A Helicopter Tour of
Past Progress and Current Challenges in Applied I.O.

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Backgound?

- Industrial Organization is the study of market responses to environmental and/or policy changes.
- In the 1980's theorists took up the challenge of analyzing responses to changes in institutions in "oligopolistic" markets – markets where each firm knew its actions affected all firms' payoffs.
- This provided a conceptual framework for analyzing imperfectly competitive markets; i.e. **virtually all markets**. What followed was a revolution in the way markets were analyzed.
- Applied theory models used different assumptions and came to different conclusions. This generated an understanding of what could happen.
- What was not clear was which assumptions were appropriate for which situation.

Enter Empirical Industrial Organization.

- General Goal; build frameworks that let the data tie down the assumptions needed in order to use the theory to generate market responses to environmental change.
- Earlier attempts to merge empirical work with theory (e.g. Houthakker, 1955, for production and Gorman, unpublished circa 1960, on demand systems) were difficult to generalize in a useable way. The generality was needed to enable the data to determine the appropriate assumptions.
- What changed? The computer revolution; and the data, econometric techniques, and computational abilities that accompanied it.
- What I want to do here is quickly review both; (i) the issues that we have a pretty good handle on and (ii) recent developments that the lecturers will focus on – and (iii) point out some missing pieces that are needed and we have done relatively little on.

Static vs. Dynamic Analysis.

- I will start with the part of the literature that deals with competition among a known set of products with known cost functions where prices today do not have an independent effect on future profit opportunities. A part of the literature usually known as "static" analysis.
- A typical question to be analyzed is what is likely to happen to prices after a change in market conditions (e.g.'s, a merger, tariff, regulatory change ...)
- Static analysis focuses on price or quantity setting (the "static" control). It ignores the impact of current prices (or quantities);
  - (i) on future demand (as in durable, experience, or network goods),
  - (ii) future costs (as in learning by doing, or input adjustment costs), or on
  - (iii) future equilibrium conditions (as in collusion, or models with asymmetric information; signaling for firms, or search costs for individuals).

- When these conditions are relevant (or approximately so) we can ignore the impact of the static control on future profits and chose it to maximize current profits.
- Static analysis also ignores the impact of the event on investment in physical assets and/or product development
- These parts of the of the literature get us into "dynamics". We turn to dynamics in the second half of the course but
  - computational constraints on researchers,
  - cognitive constraints on the behavior of decision makers

  have made the standard dynamic models that theory has developed difficult to use (we show below that this contrasts with the standard static tools theory has generated for us).
- Several new methods of trying to overcome these issues are being developed and we return to them below.

Primitives and Equilibrium Condition: Full Information Static Analysis.

Primitives

1. A model for how much of these products would be purchased at various prices (a "demand" system)
2. A model for how much does it cost to produce those products (a "cost" or "production" function).

Equilibrium Conditions.

- If we were looking to analyze the impacts of, say a merger in a retail market, we need a model for how firms determine prices given demand and cost.
- The analysis would typically proceed by looking at Nash equilibrium conditions in prices before and after the event. This because Nash equilibrium is a "rest point":
  - At equilibrium no agent has an incentive to change its price, and

– if we are not in a Nash equilibrium at least one agent can do better by changing its price.

and hence a natural, "focal point" for the analysis.

Is Their Something Missing from the Analysis?

- Nobody believes the market will get to a rest point instantaneously.
- Unfortunately we know very little about what an appropriate adjustment model looks like.
- It is obvious that having an adjustment model, would let us investigate "transition dynamics": how long does it take to get to the new rest point? and how desirable is the transition path?
- But the need for a model of adjustment is deeper than that.
- The model has interacting agents, so there may be multiple equilibria, and the multiple equilibria possibility gets more likely with problems that involve sunk and/or fixed costs that we will come to next.

- A reasonably accurate empirical model of how firms' learn to adapt to a change would be one way of choosing between the alternatives, and we will need this when computing the likely result of a policy option.
- There has been a bit of scattered progress here , see for e.g. Doraszelski, Lewis, and Pakes (AER, 2018), but we are far from general agreement on this.

Demand Systems and Equilibrium Assumptions.

Prior work on demand was in product space and was not useable in most of our applications.

1. The "too many parameter problem".
2. Predicting demand for new goods.

We changed to characteristic space i.e.

- Products are defined as bundles of characteristics.
- Individual preferences determined by the interaction of product characteristics with the individual's characteristics.

Berry, Levinsohn and Pakes (1995,2004); or BLP and fellow travellors. This solved the two problems above:

- All we need to know is the distribution of preferences over characteristics: I.e. number of parameters are now independent of the number of products.
- Can predict demand for a new product from knowledge of its characteristics.

However moving to product space generated two computational problems.

- Aggregation. To figure out aggregate demand we had to sum up over the demands of many different individuals This is where computers and simulation techniques came in. (Prediction: McFadden and Travilte,1979; Estimation: Pakes, 1986)
- At least for retail products we need to allow for characteristics we could not condition on, and we had to be able to separate their effects from price effects (BLP), else we get back into the too many parameters problem.

