Structure and Change in Production Networks: Evidence from US Firm level Data

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Intro

- Value intermediate input transactions is as large as GDP
  - these flows take place along supplier-customer networks
  - emerging literature stresses how these production networks facilitate the propagation of shocks and affect aggregates
- Yet, limited evidence about the network structure of production and how it changes over time.
  - Supplier-customer relationships are missing in time-series or cross-sectional analysis of firms.
- Our goal is to document important empirical facts about production networks that can help to evaluate existing models and inspire new models.
- Today I will present our preliminary results based on a new proprietary database of supplier-customer relationships.

What we do

- Use a new database of supplier-customer relationships to construct production chains
- Study the relationship between firm characteristics and existence of an supplier-customer relationship
- Search for evidence of positive assortative matching in production chains
- Study whether firm characteristics help understanding the duration of supplier-customer relationships
- Investigate whether matching with more productive suppliers has an impact on the customer

Related Literature

- Firm-level network: Cohen and Frazzini (2008), Atalay et al (2011), Gofman (2011), Buraschi and Porchia (2012), Oberfield (2012)
- Industry-level network: Carvalho (2010), Menzly and Ozbas (2010), Acemoglu et al (2012), Antras et al (2012)
- Country-level network: Rizova (2011), Chaney (2012)

Description of our dataset

- New proprietary panel dataset of customer-supplier relationships
- Information is collected from SEC filings, press releases, websites, interviews, and earnings transcripts as well as primary research by provider's analysts
- The data is collected and sold to hedge funds and corporations for portfolio construction, risk management, competitive and supply chain analysis.
- The dataset is similar to Compustat segment data, but it has more relationships because it uses additional sources and is updated daily.

Data

- Quick facts about the data:
  - 180,000+ unique relationships (supplier, customer, competitors, partners) reported by for 15,000+ US-traded companies
  - Relationships reported about public, private, foreign, domestic, government organizations, and educational institutions
  - 34,000 supplier-customer relationships with percent of sales to this customer
  - Spanning 2003-2011 (daily frequency)
  - Observe start and end dates of customer-supplier relationship
- We use:
  - 38,725 unique supplier-customer relationships for publicly listed 5,260 firms
  - US firms, relationships longer than 90 days
  - Able to match with Compustat

