Idea Diffusion and Property Rights

Boyan Jovanovic[a] and Zhu Wang[b]

[a]New York University
[b]Federal Reserve Bank of Richmond

August 28, 2023

Motivation

- Does a competitive market provide incentives to innovate?
- How do innovation and diffusion/imitation interplay and drive industry evolution?
- How does the diffusion/imitation dissipate innovators' rents?
- What is the best way to compensate innovators?

Model

- A competitive industry with a fixed downward sloping demand curve for a homogeneous good.
- Production requires using an innovation referred to as the "idea."
- At the outset, a group of homogeneous measure-zero firms decide whether to innovate now or later, or wait to imitate.
- As more firms get the idea, product price falls and so does the private value of the idea.

Model (Cont'd)

- Imitation occurs as ideas are copied in random pairwise meetings.
- Imitator pays a fee to the idea seller.
  - Regime 1: Imitators cannot resell ideas to other imitators (e.g., patent licensing or franchising)
  - Regime 2: Imitators can resell ideas to other imitators (e.g., non-patented know-how)

Findings

- Under either regime, innovators enter the industry only at the beginning and the number of imitators then follows an S-shaped diffusion curve. Industry output grows faster under Regime 1 and faster when innovators' bargaining share is larger.
- The socially optimal compensation for innovators should be partial. Payment for an idea should be larger (in % terms) under Regime 2 (when imitators can resell ideas).
- A higher diffusion rate raises industry growth and welfare.
- The model fits the early evolution of the U.S. automobile and personal computer industries.

Related Literature

- *Technology diffusion*: Griliches (1957), Mansfield (1961), David (1968), Bass (1969, 2004), Comin and Hobijn (2004), Young (2009)
- *SIR models* (succeptible, infected, recovered): Fernandez-Villaverde and Jones (2020), Eichenbaum, Rebelo, and Trabandt (2020)
- *Industry life cycle*: Gort and Klepper (1982), Utterback and Suarez (1993), Jovanovic and MacDonald (1994), Klepper (1996), Filson (2001), Wang (2008), Hayashi, Li, and Wang (2017)
- *Search & matching with investment*: Mailath, Samuelson, and Shaked (2000), Burdett and Coles (2001), Nöldeke and Samuelson (2015)
- *Competitive innovation & idea sales*: Boldrin and Levine (2002, 2008), Quah (2002), Silveira and Wright (2010), Manea (2021)
- *Macro-diffusion models*: Lucas and Moll (2014), Perla and Tonetti (2014), Benhabib et al. (2014, 2019), Hopenhayn and Shi (2020)

Outline

- Introduction
- Model setup
- Theoretical analysis
- $N \to \infty$ limit
- Empirical applications
- Conclusion

Model Setup

- Competitive market and continuous time.
- A homogeneous good with an isoelastic demand curve

$$p_t = Ak_t^{-\beta}.$$

  p_t: price, k_t: output, A: market size; β: inverse demand elasticity.

- *Capacity constraint*: An idea enables a firm to produce one unit.
  $k_t =$ # output= # firms = # people with the idea.
- *Innovation*: At $t = 0$ no one has the idea.
  $c =$ cost of getting one by innovating
  $k_0 =$ # of initial innovators who pay c

Model Setup (cont'd)

- *Imitation*: Random meetings between incumbent firms and outsiders. Each meeting results in a new producer, $\frac{dk_t}{dt}$ = # of new producers.
- Buyers of idea start producing immediately;

  sellers of idea continue producing; outsiders earn zero.

  v_t = value of an innovator

  ω_t = value of an imitator

  u_t = value of an outsider
- Over time, k_t rises, p_t falls, and v_t, ω_t, and u_t evolve.
- At each date t, an agent decides whether to invest c and become an innovator or whether to take the option value of being a future imitator.

