# Network Bottlenecks and Market Power*

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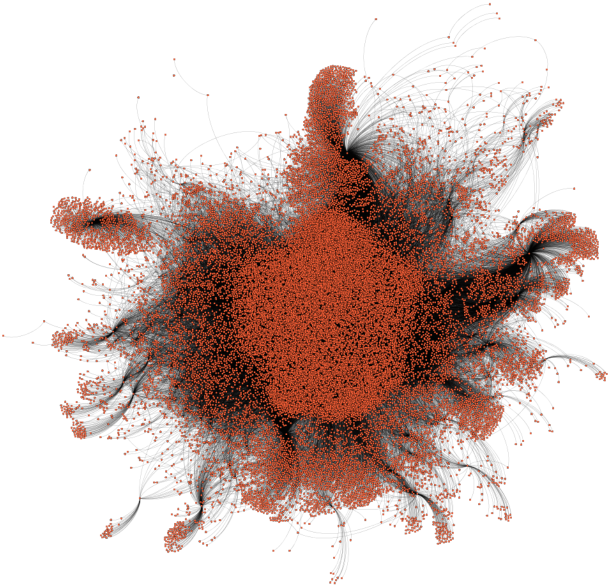
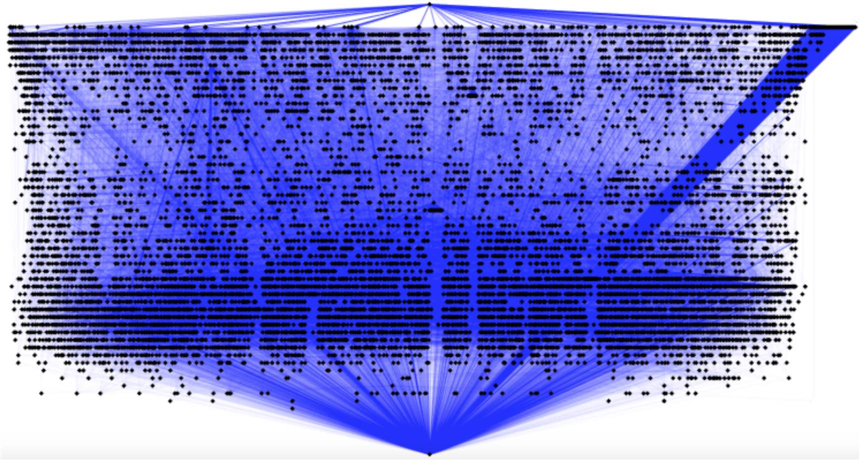
Workshop on Market Power in Supply Chains, February 2025

*The views expressed in the paper are solely those of the authors and do not necessarily represent the views of the IMF, its Executive Board, or its Management.

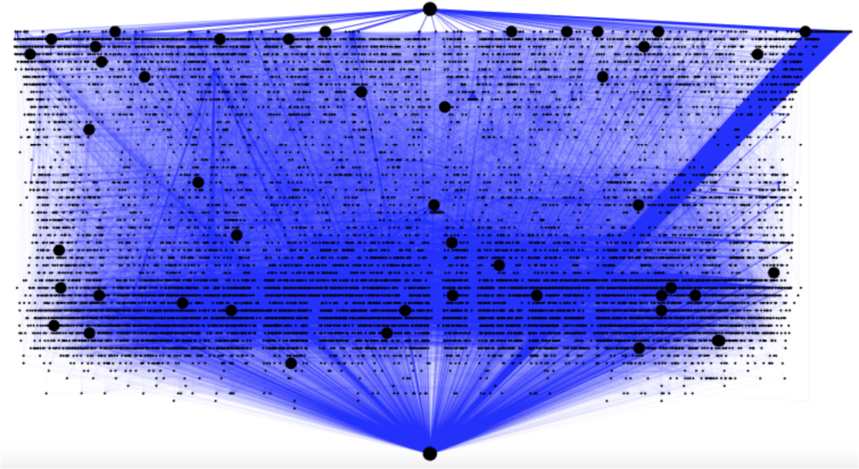
# Business to business transactions–Uganda



# Same data: Organized as a flow problem



# Bottlenecks



# Plan for Today

- Model
  - Environment
  - How we define bottleneck firms
  - Some theory to help justify this choice
- Scalable algorithm to find bottleneck firms
- Proof of concept based on Uganda VAT tax data

# Setting

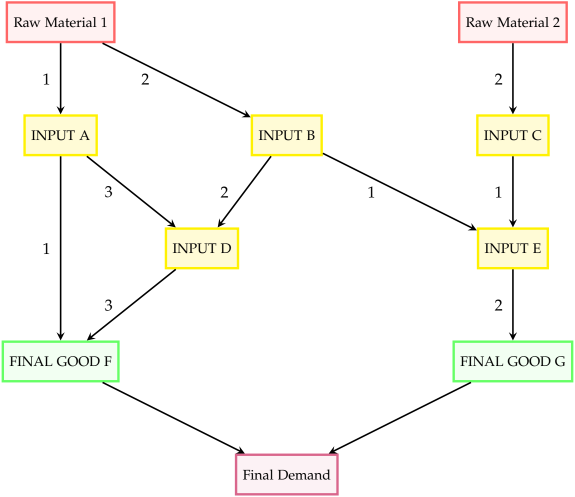
- Raw materials $R$, intermediate goods $I$, final goods $F$

- Intermediate goods and final goods produced by combining input goods

- Input proportions are fixed
  - Beer: fixed proportions of water, malt barley, yeast and hops
  - $A_{\theta\theta'}$ represents the amount of good $\theta'$ that is required to make one unit of good $\theta$
  - Using $x_{\theta'}$ units of input $\theta'$, the amount of good $\theta$ that can be made is $\min_{\theta' : A_{\theta\theta'} > 0} x_{\theta'} / A_{\theta\theta'}$
  - i.e., production is Leontief

- We assume input interdependencies can be represented by a directed acyclic graph (DAG)
  - Raw materials are ultimately transformed into final goods
  - e.g., hops get used to produce beer
  - DAG restriction: beer is not used to make hops

# Simple Example—Technology DAG



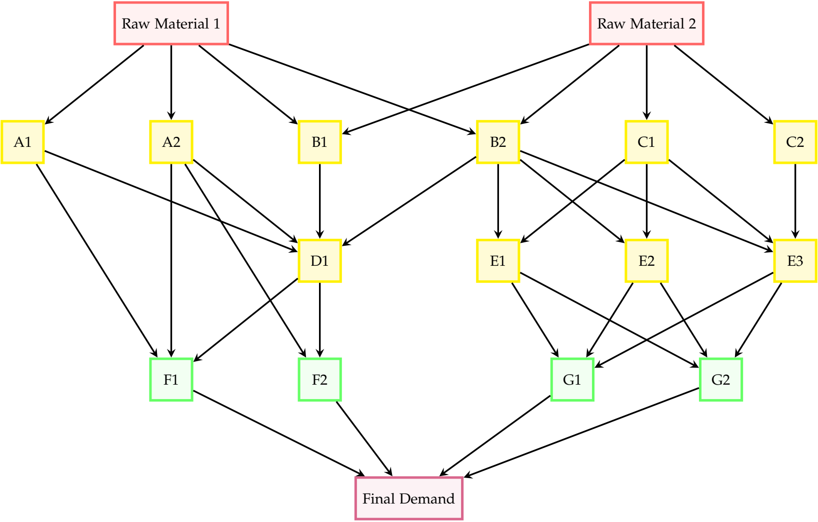
# Supply Network

- Set of firms $N$, with each producing a single good
  - Constant marginal cost of producing good $\theta$ common across producers
- Firms are embedded in a weighted supply network $G := \{N, (w_{ij})_{ij}\}$
  - Can only source inputs from firms they are connected to
  - Each firm has a capacity limit on its output of $\phi_i$
  - Each link has a capacity limit given by $w_{ij}$

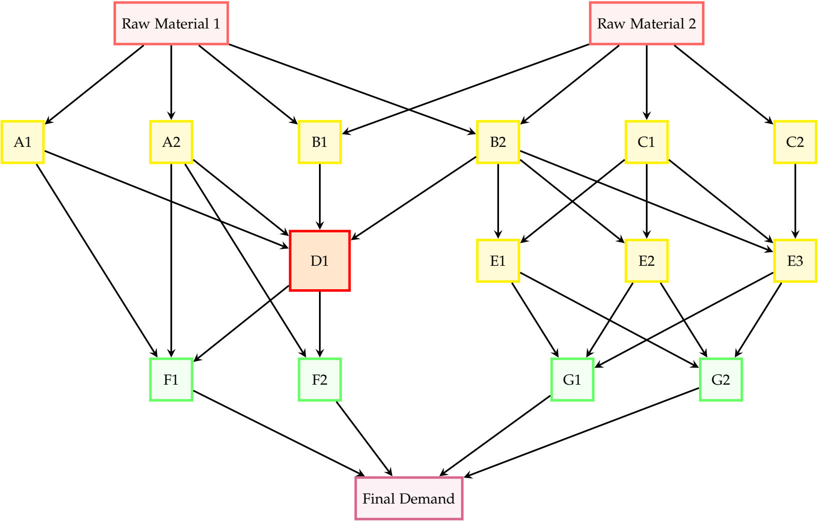
### Definition

A firm $i$ is a bottleneck if and only if the supply of final goods cannot meet consumer demand with firm $i$ removed from the network.

