Long-Run Market Configurations in a Dynamic Quality-Ladder Model with Externalities

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Introduction

- **Motivation:** A firm may decide to release its patents in order to increase the overall market share of the industry by increasing the degree of compatibility among all competitors
  - Ex.: Recently, this has been the strategy taken by Tesla Motors, the manufacturer of electric vehicles (EVs) [Tesla Motors, 2014]
  - Ex.: NVIDIA has announced it will open source the accelerator technology used in its next generation autonomous driving SOC, code-named “Xavier” [Forbes, 2017]
  - More formally, this sharing process is implemented through Standard-setting Organizations (SSOs)
- Is this a good business strategy?

TESLA MODEL S MODEL X MODEL 3 ENERGY

All Our Patent Are Belong To You

Elon Musk, CEO • June 12, 2014

At Tesla, however, we felt compelled to create patents out of concern that the big car companies would copy our technology and then use their massive manufacturing, sales and marketing power to overwhelm Tesla. We couldn't have been more wrong. The unfortunate reality is the opposite: electric car programs (or programs for any vehicle that doesn't burn hydrocarbons) at the major manufacturers are small to non-existent, constituting an average of far less than 1% of their total vehicle sales.

We believe that Tesla, other companies making electric cars, and the world would all benefit from a common, rapidly-evolving technology platform.

- We study situations in which the leading firm causes a positive externality on the quality of the good produced by its competitors.
- **Questions:**
  - How the presence of this positive externality −due either to a firm's unilateral decision or to regulation− affects the leading firm and the industry overall?
  - What is the effect of the heterogeneity in firms' ability to invest in quality on long-run market configurations?

What we do

- We model quality of a product as a function of **its own innovation level** + **the spillover**
- This aggregate of innovation enters directly into the utility function to capture higher compatibility among the products in the market
- We embed the associated maximization utility problem into a dynamic quality-ladder model (Ericson and Pakes (1995)) in which firms differ in their return to investment and the intensity of the spillover
- We find the long-run market configurations under different parameter values
  - We check for potential multiplicity of equilibria solving the game in consecutive finite time horizons versions of the model a la Levhari and Mirman (1980)
- Model can generate different long-run market configurations: **market collapse, market dominance by *either* firm, duopoly, and combinations of these cases**

Previous evidence and our approach

- Empirical evidence on the existence of technological spillovers has been documented by Bloom et al. (2013).
  - They separate the technology spillovers from the product rivalry effect of R&D
- Even in the absence of positive externalities on quality, firms have different likelihoods of success of investment.
  - Goettler and Gordon (2011) find a parameter value for the likelihood of success of investment of 0.0010 for Intel and 0.0019 for AMD

Model: Heterogeneity

- *Innovation externality*
  1. *No externalities* $\kappa_{\cdot} = 0$ No compatibility among different firms

     $\Rightarrow$ a firm's innovations affect only consumers' valuation for this firm's good

  2. *Externalities* $\kappa_{\cdot} > 0$ Imperfect compatibility

     $\Rightarrow$ e.g. many different apps can use the same video compressing algorithm

- *Likelihood of success of investment.* Technological ability to improve quality varies across firms
  - i.e., some firms are more capable than others to turn investment into a successful upgrade in quality (parameter $\alpha_{\cdot}$)

- Innovation: ω_j

- Demand:

$$D(p_j, p_{3-j}; \omega_j, \omega_{3-j}) = m\frac{e^{g_j(\omega_j,\omega_{3-j})-\lambda p_j}}{1 + e^{g_j(\omega_j,\omega_{3-j})-\lambda p_j} + e^{g_{3-j}(\omega_{3-j},\omega_j)-\lambda p_{3-j}}}$$

where $m > 0$ is the size of the market and

$$g_j(\omega_j, \omega_{3-j}) = \begin{cases} -\infty, & \omega_j + \kappa_j \omega_{3-j} \leq 0 \\ \omega_j + \kappa_j \omega_{3-j}, & 1 \leq \omega_j + \kappa_j \omega_{3-j} < \omega^* \\ \omega^* + \log(2 - \exp(\omega^* - \omega_j - \kappa_j \omega_{3-j}), & \omega^* \leq \omega_j + \kappa_j \omega_{3-j} \leq M \end{cases}$$

M is the max quality level

- Profits:

$$\pi(p_j, p_{3-j}; \omega_j, \omega_{3-j}) = D(p_j, p_{3-j}; \omega_j, \omega_{3-j})(p_j - c)$$