Structure of Production Chains

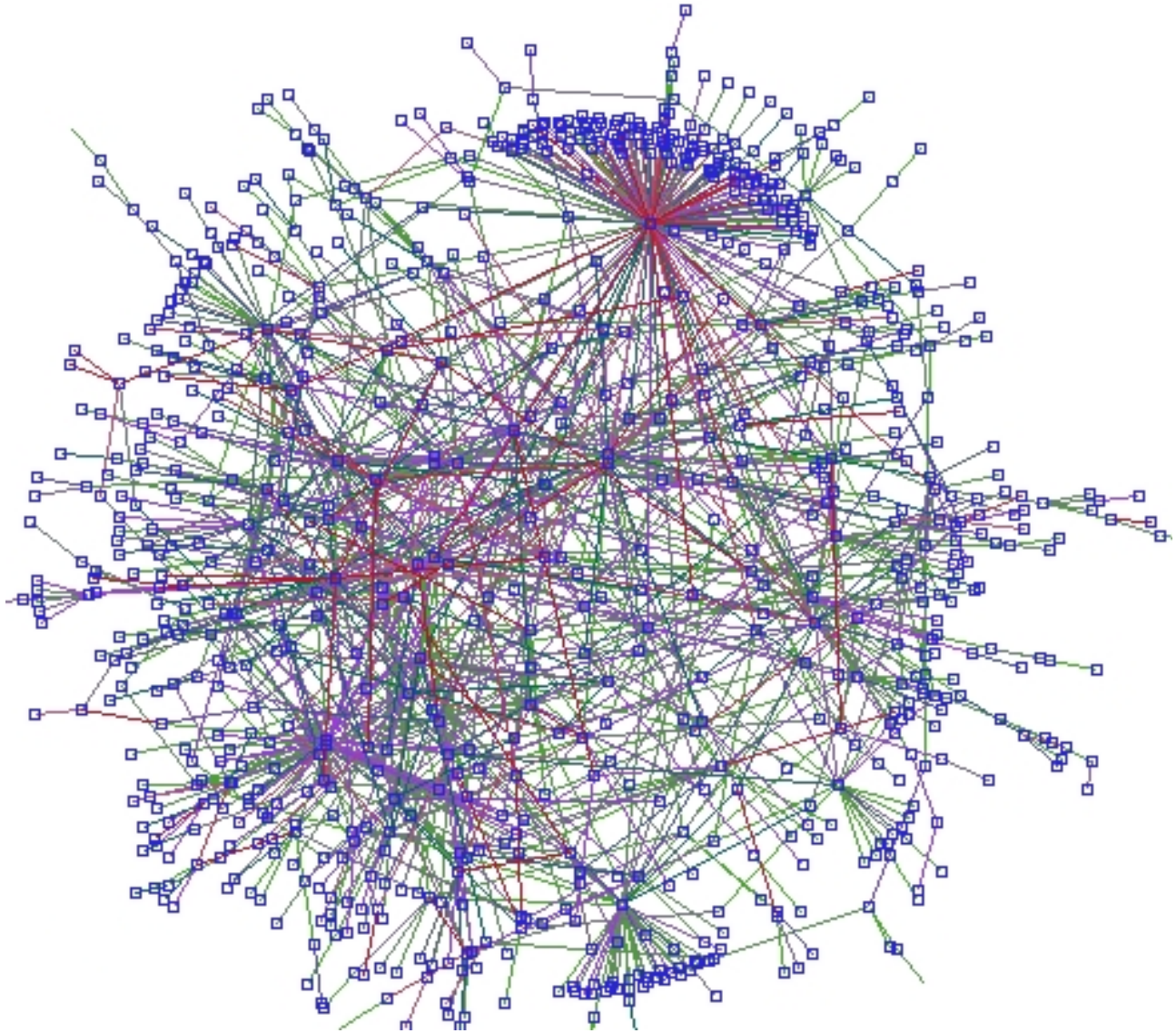


Figure: Core of the Production Chains in 2010.