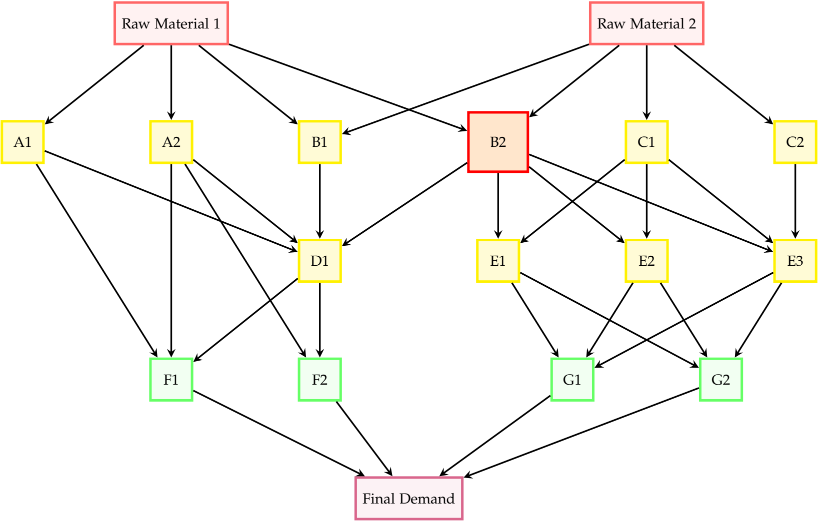
# Simple Example—Supply-Chain DAG



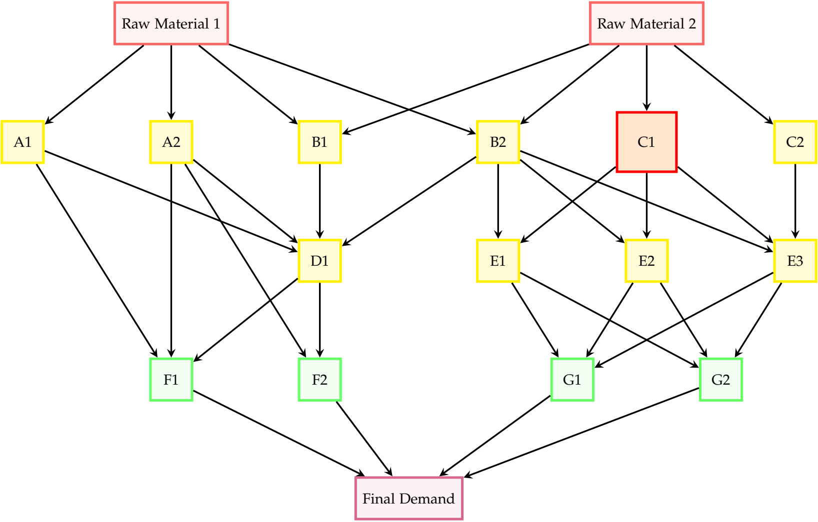
# Simple Example—Bottleneck firms



# Bottleneck Firms



# Bottleneck Firms



# Flow Problem

- Augment the supply network by adding
  - a source node $s$ connected to the raw materials
  - a consumer demand node for each product connected to all producers of that product with capacity equal to demand
  - a sink node $t$ connected to all consumer demand nodes
- let $f_{ki}$ denote the flow from $k$ to $i$ with $f_k = \sum_i f_{ki}$ denoting the total flow out of $k$.
- Technology (Leontief) constraints:

$$f_i \leq \frac{1}{A_{\hat{\theta}\theta}} \sum_{k \in Z(\theta)} f_{ki}, \quad \text{for all } \theta \text{ required to produce good } i.$$

- capacity constraints:

$$\begin{aligned} f_i &\leq \phi_i \\ f_{ij} &\leq w_{ij} \end{aligned}$$

- non-negativity constraints

$$f_{ij} \geq 0$$

# Flow Problem

$$\max_{(f_{ij})_{ij}} \quad \underbrace{\sum_k f_{kt}}_{\text{flow into the sink}} \qquad \text{subject to}$$

- technology constraints (conservation of flow)
- node capacity constraints
- edge capacity constraints
- non-negativity constraints

A firm is a bottleneck if and only if it makes a positive contribution to the maximum flow (i.e., the maximum flow with it removed is lower).

# Theory: Bottleneck firms and market power

- The network structure is common knowledge
- Timing:
  (i) All firms simultaneously set prices
  (ii) Given the prices of final goods, a representative consumer with wealth $\omega$ chooses a consumption bundle.
  (iii) Markets (attempt to) clear and payoffs are realized
- Given prices $\mathbf{p}$, consumer problem induces demands $D^c_\theta(p)$ for final goods.
- Step (iii) maps prices into pairwise demands and supplies throughout the economy, and hence payoffs.

Market clearing formalization

# Solution Concept

**Definition**

An equilibrium is prices, demand and supplies $(\mathbf{p}, D, S)$ such that

(i) Firms choosing prices $\mathbf{p}$ is a Nash equilibrium of the pricing game

(ii) Prices, demand and supplies $(\mathbf{p}, D, S)$ clear the market

**Definition**

An economy is <u>competitive</u> if there is an equilibrium in which all goods are priced at marginal cost

Planner's problem

# Results

### Proposition

An economy is competitive if and only if no firm is a bottleneck.

Intuition

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Intuition

### Corollary

Distortions propagate: The set of firms that price above marginal cost in an equilibrium is always a (weak) superset of the bottleneck firms. But removing market power from just the bottleneck firms restores competitiveness.

# Plan for Today

- Model
- Scalable algorithm to find bottleneck firms
  - Identifying bottleneck firms with ideal data
  - Identifying bottleneck firms in practice
- Proof of concept based on Uganda VAT tax data

Skip to conclusions

# Identifying Bottlenecks (with ideal data)

- Assume:
  - You observe technology DAG and supply chain and edge/node capacities
  - You observe final demand, **D**
  - Economy is in equilibrium for some price vector **p**

- Then take following algorithm:
  - Use Max-Flow Ford-Fulkerson algorithm to:
  - (i) Calculate maximum flow of goods, $f(G)$, for the original network
  - (ii) for each firm $i$, find maximum flow in the network without firm $i$, $f(G-i)$

- Recall: if prices **p** are an equilibrium, a firm $i$ is a bottleneck if and only if supply cannot meet final demand at these prices with $i$ removed from the network
  - bottleneck if $f(G-i) < f(G) \iff f(G-i) < D$

# Identifying Bottlenecks (in practice)

- In practice, we have:
  - Universe of firm-to-firm recorded transactions and final sales
- But:
  - Supply chain is not a DAG in general
  - Don't always know who supplies what
  - Don't know edge/node capacities

# Identifying Bottlenecks (in practice)

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  - Universe of firm-to-firm recorded transactions and final sales
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  - Don't always know who supplies what
    - Solution: Find alternative suppliers of the same input using a hierarchical clustering algorithm
  - Don't know edge/node capacities
    - Solution: Estimate using the maximum flow in recent times

# Plan for Today

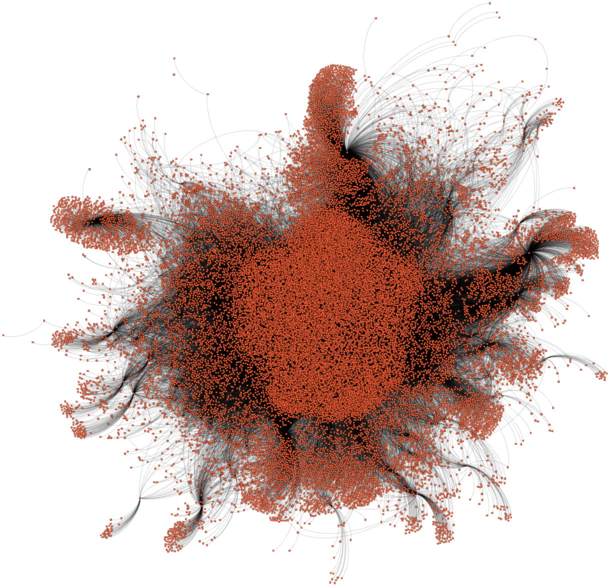
- Model
- Scalable algorithm to find bottleneck firms
- Proof of concept
  - Deploy algorithm on supply chain transaction data from Uganda VAT tax declarations
  - Characterization of bottlenecks
  - Consequences of bottlenecks

Skip to conclusions

# Data

- Uganda Tax Administration Data - 2010-2015
  - VAT transaction level data
  - Transaction level customs data
  - Corporate Income Tax data
  - Business Registration data
  - Deflate all transactions using aggregate CPI