Model Setup (cont'd)

- *Property right*:

  An imitator buys the idea for a fee:

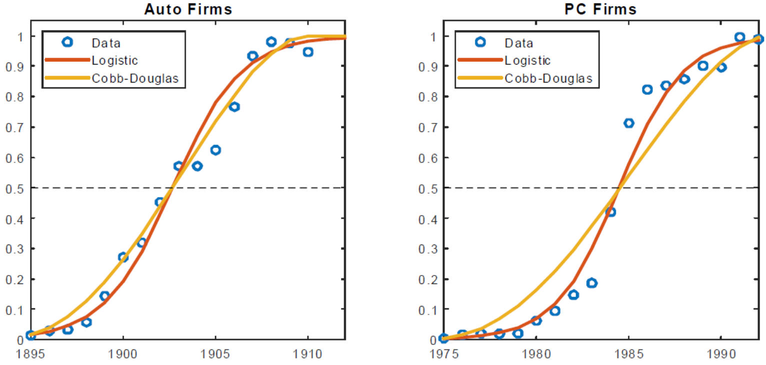
  $$F_t = \alpha \omega_t.$$

  α = bargaining share of the idea seller.

- *Regime* 1: Imitators cannot resell ideas to other imitators.
  - A potential imitator can copy an incumbent imitator.
  - However, the fee goes to an original innovator.
- *Regime* 2: Imitators can resell ideas to other imitators.
  - Diffusion process is the same as Regime 1.
  - However, agents' revenues differ.

Logistic Diffusion

- Auto and PC firm numbers follow logistic curves.



Logistic Diffusion

- Meeting rate is proportional to the number of potential partners:

$$\frac{dk_t}{dt} = \gamma k_t \left(N - k_t\right).$$

- Conditional on k_0,

$$k_t = \frac{Ne^{\gamma N t}}{e^{\gamma N t} + \frac{N}{k_0} - 1}.$$

- More generally,

$$\frac{dk_t}{dt} = \frac{\gamma}{N^{\theta}} k_t \left(N - k_t\right) \implies k_t = \frac{Ne^{\gamma N^{1-\theta} t}}{e^{\gamma N^{1-\theta} t} + \frac{N}{k_0} - 1}.$$

Regime 1: Equilibrium

- Imitators cannot resell ideas. At equilibrium, $(k_0, v_t, v_t^\tau, \omega_t, u_t)$ satisfy equations

$$\text{Imitator:} \quad r\omega_t = p_t + \frac{d\omega_t}{dt},$$

$$\text{Innovator (enters at date 0):} \quad rv_t = p_t + \frac{\gamma k_t (N - k_t)}{k_0} \alpha\omega_t + \frac{dv_t}{dt},$$

$$\text{Innovator (enters at date } \tau > 0\text{):} \quad rv_t^\tau = p_t + \frac{\gamma k_t (N - k_t)}{k_\tau} \alpha\omega_t + \frac{dv_t^\tau}{dt},$$

$$\text{Outsider:} \quad ru_t = \gamma k_t \left[(1-\alpha)\omega_t - u_t\right] + \frac{du_t}{dt},$$

$$\text{Free entry:} \quad v_0 - u_0 = c \ \text{ and } \ v_\tau^\tau - u_\tau < c \text{ for } \tau > 0.$$

Regime 2: Equilibrium

- Imitators can resell ideas. At equilibrium, $(k_0, v_t, \omega_t, u_t)$ satisfy equations

$$\text{Imitator:} \quad \omega_t = v_t,$$

$$\text{Innovator:} \quad rv_t = p_t + \gamma\left(N - k_t\right)\alpha v_t + \frac{dv_t}{dt},$$

$$\text{Outsider:} \quad ru_t = \gamma k_t\left[(1-\alpha)v_t - u_t\right] + \frac{du_t}{dt},$$

$$\text{Free entry:} \quad v_0 - u_0 = c \;\text{ and }\; v_t - u_t < c \text{ for } t > 0.$$

Equilibrium Characterization

Proposition

- *In both regimes, innovators only enter at date 0.*
- *In Regime 1, the number of innovators k_0^I is determined by*

$$\underbrace{\frac{1}{N-k_0}\int_0^\infty e^{-rt}\left(\alpha\frac{N}{k_0}+(1-\alpha)\frac{N}{k_t}-1\right)Ak_t^{1-\beta}dt}_{v_0-u_0} = c.$$

