Subsidies to Innovation with Endogenous Uncertainty

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This Paper

- Firms face uncertainty about the returns to their investment in new technologies
- The return to investment depends on both unknown fundamentals and the investment decisions of other firms
- Uncertainty is largely endogenous: firms can acquire information about the fundamentals affecting profitability
- The combination of market power with firms' investment spillovers makes it unlikely that they will acquire and use information efficiently

$\Rightarrow$ How should policy be designed to alleviate the inefficiencies?

Main take-aways

1. Under exogenous information, inefficiencies in investment can be corrected with a constant subsidy to innovative firms, along with a subsidy that corrects for firms' market power
2. Under endogenous information, inefficiencies in both the acquisition of information and investment decisions must be corrected with a Pigouvian policy conditioning subsidies on the investment in the new technology
3. (Optimal) policies with exogenous information need not be optimal with endogenous information
4. The insights extend to richer economies with both nominal and real rigidities in which firms make investment decisions and set prices under endogenous dispersed information

Related Literature

- **Investment under uncertainty**
  - → Dixit and Pindyck (1994)
- **Subsidies to innovation**
  - → Akcigit, Caicedo, Miguelez, Stantcheva, and Sterzi (2018); Akcigit, Hanley, and Stantcheva (2021); Akcigit, Grigsby, Nicholas, and Stantcheva (2022))
- **Policy with dispersed Information**
  - → Angeletos and Pavan (2009); Paciello and Wiederholt (2013); Angeletos, Iovino, and La'O (2016); Colombo, Femminis, and Pavan (2014)
- **Inefficiency in information acquisition**
  - → Colombo, Femminis, Pavan (2014); Pavan (2017); Hebert and La'O (2020)

Plan

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Model

- We focus on an economy populated by
  - $\longrightarrow$ a (measure 1) continuum of agents
  - $\longrightarrow$ a (measure 1) continuum of monopolistically-competitive firms producing differentiated intermediate goods
  - $\longrightarrow$ a competitive retail sector producing the final good (using the intermediate goods as inputs)
  - $\longrightarrow$ a benevolent planner controlling fiscal (and monetary) policy

Model

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

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

    with $\gamma > 1$, $\beta \geq 0$, $\alpha \geq 0$, $\psi \leq 1$
  - $\longrightarrow$ $N = \int n_i di$: aggregate investment in new technology
  - $\longrightarrow$ l_i: undifferentiated labor
  - $\longrightarrow$ the decision is taken under imperfect information about fundamentals (Θ)
- Differential $y_i(n_i = 1) - y_i(n_i = 0)$ increasing in Θ and N
- Dependence on N: spillover (within and across technologies)
- Cost of new technology: $k > 0$ (cost of exerting effort $n_i = 1$ in utility terms)

Model

- The final good is produced by a competitive retail sector using a 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

- Each entrepreneur maximizes her firm's profits (which are then used to finance the purchase of the final consumption good)

$$\Pi_i = \frac{p_i y_i - W l_i}{P} + T - k n_i - \mathcal{I}(\pi_i^x)$$

  - $\longrightarrow$ W: wage rate
  - $\longrightarrow$ T: transfer to the firm in terms of the final consumption good
  - $\longrightarrow$ $l_i = l$ for each agent, consistent with a single competitive market for late labor and the marginal disutility of labor being the same for every agent
  - $\longrightarrow$ $\mathcal{I}(\pi^x)$: disutility of acquiring information of precision π^x, $\mathcal{I}' > 0$, $\mathcal{I}'' \geq 0$, $\mathcal{I}'(0) = 0$

Model

- Each worker uses labor income to purchase the final consumption good by maximizing

$$U = \frac{W}{P} l - \frac{l^{1+\varepsilon}}{1+\varepsilon} - \Upsilon$$

  - → $l^{1+\varepsilon}/(1+\varepsilon)$: disutility of labor
  - → Υ: tax collected by the government (budget is balanced: $\int T_i di = \Upsilon$)

- The benevolent planner maximizes the ex-ante sum of firms' profits and of all workers' utilities

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

  - → C: total consumption of the final good (coinciding with its production Y)
  - → The planner maximizes aggregate consumption, net of the costs to upgrade the technology, the labor costs, and the information-acquisition costs

