Optimal Taxation and R&D Policies

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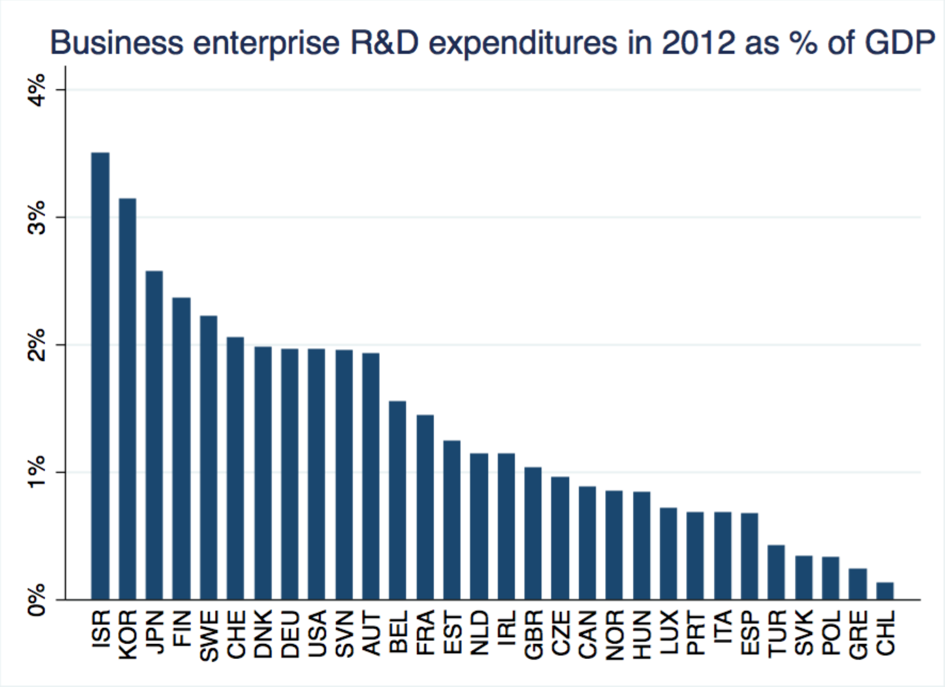
Motivation: Widespread R&D and Industrial Policies

- Industrial policies are widespread, costly and not fully understood.
- EU: 9.6% of EU GDP on industrial policies in 2010.
- Lots of policies target **innovation and R&D**.


Business enterprise R&D expenditures in 2012 as % of GDP
4%
3%
2%
1%
0%
ISR
KOR
JPN
FIN
SWE
CHE
DNK
DEU
USA
SVN
AUT
BEL
FRA
EST
NLD
IRL
GBR
CZE
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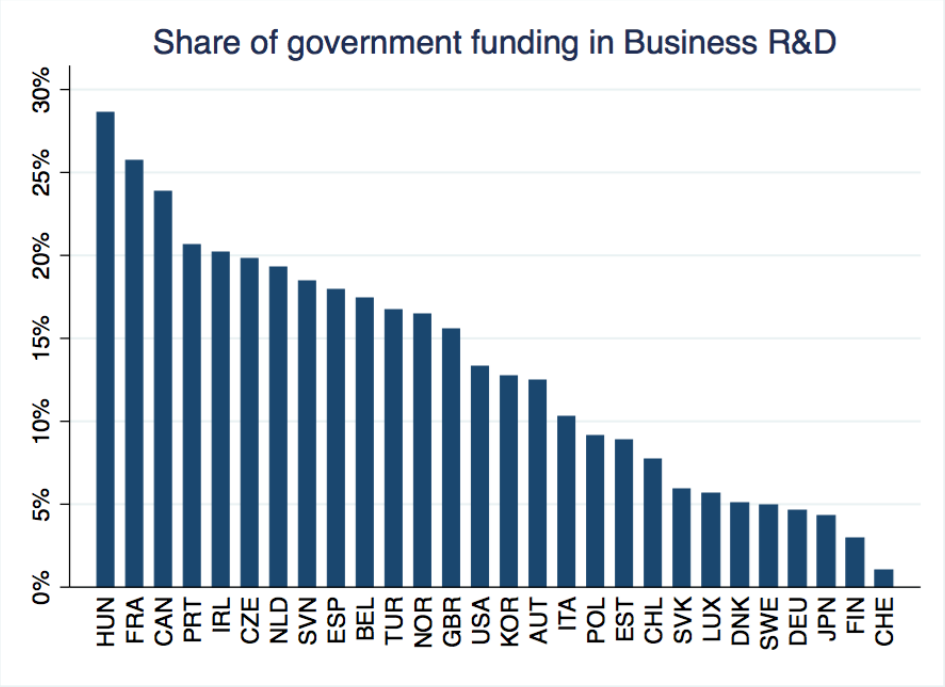
Share of government funding in Business R&D
30%
25%
20%
15%
10%
5%
0%
HUN
FRA
CAN
PRT
IRL
CZE
NLD
SVN
ESP
BEL
TUR
NOR
GBR
USA
KOR
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ITA
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Goal: Optimal Design of R&D and Corporate Taxation