- *In Regime 2, the number of innovators k_0^{II} is determined by*

$$\underbrace{\frac{1}{N-k_0}\int_0^\infty e^{-rt}\left(\left(\frac{N}{k_0}\right)^\alpha\left(\frac{N}{k_t}\right)^{1-\alpha}-1\right)Ak_t^{1-\beta}dt}_{v_0-u_0} = c.$$

Equilibrium Characterization

Proposition

All other parameters being equal across the two regimes,

$$\text{(A)} \quad \frac{k_0^I}{k_0^{II}} = \begin{cases} 1 & \text{for } \alpha \in \{0,1\} \\ >1 & \text{for } \alpha \in (0,1) \end{cases} .$$

$$\text{(B)} \quad k_0^I \text{ and } k_0^{II} \begin{cases} \text{increase with } \alpha \text{ and } A, \\ \text{decrease with } c \text{ and } r. \end{cases}$$

Equilibrium Characterization

Proposition

The effect of diffusion rate γ on k_0^I and k_0^{II} depends on α and β.

- *For inelastic demand $\beta > 1$,*

$$k_0^I \text{ and } k_0^{II} \text{ decrease with } \gamma \text{ given that } \beta > 1 \geq \alpha.$$

- *For unit elastic demand $\beta = 1$,*

$$\begin{aligned} k_0^I \text{ and } k_0^{II} \text{ decrease with } \gamma \text{ when } \beta &= 1 > \alpha, \\ k_0^I \text{ and } k_0^{II} \text{ do not vary with } \gamma \text{ when } \beta &= \alpha = 1. \end{aligned}$$

- *For elastic demand $\beta < 1$,*

$$k_0^I \text{ and } k_0^{II} \begin{cases} \text{decrease with } \gamma \text{ if } \alpha \text{ is sufficiently small} \\ \text{increase with } \gamma \text{ if } \alpha \text{ is sufficiently large} \end{cases}.$$

Welfare Analysis

- Social planner maximizes consumers'+producers' surplus W_0:

$$\max_{k_0} \left\{ -ck_0 + \int_0^\infty e^{-rt} \int_0^{k_t} D(s)\, dsdt \right\}$$

$$s.t. \quad k_t = \frac{Ne^{\gamma N t}}{e^{\gamma N t} + \frac{N}{k_0} - 1}.$$

Welfare Findings

Proposition

- *It is socially optimal for innovators to enter only at date 0.*
- *The socially optimal number of innovators k_0^* is determined by*

$$\underbrace{\int_0^\infty e^{-(r+\gamma N)t} \left(\frac{k_t}{k_0}\right)^2 A k_t^{-\beta} dt}_{\textit{marginal social return to } k_0} = c$$

Welfare Findings

Proposition

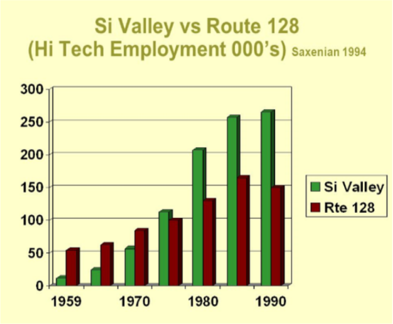
- *Social optimum implies* $0 < \alpha^{I^*} < \alpha^{II^*} < 1$
    - $\alpha^* > 0$ *is needed to internalize knowledge spillovers and* $\alpha^* < 1$ *to internalize congestion externalities:*

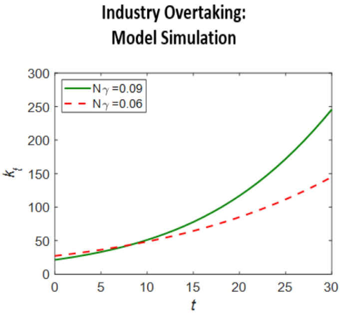
$$\frac{dk_t/dt}{k_t} = \gamma\left(N - k_t\right).$$

    - α^* *is higher under Regime 2 than under Regime 1.*
- *Planner wants* γ *to be higher:* $\partial W_0/\partial\gamma > 0$.

