Investment Subsidies with Spillovers and Endogenous Private Information

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This paper

- Firms face uncertainty about return to investment in new technologies
  - unknown fundamentals
  - spillovers
- Uncertainty largely endogenous
  - firms can acquire information about fundamentals affecting profitability
- Combination of market power with firms' investment spillovers
  - inefficiency in information **acquisition** and **usage**
- How should policy be designed to alleviate inefficiencies?

Main take-aways

- Exogenous information
  - inefficiencies corrected with constant subsidy to innovative firms
- Endogenous information
  - **Pigouvian corrections**
- Insights extend to richer economies with nominal rigidities

Related Literature

- **Complementarities and investment spillovers**
  - Cooper and John (1988); Matsuyama (1991)
- **Corrective taxation in presence of externalities**
  - Sandmo (1975); Bovenberg and Goulder (1996); Barrage (2020)
- **(Pigouvian) subsidies in macro**
  - Heutel (2012); Grossman et al. (2013); Jeanne and Korinek (2019)
- **Policy with dispersed information**
  - Angeletos and Pavan (2009); Angeletos and La'O (2020); Angeletos, Iovino, and La'O (2020); Colombo, Femminis, and Pavan (2014); Llosa and Venkatesvaran (2022); Bergemann and Välimäki (2002)
- **Inefficiency in information acquisition**
  - Colombo, Femminis, Pavan (2014); Pavan (2017), Hebert and La'O (2020), Pavan, Sundaresan, Vives (2024)

Plan

1. Introduction
2. **Model (flexible prices)**
3. Efficiency
4. Optimal Fiscal Policy
5. Richer Economies (sticky prices)
6. Conclusions

Model

- Economy populated by
  - (measure 1) continuum of agents
  - (measure 1) continuum of monopolistically-competitive firms producing differentiated intermediate goods
  - competitive retail sector producing final good (using intermediate goods as inputs)
  - benevolent public authority controlling fiscal (and monetary) policy

Model

- Each firm run by single entrepreneur
  - chooses whether to upgrade technology for producing intermediate good $i \in [0,1]$

$$y_i = \begin{cases} \gamma\Theta\left(1+\beta N\right)^{\alpha} l_i^{\psi} \text{ if } n_i = 1 \text{ (new)} \\ \\ \Theta\left(1+\beta N\right)^{\alpha} l_i^{\psi} \quad \text{if } n_i = 0 \ \text{ (old)} \end{cases}$$

  - with $\gamma > 1$, $\beta \geq 0$, $\alpha \geq 0$, and $\psi \leq 1$
  - $N = \int n_i di$: **aggregate investment** in new technology
  - l_i undifferentiated labor
  - Θ: aggregate fundamentals
- Differential $y_i(n_i = 1) - y_i(n_i = 0)$ increasing in Θ and N
- Spillovers (within and across technologies)
- Cost of new technology: $k > 0$

Model

- Final good produced by competitive retail sector using CES technology

$$Y = \left(\int y_i^{\frac{v-1}{v}} di \right)^{\frac{v}{v-1}}$$

- Profits of competitive retail sector

$$\Pi = PY - \int p_i y_i di,$$

- P: price of final good
- p_i: price of intermediate good of variety i

Model (alternative production setup)

- Firms choose whether to produce intermediate goods in
  - traditional ($n_i = 0$)
  - "smart" (Industry 4.0) specification ($n_i = 1$)
- Each firm produces
$$y_i = l_i^{\psi}$$
- Final good:
$$Y = \Theta \left(1 + \beta N\right)^{\alpha} \left(\int \left(\left(1 - n_i + \gamma n_i\right) y_i\right)^{\frac{v-1}{v}} di \right)^{\frac{v}{v-1}},$$

with $\gamma > 1$

Model (alternative production setup)

- Smart specification increases production of final good
  - directly
  - enhancing interoperability/productivity of other intermediate goods, including those supplied in traditional specification
- Inputs produced under smart specification: higher price.

