How Efficient Is Dynamic Competition? The Case of Price as Investment

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Welfare Economics When Price Serves as Investment

- In many interesting settings, sacrificing current profit by charging low prices to generate volume can serve as an investment to build dynamic resources at the core of a competitive advantage:
  - Learning curve
  - Network externalities
  - Switching costs and lock-in
  - Habit formation

- These settings can give rise to interesting policy questions:
  - Competition policy (e.g., proscriptions on below-cost pricing)
  - Industrial policy (e.g., subsidies to facilitate industry take-off)

- A well-formed understanding of the welfare economics of competition for the market when price serves as an investment should be an important foundation for policy discussion:
  - For example, if unfettered dynamic price competition is fairly efficient perhaps the downside from subsidization would be problematic

Nothing to See Here ... Move Along

- Welfare economics of price as an investment seem fairly clear
- Jostle for advantage $\rightarrow$ low prices (at least in short run)$\rightarrow$good for consumers and society
- Unlike rent-seeking (Posner 1975), value is transferred to consumers through low prices, so competition for advantage not socially wasteful

But in Oligopoly Markets the Case for Efficiency When Price Serves as an Investment is not Clear Cut

- The good:
  - Competition for advantage via price could offset market power (at least in short run)
  - Aggressive competition for advantage hastens investment in socially valuable resources (e.g., cumulative know-how that lowers costs)

- The potentially not so good:
  - Prices that are too low can cause deadweight loss, too
  - Interaction with inefficient entry and exit dynamics:
    - Coordination failures (Bolton & Farrell 1990)
    - Wars of attrition (Tirole 1988, Bulow & Klemperer 1999)
  - Equilibria involving predatory-like pricing, with industry quickly monopolized may arise (Besanko, Doraszelksi, Kryukov, 2014; more on this below)

Research Agenda and Objectives of this Talk

- We use quantitative theory in Ericson & Pakes (1995) tradition to assess how efficient dynamic competition is when price serves as an investment:
  - Analyze discrete-time stochastic game
  - Compute equilibria over wide swath of parameter space and highlight implications for industry dynamics
  - Assess deadweight loss against interesting benchmarks
  - Anatomize DWL to explain what drives it when price serves as investment

- Objectives of talk:
  - To say something (I hope) interesting about the welfare economics of dynamic price competition
  - To illustrate a research question for which quantitative theory is well suited:
    - Dynamic Markovian models in stylized settings (e.g., in spirit of Maskin & Tirole 1988) suggest that "almost anything can happen"
    - Quantitative theory useful when, in the face of this, we want to understand magnitudes and patterns

We Focus on One Application: Learning-by-Doing

- Economically and empirically important (Levitt, List & Syverson 2013 and dozens of other references)

- LBD can give rise to interesting pricing and market structure dynamics ...
  - ... past, e.g., wide-body jets (Benkard, 2004)
  - ... and present, e.g., solar panels (Reichelstein & Sahoo, 2017)

- Policy implications "complicated":
  - *Competition policy is necessarily rather complicated in such circumstances, both in terms of philosophy (traditional antitrust policies may be unwise), and implementation (pricing below marginal cost need not signify predatory behavior). Moreover, LBD leads to hysteresis effects, where temporary shocks and policy interventions that alter output have permanent effects on productivity. Thus, not only the design of policy interventions but also their appropriate duration are more complicated in the presence of LBD*—Thompson, *Handbook of the Economics of Innovation* (2010)

Outline of the Model

- Discrete-time, infinite-horizon stochastic game:
  - Action within a time period: (1) Price-setting phase; (2) Exit-entry phase

- State $e_n \in \{1, \ldots, M\}$ is firm's cumulative experience. State $e_n = 0$ denotes firm n as potential entrant. At most two firms: $n \in \{1, 2\}$
  - Proprietary learning: gain cost-reducing know-how only by making sales over time
  - Equation of motion in price-setting phase: $e_n' = e_n + q_n$, $q_n \in \{0, 1\}$ indicates if firm n makes a sale in the period

- Entry/exit phase:
  - If firm n is outside industry: incurs (privately observed) set-up cost S_n if it enters, drawn from $[\overline{S} - \Delta_S, \overline{S} + \Delta_S]$, where $E(S_n) = \overline{S}$
  - If firm n is incumbent: can collect (private observed) scrap value X_n if it exits, drawn from $[\overline{X} - \Delta_X, \overline{X} + \Delta_S]$, where $E(X_n) = \overline{X}$
  - From perspective of rival, entry/exit decisions induce probability exit/non-entry $\phi_n(\mathbf{e})$ in state $\mathbf{e} = (e_1, e_2)$

Outline of the Model (continued)