Model Implications

- Diffusion rate γ explains industry development patterns.
  - Example: Silicon Valley overtook Route 128 due to banning non-compete contracts.





- Higher diffusion rate γ raises welfare.

A Limiting Model

- Suppose there is a constant $\lambda > 0$ and that

$$\lim_{N\to\infty} \gamma N = \lambda.$$

Then

$$\lim_{N\to\infty} \frac{dk_t}{dt} = \lim_{N\to\infty} \gamma k_t(N - k_t) = \lambda k_t,$$

and

$$k_t = k_0 e^{\lambda t}.$$

- This is the diffusion process assumed in previous competitive innovation studies (e.g., Boldrin and Levine, 2008, Quah, 2002).

A Limiting Model: Characterization

Proposition

- *Innovators only enter at date 0 in both regimes.*
- $k_0^I = k_0^{II}$ *for* $\alpha \in \{0, 1\}$; $k_0^I > k_0^{II}$ *for* $1 > \alpha > 0$.
- *Full protection* ($\alpha^* = 1$) *for innovators is socially optimal*
  - *no congestion externality*

$$\frac{dk_t/dt}{k_t} = \lambda.$$

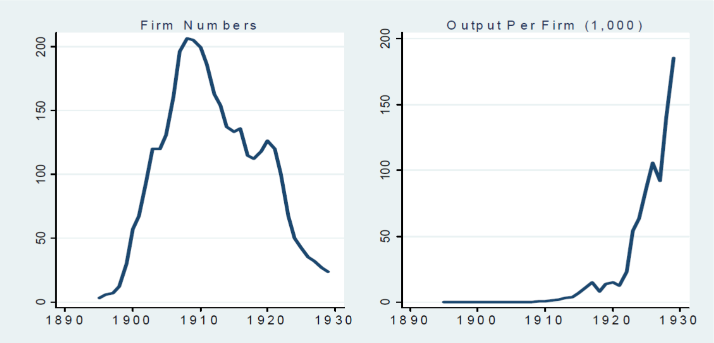
- *Planner wants* γ *to be higher:* $\partial W_0 / \partial \gamma > 0$.

Empirical Applications

- We consider two historically important industries: automobile and personal computer.
- Using model calibration and counterfactual exercises, we evaluate and quantify our theoretical predictions.

Auto Industry Evolution

- The U.S. auto industry started with 3 firms in 1895 and the firm numbers exceeded 200 around 1910 before the shakeout.



Auto Diffusion Estimation

- Rewriting the logistic diffusion process as

$$\ln \frac{k_t}{N - k_t} = z + \lambda t,$$

where $z = \ln \frac{k_0}{N-k_0}$ and $\lambda = \gamma N$.

- Assume the shakeout started after all the potential firms had entered (i.e., $N = 210$). We estimate the diffusion equation using annual data of firm numbers 1895-1910.

$$\ln \frac{k_t}{N - k_t} = \underset{(0.26)^{***}}{-4.13} + \underset{(0.03)^{***}}{0.53}\ t.$$

- The results suggest $\gamma N = 0.53$ and $k_0 = 3.31$ (i.e., $\ln \frac{k_0}{N-k_0} = -4.13$).

Auto Demand Estimation

- We estimate the industry demand function using annual data of auto prices p_t and output Q_t from 1900–1929.

$$\ln(Q_t) = a - \phi \ln(p_t).$$

- Two-stage regressions:

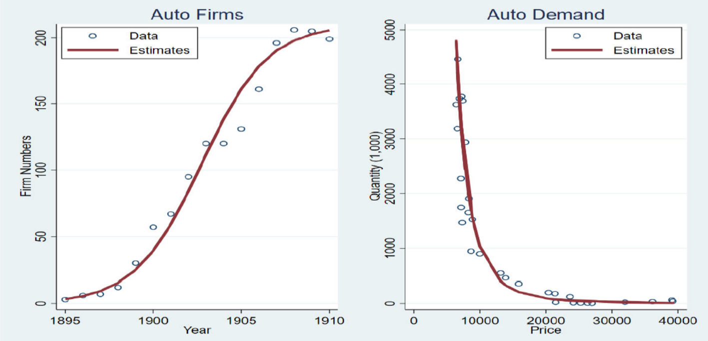
$$\ln(p_t) = \underset{(0.14)^{***}}{11.37} - \underset{(0.02)^{***}}{0.24} \times \ln(output\ per\ firm)_{t-1}.$$

$$\ln(Q_t) = \underset{(2.75)^{***}}{47.05} - \underset{(0.29)^{***}}{3.61} \times \ln(p_t).$$

- The result suggests $\beta = \frac{1}{\phi} = 0.28$.

