Specialization, Complexity & Resilience in Supply Chains

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Introduction

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Research Question

How do specialization choices and network complexity shape resilience in supply chains? Should governments promote resilience? If so, how?

This Paper

1. Static model of sourcing with **endogenous product specialization**
   - Input design problem: specialization $\uparrow \implies$ price $\uparrow$ but share of compatible buyers $\downarrow$
   - Complex network: Multiple key inputs needed for final production

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   - Complex network: Multiple key inputs needed for final production
2. **Dynamic model of supply chain formation**
   - Introduce long-term relationships and (stochastic) disruptions of final producers
   - **Welfare-relevant notion of resilience** = avg time it takes for a final producer to restore production following a disruption
   - Decompose resilience into search efficiency, avg specialization, and complexity

This Paper – Cont'd

3. Normative analysis
   - **Novel network externality in specialization**: intermediate producers do not internalize the cascading effect of halting final production on complementary input producers
   - **If network is complex enough**, equilibrium displays over- specialization $\implies$ **resilience is inefficiently low**
4. Normative implications
   - **Targeted transaction subsidy** decentralizes efficient allocation
   - Planner would like intermediate producers to have more *skin in the* (final production) *game* $\implies$ align private and social cost of specialization

Related Literature

- **Fragility in production networks**

  Levine (2012), Elliott et al. (2022), Acemoglu and Tahbaz-Salehi (2023), Carvalho et al. (2023), Grossman et al. (2023a)

  ⇒ *Separately identify fragility of production ("robustness") from ability to recover quickly from shocks ("resilience").*

- **Product design**

  Bar-Isaac et al. (2012, 2023), Menzio (2023), Albrecht et al. (2023)

  ⇒ *Study product design choices with complementary inputs.*

- **Optimal number of varieties**

  Spence (1976), Dixit and Stiglitz (1977), Zhelobodko et al. (2012), Parenti et al. (2017), Dhingra and Morrow (2019), Grossman et al. (2023b)

  ⇒ *Endogenous specialization and price posting make appropriability and business-stealing effects perfectly offset each other.*

Static Model

Key Concepts

- **Specialization**
  - Characteristic of intermediate products
  - Determines the degree of **compatibility with final good production functions**
  - $\neq$ general quality
- **Complexity**
  - Characteristic of final good production function
  - Equal the **number of key inputs** needed to produce
- **Resilience**
  - Equilibrium sourcing capacity of final producers
  - Equal the **probability that a final producer sources all key inputs**

Environment

- Rep household, measure 1 of final producers, measure m of intermediate producers
- Ex ante identical final producers, heterogeneous intermediate producers
- Perfectly competitive market for consumption good, **frictional markets for intermediate goods**
- Consumption good (of unit quality) is the numeraire

Rep Household

- Rep household's problem:

$$\max_{C_i,\ell} \mathcal{U} = C + \psi \log(1-\ell)$$

$$\text{s.t } C = w\ell + \bar{\Pi}$$

$$C = \int_0^1 \mathcal{Q}_i C_i \, di$$

- $\mathcal{Q}_i$ and C_i are quality and quantity of the consumption good produced by final producer i

- $\bar{\Pi}$ are profits rebated to the rep household

Final producers

- Each final producer needs to source ***N* key inputs** to produce $Y_i = 1$ unit of output (consumption good):

$$Y_i = \mathbb{1}\{\min\{y_1, \ldots, y_N\} > 0\}$$

- Output quality $\mathcal{Q}_i$ depends on the value of inputs sourced A_j:

$$\mathcal{Q}_i = \sum_{j=1}^{N} A_j$$

- Each final producer makes profits:

$$\pi_i = \left(\mathcal{Q}_i Y_i - \sum_{j=1}^{N} p_j \right) \mathbb{1}\{Y_i = 1\}$$

Sourcing frictions in the real world . . .

"At most organizations [...], hunting for new suppliers is a daunting, manual process. On average, it takes about three months to complete a single supplier search, with a sourcing professional logging more than 40 hours of work—and yet able to consider only a few dozen suppliers from a total population of thousands."

