Commodity Prices and Production Networks in Small Open Economies

A. Silva P. Caraiani J. Miranda-Pinto J. Olaya

U. of Maryland Romanian Academy IMF and UQ Dpt of Industry, Australia

Workshop of the Australasian Macroeconomics Society
December 7, 2023

Disclaimer: the views expressed in this paper are those of the authors and do not represent the views of the International Monetary Fund.

Motivation

- Commodity price fluctuations have important effects on
  - Macroeconomic volatility (e.g., Kulish and Rees, 2017; Fernández, Schmitt-Grohé; and Uribe, 2020)
  - Sectoral/regional reallocation (e.g., Allcot and Keniston, 2018; Benguria, Saffie, Urzua, 2023)
- Commodity sectors are also central actors in the domestic production network of small open economies IO network
  - Production networks shape the amplification and propagation of sectoral/aggregate shocks (e.g., Carvalho et al., 2021; Baqaee and Fahri, 2019)

This paper

Provide theory and evidence of the importance of the domestic production network in propagating and amplifying commodity price fluctuations

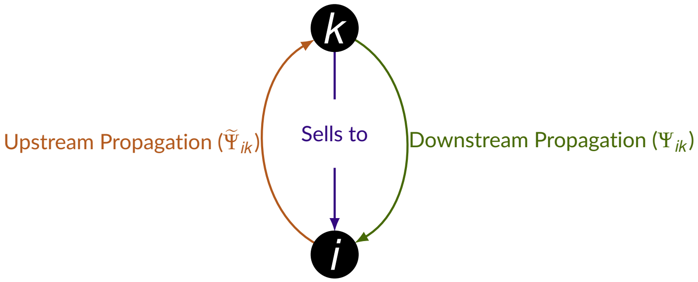
Preview of main results

- Theory: Commodity prices propagate and amplify as ”aggregate productivity shock” only in a world without networks. Domestic network breaks this isomorphism.
  - Commodity prices do not affect real GDP as measured in the data, only GDP in units of importable goods prices
- Theory: Commodity sector size is not a sufficient statistic. Network is necessary
  - Upstream propagation shaped by network, production elasticities, and export share
  - Downstream propagation driven mainly by network
- Quantitative: calibration suggests high production elasticities, driving muted downstream and amplified upstream propagation on quantities
  - Small open economies with strongly connected commodity sectors are more volatile (real wage/real GDP in units of importable goods)

Network centrality of commodity sectors

The case of commodity-exporting countries

Define network centrality

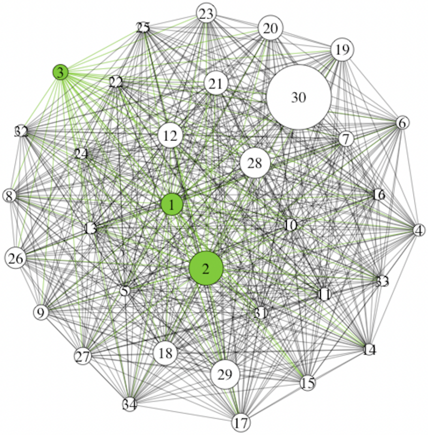


This figure shows the propagation of shocks along the production network where we remove all other nodes and focus on total propagation (both direct and indirect).

Downstream propagation from seller k to buyer i (Ψ_{ik}) and upstream propagation from buyer i to seller k ($\tilde{\Psi}_{ik}$).

Where supplier centrality is $\Psi_{ik} = (I - \Omega)^{-1}$ and $\Omega_{ji} = \frac{P_i M_{ji}}{P_j Q_j}$, and customer centrality is $\tilde{\Psi}_{ik} = (I - \tilde{\Omega})^{-1}$ and $\tilde{\Omega}_{ji} = \Omega_{ji} \frac{P_j Q_j}{P_i Q_i} = \frac{P_i M_{ji}}{P_i Q_i}$.