I-O Network Data: Firms

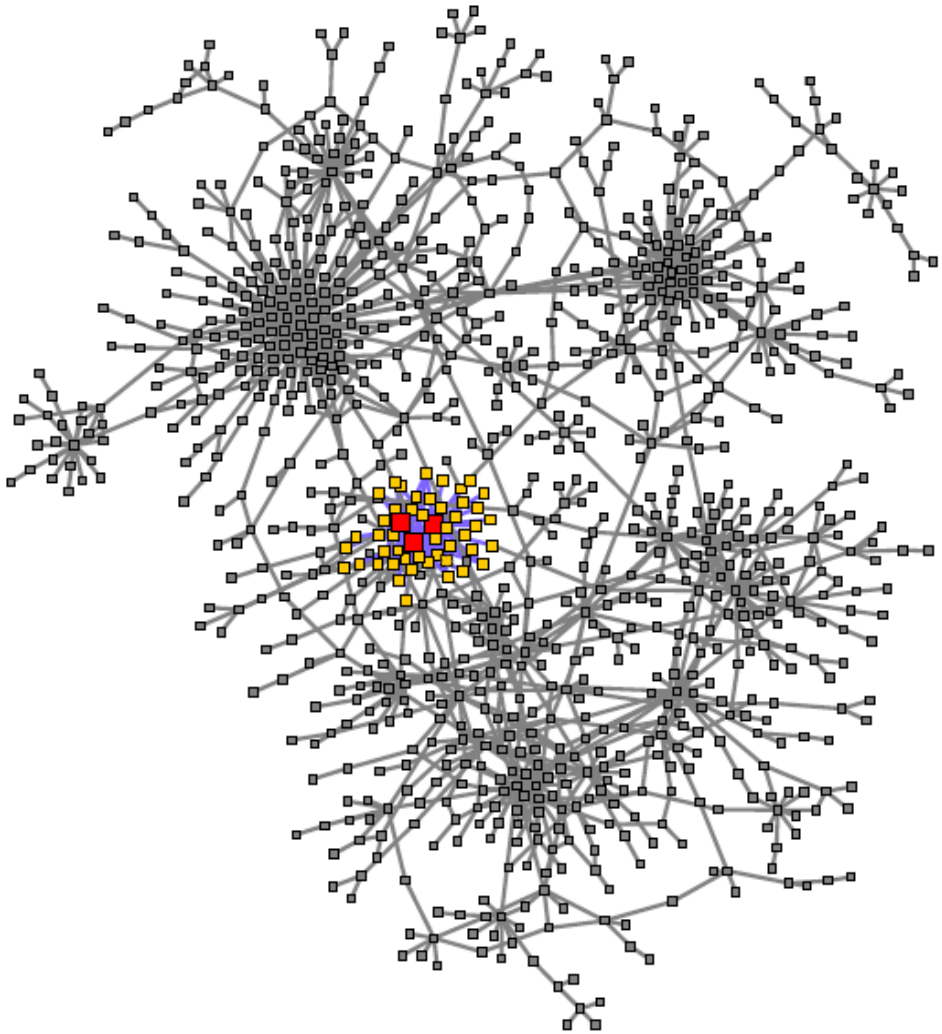
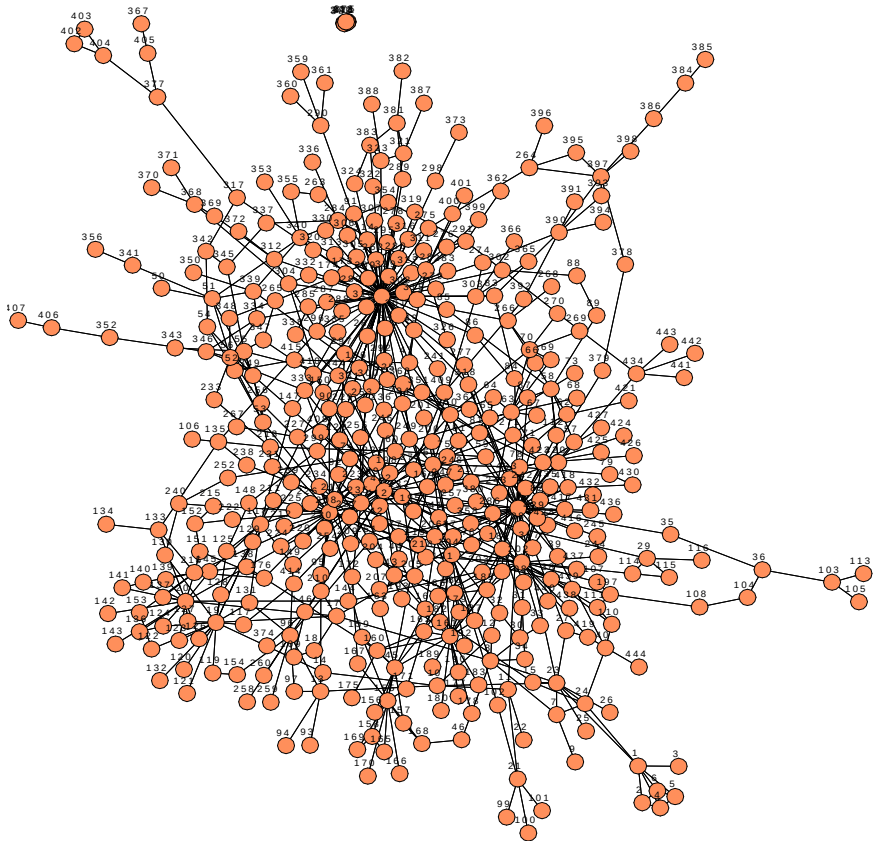


Fig. 2. Buyer–supplier network in 2006. GM, Ford, and Chrysler are colored red. Their suppliers are colored orange. All other firms are gray.