Model: Timing

1. Nature draws $\theta \equiv \log \Theta$ from $\mathcal{N}(\theta_0, \pi_\theta^{-1})$; θ unobserved by all agents
2. Each entrepreneur i chooses π_i^x and then receives signal $x_i = \theta + \xi_i$, with ξ_i drawn from $\mathcal{N}\left(0, (\pi_i^x)^{-1}\right)$, independently from θ and independently across i
3. Each entrepreneur chooses (after observing x_i but without observing θ or the choices of other entrepreneurs) whether to upgrade technology
4. After θ and N are revealed, entrepreneurs simultaneously set prices p_i
5. Retail sector chooses demand y_i of each intermediate good to purchase (taking all p_i and P as given)
6. Given the demand for y_i, entrepreneur i hires l_i to meet demand (taking N and θ as given)
7. A representative household comprising all workers and entrepreneurs chooses how much of the final good to buy (taking P as given)

Model

- Note that

  1. All firms set prices under complete information about θ
  2. Money – used to finance the relevant transactions – has only a nominal effect on prices and plays no other role (it can be omitted)

- Our economy has two distinctive features

  1. The endogeneity of firms' private information
  2. The complementarity in firms' investment decisions (investment spillovers)

Decentralized Efficiency: Efficient Information Use

- Suppose that the precision of private information is given and equal to π^x for all i

- The **efficient use of private information** (for the economy with precision π^x) is given by a pair of functions $\hat{n}(x;\pi^x)$ and $\hat{l}(x,\theta;\pi^x)$ that jointly maximize the ex-ante expectation of $\mathcal{W}$ subject to the technology constraints

Efficient Information Use

- Efficient upgrade policy: for any precision of private information π^x, there exists a constant $\hat{x}(\pi^x)$ such that $\hat{n}(x;\pi^x) = \mathbb{I}(x \geq \hat{x}(\pi^x))$
- Let $\varphi \equiv \frac{v-1}{v+\psi(1-v)}$, and assume that γ and α are sufficiently large. The threshold $\hat{x}(\pi^x)$, along with the functions $\hat{N}(\theta;\pi^x)$, $\hat{l}_1(\theta;\pi^x)$, and $\hat{l}_0(\theta;\pi^x)$ satisfy

$$\mathbb{E}\left[\psi^{\frac{\psi}{1+\varepsilon-\psi}}\left(\Theta\left(1+\beta\hat{N}(\theta;\pi^x)\right)^{\alpha}\left(\left(\gamma^{\varphi}-1\right)\hat{N}(\theta;\pi^x)+1\right)^{\frac{1}{\varphi}}\right)^{\frac{1+\varepsilon}{1+\varepsilon-\psi}}\times\right.$$

$$\left.\times\left(\frac{\gamma^{\varphi}-1}{\varphi\left(\left(\gamma^{\varphi}-1\right)\hat{N}(\theta;\pi^x)+1\right)}+\frac{\alpha\beta}{1+\beta\hat{N}(\theta;\pi^x)}\right)\middle|\hat{x}(\pi^x),\pi^x\right]=k,$$

$$\hat{N}(\theta;\pi^x) = 1-\Phi\left(\hat{x}(\pi^x)|\theta;\pi^x\right)$$

$$\hat{l}_0(\theta;\pi^x) = \psi^{\frac{1}{1+\varepsilon-\psi}}\left(\Theta\left(1+\beta\hat{N}(\theta;\pi^x)\right)^{\alpha}\right)^{\frac{1}{1+\varepsilon-\psi}}\times$$

$$\times\left(\gamma^{\varphi}\hat{N}(\theta;\pi^x)+1-\hat{N}(\theta;\pi^x)\right)^{\frac{1+\varepsilon-v\varepsilon}{(v-1)(1+\varepsilon-\psi)}}$$

$$\hat{l}_1(\theta;\pi^x) = \gamma^{\varphi}\hat{l}_0(\theta;\pi^x)$$

Efficient Information Acquisition

- The **efficient acquisition of private information** is a precision π^{x*} that maximizes the ex-ante expectation of $\mathcal{W}$ when, for any π^x, the firms' decisions are determined by the functions $\hat{n}(x;\pi^x)$, $\hat{l}_1(\theta;\pi^x)$, and $\hat{l}_0(\theta;\pi^x)$

