Discussion of
“Innovation Networks and R&D Allocation”
Liu and Ma (2023)

Alireza Tahbaz-Salehi

Northwestern University

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Model on a Single Slide

- Household preferences:

$$V_t = \int_t^\infty e^{\rho(s-t)} \log y_s \mathrm{d}s$$

- Consumption good bundle:

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- Productivity growth:

$$\frac{\mathrm{d}}{\mathrm{d}t} \log q_{it} = \lambda \left[\gamma_i \log \bar{s} + \log \eta_i + \sum_{j=1}^{n} \omega_{ij} \log q_{jt} - \log q_{it} \right]$$

Results on a Single Slide

- Optimal targeting policy:

$$\gamma' = \frac{\rho}{\rho + \lambda}\beta' \left(\mathbf{I} - \frac{1}{1 + \rho/\lambda}\boldsymbol{\Omega} \right)^{-1}$$

  Targeting more upstream industries creates a benefit due to spillover effects.

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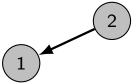

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- Welfare loss measure: entropy

$$\text{Loss} = \frac{\psi\lambda}{\rho}\sum_{i=1}^{n}\gamma_i(\log\gamma_i - \log b_i)$$

Empirical Results on a Few Slides

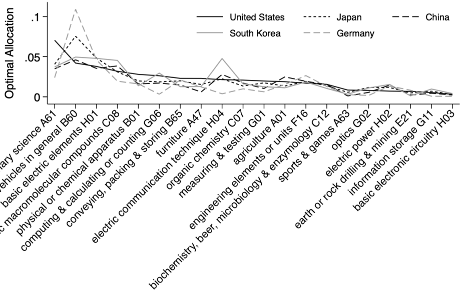
- Evidence for spillover effects: does "stock of past innovation" in upstream sectors predict innovation in sector i?

$$\log n_{i,t} = \beta_1 \log \text{R\&D}_{i,t-1} + \beta_2 \underbrace{\sum_{j \neq i} \sum_{\tau=1}^{10} \omega_{ij,t-\tau} \log n_{j,t-\tau}}_{\text{upstream innovation}} + \beta_3 \underbrace{\sum_{j \neq i} \sum_{\tau=1}^{10} \omega_{ji,t-\tau} \log n_{j,t-\tau}}_{\text{downstream innovation}}$$

$Y=$	ln(Patents)			
	(1)	(2)	(3)	(4)
$Knowledge_{it}^{Up}$	0.586***	0.600***	0.508***	0.679**
	(0.180)	(0.205)	(0.174)	(0.266)
$ln(R\&D)_{i,t-1}$	0.275***	0.274***	0.279***	0.269***
	(0.063)	(0.062)	(0.060)	(0.070)
$Knowledge_{it}^{Down}$		-0.029		
		(0.157)		
$Knowledge_{it}^{Up,IO}$			0.363**	
			(0.173)	

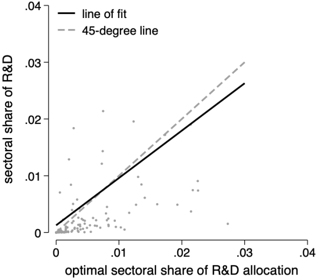
Empirical Results on a Few Slides

- Optimal R&D allocation:
  cross-country variation due to (i) different innovation networks (ii) difference in reliance on foreign innovation



Empirical Results on a Few Slides

- Mismatch between data and optimal allocation of innovation resources:



Very Impressive Paper

- Highly intuitive and tractable model
  - interpretable structural properties of the innovation network

- Easily maps to the data

- Convincing evidence for innovation spillovers

- Model and data go hand-in-hand $\Rightarrow \begin{cases} \text{optimal allocation of R\&D resources} \\ \text{measure of misallocation of resources} \end{cases}$

Comments

- A high-level overview of the mechanics of the underlying network model
- Measurement issues in network models

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- Measurement issues in network models

- **Warning**: too much linear algebra for an EFEG discussion

Dirty Little Secret of Network Models

All (Log-Linear) Network Models Are the Same

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- Reduced-form network model:

$$\log x_i = \log \gamma_i + \alpha \sum_{j=1}^{n} \omega_{ij} \log x_j$$

state variable
(price, productivity, etc.)

policy instrument
(taxes, R&D, etc.)

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- In vector form:

$$\log x = \log \gamma + \alpha \boldsymbol{\Omega} \log x$$
$$\Rightarrow \log x = (\mathbf{I} - \alpha \boldsymbol{\Omega})^{-1} \log \gamma.$$

- The network interactions propagate the effect of shocks/policy

All (Log-Linear) Network Models Are the Same

- Add a policy objective:

$$\max \quad \sum_{i=1}^{n} \beta_i \log x_i = \beta' (\mathbf{I} - \alpha \mathbf{\Omega})^{-1} \log \gamma$$

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- Solution:

$$\begin{aligned} \text{optimal policy:} \quad & \gamma_*' \propto \beta' (\mathbf{I} - \alpha \mathbf{\Omega})^{-1} \\ \text{opt. gap/misallocation:} \quad & \Delta \propto \gamma_*' (\log \gamma_* - \log \gamma). \end{aligned}$$

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- Two extremes:

$$\text{weak interactions } (\alpha \to 0): \quad \gamma_*' = \beta' \qquad \text{ignore the network}$$

$$\text{strong interactions } (\alpha \to 1): \quad \gamma_*' = \gamma_*' \boldsymbol{\Omega} \qquad \text{target eig. centrality}$$

Measurement Error in Innovation Network?