- Proprietary data: for each firm gives most important suppliers & customers
- Updates it on a weekly basis; Jan 2003 - December 2011
- Hundreds of thousands of I-O relationships
- Over 15000 firms (>6000 publicly traded firms in US)
- Source: SEC filings, press releases, websites, interviews, earnings transcripts
- & primary research by the data provider's analysts

I-O Network Data: Sectors

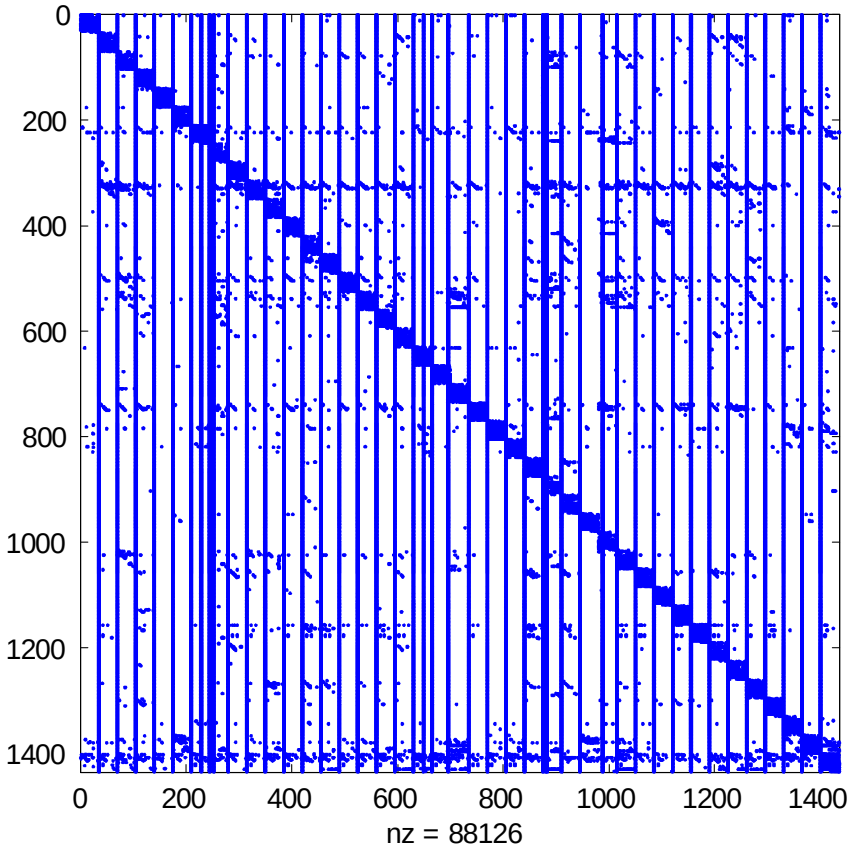


BEA Detailed Input-Use Data 1997.

(5% Threshold)

- Detailed Sector I-O data from BEA
- Every five years: 1967-2002
- $\simeq$ 500 sectors
- Consistent with US National Accounts

I-O Network Data: Sectors-Countries



- Sector-Country I-O data from WIOD
- Every year: 1995-2009
- 35 sectors in 40 countries
- Most of world trade included.

Network Topology of I-O Flows

IO/Year	n	n_scc	$\overline{d}$	ℓ	dm	$r(out, in)$	$\overline{c}$
Firms (06)	8961	1709	5	5.88	19	-0.04	0.08
US Sectors (02)	422	259	11	4	10	-0.11	0.32
Int. Trade (06)	1485	964	11	6.51	19	-0.05	0.42

- All Directed, Unweighted Networks

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  - Short Average Path Length

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  - Short Diameter

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  - Some Evidence for Negative Assortativity

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- All Directed, Unweighted Networks
  - Short Average Path Length
  - Short Diameter
  - Some Evidence for Negative Assortativity
  - Little Clustering in Firm Net relative to IO or International Nets

Probability of Input-Supply Relations

- Do firm characteristics help predict the existence of supplier-customer relationship?
- Logit specification:

$$\Pr(i \rightarrow j) = F(\beta_0 + \beta_1 \text{Size}_i + \beta_2 \text{Size}_j + \beta_3 \text{L.Prod.}_i + \beta_4 \text{L.Prod.}_j + \beta_5 \text{SIC}_{ij})$$

  - where:
    - $F(.)$ is the cumulative logistic distribution
    - Size Proxies $= \log\{Sales\}$ or $log\{Employees\}$
    - Labor Productivity$\equiv \log(Sales) - \log(Employees)$
    - SIC_{ij} =1 if i and j are in the same 4 digit SIC sector
    - We implement logit for all input-supply diads in 2005