How have we done with our demand and equilibrium assumptions in retail markets?

- In any given market this is easily checked.
- If we rely on
  - our demand system and
  - our equilibrium or "rest point" assumption,
- then price should equal cost plus a markup.
- The markup can be obtained separately from the estimates of the demand system and should have a coefficient of one in the pricing equation.

Data taken from The Wollman (*AER, 2018*)

What we did.

- Tom had a separately estimated demand system for trucks.
- We regress price on the determinants of costs and the predicted markup calculated from the demand system.
- Then look at
  - fit
  - coefficient of markup
  - how well we fit changes in a products price over time.

Note. This is all without direct cost or production function data. We come back to estimating these functions below, but often counterfactual analysis has to be done without it, as cost data is frequently proprietary.

We do pretty well.

- One of the best fitting equations in the social sciences.
- However hedonics alone works pretty well in the cross-section.
- Look to differences over time: still 50-60% fit, and it is pretty much all due to changes in markup (i.e. changes in the characteristics of competitors).

Table 1: Wollman & Pricing Equilibrium.

	Price	(S.E.)	Price	(S.E.)
Gross Weight	.36	(0.01)	.36	(.003)
Cab-over	.13	(0.01)	.13	(0.01)
Compact front	-.19	(0.04)	0.21	(0.03)
long cab	-.01	(0.04)	0.03	(0.03)
Wage	.08	(.003)	0.08	(.003)
$\hat{Markup}$	.92	(0.31)	1.12	(0.22)
Time dummies?	No	n.r.	Yes	n.r.
R^2	0.86	n.r.	0.94	n.r.

Note. There are 1,777 observations; 16 firms over the period 1992-2012. S.E.=Standard error.

Accordingly the demand framwork

- Is used in economic analysis outside of I.O. (Public Finance, Marketing, Development ...)
- There are more subtle questions in demand that are not as well studied:
  1. The dependence of current choices on past choices;
  2. The interactions between the choices of different individuals;
  3. The determination of the "relevant" choice set for each individual.
- 1) and 2) above . It has been hard to separate out the effect of prior choices (or choices by neighbors) from unmeasured factors that are similar across time (among the neighbors). There are many issues in social science where these questions are crucial (switching cost and diffusion of innovations in I.O, state dependence vs unobserved heterogeneity in the determinants of unemployment in labor, ...)
- 3) raises at least two issues; i) how do consumers obtain information on possible choices? and ii) what is the relationship of the information they do obtain to the policies of firm's.

The equilibrium framework is used in

- much of academic economic research that analyzes market outcomes (health, environment, ...)
- consultancies analyzing markets and, to an increasing extent, both government agencies (in evaluating counterfactuals), and by firms in their planning.

Use and Extensions.

- I now review how the framework above is used.
- For some industries, a similar kind of analysis requires quite basic methodological changes in the framework.
- Accordingly there have been several important extensions to this framework. I review three of them below. Each of these were designed to enable the analysis to issues that arise in industries with a more complicated set of characteristics.

The Analysis Assuming Static Symmetric Information Profit Maximizing Behavior.

There may be more than one set of prices or quantities that satisfy the Nash condition. If however we do assume (or prove) uniqueness (a condition which becomes more questionable in the more complex market situations we come to later in the course), if there are J products the static equilibrium

- delivers J equations in J unknowns (prices or quantities), which typically allows us to solve for each firm's prices (quantities) as a function of:
  - that firm's own state variables. These typically include the characteristics of its cost function and the characteristics of its products.
  - the state variables of the other firms active in the industry,
  - and "exogenous" state variables. These typically include factor prices (or factor supply functions if these have some elasticity), exogenous factors which determine demand conditions, institutional detail like tariffs and taxes, ...
- We then substitute these price and quantities into the profit functions – for

a price equilibrium we would compute $p(\cdot)$ and then calculate

$$p(\cdot) \times q(\cdot, p(\cdot)) - c(q(\cdot)),$$

– thereby calculating the profits of each firm as a function of all state variables (those of the firm in question, its competitors, and exogenous state variables)

- If the demand function is derived from a model which aggregates over household's maximizing choices subject to their budget constraints, the equilibrium will allow you to solve for the distribution of consumer surplus as a function of prices (and hence of the state variables) and the distribution of household characteristics.
- The distribution of profits and of consumer surplus from a given set of products and cost functions are usually the objectives of static analysis.

Note. In this analysis the cost of supplying the good or service did not depend on the characteristics of the purchaser.

Extension 1: Markets where the cost function depends on the characteristics of the purchaser and conditions of sale.

These are also markets where, because of government involvement, a certain amount of cost data is often available.

- Relevance:
  - Insurance Markets (personal characteristic: probability of sickness, accident....)
  - Loan Markets (personal characteristic: probability of default).
- Extension: allow the cost function to depend on; (i) the characteristics of the purchaser (adverse selection) and (ii) conditions of sale (moral hazard).
- Implication: demand responses to price changes effect unit costs; generates new first order conditions for equilibrium.
- Relevant empirical literature: Einav and coauthors on health (Finkelstein, Levin,...); Chiappori and Salanie on car insurance.