Investment

- Innovation is affected by a firm-specific shock $\tau_j \in \{0, 1\}$ and an industry-wide depreciation shock $\eta \in \{-1, 0\}$

$$\omega_j' | \omega_j = \min\{\max\{\omega_j + \tau_j + \eta, 0\}, M\}$$

- Probability of success conditional on investing $x_j \geq 0$ is

$$\Pr(\tau_j = 1 | x_j) = \frac{\alpha_j x_j}{1 + \alpha_j x_j} \equiv \phi_j(x_j)$$

- Industry-wide depreciation has probability

$$\Pr(\eta = -1) = \delta \in [0, 1]$$

Value function

- Each firm (simultaneously) maximizes the sum of current profits minus the investment plus the continuation value of net profits

$$v_j(\omega_j, \omega_{3-j}) =$$

$$\max_{x_j \geq 0} \left\{ \Pi(\omega_j, \omega_{3-j}) - x_j + \beta \mathbf{E}[v_j(\omega_j', \omega_{3-j}') | \omega_j, \omega_{3-j}, x_j, x_{3-j}] \right\}$$

- In what follows we use the parametrization $\alpha_A = \mu$ and $\alpha_B = \mu - \epsilon$

$\Rightarrow$ the larger ϵ is, the more asymmetry there is in the likelihood of success of investment between the leader (A) and the laggard (B)

Value, policy, and probability of success functions

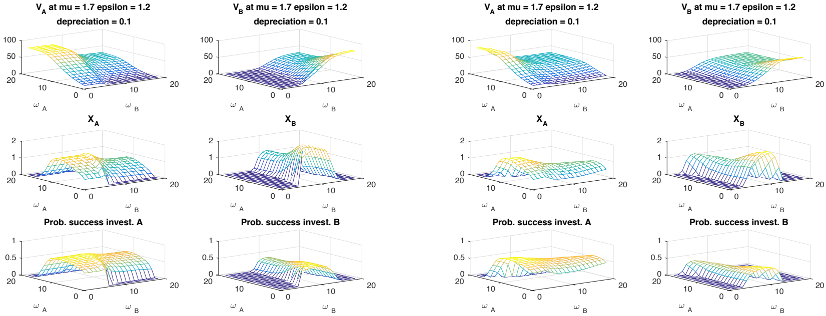

Figure: Notes: Left panel: asymmetric R&D capabilities and no externalities. Right panel: Asymmetric R&D capabilities with externalities $\kappa_A = \kappa_B = 0.3$. In both panels $\lambda = 1.7$ and $\delta = 0.1$.

Transient distributions

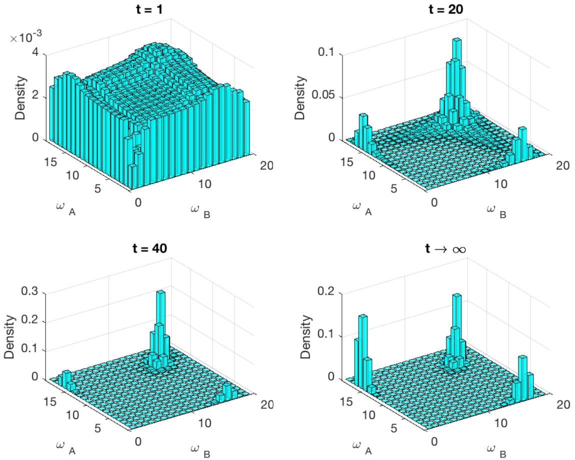

Figure: Transient distributions from same policy function at different time periods. Initial distribution $\mathbf{a}_0$ is uniform.

Market structures: no externalities

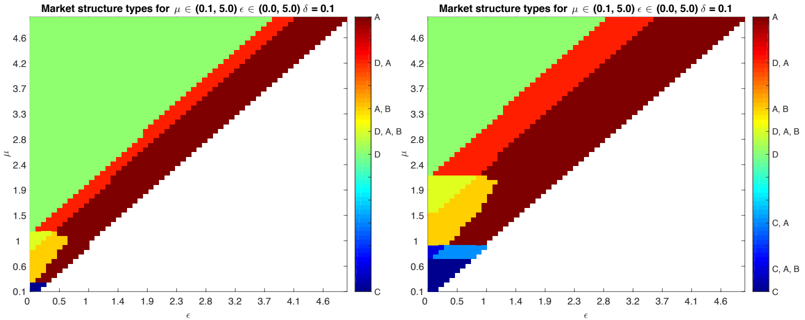

Figure: $\alpha_A = \mu$ and $\alpha_B = \mu - \epsilon$. The letter *A* means that firm *A* dominates the market. The letter *D* refers to duopoly. The term *A*, *B* means that the limiting distribution for quality is bimodal, i.e., either firm may take over as a monopoly. Finally, the letter *C* indicates that the market collapses. Left panel represents the outcomes $\lambda = 1.2$ and right panel when $\lambda = 1.7$.

