Endogenous production networks with bargaining

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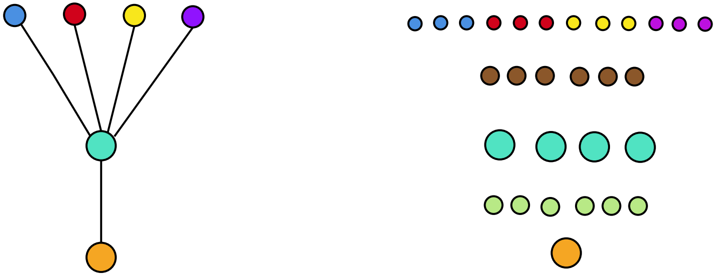
Motivation(1)



Motivation (2)

Firms will choose to buy the most cost-efficient production inputs that better match their technology at the lowest price. In the presence of market power, buyers might choose a different set of inputs than in competitive markets.

Main Research question

Does upstream and downstream market power inefficiently shape production networks?

$\Longrightarrow$ What are the aggregate effects of distorted network formation?

What this paper do (1)

Structural

(a) Builds an endogenous network formation model with bargaining.

(b) Develops a method to estimate production functions with factor augmenting productivity and spillovers.

Applied

(a) Computes firm-level bargaining weights.

(b) Estimates production functions with spillovers (recover firm-level TFP, markups, and markdowns)

(c) Describes how production inputs intensity changes in time (intensive and extensive margins), is this process innovation?

What this paper do (2)

Counterfactuals

(a) Production networks density, observed vs. production networks with efficient contracts; extensive and intensive margins.

(b) Aggregate TFP with efficient production network formation vs. observed network.

Policy application

(a) Industrial Policy might be focused on solving upstream inefficiencies.

Related Literature

Endogenous production networks

Oberfield (2018), Acemoglu (2020), Dhyne et al. (2023), Arkolakis (2023)

None with firm level bargaing weights

Bargaing

Collard-Wexler et al (2019), Ho and Lee (2019), Grossman et al (2023)

None with observed data bargaing weigts computation.

Production function estimation

OP, LP, ACF, DLW, de Roux (2021), Raval (2022), Iyoha (2022), Demirer (2022)

None with TFP spillovers and factor augmenting productivity.

Model: Households

A representative household utility is $u(C_1, ..., C_n)$ and provides L labor units at a price w.

Model: Producers

Firm i produces using labor and intermediate inputs ($X_j \in B_i$) where B_i is firm i providers set. The importance of each factor j is given by α, while σ is the constant elasticity of substitution between production inputs. Each input has an input-specific productivity (A_{ij}), while firm i has a Hicks neutral firm-specific productivity (A_i):

$$Q_i(L_i, X_{ij}) = A_i \left(\alpha_{L_i} L_i^{\frac{\sigma-1}{\sigma}} + \sum_{j \in B_i} \alpha_{ji} (A_{ij} X_{ji})^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

Q_i exhibits constant returns to scale (in L_i and X_{ij}), and is increasing and continuous in A_i, L_i and X_{ij},

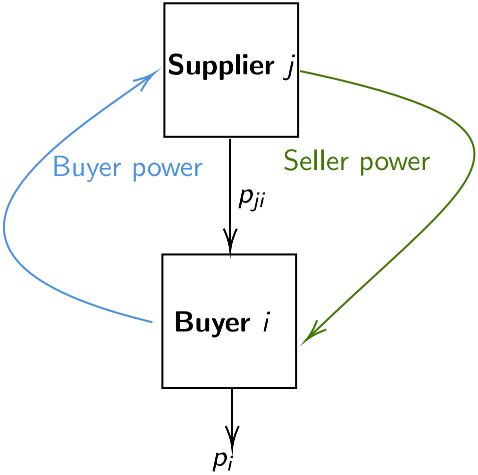
Model: Market Structure

Final consumers
Monopolistic competition framework to provide goods to households.

Intermediate transactions
Firms bargain to form contracts. Each contract $\mathbb{C}(i, j, m, p)$ consist on a seller (i), a buyer (j), a quantity traded (m) and a payment (p).

Firms
First (exogenously), decide a level of output to produce (Q_i). Then chooses which contracts to sign and finally makes its remaining production decisions to minimize costs given a fixed Q_i.

Model: Bargaining process (1)



Model: Bargaining process (2)

Surplus:

- Downstream profits (buyers profit) is $\pi_i^D(\mathbb{C})$.
- Upstream profits (seller profits) are $\pi_j^U(\mathbb{C})$.

