, respectively. Columns (4) and (5) presents a 10% increase in the degree of demand and supply of materials by the commodity sector by the commodity sector, respectively. On each panel, the first row GDP presents the level of GDP, while the second row presents the percentage change in GDP relative to the baseline model in column (1).

C.2.2 GDP Volatility under Counterfactual Domestic Linkages

This section extends the baseline model to consider other driving forces to study the effect of linkages in the volatility of GDP. To fully capture those fluctuations, we proceed as follows.

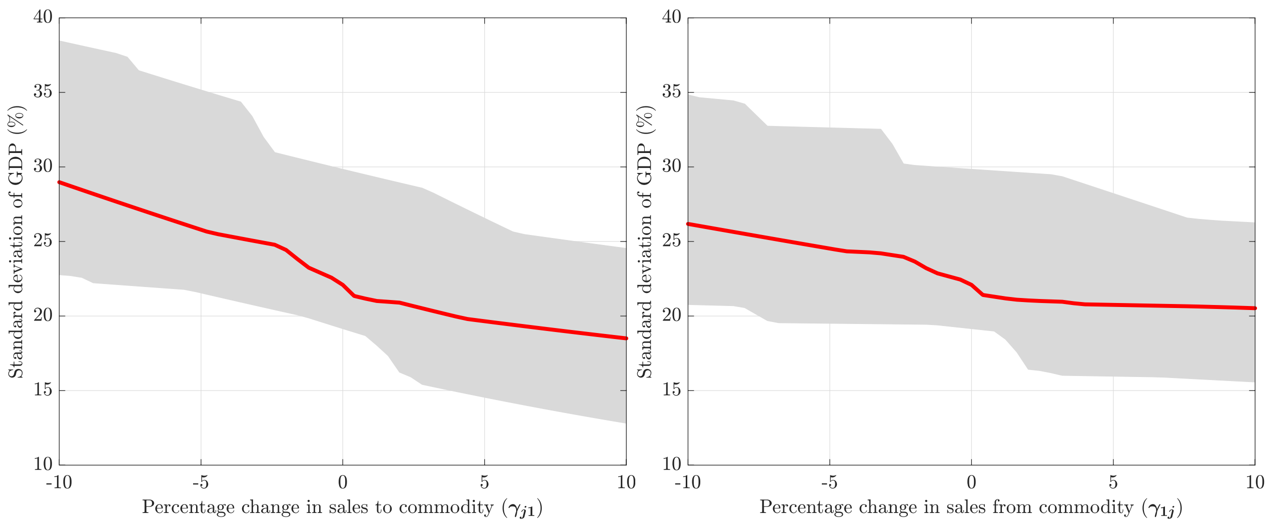
First, to account for the role of commodity linkages, we assume that, besides the commodity price shock, each country is subject to productivity shocks common across sectors ($Z_j = Z$) but country-specific. Then we use data for GDP and commodity prices between 2000-2015 to recover the level of productivity that exactly matches GDP over the period. Next, using the level of productivity recovered by the model and the observed commodity price, we simulate counterfactual economies with different degrees of linkages between the commodity sector and the rest of the economy. We implement this exercise by changing the parameters contained in vectors $\boldsymbol{\gamma}_{1j}$ (the intensity of demand of other sectors for commodity goods) and $\boldsymbol{\gamma}_{j1}$ (the intensity of demand of the commodity sector for other domestic materials). Given the Cobb-Douglas nature of the productive side of the model, those changes connect naturally to the Down and Up measures presented in the empirical section. Then, for each counterfactual, we compute the standard deviation of the GDP predicted by the model to study the impact of linkages over volatility.

The exercise considers the same 34 countries analyzed in section 2, with data on GDP from WDI and commodity prices from the IMF. We calibrate the model for each country following the same strategy of section 5. With all this information, we compute the volatility of a counterfactual GDP with different intensities in connections between the commodity sector and the rest of the economy.

Figure C.1 presents the results of this exercise. On each panel, the solid red line corresponds to the median volatility across countries under the different counterfactuals, while the grey area denotes the interquartile range. The horizontal axis denotes the percentage deviation in either $\boldsymbol{\gamma}_{j1}$ or $\boldsymbol{\gamma}_{1j}$, measuring changes in the intensity of the commodity sector as customer or supplier, respectively. For comparison purposes, note that the median volatility under the baseline calibration (when the percentage change equals zero) is 22.1%. Starting with panel (a), we observe that a decrease in the demand of the commodity sector for domestic materials translates into more volatility of GDP. In particular, a counterfactual economy in which the demand for all domestic materials is 10 percent lower would have experienced a degree of volatility of 29.9%, which is 1.4 times larger than in the baseline calibration.

On the contrary, a 10 percent increase in the demand for materials would imply a level of volatility of 18.5% for GDP. Panel (b) presents a different picture by comparing different scenarios in the intensity of sales from commodity to the rest of the economy. In particular, decreasing such intensity would produce a volatility 1.2 times larger than in the baseline, reaching a level of 26.2%, while a decrease in the domestic demand for commodity goods generates a degree of volatility of 20.5%.

FIGURE C.1. GDP Volatility and Counterfactual Commodity Linkages



(a) Changes in Commodity as Customer (Downstream) (b) Changes in Commodity as Supplier (Upstream)

NOTES: This figure presents the standard deviation of GDP under counterfactual calibrations of the model. Panel (a) presents results for changes in γ_{j1}, while panel (b) presents results for changes in γ_{1j}. Horizontal axis shows the percentage change relative to baseline calibration. Vertical axis presents the volatility of GDP in deviations from trend. Solid red line corresponds to the median volatility across countries. Grey area corresponds to the interquartile range.

These results uncover two asymmetries about the importance of production linkages between the commodity sector and the rest of the economy. First, changes in the role of the commodity sector as a customer generate more significant differences in volatility than changes in its role as a supplier, even though those differences are not very large. Second, decreases in the degree of connections with the rest of the economy produce more significant differences relative to the baseline economy than increases.

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