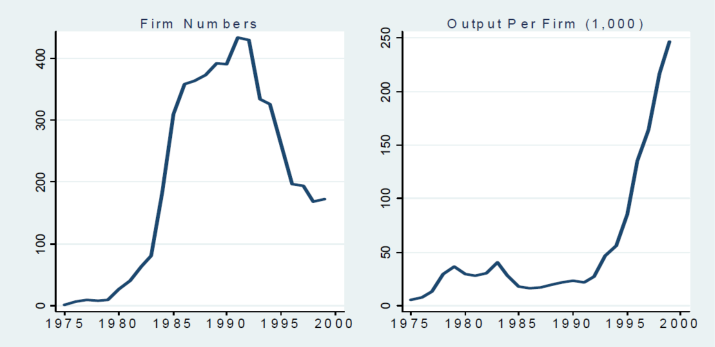
Auto Industry Estimation

- The estimation results fit data well.



PC Industry Evolution

- The U.S. PC industry started with two firms in 1975, and the firm numbers exceeded 430 in 1992 before the shakeout.



PC Industry Estimation

- Diffusion estimation:

$$\ln \frac{k_t}{N - k_t} = \underset{(0.29)^{***}}{-5.49} + \underset{(0.03)^{***}}{0.58} \; t.$$

- Demand estimation:

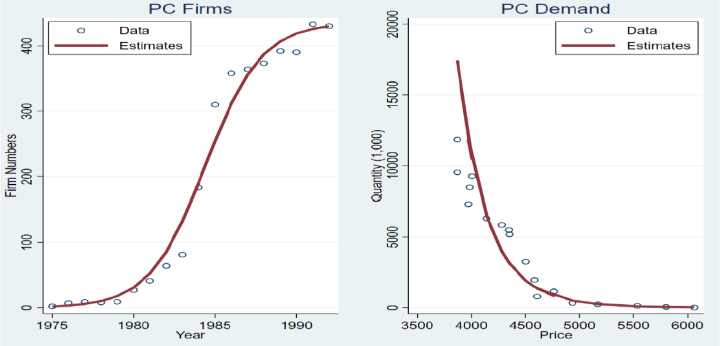
$$\ln(p_t) = \underset{(0.50)^{***}}{9.62} - \underset{(0.05)^{**}}{0.12} \times \ln(\textit{output per firm})_{t-1}.$$

$$\ln(Q_t) = \underset{(12.52)^{***}}{137.15} - \underset{(1.49)^{***}}{14.58} \times \ln(p_t).$$

- The result suggests $\beta = \frac{1}{\phi} = 0.07$.

PC Industry Estimation

- The estimation results again fit data well.



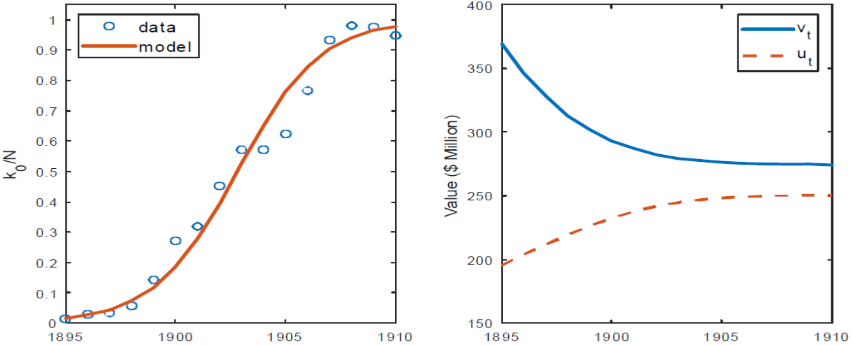
Model Parameterization

- A firm's output is normalized to 1 per period in theory. We account for a firm's production size in empirical applications.
- Model parameterization