- Pricing phase—Bellman equation (firm 1, if in industry):

$$V_1(\mathbf{e}) = \max_{p_1} D_1(p_1, p_2(\mathbf{e}))(p_1 - c(e_1)) + D_0(p_1, p_2(\mathbf{e}))U_1(\mathbf{e})$$
$$+D_1(p_1, p_2(\mathbf{e}))U_1(e_1 + 1, e_2) + D_2(p_1, p_2(\mathbf{e}))U_1(e_1, e_2 + 1),$$

where:

  - $c(e_n) = \kappa\rho^{\log_2 \min\{e_n, m\}}$ marginal cost firm n; $\rho =$ progress ratio$\rightarrow$doubling experience reduces MC by $(1-\rho)\%$
  - $D_n(p) = \frac{\exp\left(\frac{v-p_n}{\sigma}\right)}{\sum_{k=0}^{2}\exp\left(\frac{v-p_k}{\sigma}\right)} =$ probability firm n makes sale; $\sigma =$ degree of horizontal differentiation; $p_0 =$ marginal cost of outside good
  - $p_n(\mathbf{e}) =$ firm n price in state $\mathbf{e} = (e_1, e_2)$
  - $U_n(\cdot) =$ firm n continuation value after pricing phase (before exit/entry phase)

Pricing Decision Of Incumbent Firm

- Equilibrium price $p_1(\mathbf{e})$ of firm 1 in state $\mathbf{e} = (e_1, e_2)$ satisfies:

$$p_1 = \overbrace{c(e_1) + \frac{D_1}{-\frac{\partial D_1}{\partial p_1}}}^{\text{static profit}} - \overbrace{[U_1(e_1+1, e_2) - U_1(\mathbf{e})]}^{\text{advantage-building motive}}$$

$$\overbrace{-[U_1(\mathbf{e}) - U_1(e_1, e_2+1)] \underbrace{\left(\frac{\frac{\partial D_2}{\partial p_1}}{-\frac{\partial D_1}{\partial p_1}}\right)}_{\text{diversion ratio}}}^{\text{advantage-denying motive}}$$

- **Advantage-building motive**: marginal future value of improving own competitive position

- **Advantage-denying motive**: marginal future value of preventing rival from improving its competitive position

Computational Approach

- Compute symmetric Markov perfect equilibria of model and first-best planner solution (FB), varying four key parameters—ρ, σ, p_0, $\overline{X}$:
  - Use homotopy method to compute MPE for six two-dimensional "slices":(ρ, σ), (ρ, p_0), $(\rho, \overline{X})$, (σ, p_0), $(\sigma, \overline{X})$, and $(\overline{X}, p_0)$

- Ranges of ρ, σ, p_0, $\overline{X}$ chosen to:
  - reflect natural economic values (e.g., $\rho \in [0, 1]$ or $\sigma, p_0 \geq 0$)
  - ensure interesting economic properties (e.g., upper bound of $\overline{X}$ chosen to ensure entry costs are always partly sunk)
  - span interesting economic environments (e.g., range of σ takes us from no horizontal differentation to virtually complete differentiation)
  - avoid over-representing essentially identical economic environments (e.g.,upper bounds of σ and p_0 chosen so beyond them "things don't change much")

- 2,025 distinct parameterizations, resulting in about 68,500 symmetric MPE (some parameterizations have over 200 equilibria)

Equilibrium Typology

- Equilibria tend to be one of two types—accommodative equilibria and aggressive equilibria
- Quite different MPE policy functions, implied market dynamics, and performance

Example: $\rho = 0.75, \sigma = 1, p_0 = 10, \overline{X} = 1.5$	aggr. eqbm.	accom. eqbm.	first-best solution
expected short-run number of firms N_1	1.92	1.91	1.00
expected long-run number of firms N_∞	1.08	2.00	1.00
expected long-run average price $\overline{p}_\infty$	8.28	5.24	3.25
expected time to maturity T^m	19.09	37.54	15.02

Deadweight Loss: Example

- Deadweight loss as percentage of industry value added, $\frac{DWL_\beta}{VA_\beta}$:
  - Accommodative equilibrium: **4.54%**
  - Aggressive equilibrium:**13.06%**
- Some benchmarks:
  - Single-period monopoly: **52.3%/21.0%** (top/bottom learning curve)
  - Dynamic model—"turn off" investment role of pricing: **16.7%**
  - Dynamic model—"turn off" non-cooperative pricing: **16.4%**
  - Dynamic model—"turn off" investment role of pricing and non-cooperative pricing: **28.3%**
  - Dynamic model—collusion: **14.3%**
- Some observations:
  - Nothing in primitives suggests relative DWL should be "low"
  - "Turning off" investment role of pricing is slightly more damaging than "turning off" non-cooperative pricing→investment role of pricing may be strong force for efficiency