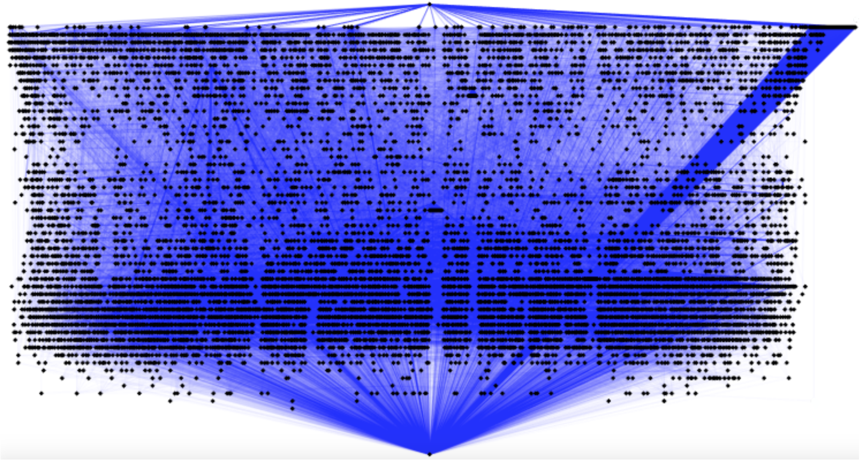
- Summary stats
  - $\approx$ 12m transactions
  - $\approx$ 40K firms
  - $\approx$ 90K edges



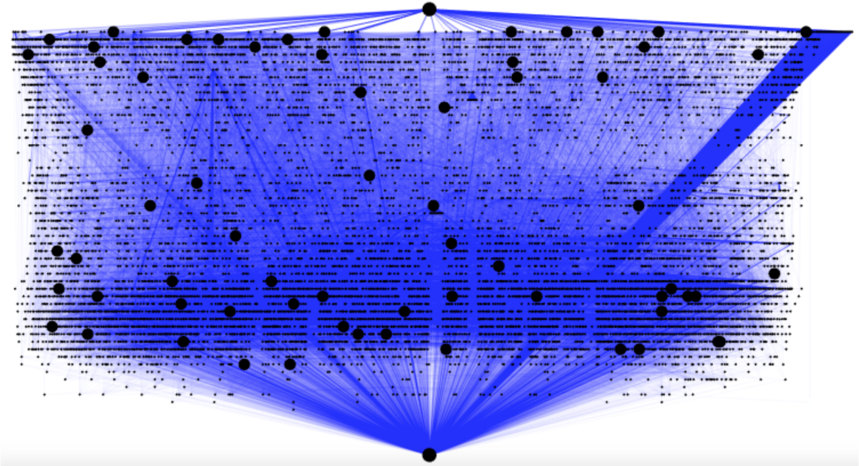
# Deploy Algorithm

- Input: All firm-to-firm transactions (from VAT data) plus total sales, every semester, 2010:2015
- Step 1: Obtain DAG
  - 14.7% of links dropped, 3.7% of total value More on DAG
- Step 2: Identify Leontieff production technology HAC Detail
- Step 3: Assign edge capacities: maximum observed over all semesters.
- Step 4: Connect firms to sink and source
- Step 5: Run Max-Flow Ford-Fulkerson algorithm for full DAG and then run it 37000 times more (one for each firm removed)
- Output: Set of bottleneck firms

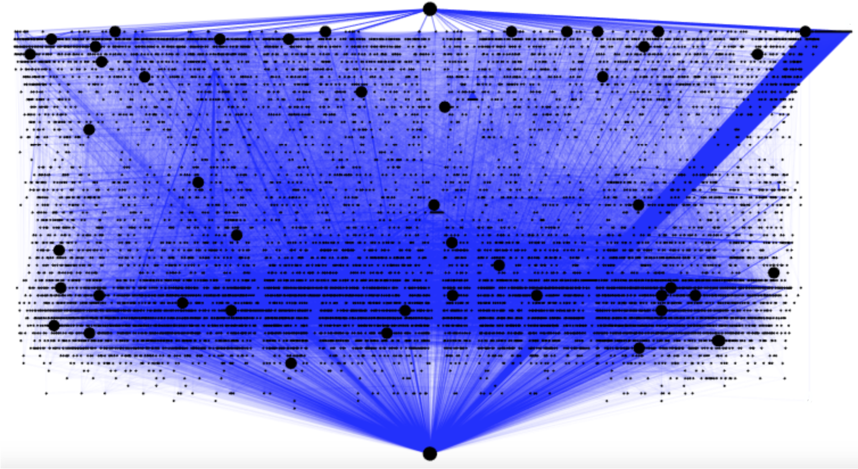
# Full Network DAG



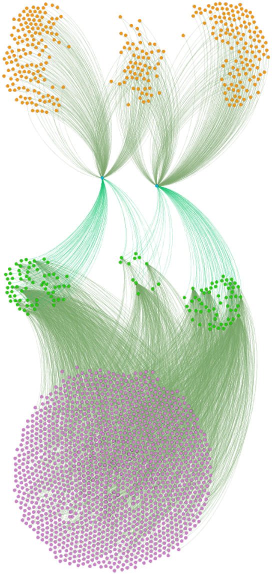
# Full Network DAG - All bottlenecks



# Full Network DAG - Bottlenecks in one period



# Example: Market Power in a Particular Supply Chain



# Bottlenecks in Ugandan Supply Chains

- We identify an average of 50 critical firms per semester (out of 37K)
- Bottlenecks status is persistent
  - Prob(Firm $i$ bottleneck at $t \mid i$ bottleneck at $(t-1)$) = 0.77
- Sectors with greatest number of bottleneck firms:
  - Agriculture, Food and Drinks Supply Chain
    - Primary Production
    - Manufacturing Processing
    - Wholesalers
  - Natural Monopolies
    - Energy Generation and Distribution
  - Service Sector Inputs

# Findings

- Bottleneck firms are (statistically significantly)
  - Larger (in terms of both revenues and wages)
  - Older
  - More profitable (overall and per unit sold)
  - More central
  - In industries with fewer entrants
  - In industries with a higher HHI

Bar charts with confidence intervals

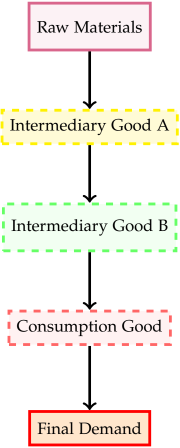
- Some evidence supports bottleneck status being a source of higher profits, revenues and profit margins:
  - Use exogenous variation in demand for exports caused by the outbreak of war in neighboring Sudan.
  - Reduced export demand increases supply within Uganda and stops some non-exporting firms from being bottlenecks.
  - This change in bottleneck status is associated with lower profits, lower revenues and lower profit margins.

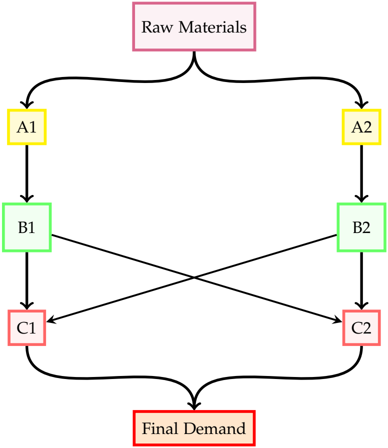
IV

# Conclusion

- Tractable theory of market power bottlenecks in production networks
- Application at scale: detect bottlenecks using data on all transactions in Uganda
- Theoretical and empirical evidence that market power has non-local consequences outside of immediate market
- A diagnostic tool to identify potential sources of market power distortions that may warrant further scrutiny
- Some interesting implications:
  - Bottleneck firms are the source of market power, while firms with high price-cost margins are the symptom.
  - Mergers with vertically related non-suppliers more likely to generate market power—control more of the flow.

# Market clearing: Example

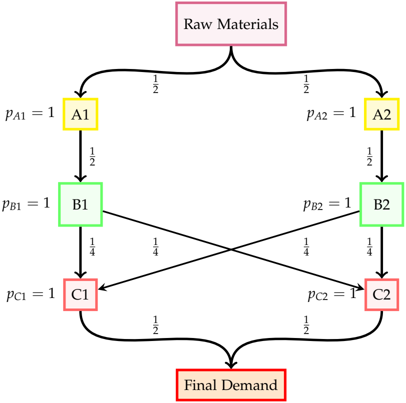


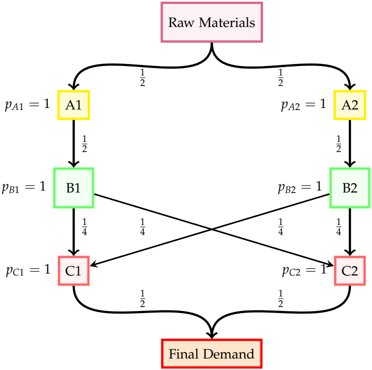
# Example continued

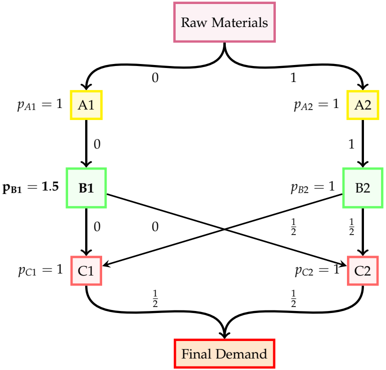
- Each producer has capacity 1
- Cost of extracting one unit of the raw material be 1
- No other production costs
- Suppose all firms set prices equal to 1
- Suppose $D_{cC}(1) = 1$—the representative consumer has demand 1 when the price of good $C$ is 1.
- Does any firm have a profitable deviation?