The set of contracts with non-negative gains to trade for both the seller and the buyer is (the contract value of disagreeing is $\mathbb{C}_0$):

$$\mathbb{C}_{ij}^+ = \{\pi_i^D(\mathbb{C}_{ij}, \mathbb{C}_{-ij}) - \pi_i^D(\mathbb{C}_0, \mathbb{C}_{-ij}) \geq 0\}$$
$$\cap \{\pi_i^U(\mathbb{C}_{ij}, \mathbb{C}_{-ij}) - \pi_j^U(\mathbb{C}_0, \mathbb{C}_{-ij}) \geq 0\}$$

Model: Bargaining process (3) $J = 1$

Upstream firms (suppliers) receive price p_{ji}, while downstream firms (buyers) will receive price p_i from firms or final consumers. Downstream demand is D_i, while upstream demand is D_{ij}; hence the total surplus of a bilateral relationship can be expressed as:

$$\underset{\{X_{ji}\}}{\text{Max}} \underbrace{\left[D_i \cdot (p_i - mc^D_{i-j} - \min\{p_{ji}, w_{ji}\})\right]^{b_{ij}}}_{\text{buyer surplus}} \underbrace{\left[D_{ji} \cdot (p_{ji} - mc^U_j)\right]^{1-b_{ij}}}_{\text{seller surplus}}$$

Where X_{ji} is the amount traded between buyer i and seller j, mc^D_i, and mc^U_j are the marginal costs of the downstream and upstream firms respectively, and w_{ij} are firm i cost of build input from firm j with labor.

$b_{ij} \in [0, 1]$ represents the bargaining weight; if $b_{ij} = 1$, then the buyer has all the bargaining power, while if $b_{ij} = 0$, the seller has full bargaining power.

Model: Bargaining process (4): Coalition surplus

Define a coalition as a buyer and all its suppliers.

Buyer i total surplus

$\pi_i = \text{Sales}_i - \text{Wagebil}_i - r \cdot K_i - \sum_j p_{ji} X_{ij}$

Seller j surplus from selling to i

$\pi_{ji} = \text{Sales}_{ji} - \text{Wagebil}_{ji} - r \cdot K_{ji} - \sum_k p_{jk} X_{jki}$

Coalition surplus of buyer i

$S_i = \pi_i + \sum_{j \in B_i} \pi_{ji}$

Buyer i surplus share

$\nu_i = \frac{\pi_i}{S_i}$

Seller j surplus share from buyer i

$\nu_{ji} = \frac{\pi_{ji}}{S_i}$

Model: Links formation with $J = 1$ (1)

Decisions timing:

(a) Buyer i chooses its production level (sells to final consumers and other firms)

(b) Observes its bargaining weights to asses its buyer power.

(c) Buyers choose the optimal set of suppliers within their potential suppliers (form a link is costless).

Firms make a fixed markup for selling to final consumers, while their intermediate sales profits depend on their buyer's bargaining weights.

Model: Links formation with $J = 1$ (2)

CES production function:

$$Q_i(L_i, X_{ij}) = A_i \left[\alpha_{L_i} L_i^{\frac{\sigma-1}{\sigma}} + \alpha_{1i}(A_{1i}X_{1i})^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$$

Unit cost function:

$$c_i = \frac{1}{A_i}\left[\alpha_{L_i}^{\rho} w^{1-\sigma} + \alpha_{1i}^{\rho}\left(\frac{p_{1i}}{A_{1i}}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$$

Cost effectiveness, $\frac{p_{1i}}{A_{1i}}$, will govern the process of links formation.

Model: Links formation, buyer bargain power ($J = 1$)

Assuming surplus shares equal bargaing weights ($b_{1i} = \nu_i$ and $1 - b_{1i} = \nu_{1i}$), the price buyer i will pay to seller $j = 1$ can be expressed as:

$$p_{1i} = mc_1 + \nu_{1i} \frac{\pi_i}{X_{1i}}$$

- If the buyer has all the bargaing power ($b_{1i} = \nu_i = 1$); $\nu_{1i} = 0$; buyer i pays marginal cost to the seller.
- If the seller has all the bargaining power ($b_{1i} = \nu_i = 0$); $\nu_{1i} = 1$, the buyer will need to give all its surplus to the seller to buy the input.

Model: Links formation, final sells markups ($J = 1$)

Firm i markups to final consumers: $\mu_i = \frac{\theta_x}{s_x}$

$$s_{x1i} = \frac{p_{1i} X_{1i}}{P_i Q_i} \quad \text{and} \quad \theta_x = \left(\frac{p_{1i}}{A_i \cdot MC_i} \right)^{1-\sigma} \alpha_{1i}^{\sigma} A_{1i}^{\sigma-1}$$