Deadweight Loss: All Parameterizations

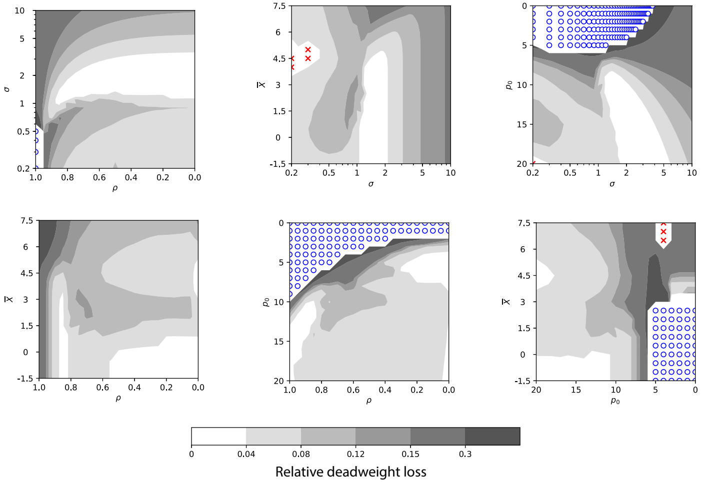
- **Relative DWL, $\frac{DWL_\beta}{VA_\beta}$**

	Median	% param. $< 10\%$
All MPE	7.7%	65.8%
Best MPE	5.7%	71.1%
Worst MPE	9.2%	56.4%

- **DWL relative to counterfactual benchmarks, $\frac{DWL^k_\beta}{DWL_\beta}$**

Counterfactual k	Median	% param.≥ 2
"Turn-off" investment role of pricing	1.78	44.0%
Collusion	1.44	35.5%

Deadweight Loss: All Parameterizations



Average over multiple MPE's at parameterization. Blue 'o's indicate parameterizations where no firms enter into an empty industry. Red 'x' indicates parameterizations where we failed to compute any MPEs.

Some Tentative Observations

- Best equilibria—usually accommodative—are reasonably efficient
- Worst equilibria—usually aggressive—are not great ...
  - ... but they are still more efficient than if firms ignored the investment motive for pricing
  - ... and somewhat more efficient than if firms colluded
- Faster learning—lower progress ratio ρ—often, though not always, entails lower relative DWL

Dynamic Price Competition is Reasonably Efficient (or At Least not "Too Inefficient") Even Though There are Non-trivial Distortions

- Too low prices in some states:
  - Equilibrium price $<$ FB price in at least one state $\mathbf{e}$ in more than 55% of cases
- Too many firms in short run $\rightarrow$ over-entry:
  - Equilibrium has more than FB number of firms in more than 75% of cases
- Too many firms in long run $\rightarrow$ under-exit:
  - Equilibrium has more than FB number of firms in more than 50% of cases. Even more so for best equilibria
- Too slow learning:
  - Equilibrium time to maturity exceeds first-best time in more than 90% of cases. Even more so for best equilibria

Anatomizing the Deadweight Loss

- Expected NPV of total surplus: $TS_\beta = \sum_{t=0}^{\infty} \beta^t \sum_{\mathbf{e}} \mu_t(\mathbf{e}) \, TS(\mathbf{e})$, where $\mu_t(\cdot)$ is the transient distribution over states in period t starting from state $(0,0)$ in period 0.

- Deadweight loss: $DWL_\beta = TS_\beta^{FB} - TS_\beta$

- DWL shaped by:
  - statewise Δ static surplus: $\left[CS^{FB}(\mathbf{e}) + \Pi^{FB}(\mathbf{e})\right] - \left[CS(\mathbf{e}) + \Pi(\mathbf{e})\right]$
  - statewise Δ (receipts$-$outlays) from exit/entry: $Z^{FB}(\mathbf{e}) - Z(\mathbf{e})$
  - differences in likelihood that industry to evolves toward high surplus states: $\left[\mu_t^{FB}(\mathbf{e}) - \mu_t(\mathbf{e})\right] TS^{FB}(\mathbf{e})$

- Accordingly, decompose deadweight loss as:

$$DWL_\beta = \underbrace{DWL_\beta^{PR}}_{\text{pricing distortion}} + \underbrace{DWL_\beta^{EE}}_{\text{exit and entry distortion}} + \underbrace{DWL_\beta^{MS}}_{\text{market structure distortion}}.$$