- Little agreement on how effective these policies are and how to design them.
- In this paper: Optimal R&D and Corporate Taxation Policies.
  - Consider heterogeneous firms $\rightarrow$ Firm quality is **private information**.
  - Firm faces uncertainty about its quality over time.
  - R&D returns are stochastic.
  - **Spillovers** between firms.
  - Do not restrict policies ex ante: let optimal policy tools arise endogenously.
  - First: optimal mechanism design, then consider "simpler" policies.

What we do:

- Model of R&D and endogenous growth with heterogeneous firms.
- Mechanism design setup: Firms are agents, government is the Principal.
- Derive analytically fully unrestricted optimal dynamic mechanism $\rightarrow$ characterize allocations using "wedges" or implicit taxes and subsidies.
- Estimate important parameters of the model using patent data matched to Compustat (not yet today)
  - Numerically illustrate life cycle path of optimal policies for firms (by age, quality..).
- How well do simpler policies perform (linear size-independent age-dependent, linear size and age-independent policies, etc..).
  - Formulas in terms of "sufficient statistics."

Related Literature

R&D Policies and Growth: Acemoglu, Akcigit, Bloom and Kerr (2013), Atkeson and Burstein (2014), Lentz and Mortensen (2015).

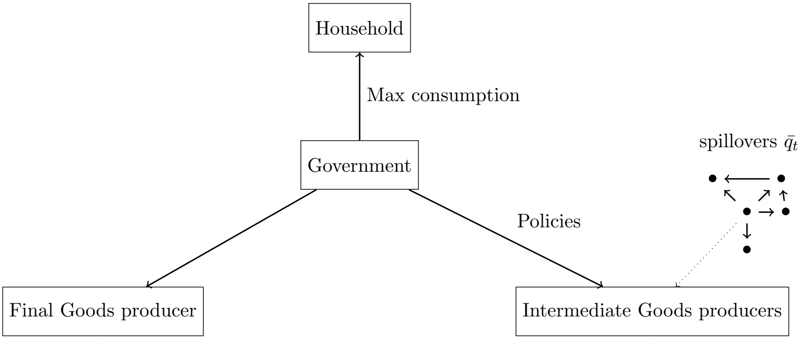
Empirics of R&D Policies: Bloom, Griffith, Van Reenen (2000), Criscuolo *et al.* (2013), Hall (1992), Goolsbee (1998), Romer (2001), Wilson (2009)

Optimal Policy Design: Hopenhayn and Nicolini (1997), Golosov, Tsyvinski and Werning (2006), Shourideh (2012), Farhi and Werning (2013, 2014), Stantcheva (2014), Pavan, Segal and Toikka (2013).

Outline

Outline

Model: Summary



$Y(\bar{q}_t) = \int_{\Theta^t} k(\theta^t)^{1-\beta} q(\theta^t)^{\beta} p(\theta^t)\, d\theta^t$

- Manager: effort l_t
- R&D : $q(\theta^t) = q(\theta^{t-1}) + \lambda_t(r(\theta^{t-1}), l(\theta^t), \theta_t)$
- Produce $k(\theta^t)$
- $\pi(\theta^t, \bar{q}_t) = \max_k \{p(\theta^t)k - C(k, \bar{q}_t)\}$

Model: Intermediate Producers R&D Investments and Efforts

- Each producer can improve his quality q_t through R&D: $q_t = (1-\delta)q_{t-1} + \lambda_t$
  - λ_t: step size, δ: depreciation factor.
- The step size $\lambda_t(r_{t-1}, l_t, \theta_t)$ depends on:
  - R&D resources r_t cost $M_t(r_t)$.
  - Type θ_t (managerial/firm quality).
  - Managerial/firm effort: l_t at cost $\phi_t(l_t)$.
  - $\frac{\partial\lambda}{\partial\theta} > 0$, $\frac{\partial\lambda}{\partial r} > 0$, $\frac{\partial\lambda}{\partial l} > 0$, $\frac{\partial^2\lambda}{\partial\theta\partial l} > 0$ (screening).
  - Returns to R&D are stochastic, depend on stochastic type.