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$\Longrightarrow$ Intermediate market with **search and compatibility frictions**

…and in the model

- **Search and compatibility frictions**: each final producer meets a finite number n^c of *compatible* intermediate producers

$$n^c \sim \text{Poisson}(\lambda \bar{\phi})$$

  - λ = exogenous expected number of sellers met $\implies$ (search frictions)$^{-1}$
  - $\bar{\phi}$ = endogenous average compatibility probability $\implies$ (compatibility frictions)$^{-1}$

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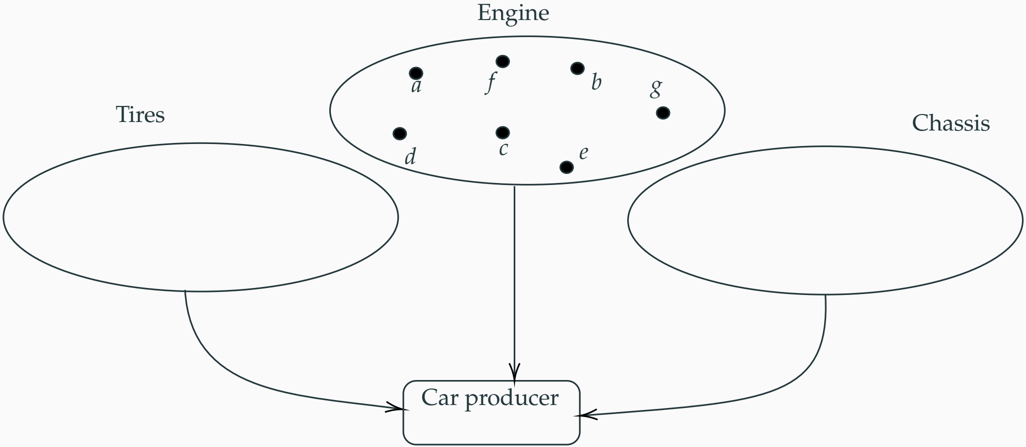
- **Finding probability** = probability that a final producer finds a compatible input:

$$f = 1 - \exp\{-\lambda\bar{\phi}\}$$

- Final producer **trades w/ best compatible seller** (= offering highest surplus), if any

Details

Market Structure



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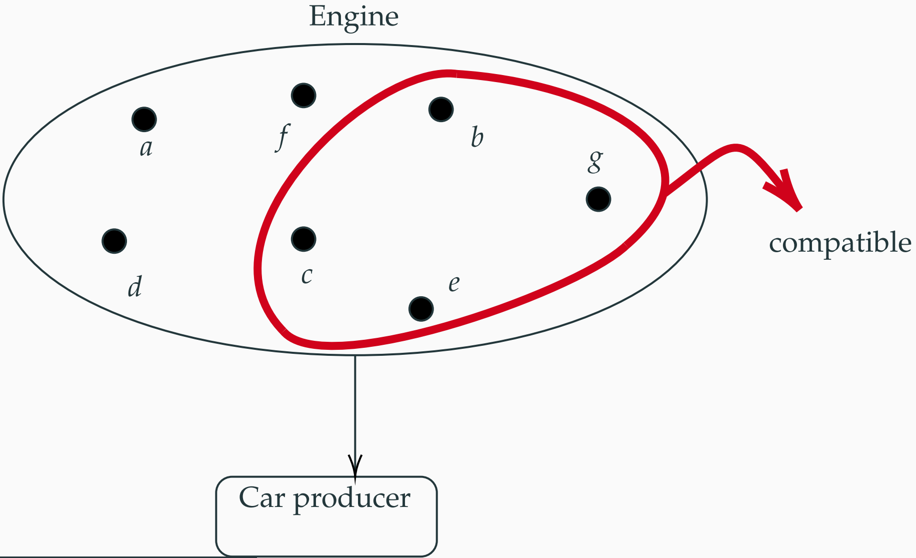