Model

- Each entrepreneur is member of representative household with utility

$$U = C - kN - \frac{l^{1+\varepsilon}}{1+\varepsilon} - \int \mathcal{I}(\pi_i^x)di$$

→ C: consumption

→ $l^{1+\varepsilon}/(1+\varepsilon)$, $\varepsilon > 0$: disutility of labor

→ Homogenous labor exchanged in competitive market

→ Each worker provides same amount of labor

→ $I(\pi_i^x)$: disutility of acquiring information of precision π_i^x

Model

- Representative household collects profits and wages and purchases final good under **budget constraint**

$$C \leq \int \left(\frac{p_i y_i - W l_i}{P} + T_i \right) di + \frac{W}{P} \int l_i di - \Upsilon$$

$\rightarrow$ W: nominal wage rate,

$\rightarrow$ Υ: lump-sum tax (consumption of final good)

$\rightarrow$ T_i: transfer to firm i (consumption of final good) as fn of whether firm invested or not, and real revenues $r = p_i y_i / P$

Model

- Each entrepreneur maximizes firm's market valuation

$$\mathbb{E}\left[\frac{p_i y_i - W l_i}{P} + T_i - k n_i - \mathcal{I}(\pi_i^x)\right]$$

- Government maximizes welfare

$$\mathcal{W} = \mathbb{E}\left[C - kN - \frac{l^{1+\varepsilon}}{1+\varepsilon} - \mathcal{I}(\pi^x)\right]$$

by designing fiscal (and monetary) policies

Model - Timing

1. Government announces its policies
2. Nature draws $\theta = \ln(\Theta)$
3. Each entrepreneur chooses precision π_i^x of private signal $x_i = \theta + \xi_i$ (with $\xi_i \backsim N(0, 1/\pi_i^x)$)
4. Entrepreneurs simultaneously choose n_i after observing x_i
5. θ and N publicly revealed
6. Entrepreneurs simultaneously set prices p_i
7. Retail sector chooses demand y_i of each intermediate good, taking prices of intermediate goods p_i and price of final good P as given
8. Each entrepreneur hires l_i on competitive labor market to produce y_i (taking N and θ as given)
9. Representative household purchases final good, taking P as given

Equilibrium and Optimality

- Prices and employment depend on technology choice
  - old technology: $p_0\left(\theta; \pi^x\right)$ and $l_0\left(\theta; \pi^x\right)$
  - new technology: $p_1\left(\theta; \pi^x\right)$ and $l_1\left(\theta; \pi^x\right)$

Definition

Equilibrium is precision π^x along with $n(x; \pi^x)$, $p_0(x; \pi^x)$ and $p_1(x; \pi^x)$ s.t., when each firm $j \neq i$, chooses π^x and then invests according to $n(x; \pi^x)$ and sets prices $p_0(\theta; \pi^x)$ and $p_1(\theta; \pi^x)$, each entrepreneur i maximizes her mkt valuation by doing the same.

Model

- Key features:
  1. **endogeneity of private information**
  2. **investment spillovers**

Plan

Decentralized Efficiency: Efficient Information Use

- Suppose precision fixed at π^x for all i
- Efficient use of information:
  - $\hat{n}(x; \pi^x)$: investment
  - $\hat{l}_1(x, \theta; \pi^x)$, $\hat{l}_0(x, \theta; \pi^x)$: employment
- $\hat{N}(\theta; \pi^x)$: efficient aggregate investment
- $\hat{C}(\theta; \pi^x)$: efficient consumption of final good

Efficient Information Use

- $y_i = (\gamma n_i + (1 - n_i))\Theta\,(1 + \beta N)^{\alpha}\, I_i^{\psi}$
- $Y = \left(\int y_i^{\frac{v-1}{v}}\, di\right)^{\frac{v}{v-1}}$

Definition

Production is regular if $\gamma^{\frac{v-1}{v-\psi(v-1)}} \geq 1 + \beta$ and $\psi < \min\left\{1, \frac{1+\varepsilon}{\varepsilon(v-1)}\right\}$.

Lemma

Under regularity, for any π^x, there exists $\hat{x}(\pi^x)$ s.t. efficiency in technology adoption requires investing iff $x > \hat{x}(\pi^x)$.

Efficient Information Acquisition

- **Efficient precision** π^{x*} computed with envelope theorem taking efficient rules $\hat{n}\left(\theta;\pi^{x*}\right)$, $\hat{l}_0\left(\theta;\pi^{x*}\right)$ and $\hat{l}_1\left(\theta;\pi^{x*}\right)$ fixed.