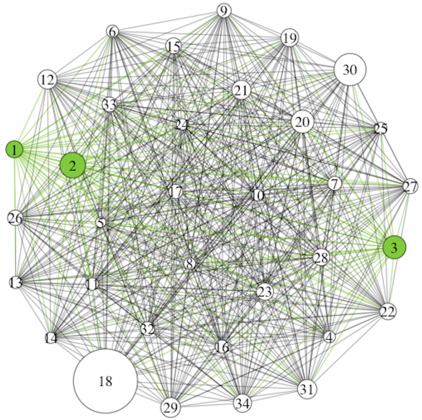
Commodity sectors are central suppliers in the domestic network



This figure shows the domestic production network of Australia (WIOD Input-Output data) in 1995 at the sector level (ISIC rev. 3). Each node (circle) is a different sector in the economy, and the size of the node represents sectoral network centrality. Sector 1 is agriculture, sector 2 is mining, and sector 2 is food products.

Back

Commodity sectors are central customers in the domestic network



This figure shows the domestic production network of Australia (WIOD Input-Output data) in 1995 at the sector level (ISIC rev. 3). Each node (circle) is a different sector in the economy, and the size of the node represents sectoral network centrality. Sector 1 is agriculture, sector 2 is mining, and sector 2 is food products

Commodity sectors are central in the domestic production network

Table: Ranking of Network Centrality of Commodity Sectors in 1995

	Customer Centrality			*Supplier Centrality*		
Country	Agric.	Mining	Food	Agric.	Mining	Food
Australia	10	11	3	13	6	17
Bulgaria	2	8	1	2	9	13
Brazil	14	25	2	7	14	10
Canada	6	18	3	4	10	15
Denmark	6	33	1	8	17	11
India	9	25	6	3	9	23
Lithuania	1	33	3	2	34	9
Mexico	10	18	1	7	1	15
Russia	3	6	2	5	3	14
Average	**7**	**20**	**2**	**6**	**11**	**4**

This table presents, for each country and commodity sector, the customer and supplier network centrality. Source: WIOD Input-Output database, 1995. Supplier centrality is obtained using the Leontief inverse elements of the IO network with a typical element $\Omega_{ji} = \frac{P_i M_{ji}}{P_j Q_j}$. Customer centrality is calculated using the Leontief inverse elements of a typical element $\tilde{\Omega}_{ji} = \Omega_{ji} \frac{P_j Q_j}{P_i Q_i} = \frac{P_i M_{ji}}{P_i Q_i}$

A production network model of a small open economy

A simple environment

- The household:
  - consumes $N + 1$ goods (N domestically produced goods and one imported good) in a static setting
  - and supplies labor inelastically

- There are $N - 1$ competitive *non-commodity/non-tradable* sectors
  - inputs of production: labor and domestic and imported intermediate inputs
  - output is sold domestically by households and firms
  - prices are endogenously determined within the economy

- There is one competitive commodity sector (sector N)
  - firms use labor, domestic intermediates, and imported intermediates inputs
  - commodity production is sold domestically (households and firms) and exported abroad
  - commodity price, in foreign currency, is determined in international markets (exogenous to the small open economy)

Notation

Input-output elements:

$$\boldsymbol{\Omega} = \{\Omega_{ij}\} = \frac{P_j M_{ij}}{P_i Q_i} \quad \text{for all } i, j = 1, ..., N.$$

we also define producer's i expenditure on labor and imported intermediates

$$a_{iL} = \frac{WL_i}{P_i Q_i}; \qquad \eta_i = \frac{P_M M_{iM}}{P_i Q_i},$$

We define $\boldsymbol{\Psi}$ as the *Leontieff-Inverse matrix*, dimension N, N, between domestic sectors, that satisfy

$$\boldsymbol{\Psi} = (\boldsymbol{I} - \boldsymbol{\Omega})^{-1} = \sum_{s=0}^{\infty} \boldsymbol{\Omega}^s \text{ with typical element } \{\Psi_{ij}\}.$$