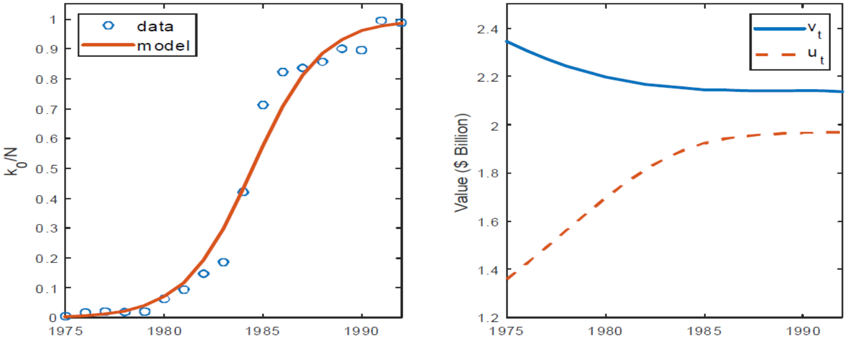
	r	N	γN	k_0	β	$\bar{A} = Aq^{1-\beta}$
Auto	0.05	210	0.53	3.31	0.28	61.28
PC	0.05	435	0.58	1.78	0.07	163.63

- Two remaining parameters to calibrate: α and c. Assume $\alpha = 0$ to pin down c in the benchmark calibration and we consider alternative values of α in robustness checks.

Model Calibration: Auto

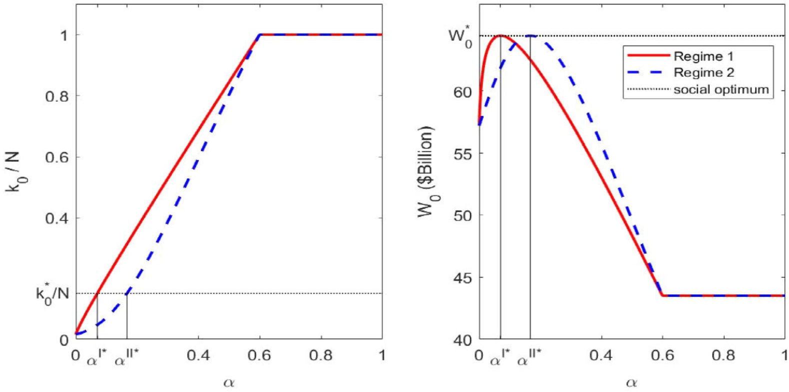


Model Calibration: PC



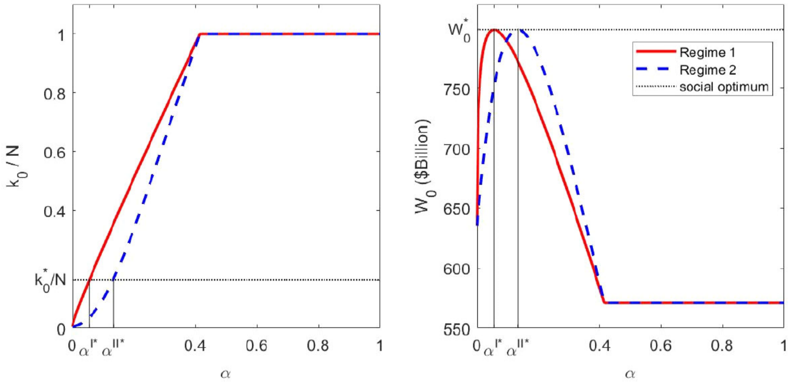
Auto: Optimal Compensation

- Socially optimal k_0/N is 15.1%, which can be achieved by choosing $\alpha^{I^*} = 7\%$ in Regime 1 and $\alpha^{II^*} = 16.7\%$ in Regime 2.
- Optimal social surplus reaches \$64.45 billion (in 2012 price).