# Market clearing

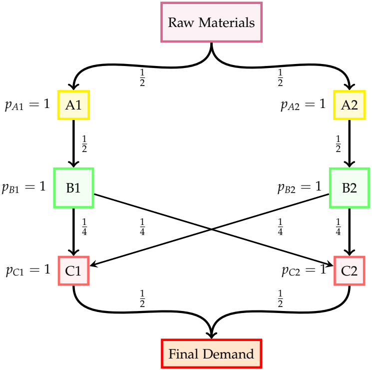


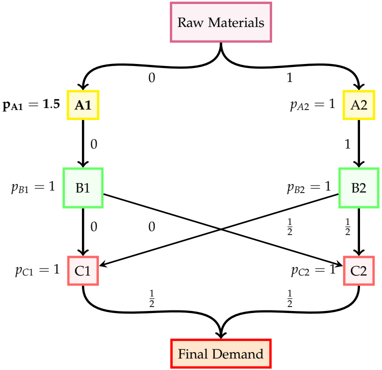
# A deviation by $B1$



# A deviation by $B2$



# Market Clearing Definition

### Definition

Given prices $\mathbf{p}$, demands $D$ and supplies $S$ clear the market if

(i) demand for firm $i$'s output induces $i$'s input demand
- $\sum_{i \in Z(\theta)} D_{ci} = D_{c\theta}(p)$
- if input $\theta'$ is required by firm $i$, then $\sum_j D_{ji} = \frac{\sum_{k \in Z(\theta')} D_{ik}}{A_{\theta\theta'}}$.

(ii) network supply constraints are satisfied
- $S_{ij} \leq w_{ij}$
- $\sum_i S_{ij} \leq \phi_j$

(iii) pairwise demands are satisfied
- $S_{ij} = D_{ji}$ .

(iv) no firm can source any input cheaper via a supply relationship that is not supply-constrained

(v) indifference about whom to buy from is resolved in favor of lower total transacted cost suppliers for all $i \in N \cup \{c\}$

# Supply constrained supply relationships

Consider a supply profile $S = S_{ij}$ for all $ij$.

We say firm $j$'s supply to $i$ is supply-constrained if either

(i) $w_{ji} = S_{ji}$; or

(ii) $\phi_j = \sum_k S_{jk}$; or

(iii) there exists an input type $\theta$ used by $j$ such that $k$'s supply to $j$ is supply-constrained for all suppliers $k \in Z(\theta)$.

Result: There is a unique such assignment of firms to being supply constrained or not.

# Total transaction costs

Given supplies $S = (S_{ij})_{ij}$ and demands $D = (D_{ij})_{ij}$, $i$'s production costs are

$$\kappa_i + \sum_j p_j \min\{S_{ji}, D_{ij}\}.$$

We define the total transacted cost associated with $i$'s output by

$$\Psi_i := \kappa_i + \frac{\sum_j (p_j + \Psi_j) \min\{S_{ji}, D_{ij}\}}{\sum_k S_{ik}},$$

setting $\Psi_i = 0$ for raw materials

Result: $\Psi_i$ is well defined and unique for all $i$

# When markets can't clear

Need to pin down what happens following pricing deviations that prevent the market from clearing

Given prices $\mathbf{p}$, pairwise demands $D$ and supplies $S$ are selected to:

1. Clear the market (satisfy market clearing conditions (i)-(v))
2. Otherwise, to meet conditions (i)-(iii)
3. Otherwise, to maximize final consumer demands such that conditions (i)-(iii) are met

A mapping from prices to pairwise demands $D$ and supplies $S$ is feasible if given prices $p$, pairwise demand and supplies are selected in a way consistent with the above criteria

Often there will be many feasible demands and supplies

Back

# Intuition

(i) No bottleneck firm implies economy is competitive

- Must be possible to satisfy demands given marginal cost pricing
- Any maximum flow provides a means of doing this. Use this to construct demands and supplies $(D, S)$
- Need to show that marginal cost pricing with $(D, S)$ is an equilibrium
- Given these prices market clears—just need to check no profitable deviation by a firm $i$
- As $i$ is not a bottleneck, there exists a maximum flow with no flow through $i$
- The demands and supplies associated with such a flow clear the market
- After deviation $i$ markets cannot clear and give $i$ positive demand (mk clearing conditions (iv) and (v))
- Thus $i$ gets zero demand and the deviation is unprofitable

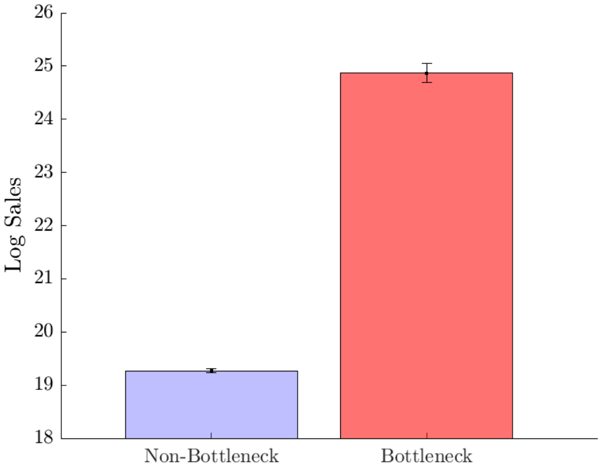
# Intuition

(ii) No bottleneck firm implies no competitive economy

- Towards a contradiction, suppose marginal cost pricing in equilibrium and $i$ is a bottleneck
- As $i$ is a bottleneck, there does not exist a maximum flow with no flow through $i$
- Were $i$ to increase its price, market clearing still selects a maximum flow
- Hence $i$ would continue to have positive demand and the deviation would be profitable

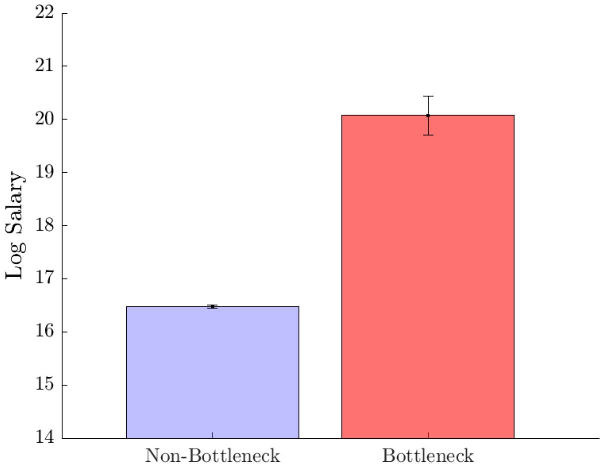
Back

# Sales



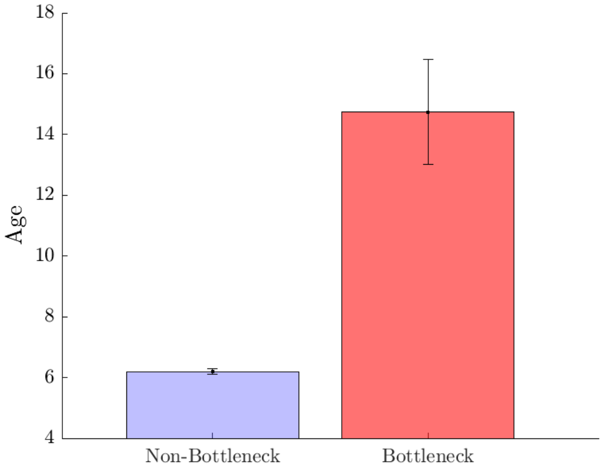

Mean and 95% confidence interval of log firm sales for critical bottlenecks and non-bottlenecks.

# Wage Bill



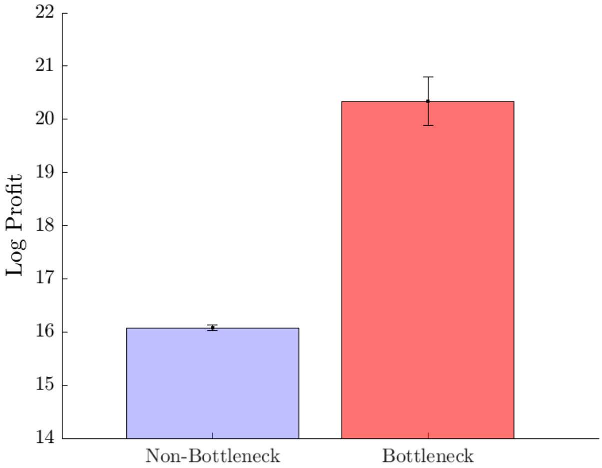

Mean and 95% confidence interval of log firm salaries for critical bottlenecks and non-bottlenecks.