Then:

$$\mu = \frac{\left(\frac{p_{1i}}{A_i \cdot MC_i} \right)^{1-\sigma} \alpha_{1i}^{\sigma} A_{1i}^{\sigma-1}}{\frac{p_{1i} X_{1i}}{P_i Q_i}}$$

$$\mu = p_{1i}^{-\sigma} \; \left(\frac{1}{A_i \cdot mc_i} \right)^{1-\sigma} \alpha_{1i}^{\sigma} A_{1i}^{\sigma-1} \; \frac{P_i Q_i}{X_{1i}}$$

Replacing the price expression:

$$\mu = (mc_1 + \nu_{1i} \frac{\pi_i}{X_{1i}})^{-\sigma} \; \left(\frac{1}{A_i \cdot mc_i} \right)^{1-\sigma} \alpha_1^{\sigma} \; \frac{P_i Q_i}{X_{1i}}$$

Model: Multiple equilibria ($J = 1$)

The production networks are assumed to be cyclic: a buyer can sell directly or indirectly to one or many of its suppliers. Thus, the marginal cost of a firm's supplier is potentially dependent on the marginal cost of the firm itself.

Two possible equilibria with one firm ($i = 1$) and one supplier ($j = 1$) in a cyclic network:

- If the supplier j has a high marginal cost, then firm i might decide to produce j input with labor, increasing is own marginal cost. Because the later firm i will have a high marginal cost, and thus firm j will not buy from i.
- If j has a low marginal cost, then i might buy from j resulting in i having a low marginal cost and thus being attractive to firm j as a supplier.

Production function: Productivity with spillovers

Different approach to include providers TFP on firms production function estimation: Talk to Hugo to choose which approach to use

Productivity:

$$A_{it} = A_{it-1} + \tilde{\Lambda}'_{it}\Theta_{ijt}A_{jt} + \nu_{it} \tag{1}$$

Where $\tilde{\Lambda}$ is the cost-based Domar weights vector, and Θ captures the importance of each provider j on firm i total intermediate inputs expenditure. Suppose that $E[\nu_{it}|I_{it}] = 0$, where I_{it} is the information set available to firm i at the beginning of period t.

Production function: Input-output structure

The cost-based Domar weights vector is composed of the interaction of each firm production network relevance (the cost-based Leontief Inverse, $\tilde{\Psi}_t = (I - \tilde{\Omega})^{-1}$) and the firm's importance on total intermediate inputs sales of the economy (b_t).

In the presence of distortions (e.g., markups), the cost-based Leontief inverse captures how distortions propagate through a production network. Specifically, it captures the forward propagation of costs; how upstream production network shocks affect downstream prices through costs.

Production function: Input-output structure

The cost-based input-output matrix ($\tilde{\Omega}$) of size NxN (N is the total number of firms in the economy) has at the ij^{th} element the elasticity of firm i marginal costs (MC) relative to the price of firm j. Using Sheppard's Lemma is possible to express each element of $\tilde{\Omega}$ as the expenditure of firm i on inputs from j as a share of i total costs:

$$\tilde{\Omega}_{ij} \equiv \frac{\partial \log MC_i}{\partial \log p_j} = \frac{p_j x_{ij}}{\sum_{k=1}^{K} p_k x_{ik}}$$

The cost-based Leontief inverse matrix ($\tilde{\Psi}$) captures both; the direct and indirect firm exposures through the production network of an economy. The cost-based Leontief has at its ij^{th} element a measure of the weighted sums of all paths (steps) of length k from firm i to firm j:

$$\tilde{\Psi} = (I - \tilde{\Omega})^{-1}$$

Production function: Input-output structure

Where I is the identity matrix of size N (the total amount of firms in the economy). b_i (of length N) is defined as the vector that contains each share of producer i good relative to total sales to other firms. b_i represents the relevance of firm i on total sales of intermediate inputs of the economy.

By multiplying the direct and indirect exposure of firms with relevance on total sales, the cost-based Domar Weights are built ($\tilde{\Lambda}_{it}$):

$$\tilde{\Lambda}_{it} = b'_{it}\tilde{\Psi}$$

The cost-based Domar weight weighs the firm's i provider's productivity.

Data Sources

1. Sales, materials, investment: F29 (2005-2021)

2. Wage bill, employment: DJ1887 (2005-2021)

3. Initial capital stock: F22 (2005-2021)
   - Capital stock using perpetual inventory methods combining capital stock with investment.

4. I-O matrices: Buying and selling books (forms 3327-3328) (2005-2018)
   - Firm-year level output and input flows.

5. Output and input prices: F2F electronic receipts (2014-2021)
   - Firm-year level output and input prices weighted by F2F transaction flows.

Data Cleaning

- Final sample does not include firms with a missing variable of sales, capital, wage bill, or materials.
- Winzorized labor, capital, and materials shares over sales at 1% of both distribution tails.
- Firms with negative value added (sales minus materials), less than two workers, or capital less than 10.000 CLP (USD 15) are excluded.

Around 120,000 firms a year in the final sample.