Probability of Input-Supply Relations

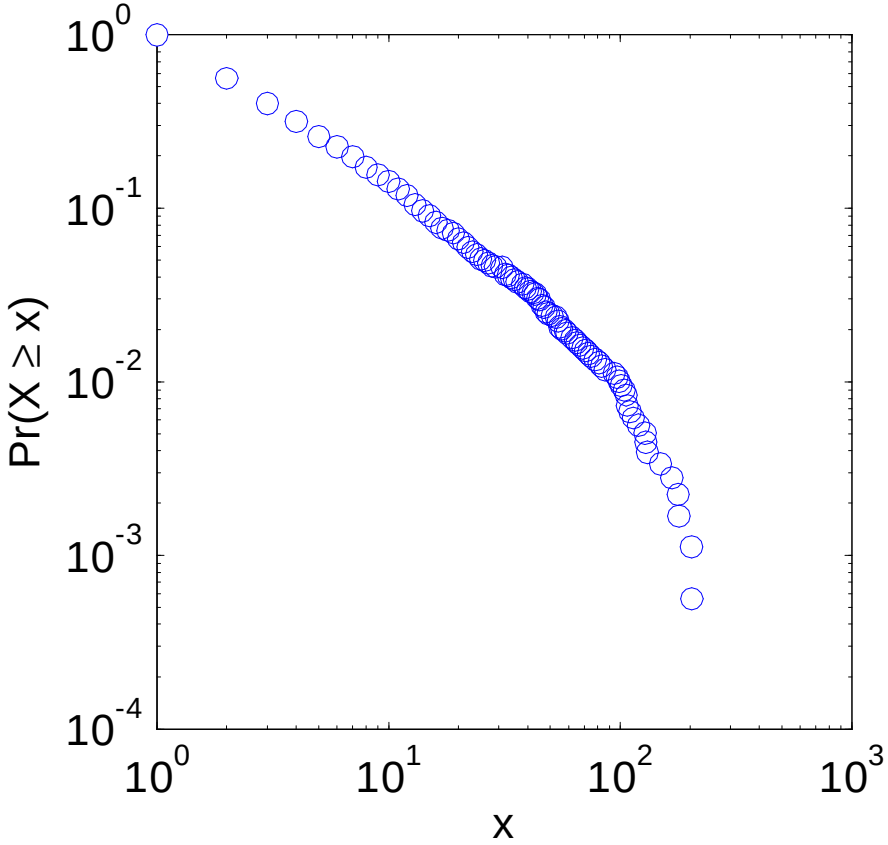
Indep. variable	$\Pr(i \rightarrow j)$
Log employees of supplier	0.04^{***}
Log employees of customer	0.75^{***}
Labor productivity supplier	0.02^{*}
Labor productivity customer	0.59^{***}
Same 4 digit SIC	2.24^{***}
N	3676158
Pseudo R^2	0.134

Robust Standard Errors; *** significant at 1%

- Large, productive firms are more likely to demand from more firms
  - 1 s.d. of size (labor prod.) associated to 75% (59%) higher prob. that a link exists
- Large, productive firms are more likely to supply to more firms
  - 1 s.d. of size (labor prod.) associated to 4% (2%) higher prob. that a link exists
- Most trade is within narrowly defined sectors
  - Firms in same 4 digit SIC are twice as likely to trade with each other

Data

Dispersion in size of firms as input demanders



Top 10 Input Demanders, 2005

Firm	# Suppliers
Wal-Mart	204
IBM	203
General Electric	179
Hewlett-Packard	178
AT&T	167
Sprint Nextel	149
Verizon	131
Boeing	129
Ford	128
Lockheed Martin	120

Probability of Input-Supply relationships

Positive Assortative Matching?