Domestic Household

Taking good and factor prices, $(\boldsymbol{P}, W)$, the representative consumer solves the following program

$$\max_{\boldsymbol{C}} \left(\prod_{i=1}^{N} C_i^{b_i} \right) C_M^{b_M} \quad \text{s.t.} \quad \sum_{i=1}^{N} P_i C_i + P_M C_M \leq W\bar{L} = E,$$

where we use E as a short-cut for *total expenditure*. The solution to this program delivers consumption schedules that are a function of prices i.e. $\boldsymbol{C} = \boldsymbol{C}(\boldsymbol{P}, P_M, W)$.

Sectoral technology

Gross output in sector i, Q_i, is produced according to

$$Q_i = Z_i \left(a_i^{\frac{1}{\sigma_i}} L_i^{\frac{\sigma_i - 1}{\sigma_i}} + (1 - a_i)^{\frac{1}{\sigma_i}} M_i^{\frac{\sigma_i - 1}{\sigma_i}} \right)^{\frac{\sigma_i}{\sigma_i - 1}},$$

where Z_i is a producer-specific , L_i is labor demand, M_i is an intermediate input bundle, and σ_i is the elasticity of substitution between labor and the intermediate input bundle.

The intermediate input bundle, M_i, is, in turn,

$$M_i = \left(\omega_i^{\frac{1}{\varepsilon_i}} (M_i^D)^{\frac{\varepsilon_i - 1}{\varepsilon_i}} + (1 - \omega_i)^{\frac{1}{\varepsilon_i}} (M_i^M)^{\frac{\varepsilon_i - 1}{\varepsilon_i}} \right)^{\frac{\varepsilon_i}{\varepsilon_i - 1}},$$

$$M_i^D = \left(\sum_{j=1}^{N} (\omega_{ij}^D)^{\frac{1}{\varepsilon_i^D}} M_{ij}^{\frac{\varepsilon_i^D - 1}{\varepsilon_i^D}} \right)^{\frac{\varepsilon_i^D}{\varepsilon_i^D - 1}},$$

where ε_i is the elasticity of substitution between domestic and imported intermediate goods and ε_i^D is the elasticity of substitution across domestic intermediate inputs.

Foreign Household

Commodity good according to the CES structure

$$X_N = \omega_X^* \left(\frac{P_X^*}{P^*} \right)^{-\sigma^*} C^* = (P_X^*)^{-\sigma^*} D^*,$$

where $D^* = \omega_X^* C^* (P^*)^{-\sigma^*}$ is an export-demand shifter. In what follows we set $P^* = 1$ without loss of generality.

The commodity good price in foreign currency is a function of the export-demand shifter D^* as

$$P_X^* = (D^*)^{\phi}.$$

Therefore, export demand can be written as

$$X_N = (D^*)^{1-\phi\sigma}.$$

Commodity sector price and the terms of trade

- Since the law of one price holds for both the commodity price P_N and the imported good price P_M, then

$$P_N = P_N^* \mathcal{E}; \quad P_M = P_M^* \mathcal{E},$$

  in which $\mathcal{E}$ is the nominal exchange rate.

- As we are interested in the relative price of the commodity good with respect to the import price, the terms of trade are exogenous

$$\frac{P_N}{P_M} = \frac{P_N^* \mathcal{E}}{P_M^* \mathcal{E}} = \frac{P_N^*}{P_M^*}$$

Equilibrium

The following conditions characterize the equilibrium in our model

$$\forall i = 1, ..., N \quad : Q_i = C_i + X_i + \sum_{j=1}^{N} M_{ji}, \qquad \text{[output mkt clearing]}$$

$$P_N X_N = P_M \left(C_M + \sum_{i}^{N} P_M M_{iM} \right), \qquad \text{[trade balance]}$$

$$\bar{L} = \sum_{i=1}^{N} L_i, \qquad \text{[labor mkt clearing]}$$

Comparative statics

- We consider a perturbation around some initial equilibrium. To save on notation, we write $x = \mathrm{d}\log X = \log X - \log \bar{X}$, where $\bar{X}$ is an initial equilibrium level of X.