Using prices to recover quantities sold.

Challenge: Different units for the same product; units are not reported.

$\implies$ Build a firm-level weighted price index:

$$\ln(Q_{it}) \approx \ln(\underbrace{P_{it}Q_{it}}_{\text{data}}) - \ln(\underbrace{I_{it}}_{\text{data}})$$

Where:

- $I_{it} = \sum_{j}^{J} \alpha_{ijt} P_{ijt}$
- α_{ijt}: share of product j in firm i total revenue.

Homologous procedure for intermediate inputs.

Stats (1)

Table: number of sellers (providers) and buyers (clients)

	N sellers	N buyers
2018	96,414	123,154
2019	93,040	120,542
2020	70,525	95,739

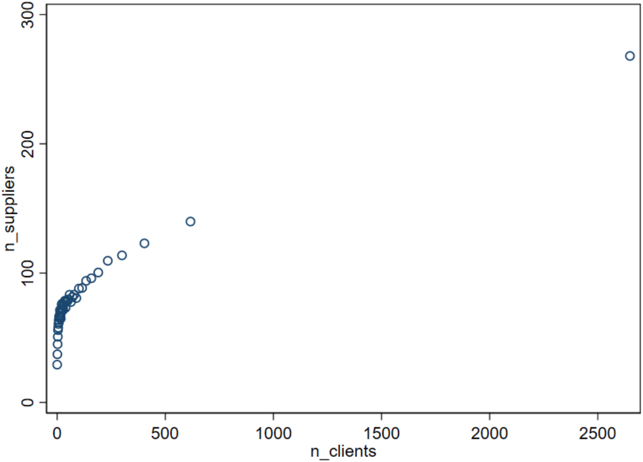
Stats (2)

	In-degree (N suppliers)	Out-degree (N clients)
Mean	59.5	76.06
Median	40	9
Sd	78	635
p1	2	1
p5	7	1
p10	11	1
p25	21	3
p75	71	35
p90	120	127
p95	169	268
p99	351	964

The distribution of outdegrees is much more unequal than indegrees, consistent with the properties of the U.S. input-output tables, as documented in Acemoglu et al. (2012).

Stats (3)

Figure: Scatter plot (100 bins) n suppliers vs. n clients by firm



1. Endogenous production network formation
2. Production function estimation method
3. Data
   - Chilean network stats
4. Estimation
   - Bargain weights estimation

Estimation (1)

Revenue from intermediate transactions R_{ij} and from final consumers R_j^f are direcyly observed in the data.

The total costs for seller j, C_j can be definds as:

$$C_j = \sum_{i \in B_j} c_{ij} x_{ij} + c_j^f y_j$$

While the RHS is not observed, the LHS is directly observed from the data.

π_{ij} is not observed; it needs to be estimated.

Estimation (2)

Buyer's i relevance on seller's j total transactions to other firms is defined as:

$$\alpha_{ij} = \frac{R_{ij}}{\sum_{i \in B_j} R_{ij} + R_j^f}$$

Hence:

$$\hat{\pi}_{ij} = \alpha_{ij}\pi_j$$

So that the estimator for the seller j surplus share from buyer i is:

$$\nu_{ij} = \frac{\tilde{\pi}_{ij}}{\pi_i + \sum \tilde{\pi}_{ij}}$$

Stats (1)

Table: Coalition surplus stats 2018 with R_j^f

	Buyer Surplus	Provider surplus
Mean	0.71	0.005
Median	0.87	0.0001
Sd	0.34	0.03
p1	0	0
p5	0	0
p10	0	0
p25	0.61	0.00001
p75	0.95	0.0009
p90	0.98	0.0057
p95	0.99	0.016
p99	0.99	0.948

Check: $0.005 \cdot 59.05 = 0.29$; $0.29 + 0.71 = 1$

Reg (1)

Table: Dependent variable: Log Seller surplus

	(1)	(2)	(3)	(4)	(5)	(6)
Log Buyer sales (CLP millions)	-	-	-	-	-0.7355	-1.2777
Log Seller sales (CLP millions)	0.1191	0.0717	0.0676	0.2548	0.2759	0.2999
Year FE (2018 omitted)						
2019	0.0175	0.037	0.0513	-0.1452	0.0065	0.039
2020	0.1036	0.14	0.1608	0.0803	0.1015	0.1543
Industry Buyer FE	No	No	Yes	Yes	Yes	
Industry Seller FE	No	Yes	Yes	No	No	No
Buyer FE	No	No	No	No	No	Yes
Seller FE	No	No	No	Yes	Yes	Yes
R2	0.0128	0.0503	0.0582	0.2912	0.5134	0.5997
N obs	16,820,549	16,820,549	16,820,549	16,811,965	16,811,965	16,811,422