Decomposition Term Regularities

Percentage of all parameterizations

term	>0	<0	median $\frac{DWL_\beta^k}{DWL_\beta}$
DWL_β^{PR}	96%	4%	0.66
DWL_β^{EE}	82%	18%	0.57
DWL_β^{MS}	30%	70%	-0.23
$DWL_\beta^{NPR} = DWL_\beta^{EE} + DWL_\beta^{MS}$	92%	8%	0.34

- Positive DWL_β^{PR} $\rightarrow$ eqbm. price farther than planner's price from static MC$\longrightarrow$market power & inefficient price investment
- Positive DWL_β^{EE} $\rightarrow$ firms in equilibrium tend to have higher outlays for setup costs and lower receipts from scrap value than planner$\longrightarrow$over-entry/under-exit
- Negative DWL_β^{MS} $\rightarrow$ eqbm. tends to put more mass on high-surplus states than planner's solution$\longrightarrow$gains from product variety outweigh losses from too-slow learning

Why Is Best Equilibrium Reasonably Efficient?

Learning economies insulate industry from outside competition, containing the pricing distortion

- **Proposition:** Consider a symmetric state $\mathbf{e} = (e, e)$, where $e > 0$. If $p_0 \geq \kappa$, $p_1(\mathbf{e}) > c(e)$, and $D_0(\mathbf{p}(\mathbf{e})) < \frac{1}{2}$, then

$$CS^{FB}(\mathbf{e}) + \Pi^{FB}(\mathbf{e}) - (CS(\mathbf{e}) + \Pi(\mathbf{e}))$$
$$\leq \frac{(p_1(\mathbf{e}) - c(e))^2}{\sigma} D_0(\mathbf{p}(\mathbf{e}))(1 - D_0(\mathbf{p}(\mathbf{e}))).$$

- Bound has bite: as incumbent firms move down learning curves, $D_0(\mathbf{p}(\mathbf{e}))$ goes down faster than $(p_1(\mathbf{e}) - c(e))^2$ goes up:
  - Result: as $t \to \infty$, $\sum_{\mathbf{e}} \mu_t(e) \left[CS^{FB}(\mathbf{e}) + \Pi^{FB}(\mathbf{e}) - (CS(\mathbf{e}) + \Pi(\mathbf{e})) \right]$ (period t component of DWL^{PR}_{β}) tends toward 0

- As firms become more cost efficient→less competitive pressure from substitutes→industry demand becomes less price elastic→Harberger triangle is "squeezed"

Why Is Best Equilibrium Reasonably Efficient?

Learning economies limit the loss from the non-price distortion

- For intermediate levels of product differentiation, accommodative equilibria tend to have more firms in market than FB solution, i.e., excessive product variety:
    - Tends to make $DWL_{\beta}^{EE} > 0$ (excessive set-up costs) ...
    - ... but serves to reduce DWL_{β}^{MS}, possibly even making it negative (if benefits from product variety offset slower learning)

- We show: gross benefit from product variety is enhanced as learning economies strengthen

- This limits magnitude of non-pricing distortion $DWL_{\beta}^{NPR} = DWL_{\beta}^{EE} + DWL_{\beta}^{MS}$

Why Is Worst Equilibrium Not “Too Inefficient”?

- Industry tends to evolve rapidly into monopoly and learning is not much slower than FB solution, so non-pricing distortion DWL_{β}^{NPR} is small
- In addition: monopoly pricing distortion is bounded
- **Proposition:** Consider a state $\mathbf{e} = (e, 0)$, where $e > 0$. Then

$$CS^{FB}(\mathbf{e}) + \Pi^{FB}(\mathbf{e}) - (CS(\mathbf{e}) + \Pi(\mathbf{e}))$$
$$< \begin{cases} \sigma \text{ if } 0 \leq U_1(e_1+1, e_2) - U_1(\mathbf{e}) < \sigma\left(1 + \exp\left(\frac{p_0 - c(e)}{\sigma}\right)\right), \\ \sigma + |U_1(e_1+1, e_2) - U_1(\mathbf{e})| \text{ otherwise.} \end{cases}$$

- Bound has bite:
  - $U_1(e_1+1, e_2) - U_1(\mathbf{e}) \to 0$ as incumbent firm moves down learning curve
  - Aggressive equilibria tend to arise when degree of product differentiation σ is low

Conclusions

- Dynamic price competition: not fully efficient, but reasonably so:
  - Reasonable efficiency despite equilibrium policy functions that often differ markedly from first-best
- Learning-by-doing plays an important (indirect) role in containing inefficiencies:
  - In best equilibria: contains pricing distortion by making industry more insulated from competition from substitute goods ("squeezes" the Harberger triangle)
  - In best equilibria: despite over-entry, limits the non-pricing distortion by accentuating the gross benefit from product variety
  - In worst equilibria, bound on the monopoly pricing distortion tightens as firm moves down the learning curve
- Implications for policy?