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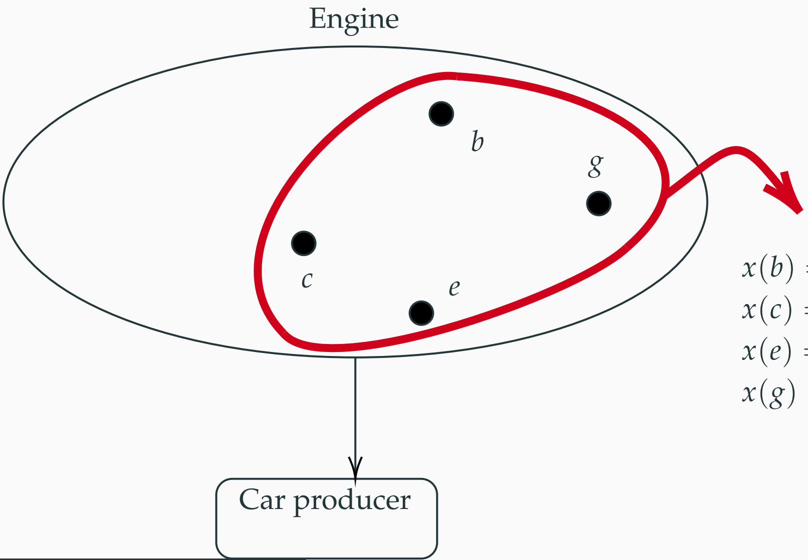
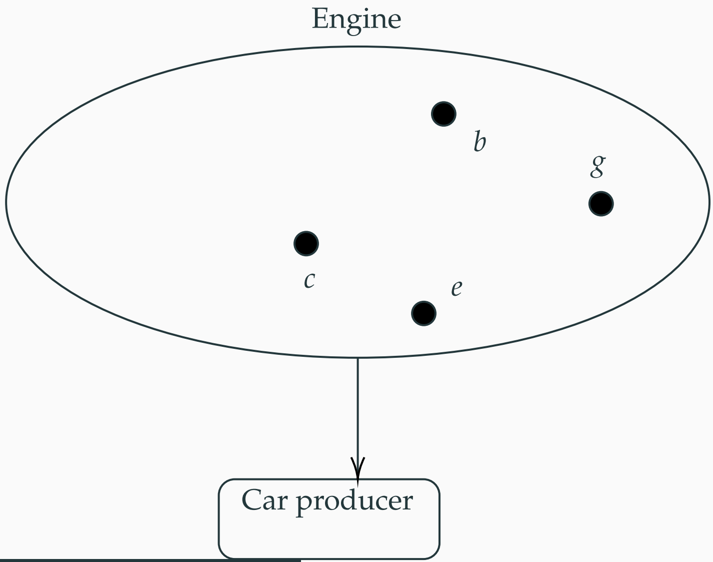


$$x(b) = (p(b), A(b))$$
$$x(c) = (p(c), A(c))$$
$$x(e) = (p(e), A(e))$$
$$x(g) = (p(g), A(g))$$

Market Structure



$$\begin{bmatrix} x(b) \\ x(c) \\ x(e) \\ x(g) \end{bmatrix} \rightarrow \begin{bmatrix} x(e) \\ x(b) \\ x(g) \\ x(c) \end{bmatrix}$$

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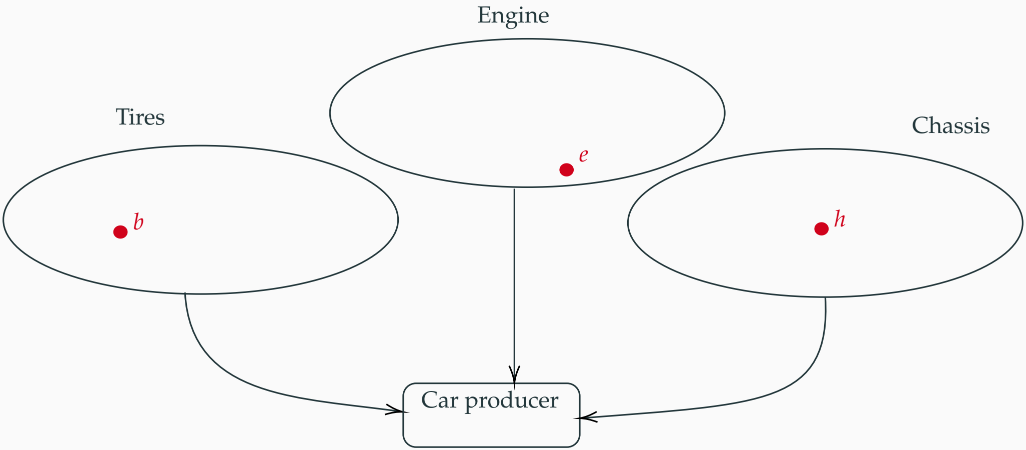

Intermediate producers

- Intermediate producers differ in marginal cost $c(z), z \sim \Gamma(z)$
- **They choose specialization** s and offered surplus x ($\iff$ post price p)
- Higher specialization increases final good quality $\boldsymbol{A'(s) > 0} \ldots$
- …but reduces the share of compatible final producers $\boldsymbol{\phi'(s) < 0}$

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- Higher specialization increases final good quality $\boldsymbol{A'(s) > 0} \ldots$
- $\ldots$ but reduces the share of compatible final producers $\boldsymbol{\phi'(s) < 0}$
- Key trade-off: $s \uparrow \implies \Pr(\text{match}) \downarrow \ \mathbb{E}[\text{Profits}|\text{match}] \uparrow$