Model: Intermediate Producers' Production

- Firm born with θ_1, evolves with Markov $f^t(\theta_t|\theta_{t-1})$.
- History: $\theta^t = \{\theta_1, ..., \theta_t\}$ with probability $P(\theta^t) = f^t(\theta_t|\theta_{t-1})...f^1(\theta_1)$.
- Firm lifecycle is T periods (max time after which exogenous death).
- $k(\theta^t)$: quantity and $q(\theta^t)$: quality.
- Linear production cost: $C(k, \bar{q}_t) = \frac{k}{\bar{q}_t}$
- Aggregate quality (Spillovers): $\bar{q}_t = \int_{\Theta^t} q(\theta^t)P(\theta^t)d\theta^t$
- Hence profits are:
  $\pi(\theta^t, \bar{q}_t) \equiv \max_k\{p(\theta^t)k - C(k, \bar{q}_t)\} = q_t(\theta^t)(1\text{-}\beta)^{\frac{1-\beta}{\beta}} \cdot \beta \cdot \bar{q}_t^{\frac{1-\beta}{\beta}}$
- Final good: $Y_t = \int_{\Theta^t} q(\theta^t)^\beta k(\theta^t)^{1-\beta}P(\theta^t)d(\theta^t)$

Government Policies Studied

- Fully unrestricted mechanism.
- Linear (size-independent) age-dependent corporate tax and R&D subsidies.
- Linear (size- and age-independent) corporate tax and R&D subsidies.
- Nonlinear (i.e., size dependent) corporate tax and R&D subsidies.

What do these policies look like at optimum?

What is the welfare gain from each?

Outline

Direct Revelation Mechanism with Spillovers

- In this section: $\theta_t = p\theta_{t-1} + \psi_t$, with ψ_t distributed $N(0, \sigma_\psi^2)$.
- History θ^t and effort l_t are private info.
- Government sees: step size λ, realized quality q, R&D spending r, and production k.
- Direct revelation: Firm reports $\theta'_t(\theta^t)$.
- History of reports: $\theta'^t = \{\theta'_1(\theta_1), ...\theta'_t(\theta^t)\}$.
- Allocations as function of history of reports: $\{\lambda(\theta'^t)$, $r(\theta'^t), T_t(\theta'^t)\}$.
- Maximize household consumption (wlog, zero weight on manager): $\mathbb{E}\left\{\sum_{t=1}^{T}\left(\frac{1}{R}\right)^{t-1}\{\pi(\theta^t, \bar{q}_t) - M_t(r(\theta^t)) - T_t(\theta^t)\}\right\}$
- First: let's assume full depreciation $\delta = 1$.

Incentive compatibility and a First-order Approach

- Lifetime expected utility from assigned allocations under truthful reporting: $V_1(\theta_1) \equiv V_1(\{\lambda(\theta^s), r(\theta^s), T_s(\theta^s)\}_{s=1}^{T}, \theta_1) = \sum_{t=1}^{T}(\frac{1}{R})^{t-1} \cdot \{\int_{\Theta^t} \{T_t(\theta^t) - \phi_t(\lambda(\theta^t), r(\theta^{t-1}), \theta_t\} P(\theta^t|\theta_1) d\theta_t\}$

- Utility for a given sequence of realizations θ^T:
$\tilde{U}(\theta^T) = \sum_{t=1}^{T} \left(\frac{1}{R}\right)^{t-1} \{T_t(\theta^t) - \phi_t(\lambda(\theta^t), r(\theta^{t-1}), \theta_t)\}$

- Envelope condition (Pavan, Segal and Toikka, 2014):
$\frac{\partial V_t(\theta^t)}{\partial \theta_t} = \mathbb{E}\{\sum_{s=t}^{T} I_{t,s} \frac{\partial \tilde{U}(\theta^T)}{\partial \theta_s}\}$
  - $I_{t,s}$: impulse response of shock θ_t on time s shock θ_s. For AR(1) is p^{s-t}.