- The efficient acquisition of private information is implicitly defined by the solution to

$$\underbrace{\mathbb{E}\left[C^*(\theta)\left(\frac{\alpha\beta}{1+\beta N^*(\theta)}+\frac{v}{v-1}\frac{(\gamma^\varphi-1)}{((\gamma^\varphi-1)N^*(\theta)+1)}\right)\frac{\partial\hat{N}(\theta;\pi^{x*})}{\partial\pi^x}\right]}_{\textit{effect on consumption}}+$$

$$+\underbrace{\mathbb{E}\left[l_0^*(\theta)^{1+\varepsilon}\left[(\gamma^\varphi-1)N^*(\theta)+1\right]^\varepsilon(\gamma^\varphi-1)\frac{\partial\hat{N}(\theta;\pi^{x*})}{\partial\pi^x}\right]}_{\textit{effect on the disutility of labor}}+$$

$$-k\mathbb{E}\left[\frac{\partial\hat{N}(\theta;\pi^{x*})}{\partial\pi^x}\right]=\frac{d\mathcal{I}(\pi^{x*})}{d\pi^x}$$

where $x^*\equiv\hat{x}(\pi^{x*})$, $l_0^*(\theta)\equiv\hat{l}_0(\theta;\pi^{x*})$, and $N^*(\theta)\equiv\hat{N}(\theta;\pi^{x*})$, whereas $\hat{N}(\theta;\pi^{x*})=\int\hat{n}(x;\pi^{x*})\,d\Phi(x|\theta,\pi^{x*})$

Equilibrium and Optimality

- Decisions are set in a decentralized and non-cooperative manner, with each entrepreneur maximizing her firm's profits
- Firms choose their investment, n, under dispersed information about θ, and then set the price for their product – $p_1(\theta; \pi^x)$ and $p_0(\theta; \pi^x)$ – and adjust their demand of labor – $l_1(\theta; \pi^x)$ and $l_0(\theta; \pi^x)$ – to meet the demand for their product after observing θ and N and given the precision of private information π^x
- Given the fiscal policy $T(\cdot)$, a (decentralized) **equilibrium** is a precision π^x along with $n(x; \pi^x)$, $p_0(x; \pi^x)$ and $p_1(x; \pi^x)$ such that, when each firm $j \neq i$, chooses a precision of information equal to π^x and then chooses its technology following the rule $n(x; \pi^x)$ and its price following the rules $p_0(\theta; \pi^x)$ and $p_1(\theta; \pi^x)$, each entrepreneur i maximizes her payoff by doing the same
- **Optimality**: the fiscal rule $T^*(\cdot)$ is optimal if it implements the efficient acquisition and usage of information as an equilibrium

Optimal Fiscal Policy: Exogenous Information

- Under exogenous information, the following fiscal policy is optimal

$$\hat{T}_1(r) = \bar{s}_{\pi^x} + \frac{1}{v-1} r \qquad \hat{T}_0(r) = \frac{1}{v-1} r$$

where the fixed subsidy $\bar{s}_{\pi^x}$ is given by

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

1. Revenue subsidy correcting for market power distortion: inversely related to elasticity of demand and proportional to firm's revenue
2. Transfer $\bar{s}_{\pi^x}$ inducing firms to internalize the marginal effect of an expansion of N on the output that other firms can produce (guaranteeing that each firm with signal $\hat{x}(\pi^x)$ is indifferent between retaining the old technology and adopting the new one)
3. When the fiscal rule takes the simple form above, following the efficient rule is optimal for each firm expecting the other firms to follow the same rule

Optimal Fiscal Policy: Endogenous Information

- Under endogenous information, optimal policies need not only to induce firms to use information efficiently, but also to acquire the efficient amount of private information π^{x*}

- The fiscal rule

$$T_0^*(r) = \frac{1}{v-1} r \qquad T_1^*(\theta, r) = s(\theta) + \frac{1}{v-1} r$$

is optimal if the subsidy $s(\theta)$ is non-decreasing and satisfies the following two conditions

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

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

⇒ The simple policy that guarantees efficiency in the use of information under exogenous information (based on the constant subsidy $\bar{s}_{\pi^x}$) fails to guarantee efficiency in information acquisition

Optimal Fiscal Policy: Endogenous Information

- The fiscal policy $T_0^*(r)$ and $T_1^*(\theta, r)$ with the state-contingent subsidy

$$s(\theta) = C^*(\theta) \frac{\alpha\beta}{1 + \beta N^*(\theta)}$$

induces efficiency in both the acquisition and usage of information

⇒ $s(\theta)$ coincides with the marginal change in the production of the final good as a result of a marginal change in N, evaluated at $N^*(\theta)$ (holding firms' technology choice and labor demand fixed at the efficient level)