Intermediate producer's profits

- Expected operating profits:

$$\Pi(s,x;z) = \underbrace{\theta\lambda}_{\substack{\text{exp \#}\\ \text{meetings}}} \underbrace{\mathcal{P}(s,x;N)}_{\substack{\text{trading prob.}|\\ \text{meeting}}} \underbrace{[A(s) - c(z) - x]}_{\substack{\text{unit profit}\\ \equiv\, p - c(z)}}$$

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Derivation

Intermediate producer's problem – Offered Surplus

- Profit maximization problem:

$$V(s,x;z) = \max_{s,x} \; \Pi(s,x;z) - \underbrace{wq(s)}_{\substack{\text{specialization}\\ \text{cost}}}$$

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Lemma (Optimal Offered Surplus)

Optimal offered surplus equals the expected outside option of a final producer trading with the intermediate producer:

$$x^{\star}(z) = \mathbb{E}_{\tilde{z},\tilde{z}<z}[A(s(\tilde{z})) - c(\tilde{z})]$$

- **First-price auction w/ unknown # bidders** $\implies$ $x^{\star}(z)$ makes buyer indifferent b/w z and the second-best compatible seller in expectation Derivation Intuition

Intermediate producer's problem – Specialization

- Optimal specialization (implicit):

$$\theta\lambda\mathcal{P}(z;N)\left[A'(s(z))+\tfrac{\phi'(s(z))}{\phi(s(z))}\left(A(s(z))-c(z)-x(z)\right)\right]-wq'(s(z))=0$$

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1. $\theta\lambda\mathcal{P}(z;N)A'(s(z)) > 0$: marginal increase in profits conditional on trading

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2. $\theta\lambda\mathcal{P}(z;N)\frac{\phi'(s(z))}{\phi(s(z))}\left(A(s(z)) - c(z) - x(z)\right) < 0$: marginal reduction in trading probability

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3. $-wq'(s(z))<0$: marginal increase in specialization cost

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Lemma (Optimal Specialization)

If $\lambda\bar{\phi}<1$, optimal specialization is increasing in search efficiency λ, and decreasing in complexity N.

General equilibrium

- Labor market clearing:

$$1 - \frac{\psi}{w} = Nm\bar{q}$$

where $\bar{q} = \int q(s(z))d\Gamma(z)$

- Final good market clearing:

$$C = Y$$

where $Y = \underbrace{f^N}_{\text{prob. active}} \underbrace{N\mathbb{E}[A - c]/f}_{\text{expected surplus} \mid \text{active}}$

Resilience – Determinants

$$f^N = [1 - \exp\{-\lambda \bar{\phi}\}]^N$$

1. **Search efficiency** $\lambda \uparrow$ (ICT, AI, ...) increases resilience
2. **Avg product specialization** $\bar{s} \uparrow$ $\bar{\phi} \downarrow$ reduces resilience
3. **Production complexity** N $\uparrow$ reduces resilience

Efficiency

- Social planner problem

$$
\begin{aligned}
\max_{s_i(z)} \; \mathcal{W} &= C + \psi \log(1-\ell) \\
\text{s.t.} \;\; \ell &= N m \bar{q} \\
C &= f^N \sum_{i=1}^{N} \mathbb{E}[A(s_i(z)) - c(z)]/f \\
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Proposition (Efficiency of Static Equilibrium)

The equilibrium is constrained efficient if and only if production is not complex, *i.e.* $N = 1$. If the production process is complex, *i.e.* $N > 1$, the equilibrium features over-specialization.

Efficiency

- Efficient specialization $\mathcal{S}(z)$:

$$\left.\frac{\partial \mathcal{W}}{\partial s(z)}\right|_{s(z)=\mathcal{S}(z)} = 0$$

Effects

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Intuition

$\Longrightarrow$ **equilibrium over-specialization**

Network Externality

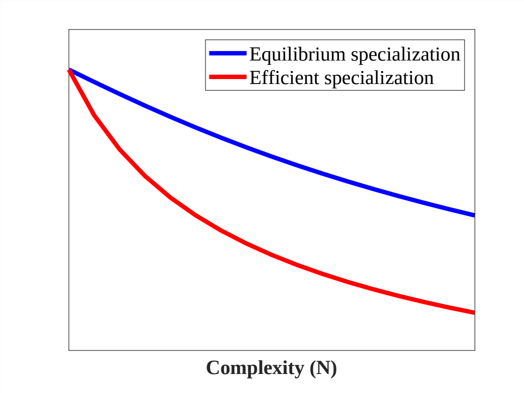
1. Compatibility frictions $\iff f < 1$
2. Endogenous specialization $\iff f'(s) < 0$
3. Complex production $\iff N > 1$