- Informational rent: $V_1(\theta_1) =$
$\mathbb{E}\left\{\frac{1-F^1(\theta_1)}{f^1(\theta_1)} \sum_{t=1}^{T} \left(I_{1,t} \frac{\partial \tilde{U}(\{\lambda(\theta^s), r(\theta^s), T_s(\theta^s)\}_{s=1}^{T}, \theta^T)}{\partial \theta_t} \right)\right\} + V_1(\underline{\theta}_1)$.

Program: Maximize Virtual Surplus with Spillovers

Notation: $\lambda(\theta^t) = \lambda(r(\theta^{t-1}), l(\theta^t), \theta_t)$.

$$\max \sum_{t=1}^{T} (\frac{1}{R})^{t+1} \{ \int_{\Theta^t} \{ \pi_t(\theta^t, \bar{q}_t) - M_t(r(\theta^t)) - \phi(l(\theta^t)) - \frac{1 - F^1(\theta_1)}{f^1(\theta_1)} p^t [\phi'(l(\theta^t)) \frac{\partial \lambda(\theta^t)/\partial \theta_t}{\partial \lambda(\theta^t)/\partial l_t}] - V_1(\underline{\theta}_1) \} P(\theta^t) d\theta^t \}$$

s.t.:

$$\int_{\Theta_t} \lambda(\theta^t) P(\theta^t) d\theta^t = \bar{q}_t$$

- Solve using this first-order approach, then verify global (IC) ("sufficiency") *ex post* (Farhi and Werning, 2013).
- Cohort-by-cohort problem (pooling across cohorts can be a second step).

Wedges: Measures of Implicit taxes and Subsidies

- Implicit corporate tax:

$$(1-\tau(\theta^t))\frac{\partial \pi_t(\theta^t)}{\partial \lambda_t}\frac{\partial \lambda(\theta^t)}{\partial l_t} = \phi_{lt}(\lambda(\theta^t), r(\theta^{t-1}), \theta_t)$$

- Implicit R&D subsidy:

$$(1-\tilde{s}(\theta^t))M_t'(r(\theta^t)) = \frac{1}{R}\mathbb{E}\left\{\frac{\partial \pi_{t+1}(\theta^{t+1})}{\partial \lambda_{t+1}}\cdot\frac{\partial \lambda(\theta^{t+1})}{\partial r_t}(1-\tau(\theta^{t+1}))\right\}$$

- Net R&D subsidy:

$$s(\theta^t) = \tilde{s}(\theta^t) - \frac{1}{M_t'(r(\theta^t))}\frac{1}{R}\mathbb{E}\left\{\frac{\partial \pi_{t+1}(\theta^{t+1})}{\partial \lambda_{t+1}}\cdot\frac{\partial \lambda(\theta^{t+1})}{\partial r_t}\tau(\theta^{t+1})\right\}$$

Sufficient Statistics: Elasticities and Coefficient of Complementarity

- Elasticity of x_t w.r.t y_t: $\varepsilon_{xy,t} \equiv \frac{\partial x_t}{\partial y_t} \frac{y_t}{x_t}$
- Hicksian coefficient of complementarity between x and y in λ: For $\{x, y\} \in \{\theta_t, r_{t-1}, l_t\}$

$$\rho_{xy} = \frac{\frac{\partial^2 \lambda}{\partial x \partial y} \lambda}{\frac{\partial \lambda}{\partial x} \frac{\partial \lambda}{\partial y}}$$

- $\lambda_t(r, l, \theta) = rl\theta \rightarrow \rho_{\theta l} = \rho_{\theta r} = \rho_{lr} = 1$.
- $\lambda_t(r, l, \theta) = r + l + \theta \rightarrow \rho_{\theta l} = \rho_{\theta r} = \rho_{lr} = 0$.

Optimal R&D Subsidy and Corporate Tax

- Optimal Corporate Tax:

$$\left(\tau(\theta^t) + \underbrace{\frac{\int \frac{\partial \pi_t(\theta^t, \bar{q}_t)}{\partial \bar{q}_t}}{\frac{\partial \pi_t(\theta^t, \bar{q}_t)}{\partial \lambda_t}}}_{\text{Externality}}\right) \frac{1}{1-\tau(\theta^t)} = \underbrace{\frac{1-F^1(\theta_1)}{f^1(\theta_1)} p^{t-1}}_{\text{Type distribution and persistence}} \underbrace{\frac{\varepsilon_{\lambda\theta,t}}{\theta_t} \left(\frac{1+\rho_{\theta I,t}\varepsilon_{\lambda(1-\tau),t}}{\varepsilon_{\lambda(1-\tau),t}}\right)}_{\text{Efficiency Cost}}$$