⇒ $s(\theta)$ operates as a Pigouvian correction that induces each firm to internalize the effect of its technology adoption on the output produced by other firms

⇒ That Pigouvian subsidies correct decisions under complete information is familiar; that they induce efficiency in the acquisition and use of information in economies in which information is dispersed and endogenous is novel

Optimal Fiscal Policy: The Power of the Pigouvian Logic

- Efficiency in information acquisition and usage can also be induced by conditioning the transfer to the innovating firms directly on the cross-sectional distribution Λ of firms' technology and employment decisions:

$$T_0^{\#}(r) = \frac{1}{v-1} r \qquad T_1^{\#}(\theta, r, \Lambda) = \frac{\delta C(\theta, \Lambda)}{\delta N} + \frac{1}{v-1} r$$

$\Rightarrow$ By announcing that innovating firms will receive a subsidy equal to the ex-post externality that each firm's technology adoption exerts on the production of the final good, the planner re-aligns firms' objective with total welfare non just at the interim stage but ex-post

$\Rightarrow$ If firms understand what efficiency entails, the planner can leave it to them to figure out the efficient allocation (the choice of the information structure and of the technology-adoption rule that jointly maximize total welfare)

Richer Economies

- Our results extend to richer families of economies in which agents are risk-averse and firms set prices under imperfect information about the underlying fundamentals
  - $\longrightarrow$ Entrepreneur belong to the representative household with utility function

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

  - $\longrightarrow$ Each firm maximizes her firm's *market value*

$$\mathbb{E}\left[C^{-R} \left(\frac{p_i y_i - W l_i}{P} + T \right) \middle| x_i, \pi_i^x \right] - kn_i - \mathcal{I}(\pi_i^x)$$

  - $\longrightarrow$ The household is endowed with an amount M of money and faces a '*cash-in-advance*' constraint such that $PY \leq M$
  - $\longrightarrow$ The benevolent planner chooses a monetary policy rule $M(\theta)$ and a fiscal policy rule T to maximize the ex-ante utility of the representative household

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

  - $\longrightarrow$ Prices are set under dispersed information about θ (i.e. based on x_i) and the supply of money $M(\theta)$ is state-dependent

Richer Economies: Optimal Policy

- The presence of nominal rigidities introduces a role for monetary policy
- The fiscal policy

$$T_0^*(r) = \frac{1}{v-1} r \qquad T_1^*(\theta, r) = C^*(\theta) \frac{\alpha\beta}{1+\beta N^*(\theta)} + \frac{1}{v-1} r$$

along with the monetary policy

$$M^*(\theta) = m l_0^*(\theta)^{1+\varepsilon} \left(\left(\gamma^{\varphi} - 1 \right) N^*(\theta) + 1 \right)^{\frac{(1+\varepsilon)(v-1)+R-1}{(v-1)(1-R)}}$$

implement the efficient acquisition and usage of information as a sticky-price equilibrium

⇒ The monetary policy $M^*(\theta)$ neutralizes the effects of price stickiness by replicating the same allocations as under flexible prices

⇒ The fiscal policy $(T_0^*(r), T_1^*(\theta, r))$ offsets market power with the revenue subsidy $r/(1-v)$ and realigns the firms' private value of upgrading their technology to the social value through the Pigouvian subsidy $s(\theta)$ to the innovating firms

⇒ Taken together, $(T_0^*(r), T_1^*(\theta, r))$ and $M^*(\theta)$ guarantee that firms choose optimally which technology to operate and then set prices that induce the efficient production of the intermediate and final goods

Conclusions

- Efficiency in the acquisition and use of information can be induced through an optimal fiscal policy entailing
  - A standard revenue subsidy correcting for market power
  - A Pigouvian subsidy to innovating firms that makes them internalizing the effects of the investment in new technology on the production of intermediate and final goods

    $\Rightarrow$ Policies that guarantee efficiency in the use of information need not guarantee efficiency in information acquisition

    $\Rightarrow$ The optimal fiscal policy can be invariant in state with exogenous information (under risk neutrality) but it must be state-dependent with endogenous information
- The key contribution of the paper is to show that the power of Pigouvian corrections extends to economies with endogenous and dispersed information

Most Important Slide

THANKS!