# Age



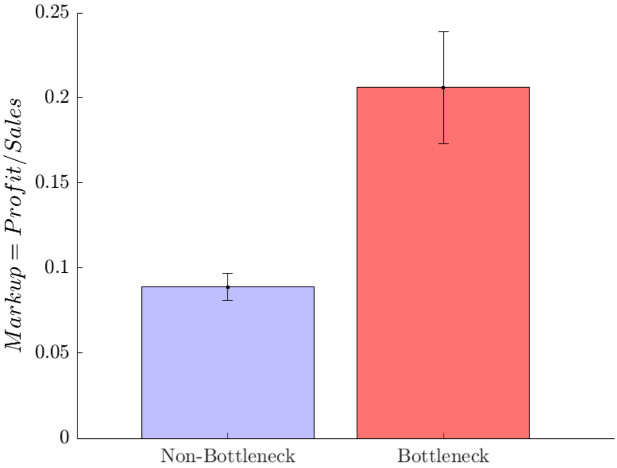

Mean and 95% confidence interval of number of years since the firm registered for a Tax Identification Number for critical bottlenecks and non-bottlenecks.

# Profit



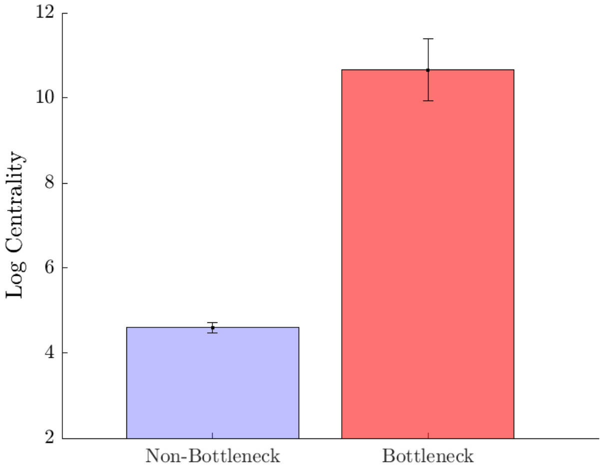

Mean and 95% confidence interval of log firm profits for critical bottlenecks and non-bottlenecks.

# Price-Cost Margin



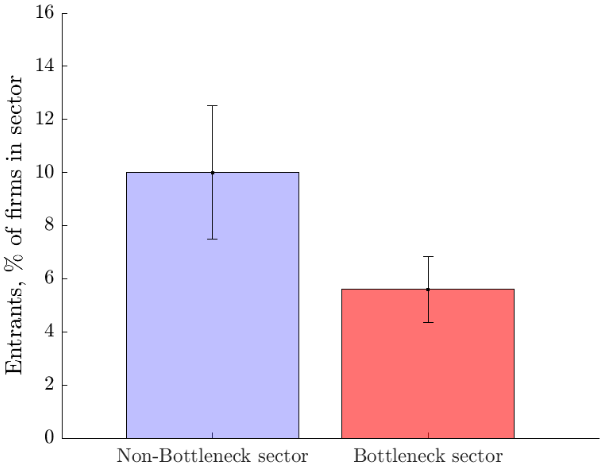

Mean and 95% confidence interval of firm Price Cost Margin: (Sales - Cost)/(Cost) for critical bottlenecks and non-bottlenecks.

# Betweenness Centrality



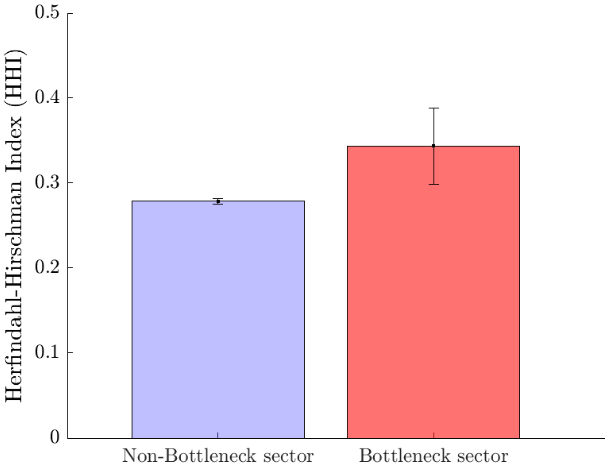

Mean and 95% confidence interval of log betweenness centrality for critical bottlenecks and non-bottlenecks.

# Entrants




Mean and 95% confidence interval of the percentage of entrants in an ISIC 4-digit sector since 2014 for sectors containing a critical bottleneck firm and sectors not containing a critical bottleneck firm.

# HHI




Mean and 95% confidence interval of log Herfindahl-Hirschman Index calculated using ISIC 4 digit sectors for critical bottlenecks and non-bottlenecks.

# Bottleneck Consequences

- Identify if bottleneck status over time influences firm-level variables
- Run within-firm spec

$$Y_{it} = \beta_1 Bottleneck_{it} + \delta_t + \alpha_i + u_{it} \quad (1)$$

where $Y_{it}$ is a vector of outcome variables for firm $i$ at time $t$, *Bottleneck* indicates firm is a bottleneck in period $t$

# Bottleneck Consequences

Bottleneck consequences

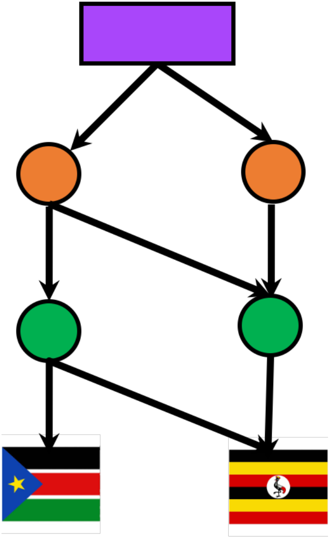
| | (1) Sales | (2) Profit | (3) Profit/Sales |
|---|---|---|---|
| Bottleneck | 0.112** | 0.460** | 0.0314** |
| | (0.0554) | (0.215) | (0.0123) |
| Observations | 68040 | 68040 | 68040 |

With Firm Year FE; Clustered standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

# Bottleneck Consequences - Instrument for Bottleneck

- Instrument for Bottleneck status using South Sudan war as a demand shock (Rauschendorfer and Shepherd, 2020) Violence
- $Impacted_{it}$: a bottleneck before 2014, does not export to South Sudan, but where a firm in the same sector does export to South Sudan

# Bottleneck Consequences - Instrument Example



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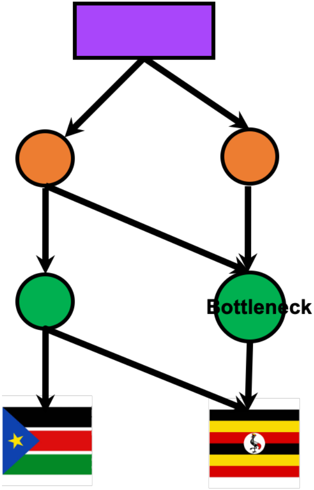

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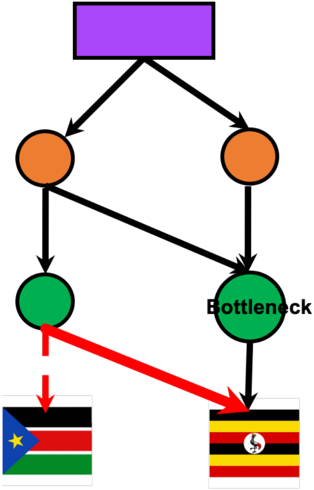

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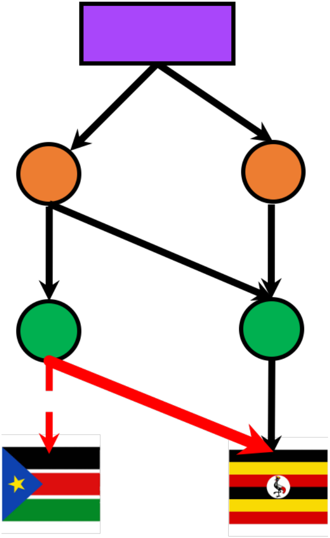

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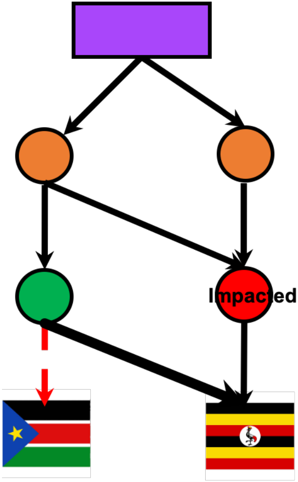