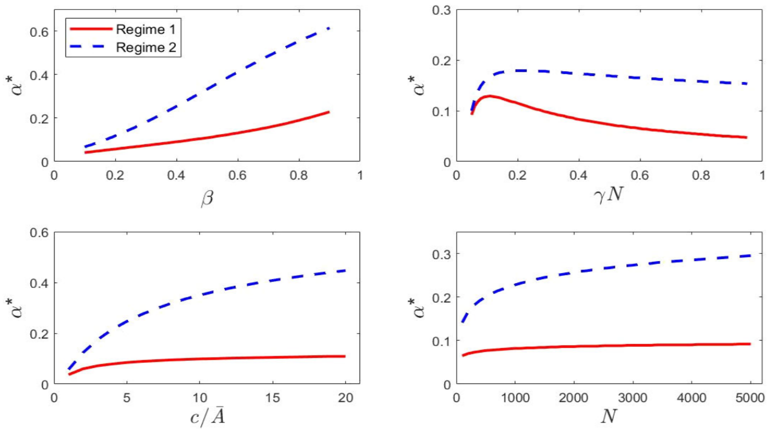
PC: Optimal Compensation

- Socially optimal k_0/N is 16.4%, which can be achieved by choosing $\alpha^{I^*} = 5.5\%$ in Regime 1 and $\alpha^{II^*} = 13.5\%$ in Regime 2.
- Optimal social surplus reaches $798.9 billion (in 2012 price).



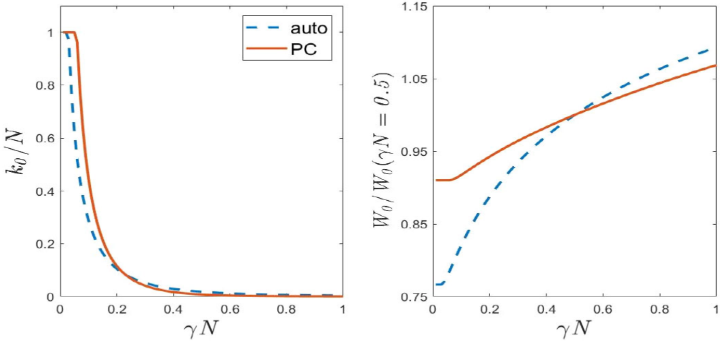
Optimal Compensation: Comparative Statics

- α^* increases with $\beta, c/A, N$, but decreases with γ.
- Auto has a larger α^* than PC due to a larger β and a smaller γN.



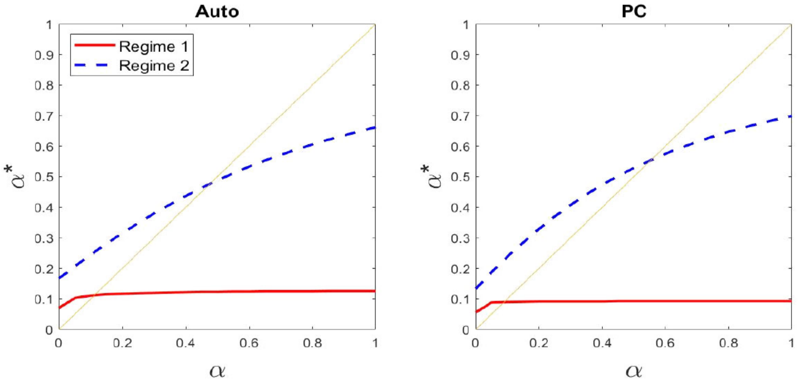
Optimal Diffusion Rate

- Raising γ reduces innovation k_0 but increases welfare W_0.



Robustness Checks

- Pool of potential entrants (alternative N)
- Anticipated shakeout (alternative r)
- Idea sellers' bargaining share (alternative α)



Conclusion

- Capacity constraints imply that licensing raises the revenues of innovators and that licensing is also socially beneficial to a degree.
- The socially optimal compensation for innovators should be only partial due to congestion externalities in meetings.
- Payment for an idea should be larger (in % terms) in Regime 2 (when imitators can resell ideas).
- Slowing down diffusion boosts innovation, but lowers imitation and welfare. This may explain the overtaking of Route 128 by Silicon Valley.