- Optimal R&D Subsidy: tension between externality and asymmetric info.

$$s(\theta^t) = \frac{1}{M_t'} \frac{1}{R} \mathbb{E}(\underbrace{\frac{\partial \lambda(\theta^{t+1})}{\partial r_t} \int \frac{\partial \pi_{t+1}(\theta^{t+1}, \bar{q}_{t+1})}{\partial \bar{q}_{t+1}}}_{\text{Externality}}$$

$$+ \underbrace{\frac{1-F^1(\theta_1)}{f^1(\theta_1)} p^t}_{\text{Type distribution and persistence}} (1-\tau(\theta^{t+1})) \frac{\partial \pi_{t+1}(\theta^t, \bar{q}_{t+1})}{\partial \lambda_{t+1}} \frac{\partial \lambda_{t+1}}{\partial \theta_{t+1}} \frac{\partial \lambda_{t+1}}{\partial r_t} \frac{1}{\lambda_{t+1}} \underbrace{(\rho_{Ir} - \rho_{\theta r}))}_{\text{Complementarity coefficients}}$$

Special Cases for the Optimal R&D Subsidy when only Externality Matters

- Multiplicatively separable step size: $\lambda_t(r, l, \theta) = h^1(r)h^2(\theta)h^3(l)$ has $\rho_{lr} = \rho_{\theta l} = \rho_{\theta r} = 1$.

$$s(\theta^t) = \frac{1}{M_t'(r(\theta^t))}\frac{1}{R}\mathbb{E}\left(\frac{\partial h^1(r(\theta^t))}{\partial r_t}h^2(\theta_{t+1})h^3(l(\theta^{t+1}))\int \frac{\partial \pi_{t+1}(\theta^{t+1}, \bar{q}_{t+1})}{\partial \bar{q}_{t+1}}\right)$$

- CES step size: $\lambda(l, r, \theta) = (\alpha_1 l^{(1-\rho)} + \alpha_2 r^{(1-\rho)} + \alpha_3 \theta^{(1-\rho)})^{\frac{1}{1-\rho}}$ has $\rho_{lr} = \rho_{\theta l} = \rho_{\theta r} = \rho$.

$$s(\theta^t) = \frac{1}{M_t'(r(\theta^t))}\frac{1}{R}\mathbb{E}\left(\alpha_2\left(\frac{\lambda(\theta^t)}{r(\theta^t)}\right)^{\rho}\int \frac{\partial \pi_{t+1}(\theta^{t+1}, \bar{q}_{t+1})}{\partial \bar{q}_{t+1}}\right)$$

A Simple Numerical Illustration

- Next step: Estimation from Patent data matched to Compustat.

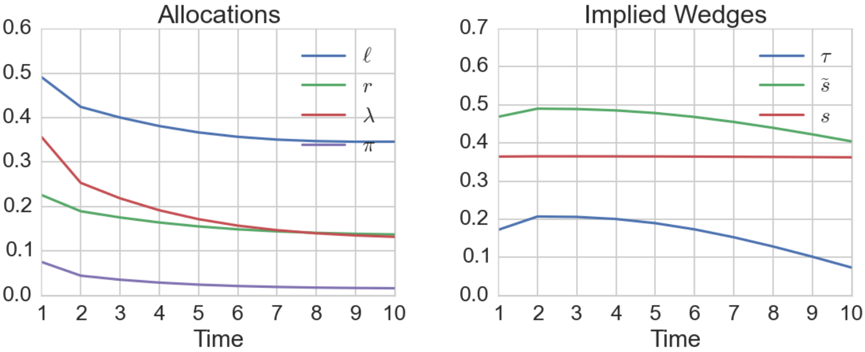
- Functional forms: $\lambda(r, l, \theta) = w(\theta, r) = (\alpha r^{(1-\rho)} + (1-\alpha)\theta^{(1-\rho)})^{\frac{1}{1-\rho}} l$.
  - Two cases: $\rho = 0.8$ and $\rho = 1.2$ (keep average λ constant across two cases).
  - $\alpha = 0.2$.

- Constant elasticity disutility: $\phi(l) = \frac{l^{1+\gamma}}{1+\gamma}$.
  - $\gamma = 2$ generates Frisch elasticity of 0.5.