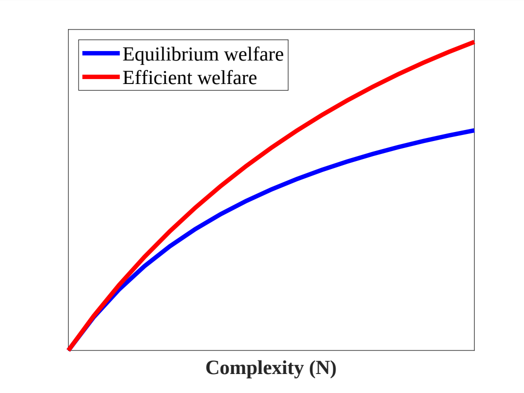
$\implies$ Network externality in specialization

- Intermediate producers do not internalize the **cascading effect of halting final production on complementary input producers**
  - Example: higher specialization of engine makers hurts tire makers because cars are less likely to be produced

Example

Comparative Statics





- Network externality exacerbates as production becomes more complex

A few Remarks

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Remark (Non-Contingent Contracts)

Economies with non-contingent contracts feature more equilibrium over-specialization than economies with contingent contracts.

Dynamic Model

Highlights

- **So far**: Complex network $\implies$ over-specialization
- **Now**: Over-specialization $\implies$ under-resilience
- **How**: Extend static model to a dynamic setting with long-term relationships
  - Final producers face a disruption each period with probability δ
  - **Resilience** $\equiv$ **avg time it takes for a final producer to restore production following a disruption**
  - **Robustness** $= 1/\delta$

Intermediate producer's problem

- Profit maximization problem:

$$\max_{x,\{s_t\}_{t=1}^{\infty}} \sum_{t=1}^{\infty} \beta^{t-1} \left[\mathcal{D}_t(\boldsymbol{s}_{1,t}, x)\left(a(s_t) - x - c(z)\right) - w_t q(s_t)\right]$$

$$\text{s.t. } \mathcal{D}_t(\boldsymbol{s}_{1,t}, x) = (1-\delta)\mathcal{D}_{t-1}(\boldsymbol{s}_{1,t-1}, x) + \theta_t \lambda \mathcal{P}(s_t, x; N),$$

$$\mathcal{D}_0 = 0$$

Customization

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The level of specialization within a match increases over time.

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- Intuition: as intermediate producers "age" they build a customer base
  $\Rightarrow$ they are less subject to search frictions
  $\Rightarrow$ they optimally increase specialization.

Resilience – Output effects

$$Y = \underbrace{\mu(f, N)}_{\substack{\text{market}\\ \text{size}}} \quad \underbrace{f^N}_{\text{resilience}} \quad \underbrace{\frac{1}{\delta}}_{\text{robustness}} \quad \underbrace{N\mathbb{E}[A - c]/f}_{\substack{\text{expected surplus} \mid \\ \text{active}}}$$

- **Separately identify** output effects of **resilience** (recovery from disruptions) **and robustness** (avoiding disruptions)
- Market size $\equiv$ stationary share of searching final producers

Efficiency

- Marginal welfare effect of equilibrium specialization:

$$\left.\frac{\partial \mathcal{W}}{\partial s(z)}\right|_{\mathcal{S}(z)=s^\star(z)} \propto \underbrace{\mathbb{E}_{\tilde{z},\tilde{z}<z}\left[A(s^\star(\tilde{z})) - c(\tilde{z})\right]}_{\text{business-stealing externality}} \underbrace{- x^\star(z)}_{\substack{\text{appropriability} \\ \text{externality}}} \qquad = 0$$

$$\underbrace{- (N-1)\exp\{-\lambda\hat{\phi}(\underline{z},z)\}\mathbb{E}[A-c]/f}_{\text{network externality}} \qquad < 0$$

$$\underbrace{+ \frac{\beta(1-\delta)}{1+\beta(1-\delta)} f^N N e^{-\lambda\hat{\phi}(\underline{z},z)} \hat{\mathbb{E}}[a(s^\star(\tilde{z})) - c(\tilde{z})]}_{\text{search externality}} \qquad > 0$$

- **If network is complex enough**, equilibrium over- specialization $\Longrightarrow$ **resilience is inefficiently low**

Comparative Statics

Proposition (Efficiency and Complexity)

If search efficiency is low enough, the equilibrium allocation features more over-specialization and under-resilience as complexity increases.

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As the frequency of disruption increases, the equilibrium allocation features more over-specialization and under-resilience.