Innovation Network

- The analysis requires constructing the innovation network $\mathbf{\Omega}$.
- Constructed from patent citation data:

$$\omega_{ijt} = \frac{Cites_{ijt}}{\sum_k Cites_{ikt}}$$

where $Cites_{ijt}$ = number of times that patents in sector i cite patents in sector j

- But patent citation data can be very noisy:
  - are all innovation spillovers captured by patents?
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- **Can be** an issue because network centrality **can be** very sensitive to measurement error in the network

Network Measurement Error: Toy Example

$$\mathbf{\Omega} = \begin{bmatrix} 1-\epsilon & \epsilon \\ \delta & 1-\delta \end{bmatrix}$$

- Eigenvector centrality:

$$\gamma_1 = \frac{\delta}{\delta+\epsilon} \quad , \quad \gamma_2 = \frac{\epsilon}{\delta+\epsilon}.$$

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- Network centrality can be extremely sensitive to the particular type of measurement error.
- Remains the case even without any measurement bias!

Measurement Error

- Somewhat of an extreme example:
  - carefully chosen perturbation
  - a matrix with two eigenvalues close to 1:

$$\lambda_1 = 1 \quad , \quad \lambda_2 = 1 - (\epsilon + \delta).$$

- More generally, and to a first-order approximation, the sensitivity of centrality to measurement error depends on the difference between the two largest eigenvalues

- In Liu and Ma:

$$\lambda_1 = 1 \quad , \quad \lambda_2 = 0.85$$

- How worried one should be? Is there a way of quantifying how sensitive the centrality and the optimal policy are to network mismeasurement?

Measurement Error

Theorem (Funderlic and Meyer (1986))

Suppose $\widetilde{\boldsymbol{\Omega}} = \boldsymbol{\Omega} + \mathbf{E}$ *and let*

$$\gamma' \boldsymbol{\Omega} = \gamma' \qquad \textit{and} \qquad \widetilde{\gamma}' \widetilde{\boldsymbol{\Omega}} = \widetilde{\gamma}'.$$

If $\mathbf{A} = \mathbf{I} - \boldsymbol{\Omega}$, *then*

$$\max_i \{\gamma_i - \widetilde{\gamma}_i\} \leq \left(\max_{ij} |a^{\sharp}_{ij}| \right) \left(\max_i \sum_{j=1}^{n} |e_{ij}| \right)$$

- In the data: $\max_{ij} |a^{\sharp}_{ij}| = 4.8$
- so, missing the spillover effects by 0.05 in absolute values for one sector **may** result in an error **up to**

$$0.05 \times 4.8 = 0.24$$

Measurement Error in R&D Expenditures?

Sectoral R&D Allocation

- To measure welfare loss of misallocation, the paper needs to determine the actual R&D expenditure in the data

- **Measure used**: Aggregated firm-level R&D expenditures to the country-sector-year level from Compustat, Worldscope, and Datastream
  - oversamples large, publicly-listed firms
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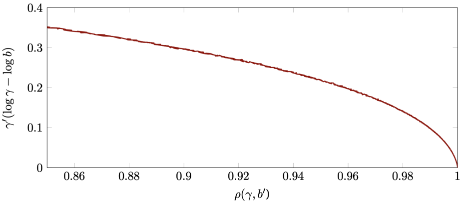
- Robustness check:
  - fraction of patents produced in each sector (correlation $= 0.74$)
  - OECD Analytical Business Enterprise Research and Development (ANBERD) Database (correlation $= 0.74$)

Innovation Allocation in the Data

- But a correlation 0.74 (or even higher) can generate gain/loss in the same order of magnitude as the welfare gains from moving to the model-implied optimal



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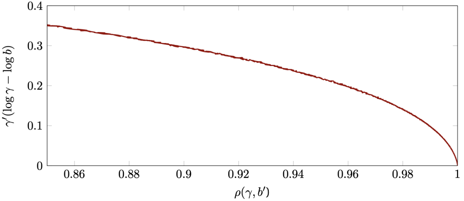
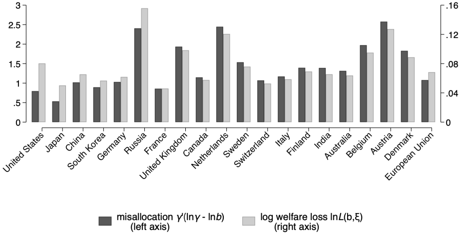


- Compare to entropy between optimal and "actual" in the paper

Figure 7. R&D Allocative Efficiency and Potential Welfare Gains Across Countries



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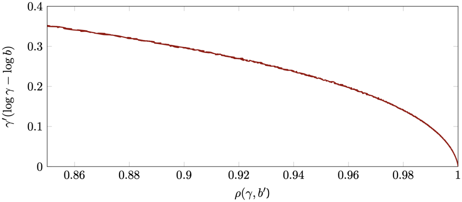

- exactly because of network effects,

high correlation $\not\Rightarrow$ small welfare loss

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- Innovation output instead of innovation input.

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- I think the paper should either
  (i) compare input to input: use the model to back out the implied allocation from patent output data
  (ii) compare output to output: use the model to calculate the innovation output from innovation input

Summary

- Very impressive paper
  - transparent and intuitive model
  - can be easily mapped to the data
  - impressive empirical results on the relevance of knowledge spillovers
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- Measurement error is a fact of life, but can become more problematic in the presence of network interactions
- Would be nice to get a sense of the extent the results are robust to measurement error (of the network and the actual R&D allocation in the data).