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- $Impacted_{it}$: a bottleneck before 2014, does not export to South Sudan, but where a firm in the same sector does export to South Sudan
- First stage

$$Bottleneck_{it} = \beta Impacted_{it} + \delta_t + \alpha_i + u_{ict} \tag{3}$$

- $H_0 : \beta < 0$

# Bottleneck Consequences

Bottleneck (Instrumented) consequences

| | (1) Sales | (2) Profit | (3) Profit/Sales |
|---|---|---|---|
| Bottleneck (Instrumented) | 0.339*** | 0.448*** | 0.0952*** |
| | (0.124) | (0.150) | (0.0325) |
| Observations | 32478 | 32478 | 32478 |

With Firm Year FE; Clustered standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Back

# Bottleneck Consequences

IV first stage

| | (1) |
|---|---|
| | Bottleneck |
| Impacted | -0.499*** |
| | (0.102) |
| Firm FE | ✓ |
| Period FE | ✓ |
| Observations | 14022 |

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

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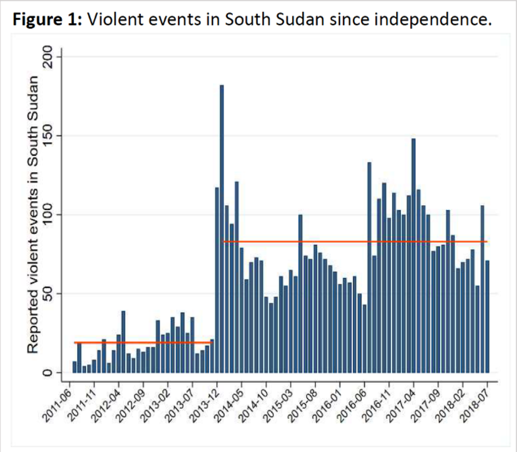
# South Sudan Violence




Source: Rauschendorfer and Shepherd, 2020

Back

# Propagation of Distortions

Propogation of Distortions

| | (1) log sales | (2) log profit | (3) price-cost margin |
|---|---|---|---|
| No bottleneck upstream | 1.492*** | 1.284*** | 0.0704 |
| | (0.0886) | (0.0779) | (0.0590) |
| No bottleneck downstream | 0.215*** | 0.180*** | 0.0187 |
| | (0.0376) | (0.0341) | (0.0211) |
| No bottleneck in sector | -0.0987*** | -0.0646*** | -0.00471 |
| | (0.0258) | (0.0244) | (0.0186) |
| Sector FE | ✓ | ✓ | ✓ |
| Period FE | ✓ | ✓ | ✓ |
| Observations | 57081 | 57081 | 57081 |

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

# Robustness Checks

- HAC vs. ISIC ISIC
- Edge Capacity vs. Node Capacity Node Capacity
- Bottlenecks vs. Between Centrality Betweenness Centrality
- Bottlenecks vs. HHI HHI
- Extend Theory and Empirics to Bottleneck Coalitions:

# HAC vs. ISIC

## Is HAC picking up sensible connections?

- 28% of HAC clusters are in the same ISIC 4 digit
- 43% of HAC clusters are in the same ISIC 2 digit
- Many others plausibly correct e.g.
  - 5224 - Cargo handling
    5320 - Courier activities
  - 4220 - Construction of utility projects
    4100 - Construction of buildings
  - 4663 - Wholesale of construction materials, hardware, plumbing and heating equipment and supplies
    4100 - Construction of buildings

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# HAC vs. ISIC

## Re-run using ISIC classifications of firms

- Strategy 1: all suppliers with the same ISIC sector are considered in the same industry

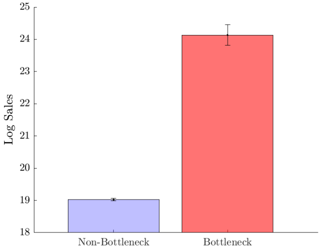
# HAC vs. ISIC

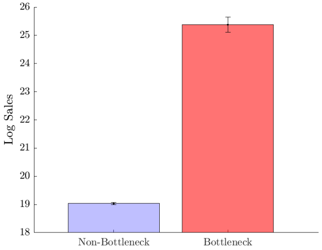
Re-run using ISIC classifications of firms

- Strategy 1: all suppliers with the same ISIC sector are considered in the same industry
  - Correlation in $F(G-i)$ is 0.55
  - Finding fewer bottlenecks when using ISIC sectors (19 compared to 50)
  - ISIC sector bottlenecks are correlated with HAC bottlenecks (11 out of 19)

# HAC vs. ISIC

## Sales

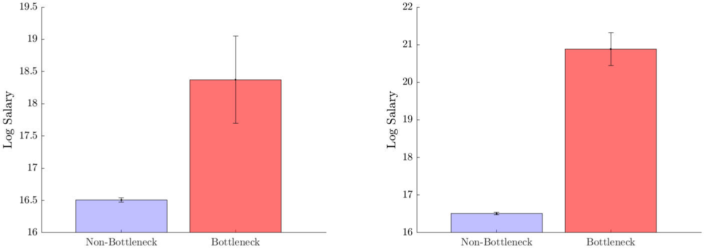



Mean and 95% confidence interval of log firm sales for critical bottlenecks and non-bottlenecks. LHS: Edge Capacity RHS: ISIC Sector

# HAC vs. ISIC

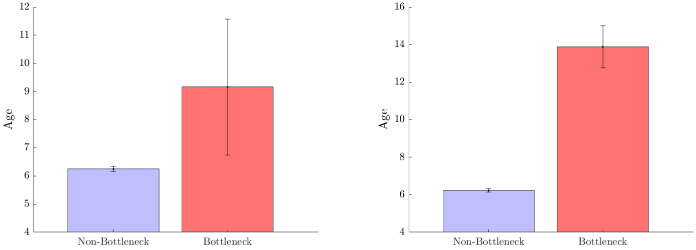
## Wage Bill




Mean and 95% confidence interval of log firm salaries for critical bottlenecks and non-bottlenecks. LHS: Edge Capacity RHS:ISIC Sector

# HAC vs. ISIC

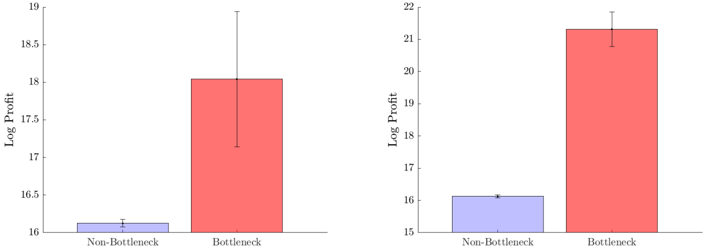
## Age




Mean and 95% confidence interval of number of years since the firm registered for a Tax Identification Number for critical bottlenecks and non-bottlenecks. LHS: Edge Capacity RHS: ISIC Sector

# HAC vs. ISIC

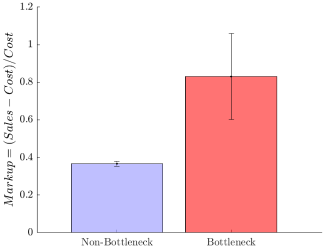
## Profit

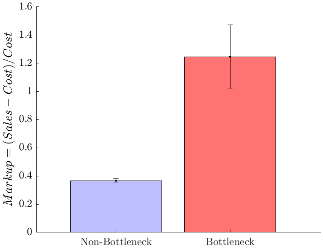



Mean and 95% confidence interval of log firm profits for critical bottlenecks and non-bottlenecks. LHS: Edge Capacity RHS: ISIC Sector

# HAC vs. ISIC

## Price-Cost Margin

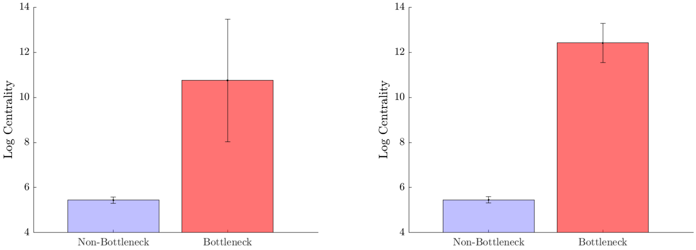



Mean and 95% confidence interval of firm Price Cost Margin: (Sales - Cost)/(Cost) for critical bottlenecks and non-bottlenecks. LHS: Edge Capacity RHS: ISIC Sector

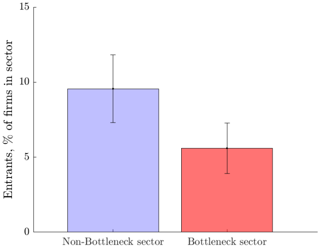
# HAC vs. ISIC

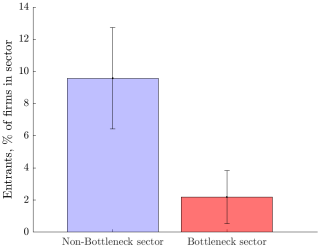
## Betweenness Centrality




Mean and 95% confidence interval of log betweenness centrality for critical bottlenecks and non-bottlenecks. LHS: Edge Capacity RHS: ISIC Sector