Proposition (Efficiency and Search Frictions)

If the elasticity of the average compatibility probability to search efficiency exceeds one, the equilibrium allocation features more over-specialization and under-resilience as search frictions decline.

Conclusions

Conclusions

- New model of **supply chain formation with endogenous compatibility frictions**
  - Heterogeneous intermediate producers solve input design problem: specialization $\uparrow \implies$ price $\uparrow$ but share of compatible buyers $\downarrow$
  - Complex network: Multiple key inputs needed for final production
- **Welfare-relevant notion of resilience** = avg time it takes for a final producer to restore production following a disruption
- **If network is complex enough**, equilibrium displays over- specialization $\implies$ **resilience is inefficiently low**
  - **Network externality**: intermediate producers do not internalize the cascading effect of halting final production on complementary input producers

In the paper

- **Dynamic model with link-specific destruction**
- **Optimal Policy**
  - **Targeted transaction subsidy** decentralizes efficient allocation
  - Planner would like intermediate producers to have more *skin in the* (final production) *game* $\implies$ align private and social cost of specialization
- **Extensions**
  - Endogenize complexity (choose N) and robustness (invest to reduce δ)

Appendix

Intermediate Market Structure

Back

- **Search frictions**: each final producer meets a finite number n of intermediate producers

$$n \sim \text{Poisson}(\lambda)$$

where $n \in \mathbb{N}$ and $\mathbb{E}[n] = \lambda$

- **Compatibility frictions**: each intermediate producer is compatible with final producer's technology with probability

$$\phi \sim \mathcal{F}$$

where the distribution $\mathcal{F}$ is endogenous and $\mathbb{E}[\phi] = \bar{\phi}$

Appendix – Trading probability

Back

- Conditional trading probability:

$$\mathcal{P}(s,x;N) \equiv \underbrace{\phi(s)}_{\text{prob. compatible}} \underbrace{\exp\left\{-\lambda\bar{\phi}\left[1-G(x)\right]\right\}}_{\substack{\text{prob. best among compatible}\\ \text{contacted}}} \underbrace{f^{N-1}}_{\substack{\text{prob. other key}\\ \text{inputs sourced}}}$$

  - $x \equiv A(s) - p$ is the **offered surplus** (profits granted to final producer)
  - $\boldsymbol{G(x)}$ denotes the **distribution of offered surplus**

Optimal offered surplus

Back

- First-order condition (DE)

$$x'(z) = \lambda\phi(s(z))\gamma(z)\left[A(s(z)) - c(z) - x(z)\right]$$

$$x(\underline{z}) = 0$$

- Optimal offered surplus:

$$\begin{aligned} x^\star(z) &= \int_{\underline{z}}^{z} [A(s(\tilde{z})) - c(\tilde{z})]\gamma^\star(\tilde{z}, z) d\tilde{z} \\ &= \mathbb{E}_{\max\{\tilde{z}\} \mid \max\{\tilde{z}\} \leq z} \left[A(s(\tilde{z})) - c(\tilde{z})\right] \end{aligned}$$

where $\gamma^\star(\tilde{z}, z) \equiv \lambda\phi(s(z))\exp\{-\lambda\hat{\phi}(\tilde{z}, z)\}\gamma(\tilde{z})$ is the final producer's **productivity density of outside option** when trading w/ intermediate of prod. z

Intermediate producer's problem – Offered Surplus

Lemma (Optimal Offered Surplus)

Optimal offered surplus equals the expected outside option of a final producer trading with the intermediate producer:

$$x^{\star}(z) = \mathbb{E}_{\max\{\tilde{z}\} \mid \max\{\tilde{z}\} \leq z} \left[A(s(\tilde{z})) - c(\tilde{z}) \right]$$

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Consider a seller with productivity z

- loses against anybody with productivity $z' > z$

Intermediate producer's problem – Offered Surplus

Back

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- buyer's outside option is given by the highest possible surplus by the best alternative

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- buyer's outside option is given by the highest possible surplus by the best alternative

$$x^\star(z) = \underbrace{\left[A(s(\tilde{z})) - c(\tilde{z})\right]}_{\substack{\text{highest possible} \\ \text{offered surplus by } \tilde{z}}}$$

Intermediate producer's problem – Offered Surplus

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$$x^\star(z) = \underbrace{\left[A(s(\tilde{z})) - c(\tilde{z})\right]}_{\substack{\text{highest possible} \\ \text{offered surplus by } \tilde{z}}} \underbrace{\lambda\phi(s(\tilde{z}))\exp\{-\lambda\hat{\phi}(\tilde{z},z)\}}_{\substack{\text{Pr } \tilde{z} \text{ is best} \\ \text{alternative}|\tilde{z}<z}}$$

Intermediate producer's problem – Offered Surplus

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Lemma (Optimal Offered Surplus)

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Intermediate producer's problem – Specialization

- Optimal specialization (implicit):

$$\theta\lambda\mathcal{P}(z;N)\left[A'(s(z))+\frac{\phi'(s(z))}{\phi(s(z))}\left(A(s(z))-c(z)-x(z)\right)\right]-wq'(s(z))=0$$

Lemma (Optimal Specialization)

Optimal specialization is decreasing in complexity N and increasing in search efficiency λ (if $\lambda\bar{\phi}<1$).