- Constant elasticity R&D cost: $M_t(r) = \frac{r^{1+\kappa}}{1+\kappa}$
  - $\kappa = 1$ (typically quadratic R&D cost estimates).

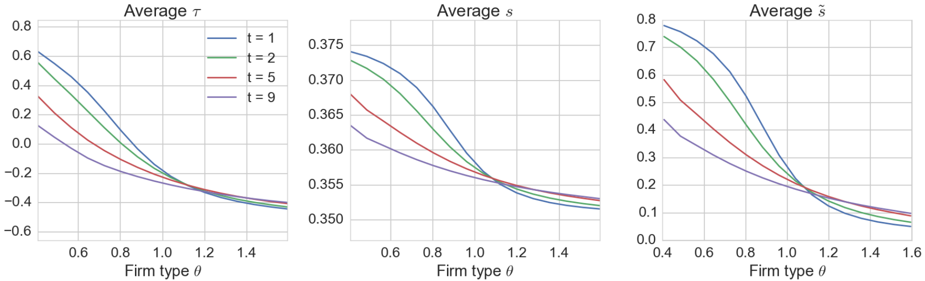
- AR(1) process for type: $\theta_t = p\theta_{t-1} + \psi_t$
  - $p = 0.9$, $\sigma_\psi^2 = 0.01$.

Policies for Old and New Firms, $\rho = 0.8$



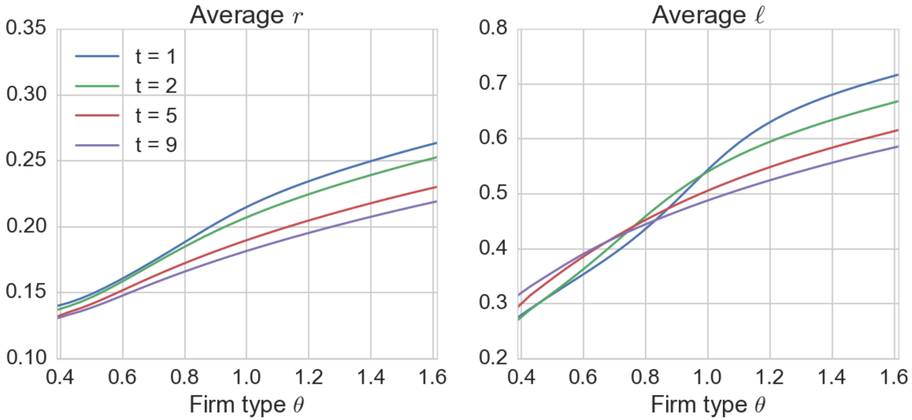
- Can incentivize less and less effort and R&D over time.
- Optimal to make young firms invest most.
- An almost constant net subsidy is optimal (but as $T \to \infty$, $s_t \to 0$.)

Wedges for Higher and Lower Quality Firms, $\rho = 0.8$



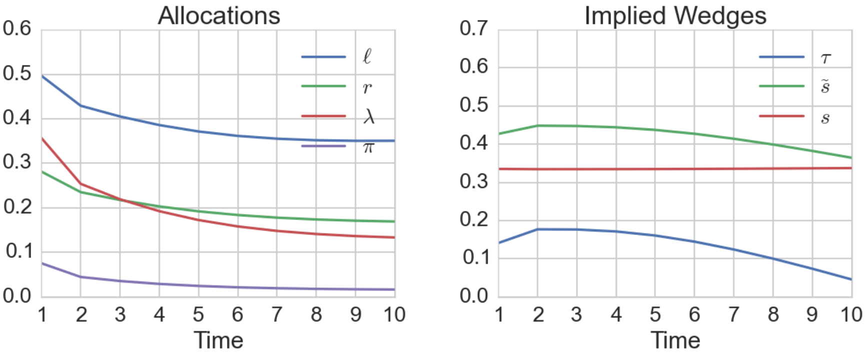
- Gross subsidy tracks corporate tax (else too high disincentive on R&D).
- Higher quality firms are subsidized to produce more (big externality).
- Optimal subsidy highly nonlinear.