Market structures: with externalities

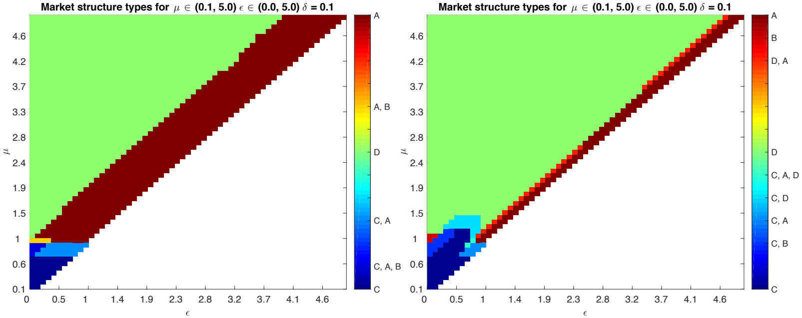

Figure: $\alpha_A = \mu$ and $\alpha_B = \mu - \epsilon$. Left column represents the outcomes from the symmetric externalities case ($\kappa_A = 0.3$ and $\kappa_B = 0.3$). Right column represents outcomes when the externalities are not symmetric ($\kappa_A = 0.3$ and $\kappa_B = 0.7$). Both at $\lambda = 1.7$.

Observation 1: *The quality ladder model with heterogeneity in the likelihood of success of investment and externalities can exhibit different long-run distributions over market structures depending on parameter values. Those different structures are: market collapse, market dominance by either firm, duopoly, and combinations of these structures.*

Observation 2: *Allowing for externalities, for instance through an Standard-setting Organization (SSO), removes market dominance by letting the lagging firm to benefit from the leading firm's investment. Depending on parameter values, this may lead to dominance by the laggard.*

Expected market shares for different levels of the externality

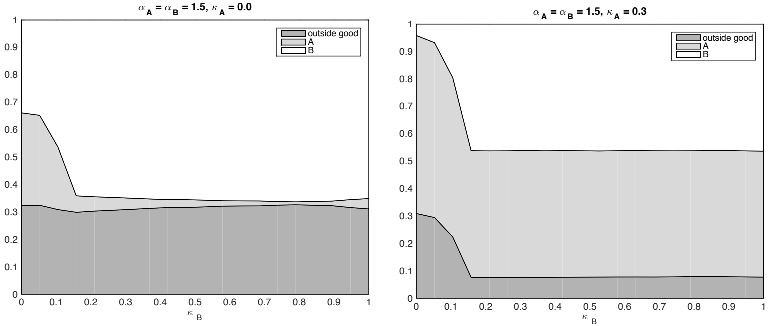

Figure: Notes: Each panel shows the stacked expected market shares at each level of the externality for firm B. $\alpha_A = \alpha_B = 1.5$ in both panels. $\kappa_A = 0$ in the first panel and $\kappa_A = 0.3$ in the second. Vertical axis represents market size.

When is it optimal to share knowledge?

$$v_A(\omega_A,\omega_B) = \max_{x_A \geq 0} \Big\{ \Pi\,(\omega_A,\omega_B;\kappa_B = 0) - x_A + \beta \mathbf{E}[v_A(\omega_A^{'},\omega_B^{'})|\omega_A,\omega_B,x_A,x_B],$$
$$\Pi\,(\omega_A,\omega_B;\kappa_B \geq 0) - x_A + \beta \mathbf{E}[v_A(\omega_A^{'},\omega_B^{'})|\omega_A,\omega_B,x_A,x_B], \Big\}$$

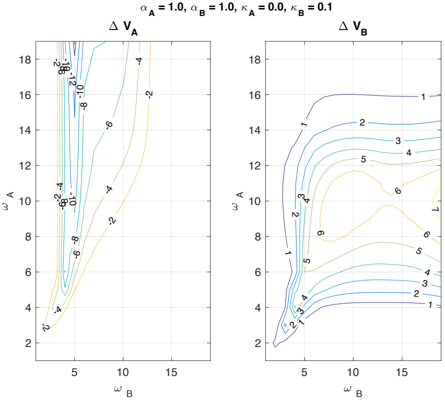

Figure: Difference in discounted profits from patent disclosure

Takeaways

- Usually, policy experiments consist of simulating a large number of different industries under some specific counterfactual scenario, each industry is simulated several time periods given the initial condition given by the data
  - Then different outcomes are provided: expected profits, consumer surplus, and investments
  - It is unlikely but possible that the transient distribution over the quality space exhibits multiple modes: positive probability of different market structures
- In a patent release event, it is possible for the laggard to dominate the market, in which case the patent release should have been avoided