Appropriability & Business-stealing Externalities

Back

- In a given product line, product specialization gives rise to two externalities:

1. $x^{\star}(z) > 0 \implies$ **appropriability externality**
   - Intermediate producers bear specialization cost but do not appropriate its whole return
2. $\mathcal{P}(\hat{z}; N) \propto \exp\left\{-\lambda \int_{\hat{z}}^{\bar{z}} \phi(s^{\star}(\tilde{z}))\gamma(\tilde{z})d\tilde{z}\right\} \implies$ **business-stealing externality**
   - Less productive intermediate producers ($\hat{z} \leq z$) increase their trading prob. if intermediate z specializes more ($\phi(s^{\star}(z)) \downarrow$)

- Price posting + compatibility frictions $\implies$ **the two externalities cancel out**

Interpreting the optimal offered surplus

Back

- Price posting protocol $\iff$ **first-price** sealed-bid **auction among unknown number of compatible intermediate producers** contacted by a final producer

- Optimal offered surplus = **expected outside option of a final producer** when intermediate z is the best compatible seller contacted:

$$
\begin{aligned}
x^{\star}(z) = & \Pr(m(z)=0)\cdot 0 + \\
& \Pr(m(z)=1)\cdot \mathbb{E}\left[\max\left\{A(s(\tilde{z})) - c(\tilde{z})\right\} \,\middle|\, \max\{\tilde{z}\} \le z, m(z)=1\right]
\end{aligned}
$$

  where $m(z) = \mathbb{1}\{\text{final producer contacts at least one firm w/ productivity } \le z\}$

- **Innovation** wrt std auction theory: **endogenous distribution of bidders** pinned down by search and compatibility frictions

Efficiency

- Efficient specialization (implicit):

$$\theta\lambda\mathcal{P}(z;N)\Bigg[A'(\mathcal{S}(z)) + \frac{\phi'(\mathcal{S}(z))}{\phi(\mathcal{S}(z))}\Bigg(\,[A(\mathcal{S}(z)) - c(z)] - \mathbb{E}_{\max\{\tilde{z}\}\,|\,\max\{\tilde{z}\}<z}\,[A(\mathcal{S}(\tilde{z})) - c(\tilde{z})]$$

$$+(N-1)\exp\{-\lambda\hat{\phi}(\underline{z},z)\}\mathbb{E}[A-c]/f\Bigg)\Bigg] - \frac{\psi}{1-Nm\bar{q}}\,q'(\mathcal{S}(z)) = 0$$

1. $\theta\lambda\mathcal{P}(z;N)A'(\mathcal{S}(z)) > 0$: marginal increase in surplus conditional on trading

Efficiency

- Efficient specialization (implicit):

$$\theta\lambda\mathcal{P}(z;N)\Bigg[A'(\mathcal{S}(z)) + \frac{\phi'(\mathcal{S}(z))}{\phi(\mathcal{S}(z))}\Bigg([A(\mathcal{S}(z)) - c(z)] - \mathbb{E}_{\max\{\tilde{z}\}\,|\,\max\{\tilde{z}\}<z}\,[A(\mathcal{S}(\tilde{z})) - c(\tilde{z})]$$

$$+(N-1)\exp\{-\lambda\hat{\phi}(\underline{z},z)\}\mathbb{E}[A-c]/f\Bigg)\Bigg] - \frac{\psi}{1-Nm\bar{q}}\,q'(\mathcal{S}(z)) = 0$$

2. $\theta\lambda\mathcal{P}(z;N)\frac{\phi'(\mathcal{S}(z))}{\phi(\mathcal{S}(z))}\,[A(\mathcal{S}(z)) - c(z)] < 0$: marginal reduction in trading probability