Plan

Optimal Fiscal Policy: Exogenous Information

Definition

Fiscal policy T **optimal** if it induces all firms to invest according to efficient rule $\hat{n}(x; \pi^x)$ and set prices $\hat{p}_1(\theta; \pi^x)$ and $\hat{p}_0(\theta; \pi^x)$ generating demands inducing efficient employment $\hat{l}_1(\theta; \pi^x)$ and $\hat{l}_0(\theta; \pi^x)$.

Optimal Fiscal Policy: Exogenous Information

- $\mathcal{R}(\theta;\pi^x)$: private benefit of investing, net of subsidy and cost

Lemma

Optimal policy T pays non-investing firms

$$T_0(r) = \frac{1}{v-1}r$$

and investing firms

$$T_1(r,\theta) = \frac{1}{v-1}r + s(\theta)$$

with **additional subsidy** $s(\theta)$ *s.t.*

- $\mathbb{E}\left[\mathcal{R}(\theta;\pi^x)|x,\pi^x\right] < 0$ *when* $x < \hat{x}(\pi^x)$
- $\mathbb{E}\left[\mathcal{R}(\theta;\pi^x)|x,\pi^x\right] > 0$ *when* $x > \hat{x}(\pi^x)$

Optimal Fiscal Policy: Exogenous Information

- Familiar revenue subsidy $r/(v-1)$ offsets mkt power
- Additional subsidy $s(\theta)$ corrects for inefficiencies due **spillovers**

Optimal Fiscal Policy: Exogenous Information

- $\mathcal{Q}(\theta;\pi^x)$: social benefit of investing
- Private benefit

$$\mathcal{R}(\theta;\pi^x) = \mathcal{Q}(\theta;\pi^x) - \frac{\alpha\beta\hat{C}(\theta;\pi^x)}{1+\beta\hat{N}(\theta;\pi^x)} + s(\theta)$$

where **spillover externality**

$$\frac{\alpha\beta\hat{C}(\theta;\pi^x)}{1+\beta\hat{N}(\theta;\pi^x)}$$

is equal to increase in production of final good when N increases around efficient level $\hat{N}(\theta;\pi^x)$, holding fixed firms' investment and employment decisions

Optimal Fiscal Policy: Exogenous Information

- Many subsidies $s(\theta)$ realign incentives
  - some simpler than others...

Corollary

When info is exogenous, **constant subsidy** *to investing firms (over and above* $r/(v-1)$*) is optimal.*

Optimal Fiscal Policy: Exogenous Information

- Constant (state invariant) subsidy is equal to spillover externality

$$\bar{s}_{\pi^x} \equiv \mathbb{E}\left[\frac{\alpha\beta\hat{C}\left(\theta;\pi^x\right)}{1+\beta\hat{N}\left(\theta;\pi^x\right)} \middle| \hat{x}(\pi^x), \pi^x \right]$$

  expected by marginal investor, with signal $\hat{x}(\pi^x)$

- Marginal agent indifferent

- Because private benefit

$$\mathcal{R}(\theta;\pi^x) = \mathcal{Q}(\theta;\pi^x) - \frac{\alpha\beta\hat{C}\left(\theta;\pi^x\right)}{1+\beta\hat{N}\left(\theta;\pi^x\right)} + \bar{s}_{\pi^x}$$

  monotone in θ, firms invest iff $x > \hat{x}(\pi^x)$, which is efficient

Optimal Fiscal Policy: Endogenous Information

Definition

When info is endogenous, policy T^* **optimal** if it induces all firms to

1. choose efficient precision π^{x*}
2. invest efficiently according to $\hat{n}(x; \pi^{x*})$
3. set prices $\hat{p}_1(\theta; \pi^{x*})$ and $\hat{p}_0(\theta; \pi^{x*})$ that induce efficient demands and hence efficient employment $\hat{l}_1(\theta; \pi^{x*})$ and $\hat{l}_0(\theta; \pi^{x*})$

Optimal Fiscal Policy: Endogenous Information

- $\partial \hat{N}(\theta; \pi^{x*}) / \partial \pi^x$: variation in investing firms at θ due to change in π_x (holding fixed efficient investment rule $\hat{n}(x; \pi^{x*})$)