# HAC vs. ISIC
## Entrants

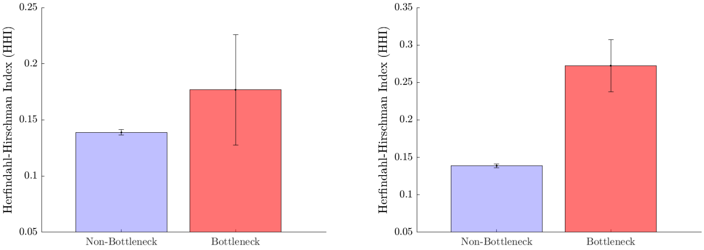



Mean and 95% confidence interval of the percentage of entrants in an ISIC 4-digit sector since 2014 for sectors containing a critical bottleneck firm and sectors not containing a critical bottleneck firm. LHS: Edge Capacity RHS: ISIC Sector

# HAC vs. ISIC

## HHI




Mean and 95% confidence interval of log Herfindahl-Hirschman Index calculated using ISIC 4 digit sectors for critical bottlenecks and non-bottlenecks. LHS: Edge Capacity RHS: ISIC Sector

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# Node Capacity vs. Edge Capacity

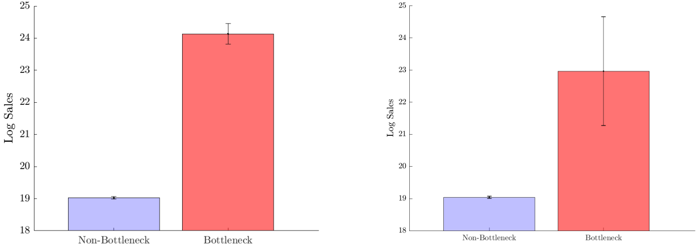
## Re-run using Node capacity of firms

- Assign each edge $g_{ij}$ the sum of the out flow in a given period from node $\sum_j g_{ij}$
  - Intuition: firm could reroute all production through any edge

- Results
  - Correlation in $F(G - i)$ between node and edge capacity is 0.56
  - Node capacity gives fewer critical bottlenecks (1-8 vs. 50 in pooled sample)
  - Node capacity bottlenecks are almost a subset of edge capacity bottlenecks

# Node Capacity vs. Edge Capacity

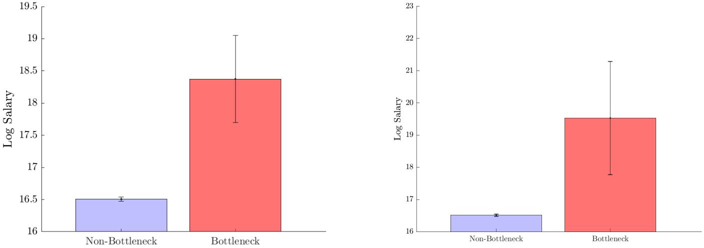
## Sales




Mean and 95% confidence interval of log firm sales for critical bottlenecks and non-bottlenecks. LHS: Edge Capacity RHS: Node Capacity

# Node Capacity vs. Edge Capacity

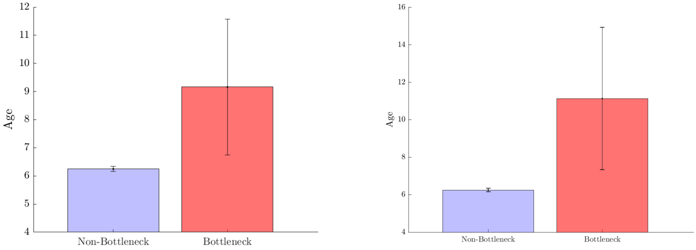
## Wage Bill




Mean and 95% confidence interval of log firm salaries for critical bottlenecks and non-bottlenecks. LHS: Edge Capacity RHS: Node Capacity

# Node Capacity vs. Edge Capacity

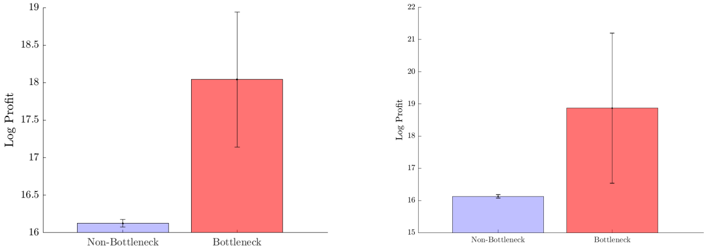
## Age




Mean and 95% confidence interval of number of years since the firm registered for a Tax Identification Number for critical bottlenecks and non-bottlenecks. LHS: Edge Capacity RHS: Node Capacity

# Node Capacity vs. Edge Capacity

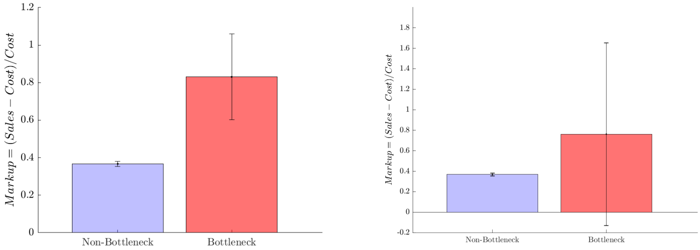
## Profit




Mean and 95% confidence interval of log firm profits for critical bottlenecks and non-bottlenecks. LHS: Edge Capacity RHS: Node Capacity

# Node Capacity vs. Edge Capacity

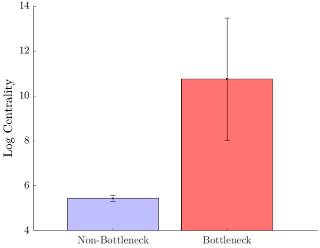
## Price-Cost Margin

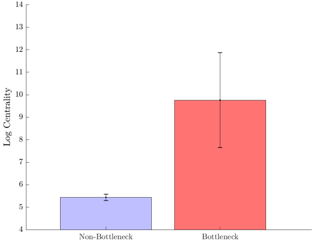



Mean and 95% confidence interval of firm Price Cost Margin: (Sales - Cost)/(Cost) for critical bottlenecks and non-bottlenecks. LHS: Edge Capacity RHS: Node Capacity

# Node Capacity vs. Edge Capacity

## Betweenness Centrality

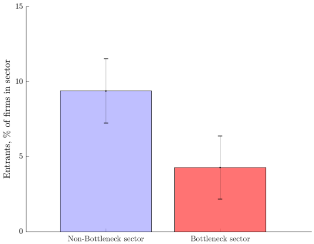



Mean and 95% confidence interval of log betweenness centrality for critical bottlenecks and non-bottlenecks. LHS: Edge Capacity RHS: Node Capacity

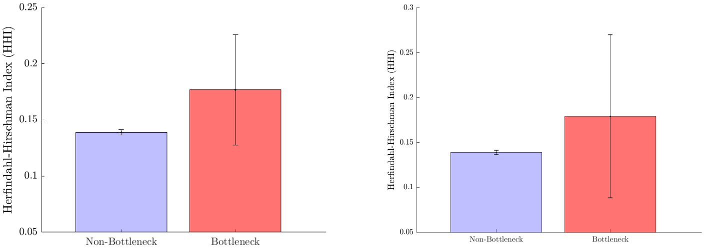
# Node Capacity vs. Edge Capacity

## Entrants


Mean and 95% confidence interval of the percentage of entrants in an ISIC 4-digit sector since 2014 for sectors containing a critical bottleneck firm and sectors not containing a critical bottleneck firm. LHS: Edge Capacity RHS: Node Capacity

# Node Capacity vs. Edge Capacity
## HHI




Mean and 95% confidence interval of log Herfindahl-Hirschman Index calculated using ISIC 4 digit sectors for critical bottlenecks and non-bottlenecks. LHS: Edge Capacity RHS: Node Capacity

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# Centrality vs. Max flow

- Are we simply picking up firm centrality within the network or are we observing some additional variation?