Policies for Higher and Lower Quality Firms, $\rho = 0.8$



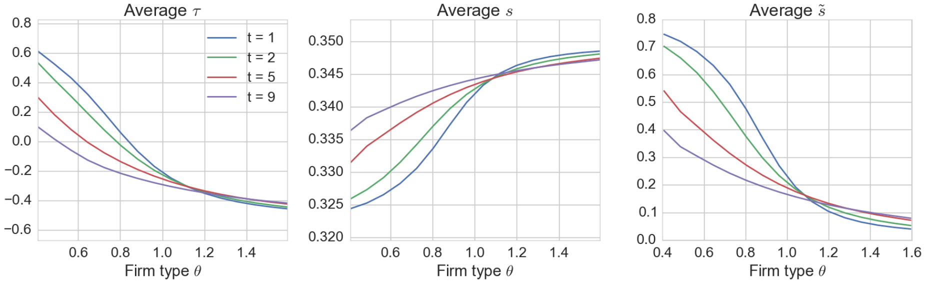
- Monotonic allocations: high quality firms have more inputs.
- Allocations get flatter over time: less able to screen.

Policies for Old and New Firms, $\rho = 1.2$



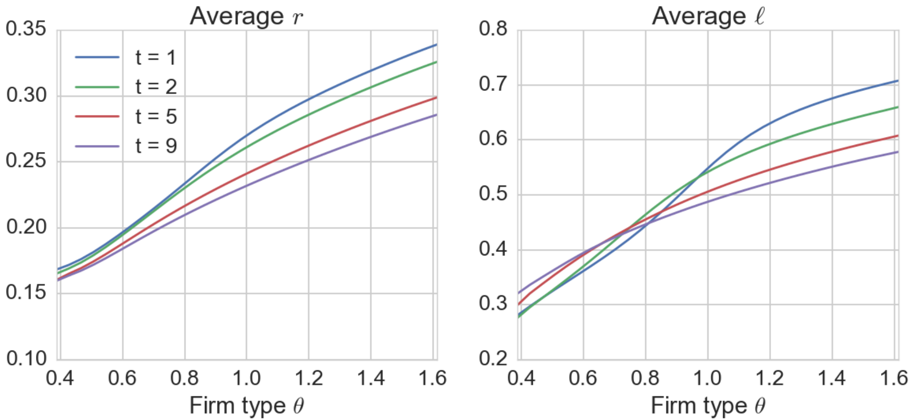
- As ρ is higher, s is lower.

Wedges for Higher and Lower Quality Firms, $\rho = 1.2$



- As ρ is higher, s is lower.

Policies for Higher and Lower Quality Firms, $\rho = 1.2$



Case with no Depreciation: Externality Persists Forever

$$\left(\tau(\theta^t) + \frac{\sum_{s=t}^{T} \int \frac{\partial \pi_s(\theta^s, \bar{q}_s)}{\partial \bar{q}_s}}{E(\sum_{s=t}^{T} (\frac{1}{R})^{s-t} \frac{\partial \pi_s(\theta^s, \bar{q}_s)}{\partial \lambda_t} \frac{\partial \lambda_t}{\partial l_t})}\right) \frac{1}{1-\tau(\theta^t)} =$$

$$\frac{1-F^1(\theta_1)}{f^1(\theta_1)} p^{t-1} \left(\frac{\varepsilon_{\lambda\theta,t}}{\theta_t}\right) \left(\frac{1+\rho_{\theta l,t}\varepsilon_{\lambda(1-\tau),t}}{\varepsilon_{\lambda(1-\tau),t}}\right)$$

$$s(\theta^t) = \frac{1}{M_t'(r(\theta^t))} \frac{1}{R} \mathbb{E}(\frac{\partial \lambda_{t+1}}{\partial r_t} \sum_{s=t+1}^{T} \int \frac{\partial \pi_s(\theta^s, \bar{q}_s)}{\partial \bar{q}_s} +$$

$$\frac{1-F^1(\theta_1)}{f^1(\theta_1)} p^t \frac{\partial \lambda_{t+1}}{\partial r_t} \frac{\partial \lambda_{t+1}}{\partial \theta_{t+1}} \frac{\phi'(l_{t+1})}{\lambda_{t+1}} \frac{1}{\frac{\partial \lambda_{t+1}}{\partial l_{t+1}}} (\rho_{lr} - \rho_{\theta r}))$$

- Same special cases apply when subsidy only set based on (now persistent) externality.

Outline

Optimal Linear (Size-independent) Age-Dependent Policies

- Linear age-dependent corporate tax τ_t and R&D subsidy s_t.