Efficiency

- Efficient specialization (implicit):

$$\theta\lambda\mathcal{P}(z;N)\Bigg[A'(\mathcal{S}(z)) + \frac{\phi'(\mathcal{S}(z))}{\phi(\mathcal{S}(z))}\Bigg(\,[A(\mathcal{S}(z)) - c(z)] - \mathbb{E}_{\max\{\tilde{z}\}\,|\,\max\{\tilde{z}\}<z}\,[A(\mathcal{S}(\tilde{z})) - c(\tilde{z})]$$

$$+(N-1)\exp\{-\lambda\hat{\phi}(\underline{z},z)\}\mathbb{E}[A-c]/f\Bigg)\Bigg] - \frac{\psi}{1-Nm\bar{q}}\,q'(\mathcal{S}(z)) = 0$$

3. $-\frac{\psi}{1-Nm\bar{q}}\,q'(\mathcal{S}(z)) < 0$: marginal increase in specialization cost

Efficiency

- Efficient specialization (implicit):

$$\theta\lambda\mathcal{P}(z;N)\Bigg[A'(\mathcal{S}(z)) + \frac{\phi'(\mathcal{S}(z))}{\phi(\mathcal{S}(z))}\Bigg([A(\mathcal{S}(z)) - c(z)] - \mathbb{E}_{\max\{\tilde{z}\}|\max\{\tilde{z}\}<z}[A(\mathcal{S}(\tilde{z})) - c(\tilde{z})]$$

$$+(N-1)\exp\{-\lambda\hat{\phi}(\underline{z},z)\}\mathbb{E}[A-c]/f\Bigg)\Bigg] - \frac{\psi}{1-Nm\bar{q}}\, q'(\mathcal{S}(z)) = 0$$

4. $-\theta\lambda\mathcal{P}(z;N)\frac{\phi'(\mathcal{S}(z))}{\phi(\mathcal{S}(z))}\mathbb{E}_{\max\{\tilde{z}\}|\max\{\tilde{z}\}<z}[A(\mathcal{S}(\tilde{z})) - c(\tilde{z})] > 0$: marginal increase in trading prob. of lower-productivity intermediates

Efficiency

Back

- Efficient specialization (implicit):

$$\theta\lambda\mathcal{P}(z;N)\Bigg[A'(\mathcal{S}(z))+\frac{\phi'(\mathcal{S}(z))}{\phi(\mathcal{S}(z))}\Bigg([A(\mathcal{S}(z))-c(z)]-\mathbb{E}_{\max\{\tilde{z}\}\mid\max\{\tilde{z}\}<z}[A(\mathcal{S}(\tilde{z}))-c(\tilde{z})]$$

$$+(N-1)\exp\{-\lambda\hat{\phi}(\underline{z},z)\}\mathbb{E}[A-c]/f\Bigg)\Bigg]-\frac{\psi}{1-Nm\bar{q}}\,q'(\mathcal{S}(z))=0$$

5. $\theta\lambda\mathcal{P}(z;N)\frac{\phi'(\mathcal{S}(z))}{\phi(\mathcal{S}(z))}(N-1)\exp\{-\lambda\bar{\phi}\}\mathbb{E}[A-c]/f<0$: marginal reduction in trading prob. of <u>other</u> inputs' providers

   Example: specialization of engine makers affecting tire makers because cars are less likely to be produced

Network Externality: Simple Example

Back

- $N = 2$, final producers only meet one intermediate at a time ($x = 0$)
- Intermediate 1 profits: $\Pi_1 = f(s_1)f(s_2)A(s_1)$
- Social welfare: $\mathcal{W} = f(s_1)f(s_2)[A(s_1) + A(s_2)]$
- Equilibrium specialization:

$$\underbrace{f(s_1^\star)A'(s_1^\star)}_{\text{private MB}} = \underbrace{(-f'(s_1^\star))A(s_1^\star)}_{\text{private MC}}$$

- Efficient specialization:

$$\underbrace{f(\mathcal{S}_1)A'(\mathcal{S}_1)}_{\text{social MB}} = \underbrace{(-f'(\mathcal{S}_1))[A(\mathcal{S}_1) + A(\mathcal{S}_2)]}_{\text{social MC}}$$

Decentralization

Targeted Transaction Subsidy

Back

Proposition (Decentralization)

The efficient allocation can be decentralized via a **targeted transaction tax schedule** $\tau(z)$ such that the price of the transactions is given by $\rho(z) = p(z) + \tau(z)$, where:

$$\tau(z) = \exp\{-\lambda\hat{\phi}(\underline{z}, z)\}T$$

$$T \equiv \Big(\mu(f;N)N - 1\Big)\mathbb{E}[A - c]/f \lesseqgtr 0 \ (> 0 \text{ if over-specialized eq'm})$$

$\implies$ price of lower-productivity firms is more distorted