- We consider perturbations of sector-specific technology, foreign demand shifter, and labor supply ($\boldsymbol{z}$, d^*, l).

- We study how prices ($\boldsymbol{p}$) and quantities ($\boldsymbol{q}$) react to these changes.

- Note that absent technology and labor supply changes, real GDP, as measured in national accound, does not respond to commodity price fluctuations

Response of sectoral prices

Proposition

Consider a perturbation $(\boldsymbol{z}, p_N^*, l)$. Up to a first-order approximation, changes in good prices satisfy

$$p_i - p_M = \frac{\tilde{a}_{iL}}{\tilde{a}_{NL}} p_N^* - \sum_{k=1}^{N} \left(\Psi_{ik} - \frac{\tilde{a}_{iL}}{\tilde{a}_{NL}} \Psi_{Nk} \right) z_k, \qquad \text{for all } i = 1, 2, ..., N,$$

where $\tilde{a}_{iL} = \sum_{k=1}^{N} \Psi_{ik} a_{kL}$ are the network-adjusted labor share of producer i, Ψ_{ij} represents how important is sector j as a supplier, both directly and indirectly, to sector i.

- Productivity has unclear effects on p_i, while commodity prices always increase it
  - A decline in Z_k increases prices but also reduces the real wage
  - Commodity prices put pressure on real wages which then affects all sectors via production linkages

Production spillovers

Proposition

Up to a first-order approximation, changes in the output of sector i, q_i, satisfy

$$
\begin{aligned}
q_i = & \overbrace{\sum_{k=1}^{N} \overbrace{\left[\sum_{h=1}^{N} \theta_{kh}(p_h - p_M) + \theta_{kL}(w - p_M) \right]}^{\textit{Substitution towards/away producer } k} \Omega_k \Psi_{ki}}^{\textit{Upstream propagation to producer } i} \\
& + \underbrace{\underbrace{\left(\frac{(1 + \phi(1 - \chi))}{\phi} p_N^* - ((w - p_M) + \bar{l}) \right)}_{\textit{Change in export share of Commodity sector}} x_N \Psi_{Ni}}_{\textit{Upstream propagation to producer } i} - \underbrace{p_i}_{\textit{Downstream propagation}} .
\end{aligned}
$$

Under Cobb-Douglas technologies and no network, a change in p_N^* is isomorphic to a change in *weighted* productivities ΨZ

Macroeconomic effects

Proposition (Real wage and GDP)

Up to first order, the real wage, in units of the importable goods, is

$$w - p_M = \frac{1}{\tilde{a}_{NL}} \left(p_N^* + \sum_{k=1}^{N} \Psi_{Nk} z_k \right).$$

- If the commodity sector does no buy domestic intermediates, $\boldsymbol{\Omega_{N,i}} = 0 \; \forall \; i$ from 1 to N (only uses labor to produce), then a commodity price change is the same as an aggregate-common productivity change
- Once the commodity sector connects to other sectors, commodity prices and productivity can differ in important ways
    - The key is that now sectors are directly and indirectly connected to a sector whose price is not endogenously responding to higher-order network effects.

Quantitative exploration

Calibration

- Intermediate input and factor shares from WIOD IO tables 1995
- Production elasticities inferred from the empirical response of sectoral output Q_i to commodity price fluctuations
  - Data on output and prices data from the WIOD for the period 1995-2009(2011) (34 sectors)
  - Commodity prices data from UNComtrade and IMF PCPS data (44 different commodities, HS 1992-4 digits) from Fernández, González, and Rodríguez (2018)
  - The merger leaves us with 9 countries (Australia, Bulgaria, Brazil, Canada, Denmark, India, Lithuania, Mexico, and Russia) and three commodity sectors