- Calculate betweenness centrality for each firm in each time period
- Run specification

$$Y_{it} = \beta Bottleneck_{it} + \gamma Centrality_{it} + \alpha_t + \alpha_i + u_{it} \tag{4}$$

where $Y_{it}$ is a vector of outcome variables for firm $i$ at time $t$

# HHI vs. Max flow

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | log sales | log profit | price-cost margin | log sales | log profit | price-cost margin |
| log centrality | 0.0226*** | 0.0163*** | -0.00493*** | 0.0226*** | 0.0163*** | -0.00493*** |
| | (0.00221) | (0.00246) | (0.00188) | (0.00221) | (0.00246) | (0.00188) |
| bottleneck | | | | 0.220*** | 0.138** | 0.0396 |
| | | | | (0.0598) | (0.0636) | (0.0341) |
| N | 40456 | 40456 | 40456 | 40456 | 40456 | 40456 |
| r2 | 0.949 | 0.916 | 0.764 | 0.949 | 0.916 | 0.764 |
| r2_a | 0.935 | 0.893 | 0.700 | 0.935 | 0.893 | 0.700 |
| r2_within | 0.00714 | 0.00262 | 0.000264 | 0.00750 | 0.00272 | 0.000273 |
| r2_a_within | 0.00711 | 0.00259 | 0.000233 | 0.00744 | 0.00266 | 0.000211 |

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

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# Centrality vs. Max flow

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | log sales | log profit | price-cost margin | log sales | log profit | price-cost margin |
| HHI | -0.221** | -0.0792 | 0.0428 | -0.220** | -0.0786 | 0.0432 |
| | (0.0926) | (0.0886) | (0.101) | (0.0926) | (0.0886) | (0.101) |
| bottleneck | | | | 0.276*** | 0.125** | 0.0786* |
| | | | | (0.0705) | (0.0629) | (0.0451) |
| N | 50459 | 47808 | 43335 | 50459 | 47808 | 43335 |
| r2 | 0.935 | 0.915 | 0.742 | 0.935 | 0.915 | 0.742 |
| r2_a | 0.918 | 0.892 | 0.675 | 0.918 | 0.892 | 0.675 |
| r2_within | 0.000383 | 0.0000454 | 0.0000117 | 0.000720 | 0.000111 | 0.0000430 |
| r2_a_within | 0.000358 | 0.0000189 | -0.0000174 | 0.000670 | 0.0000583 | -0.0000153 |

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Back

# Consumer problem and induced demands

- A representative consumer chooses consumptions $x_c \in \Re^{|N|}$

$$\max_{x_c} u(x^F) \text{ subject to } x_c \cdot p \leq \omega,$$

where $x^F$ be a vector with entries $x^F_\theta = \sum_{i \in Z(\theta)} x_{ic}$ for $\theta \in F$, representative consumer has utility $u(x^F)$ and wealth $\omega$, $u(\cdot)$ is a continuous, twice differentiable, strictly increasing and strictly quasi-concave function

- Solution is a demand correspondence: Let $D_{c\theta}(p)$ denote consumer demand function for good $\theta$ given marginal price $p$

# Planner's Problem

A social planner chooses supplies $S$ to maximize consumer surplus subject to technology and resource constraints. Specifically, the planner's problem is to

$$\max_S u(x^F)$$

subject to

(i) Resource constraint $\sum_i \sum_k S_{ik}\kappa_i \leq \omega$

(ii) Leontief production constraints and capacity constraints are satisfied

- For all goods $\theta \in I \cup F$ and all firms $i \in Z(\theta)$, $\sum_j S_{ij} \leq \min_{\theta':A_{\theta\theta'}>0} \sum_{j\in Z(\theta')} S_{ji}/A_{\theta\theta'}$.
- $\sum_j S_{ij} \leq \phi_i$ for all $i$.

(iii) Consumption of good $\theta$ is equal to amount of good $\theta$ supplied to the consumer ($x_\theta = \sum_{i\in Z(\theta)} S_{ic}$)

# Competitive economies

### Proposition

*If a competitive outcome exists it solves the planner's problem*

- If all firms are pricing at marginal cost, the planner faces final goods prices that represent their production costs
- Proof works by showing that producing any preferred bundle would violate the resource constraint

Back

# $p$-equilibrium

- Can't assume that the outcome is competitive—what can be said at other outcomes?
  - Suppose we observe equilibrium prices **p**
  - And consumer demand at these prices is observed
  - Can then construct a supply network as before, but with these demand constraints
  - Bottleneck firms are then defined analogously to before

### Proposition

If **p** is an equilibrium price vector, and firm $i \in Z(\theta)$ is a **p**-equilibrium bottleneck, then firm $i$ makes positive profits ($p_i > \kappa_i + \sum_j p_j \frac{S_{ji}}{\sum_k S_{ik}}$)

- Sufficient condition for all **p**-equilibrium bottleneck firms to also be bottleneck firms is that all goods are normal. Can then fix bottlenecks sequentially Back

# DAG implementation

- Firms at the top of the supply-chain have lower ratios of inputs purchased relative to output sales
  - Corr (ln(outputs/inputs), partial ordering) = -0.52
- Firms downstream have higher ratios final demand sales to intermediate input sales
  - Corr (ln(final demand sales/input sales), partial ordering) = -0.43

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# DAG implementation

## Top 100 firms in partial ordering sectors

| m5 | Freq. | Percent | Cum. |
|---|---|---|---|
| Wholesale and retail trade | 23 | 23.00 | 23.00 |
| Construction | 16 | 16.00 | 39.00 |
| Manufacturing | 10 | 10.00 | 49.00 |
| Other service activities | 8 | 8.00 | 57.00 |
| Administrative and support service ac.. | 7 | 7.00 | 64.00 |
| Agriculture, forestry and fishing | 5 | 5.00 | 69.00 |
| Human health and social work activities | 5 | 5.00 | 74.00 |
| Education | 4 | 4.00 | 78.00 |
| Professional, scientific and technica.. | 4 | 4.00 | 82.00 |
| Transportation and storage | 4 | 4.00 | 86.00 |
| Accommodation and food service activi.. | 3 | 3.00 | 89.00 |
| Real estate activities | 3 | 3.00 | 92.00 |
| Financial and insurance activities | 2 | 2.00 | 94.00 |
| Information and communication | 2 | 2.00 | 96.00 |
| Mining and quarrying | 2 | 2.00 | 98.00 |
| Arts, entertainment and recreation | 1 | 1.00 | 99.00 |
| Electricity, gas, steam and air condi.. | 1 | 1.00 | 100.00 |
| Total | 100 | 100.00 | |

Top 100 firms ISIC sectors

# DAG implementation

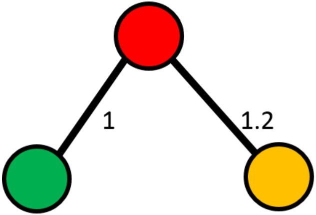
## Bottom 100 firms in partial ordering sectors

| m4 | Freq. | Percent | Cum. |
|---|---|---|---|
| Wholesale and retail trade | 41 | 41.00 | 41.00 |
| Other service activities | 11 | 11.00 | 52.00 |
| Education | 9 | 9.00 | 61.00 |
| Transportation and storage | 7 | 7.00 | 68.00 |
| Manufacturing | 5 | 5.00 | 73.00 |
| Accommodation and food service activi.. | 4 | 4.00 | 77.00 |
| Administrative and support service ac.. | 4 | 4.00 | 81.00 |
| Agriculture, forestry and fishing | 4 | 4.00 | 85.00 |
| Construction | 4 | 4.00 | 89.00 |
| Activities of extraterritorial organi.. | 3 | 3.00 | 92.00 |
| Human health and social work activities | 2 | 2.00 | 94.00 |
| Professional, scientific and technica.. | 2 | 2.00 | 96.00 |
| Public administration and defence; co.. | 2 | 2.00 | 98.00 |
| Arts, entertainment and recreation | 1 | 1.00 | 99.00 |
| Information and communication | 1 | 1.00 | 100.00 |
| Total | 100 | 100.00 | |

Bottom 100 firms ISIC sectors

# Hierarchical Firm Clustering Algorithm

- Aim: identify firms providing the same inputs
- Strategy: use assumption of Leontieff production and panel dataset to infer when two inputs are the same
- Example:
  - to produce cement you require 1 unit of limestone and 1.2 units of gypsum
  - if we observe in two periods the ratio of inputs we can infer they are the same type

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# Hierarchical Firm Clustering Algorithm

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- Strategy: use assumption of Leontieff production and panel dataset to infer when two inputs are the same
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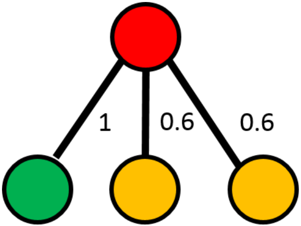


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# Hierarchical Firm Clustering Algorithm

- Generalise example
  - Take a firm. Initially consider all its inputs are in one cluster
  - Define loss function for firm $i$ of making a single partition of an input cluster, where $P_{min} \in P$ is the partition that minimises the loss function from all possible single partitions.
  - Loss function is quadratic: partitions that violate Leontieff constant proportions (over time) generate greater losses
  - Calculate a proportionate loss from making the new partition

$$\epsilon_{il} = \epsilon_{i,l-1}[1 - L_i] \tag{5}$$

  - Define cut-off $c > \epsilon_{il}$ for whether to stop the algorithm at layer $l$. We choose $c = 0.3$.
  - If proportionate loss greater than cut-off $\epsilon_{il} > c$ or number of inputs = number of partitions, then go to next firm, if not then repeat algorithm for all new possible partitions.

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