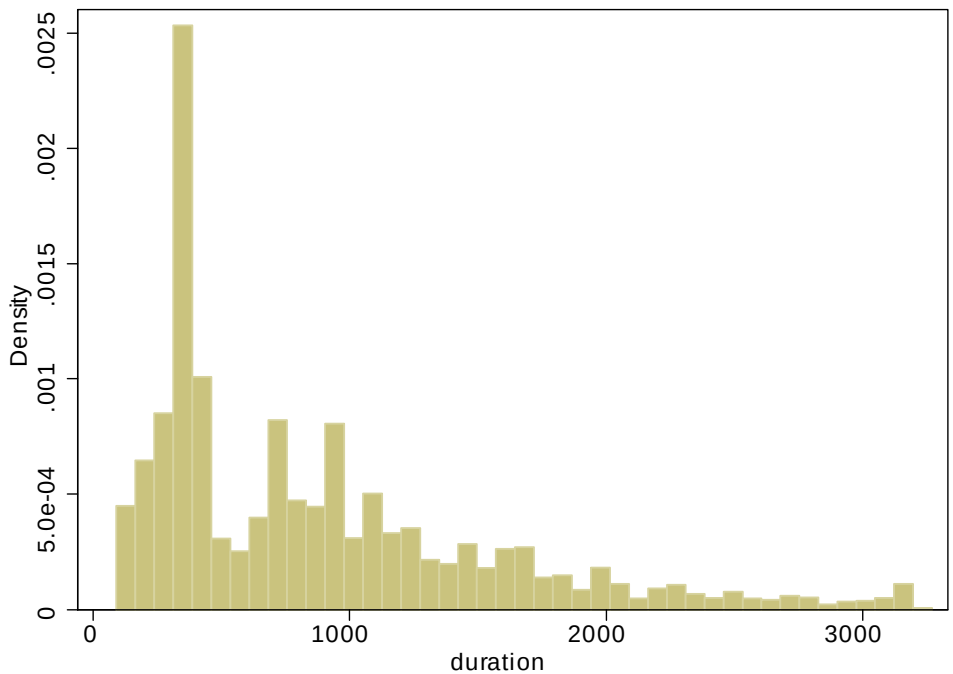
Indep. variable	$\Pr(i \longrightarrow j)$
Log employees of supplier	0.04^{***}
Log employees of customer	0.75^{***}
Interaction of Log employees	$\mathbf{0.03}^{***}$
Labor productivity supplier	0.03^{***}
Labor productivity customer	0.33^{***}
Interaction productivity	$\mathbf{0.05}^{***}$
Same 4 digit SIC	2.24^{***}
N	3676158
Pseudo R^2	0.135

Robust Standard Errors; *** significant at 1%

- Large, productive firms are more likely to supply to other large, productive firms
  - 1 s.d. of size interaction associated to 3% higher prob. that a link exists
  - 1 s.d. of productivity interaction associated to 5% higher prob. that a link exists
- Rank correlation also points to (modest) PAM:
  - Corr(Size$_i$,Size$_j$)=0.07^{***}
  - Corr(L. Prod$_i$,L. Prod$_j$)=0.06^{***}

Turnover in Input-Supply relationships

- We observe high turnover in input-supply relationships
  - For the average year, **48%** of all input-supply relations are either formed (23%) or will cease to exist (25%) during that year
  - Mean duration of an input supply relation is **2.4** years but this conceals a lot of heterogeneity:



Histogram of Duration of input-supply relations (in days)

Turnover in Input-Supply relationships

- Do firm characteristics help understanding the duration of supplier-customer relationships?
- Duration analysis (accounting for right-censoring):
  - Let $\theta(t, X_t)$ be the hazard rate at time t for input-supply relation characterized by covariates X_t
    - Recall: hazard rate gives the probability of terminating an input-supply relation at t conditional on surviving till time t
  - We implement a simple Weibull parametric specification (robust to other specifications)
  - Look at how the hazard rate depends on X_t covariates:
    - Size and productivity of supplier and customer in the relation
    - Productivity of supplier relative to (simple) average productivity other suppliers of customer i
    - Productivity of customer relative to (simple) average productivity other customers of supplier j
    - Note: all variables given by average observed during input-supply relation

Turnover in Input-Supply relationships

Determinants of duration of input-supply relationships

Indep. variable	Hazard rate
Log employees of supplier	1
Log employees of customer	0.99
Interaction of Log employees	1.01
Labor productivity supplier	0.65^{***}
Labor productivity customer	0.63^{***}
Interaction of labor productivity	1.01
Productivity of supplier w.r.t. other suppliers of j	0.82^{***}
Productivity of customer w.r.t. other customers of i	0.81^{***}
Interaction of relative productivities	0.92^{***}
N	22081