Product-Sector

Backing out production elasticities

Given the downstream propagation to prices (cost-channel), production elasticities shape the upstream propagation to quantities in non-linear ways. Define the following empirical (mis)specification

$$y_{ict} = \delta_t + \alpha_{i,c} + \delta_{c,t} + \phi_1 \, Upstream_{ict} + \phi_2 \, Downstream_{ict} + \boldsymbol{\nu}' \boldsymbol{X}_{ict-1} + \epsilon_{ict},$$

where y_{ict} is non-commodity sector sector i's output or prices in country c at time t. δ_t, $\alpha_{i,c}$, and $\delta_{c,t}$ are a full set of time, country-sector, and country-time fixed effects. $\boldsymbol{X}_{ict-1}$ is a vector of lagged controls (including the dependent variable and network measures). ϵ_{ict} is the error term.

This regression also tests the relevance of the network propagation, empirically.

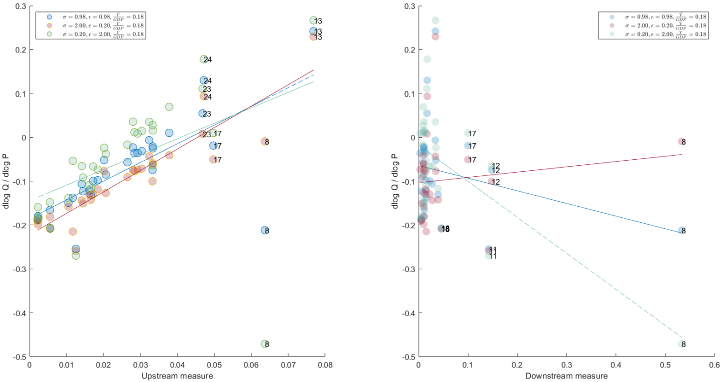
Measuring spillovers

Commodity prices propagate through the network

	Panel (a): Quantity			Panel (b): Prices		
	(1)	(2)	(3)	(4)	(5)	(6)
Upstream_{ict}	0.0067**	0.0080**	0.0072***	0.0004	0.0067	0.0019
	(0.0031)	(0.0031)	(0.0022)	(0.0067)	(0.0075)	(0.0024)
Upstream_{ict-1}	0.0027	0.0055	0.0058***	-0.0171	-0.0008	-0.0003
	(0.0035)	(0.0037)	(0.0020)	(0.0137)	(0.0070)	(0.0018)
Downstream_{ict}	0.0022	0.0018	-0.0007	0.0104*	0.0099**	0.0082***
	(0.0017)	(0.0016)	(0.0012)	(0.0054)	(0.0049)	(0.0026)
$\text{Downstream}_{ict-1}$	-0.0020	-0.0020	-0.0024**	0.0074	0.0090**	0.0115***
	(0.0015)	(0.0015)	(0.0011)	(0.0058)	(0.0039)	(0.0023)
Observations	3906	3906	3906	3906	3906	3906
Within R^2	0.924	0.777	0.766	0.959	0.737	0.694
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Country $\times$ Sector F.E.		Yes	Yes		Yes	Yes
Country $\times$ Year F.E.			Yes			Yes

A one standard deviation increase in commodity prices leads to a 0.72 percent increase in upstream non-commodity sector output. Results highlight the role of production flexibility and demand channels.

Model-implied elasticities from output responses



The higher the degree of substitutability between intermediates and labor-capital (σ) the stronger is the upstream propagation and the weaker is the downstream propagation.

Macroeconomic effects (back of the envelope)

- To study the response of prices and the real wage, up to a first order, we only need the IO tables. Model-implied volatility of real wage or GDP in units of the importable goods

$$\sqrt{Var(\widehat{w})} = (\tilde{a}_N^{-1})\sqrt{Var\left(\widehat{p}_N^*\right)}$$

- Take the mining sector: $\tilde{a}_N^{-1}$ in Mexico is 1.1 while in Brazil 1.05.