Lemma

Additional subsidy $s(\theta)$ to investing firms must satisfy

$$\mathbb{E}\left[s(\theta) \middle| \hat{x}(\pi^{x*}), \pi^{x*} \right] = \mathbb{E}\left[\frac{\alpha\beta\hat{C}(\theta; \pi^x)}{1+\beta\hat{N}(\theta; \pi^x)} \middle| \hat{x}(\pi^{x*}), \pi^{x*} \right]$$

$$\mathbb{E}\left[s(\theta) \frac{\partial \hat{N}(\theta; \pi^{x*})}{\partial \pi^x} \right] = \mathbb{E}\left[\frac{\alpha\beta\hat{C}(\theta; \pi^{x*})}{1+\beta\hat{N}(\theta; \pi^{x*})} \frac{\partial \hat{N}(\theta; \pi^{x*})}{\partial \pi^x} \right].$$

- Co-variance condition essential to realign incentives for acquisition

Optimal Fiscal Policy: Endogenous Information

Theorem

Independently of whether economy is regular, fiscal policy

$$T_0\left(r\right)=\frac{1}{v-1}r$$

$$T_1\left(r,\theta\right)=\frac{1}{v-1}r+s\left(\theta\right)$$

with state-contingent subsidy

$$s(\theta)=\frac{\alpha\beta\hat{C}\left(\theta;\pi^{x*}\right)}{1+\beta\hat{N}\left(\theta;\pi^{x*}\right)}$$

to investing firms induces efficiency in both acquisition and usage of information.

Optimal Fiscal Policy: Endogenous Information

- State-contingent subsidy

$$s(\theta) = \frac{\alpha\beta\hat{C}\left(\theta;\pi^{x*}\right)}{1+\beta\hat{N}\left(\theta;\pi^{x*}\right)}$$

  equals ex-post spillover externality, i.e., marginal change in final good production generated by marginal change in N at $\hat{N}\left(\theta;\pi^{x*}\right)$, holding firms' investment and employment rules fixed at efficient level.

- $s(\theta)$: **Pigouvian correction**

- Known fact: Pigouvian subsidies work well under complete information

- Contribution: they also induce efficient info acquisition and usage (neither verifiable)

Optimal Fiscal Policy: Endogenous Information

- Subsidy

$$s(\theta) = \frac{\alpha\beta\hat{C}\left(\theta; \pi^{x*}\right)}{1 + \beta\hat{N}\left(\theta; \pi^{x*}\right)}$$

  requires knowing π^{x*} and hence cost of information $I(\pi_x)$

- More generally, government must be familiar with information technology

- Difficulty bypassed by conditioning s on distribution Λ of
  - investing firms
  - employment decisions

Optimal Fiscal Policy: Endogenous Information

- $C_N(\theta, \Lambda)$: marginal change in C due to marginal change in N holding investment and employment decisions fixed at level specified by Λ

Theorem

Efficiency in both info acquisition and usage induced through fiscal policy

$$T_0(r) = \frac{1}{v-1} r, \quad T_1(r, \theta, \Lambda) = \frac{1}{v-1} r + s(\theta, \Lambda)$$

with

$$s(\theta, \Lambda) = C_N(\theta, \Lambda).$$

Optimal Fiscal Policy: Endogenous Information

- Subsidy equal to **ex-post spillover externality** given
  - fundamentals θ
  - cross-section distribution of firms' investment and employment
- Planner leaves it to firms to figure out efficient allocation
  - no need to know information technology/costs

Plan

Richer Economies

- Representative household's utility

$$U = \frac{C^{1-R}}{1-R} - kN - \frac{l^{1+\varepsilon}}{1+\varepsilon} - \int \mathcal{I}(\pi_i^x)di$$

with $R > 0$ in case agents are **risk averse**

- **Sticky prices**
  - p_i set under imperfect information

Richer Economies

- Money plays a role

- Money supply $M(\theta)$ used to meet "**cash-in-advance**" constraint

$$PY \leq M$$

Richer Economies: Optimal fiscal *and monetary* policy

Theorem

Above fiscal policies along with monetary policy that induces firms to disregard their private info when setting prices and only use it for investment purposes implements efficient acquisition and usage of information as a sticky-price equilibrium.

Richer Economies: Optimal fiscal *and monetary* policy

- Familiar monetary policy + novel Pigouvian corrections induce efficiency in
  - info acquisition
  - investment
  - employment
  - production and consumption of intermediate and final goods

Conclusions

- Power of **Pigouvian corrections** extends to economies with endogenous and dispersed information
- Exogenous information + regularity
  - constant subsidy
- In general, subsidy to investing firms
  - state-dependent
  - contingent on distribution of investment and employment decisions

Most Important Slide

Thank You!