Robust Standard Errors; *** significant at 1%

Not reported: Evidence for increasing hazard rate over duration of an input-supply relation

Turnover in Input-Supply relationships

Determinants of duration of supplier–customer relationships

- More productive firms are more likely to engage in longer input-supply relationships
  - a 1 s.d. increase of labor productivity of supplier (customer) leads to a 35% (37%) lower hazard rate
- For a given customer, its most productive suppliers tend to supply them for longer
  - a 1 s.d. increase in the gap between a supplier's productivity and the average productivity of suppliers of a given customer is associated with 18% lower hazard rate
- For a given supplier, its most productive customers tend to demand from them for longer times
  - a 1 s.d. increase in the gap between a customer's productivity and the average productivity of customers of a given supplier is associated with 19% lower hazard rate

Firm-level performance and turnover of suppliers

- Above findings suggest selection of suppliers (on productivity):
  - a high turnover of suppliers (increase in the number of suppliers)
  - more productive suppliers tend to supply inputs for longer times
- Does matching with more productive suppliers have an impact on the customer?
- Panel analysis:
  - Dependent variable: customer's growth rates of sales, employment and labor productivity in year t
  - Independent variables: turnover rate of a firm's suppliers in year t, growth rate of average labor productivity of input suppliers in year t and interaction term
  - Firm and year fixed effects throughout + lagged growth rates of dependent variables

Firm-level performance and turnover of suppliers

Indep. variable / Dep. variable	ΔSales$_{jt}$	ΔEmployment$_{jt}$	ΔL.P.$_{jt}$
Turnover of suppliers	**0.06*****	**0.03*****	**0.03*****
Δ Avg l.p. of suppliers	0.05***	0.01	0.05***
Turnover $\times$ ΔAvg l.p. of suppliers	0.06***	0.01	0.05*
Customer & year fixed effects	Yes	Yes	Yes
Lagged dependent variable	Yes	Yes	Yes
N	9689	9689	9689

- Higher supplier turnover rates are associated with customer's growth (in sales, employment and labor productivity)
  - a 1 s.d. increase in the turnover rate of a firm is associated with a 3p.p. increase in labor productivity growth

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Turnover $\times$ ΔAvg l.p. of suppliers	0.06^{***}	0.01	0.05^{*}
Customer & year fixed effects	Yes	Yes	Yes
Lagged dependent variable	Yes	Yes	Yes
N	9689	9689	9689

- Growth in the average productivity of suppliers is associated with growth in sales and productivity of customers
  - a 1 s.d. increase in the average productivity growth of suppliers is associated with a 5p.p. increase in labor productivity growth

Firm-level performance and turnover of suppliers

Indep. variable / Dep. variable	ΔSales$_{jt}$	ΔEmployment$_{jt}$	ΔL.P.$_{jt}$
Turnover of suppliers	0.06^{***}	0.03^{***}	0.03^{***}
Δ Avg l.p. of suppliers	0.05^{***}	0.01	0.05^{***}
Turnover $\times$ ΔAvg l.p. of suppliers	$\mathbf{0.06}^{***}$	**0.01**	$\mathbf{0.05}^{*}$
Customer & year fixed effects	Yes	Yes	Yes
Lagged dependent variable	Yes	Yes	Yes
N	9689	9689	9689

- Growth in average productivity of suppliers *through* adding and dropping suppliers is associated with growth in sales and productivity of customers
  - a 1 s.d. increase in the interaction term is associated with a further 5p.p. increase in labor productivity growth

Recap

- Preliminary set of stylized facts on firm level input-supply relationships:
  - Large, productive firms are more likely to supply to (and demand from) more firms
  - Large, productive firms are more likely to supply to other large and productive firms (PAM)
  - There is high turnover of input-supply links
  - More productive firms tend to engage in longer input-supply relationships
  - For a given customer (supplier), its most productive suppliers (customers) tend to supply (demand from) them for a longer time
  - Growth in average productivity of suppliers through adding and dropping suppliers is associated with growth in sales and productivity of customers

Future work

- Further study of supplier-customer relationships with focus on network formation models
- Using our descriptive results as moments for testing theoretical models that generate those moments
- Compare structure of production networks with other networks (e.g. social networks)