- From di Pace, Juvenal, Petrella (2023), ToT shocks in Mexico have a std of 7% while in Brazil 5%.
    - If Mexican mining had the network structure of Brazil, volatility would decline from 7.7% to 7.35%
    - If Brazilian mining had the network structure of Mexico, volatility would increase from 5.25% to 5.5%

Conclusion

- Commodity sectors are central in the production network of commodity exporters (suppliers and buyers)
- The propagation and amplification of commodity prices can significantly differ from that of productivity changes
  - This is especially true in the presence of networks and non-unitary elasticities in production

Top-5 commodities per country

Country			Top-5 commodities		
Australia	Coal (17.5%)	Aluminum (12.6%)	Crude Oil (12.6%)	Iron (7.6%)	Natural Gas (4.9%)
Brazil	Iron (16.5%)	Soybeans (12.5%)	Soybean Meal (9.3%)	Crude Oil (8.6%)	Aluminum (7.6%)
Bulgaria	Crude Oil (36.5%)	Copper (29.7%)	Zinc (6.1%)	Lead (3.3%)	Aluminum (2.6%)
Canada	Crude Oil (26.9%)	Natural Gas (25.3%)	Soft Sawn (13.1%)	Aluminum (7.8%)	Gold (3%)
Denmark	Crude Oil (34.4%)	Hides (6.1%)	Aluminum (3%)	Shrimp (2.6%)	Fish Meal (2.2%)
India	Crude Oil (24.8%)	Shrimp (11%)	Iron (8%)	Hides (7.3%)	Soybean Meal (5.6%)
Lithuania	Crude Oil (65%)	Soft Sawn (7.6%)	Hides (4.4%)	Hard Sawn (3.6%)	Soft Log (2.2%)
Mexico	Crude Oil (82.5%)	Iron (3.3%)	Shrimp (2.3%)	Hides (1.9%)	Zinc (1.3%)

back

Measuring network spillovers

$$Upstream_{ict} = \sum_{k \in \mathcal{K}} \left(\tilde{\Psi}_{kic} - \mathbf{1}_{i=k} \right) \cdot \tilde{p}_{kct},$$

$$Downstream_{ict} = \sum_{k \in \mathcal{K}} \left(\Psi_{ikc} - \mathbf{1}_{i=k} \right) \cdot \tilde{p}_{kct}.$$

in which $\tilde{p}_{kct}$ is the log change of commodity sector k price in country c and time t, and Ψ_{kic} and $\tilde{\Psi}_{kic}$ are the upstream and downstream network links of sector i from/to the commodity sector k, respectively

Back

Functional form: CES technologies

Assume the following CES production technology

$$Q_i = Z_i \left(a_i^{\frac{1}{\sigma_i}} L_i^{\frac{\sigma_i - 1}{\sigma_i}} + (1 - a_i)^{\frac{1}{\sigma_i}} M_i^{\frac{\sigma_i - 1}{\sigma_i}} \right)^{\frac{\sigma_i}{\sigma_i - 1}},$$

in which the intermediate input bundle is

$$M_i = \left(\sum_{j=1}^{N} \omega_{ij}^{\frac{1}{\varepsilon_i}} M_{ij}^{\frac{\varepsilon_i - 1}{\varepsilon_i}} \right)^{\frac{\varepsilon_i}{\varepsilon_i - 1}}.$$

In this case, the IO substitution term becomes a complex function of production elasticities and IO linkages

$$\sum_{j=1}^{N+1} \frac{\lambda_j}{\lambda_i} \Phi_j(i, N+1) = \sum_{j=1}^{N+1} \frac{\lambda_j}{\lambda_i} \left(\sum_{h=1}^{N+1} \sum_{k=1}^{N+1} \Omega_{jk} \left[(\varepsilon_j - 1) \left(\Omega_{jh}^M - \delta_{kh} \right) - (\sigma_j - 1) \Omega_{jh}^M \Omega_{jL} \right] \Psi_{ki} \frac{\Psi_{h,N+1}}{\Psi_{N+1,N+1}} \right)$$