- Manager's optimization problem:

$$\max_{\{s_{ti}, r_{ti}\}_{t=1}^{T}} \sum_{t=1}^{T} \left(\frac{1}{R}\right)^{t-1} \left((1-\tau_t)\pi_{ti} - (1-s_t)M_t(r_{ti}) - \phi_t(l_{ti})\right)$$

- Hence $\pi_{ti}((1-\tau_t), s_{t-1}, \bar{q}_t((1-\tau_t), s_{t-1})))$ and $r_{t-1i}((1-\tau_t), s_{t-1}, \bar{q}_t((1-\tau_t), s_{t-1})))$ are solutions as functions of policies.

- Social welfare is now just total revenue:

$$\max_{\{\tau, s\}_{t=1}^{T}} \sum_{t=1}^{T} (\frac{1}{R})^{t-1} (\tau_t \mathbb{E}(\pi_{ti}) - s_t \mathbb{E}(M_t(r_{ti})))$$

- Aggregate (or cross-sectional averages): $r_t = \mathbb{E}(r_{ti})$ and $\pi_t = \mathbb{E}(\pi_{ti})$.

Optimal Formulas as Function of Sufficient Statistics

- Formulas valid even if other instrument not optimally set.
- Useful to evaluate "reforms."
- Could use structural or reduced-form (sufficient stats) approach.
- Fiscal externality from one tax on other tax' base.

$$\tau_t^* = \frac{1 + s_{t-1}\varepsilon_{r,t-1}^{1-\tau}\frac{r_{t-1}}{\pi_t}}{1+\varepsilon_{\pi,t}^{1-\tau}} \qquad s_t^* = \frac{1+\tau_t\varepsilon_{\pi,t}^{s-1}\frac{\pi_t}{r_t}}{1+\varepsilon_{r,t}^{s-1}}$$

with

$$\varepsilon_{r,t-1}^{1-\tau} = \frac{d\mathbb{E}(M(r_{t-1i}))}{d(1-\tau)}\frac{1-\tau}{r_{t-1}} \qquad \varepsilon_{\pi,t}^{1-\tau} = \frac{d\pi_t}{d(1-\tau)}\frac{1-\tau}{\pi_t}$$

$$\varepsilon_{\pi,t}^{s-1} = \frac{d\pi_t}{d(s-1)}\frac{s-1}{\pi_t} \qquad \varepsilon_{r,t}^{s-1} = \frac{d\mathbb{E}(M(r_{ti}))}{d(s-1)}\frac{s-1}{r_t}$$

Optimal Size and Age-Independent Policies

- Same Formula and same sufficient stats – different estimation required in data.

$$\tau^* = \frac{1 + s\varepsilon_r^{1-\tau}\frac{r}{\pi}}{1+\varepsilon_\pi^{1-\tau}} \qquad s^* = \frac{1+\tau\varepsilon_\pi^{s-1}\frac{\pi}{r}}{1+\varepsilon_r^{s-1}}$$

$$\pi = \sum_{t=1}^{T}\left(\frac{1}{R}\right)^{t-1}\pi_t \qquad r = \sum_{t=1}^{T}\left(\frac{1}{R}\right)^{t-1} r_{t-1}$$

$$\varepsilon_r^{1-\tau} = \sum_{t=1}^{T}\left(\frac{1}{R}\right)^{t-1}\varepsilon_{r,t-1}^{1-\tau}\frac{r_{t-1}}{r} \qquad \varepsilon_\pi^{1-\tau} = \sum_{t=1}^{T}\left(\frac{1}{R}\right)^{t-1}\varepsilon_{\pi,t}^{1-\tau}\frac{\pi_t}{\pi}$$

$$\varepsilon_\pi^{s-1} = \sum_{t=1}^{T}\left(\frac{1}{R}\right)^{t-1}\varepsilon_{\pi,t}^{s-1}\frac{\pi_t}{\pi} \qquad \varepsilon_r^{s-1} = \sum_{t=1}^{T}\left(\frac{1}{R}\right)^{t-1}\varepsilon_{r,t}^{s-1}\frac{r_t}{r}$$

Outline

Conclusion

- Model of R&D investments and endogenous growth with heterogeneous firms, private information, and spillovers.
  - Use mechanism design to solve for constrained efficient allocations.
  - Characterize using "wedges."
- Optimal to subsidize R&D investments because of externality.
- Asymmetric info: could tend to reduce R&D subsidy if very complementary to firm quality.
  - But optimal R&D subsidy is nonlinear.
- Simple sufficient stats formula for R&D subsidy and corporate tax in linear, age-dependent or age-independent cases.
- Next step: estimate model using patent + compustat data.