Issues that arise

- Market unravelling (Ackerloff). More generally: existence and computational issues.
- Issues that arise.
  - Regulation and asymmetric information. Generates complex contracts and "fairness" issues. There are public institutions to monitor both insurance (a DOI in most states to review rates and characteristics of insurance products), and financial contracts (FRB).
  - Externalities: difference between cost to individual and cost to society. Attempts to mitigate these moral hazard issues include; capitation in health insurance, monitoring driving in car insurance.
  - We are just beginning to evaluate the impact of these institutions.

- Impacts through "social norms".
  - Contractarian society: a citizen who fulfills society's duties has a right to a minimal level of goods and services;
  - In our society this includes a minimal level of *health insurance*.
  - Leads to public involvement in market (e.g. health exchanges; some of which are federal, but all of which involve government subsidies and rules)
  - **Objective of Intervention.** Insure the provision of these services at minimal cost (*not* to maximize welfare). Questions of the market design which accomplish this are largely I.O. questions.

Extension 2: Vertical Markets.

Equilibrium responses to environmental changes in vertical markets requires consideration of both upstream and downstream markets; i.e. responses in one market depend on the effect of the environmental change on the other market. Also notions of equilibrium good for retail markets (Nash in prices or quantities) need not be appropriate.

- "Upstream" market: Producers of goods or services sell to intermediaries.
- Intermediaries typically either buy from or contract with many firms and re-market bundles of goods to consumers.
- Downstream market; often a retail market where intermediaries set "take it or leave it" prices to consumers.
- If both the upstream firms and the intermediary are large they bargain for the price the intermediary pays the upstream firm for its goods or services.
- Initial empirical framework; Crawford and Yurukoglu, 2012

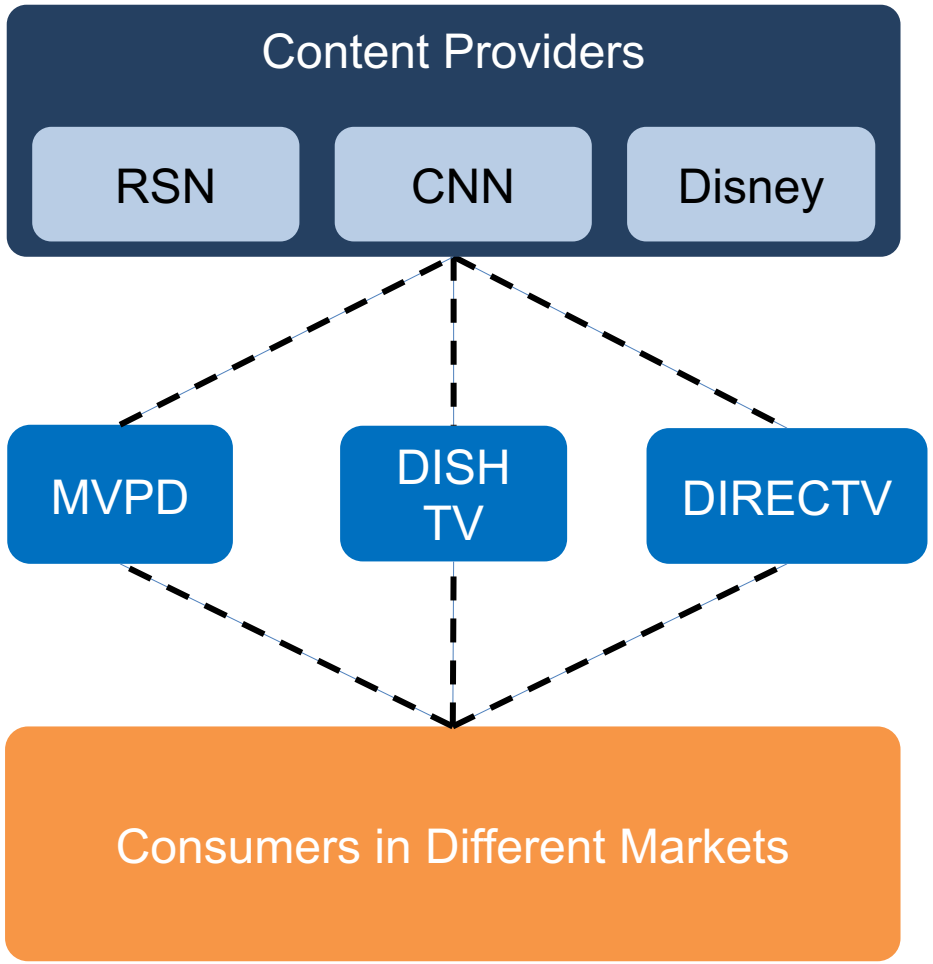
Examples; TV (content providers and cable channels), health (service providers and health insurers), manufacturer and and large retail outlets.

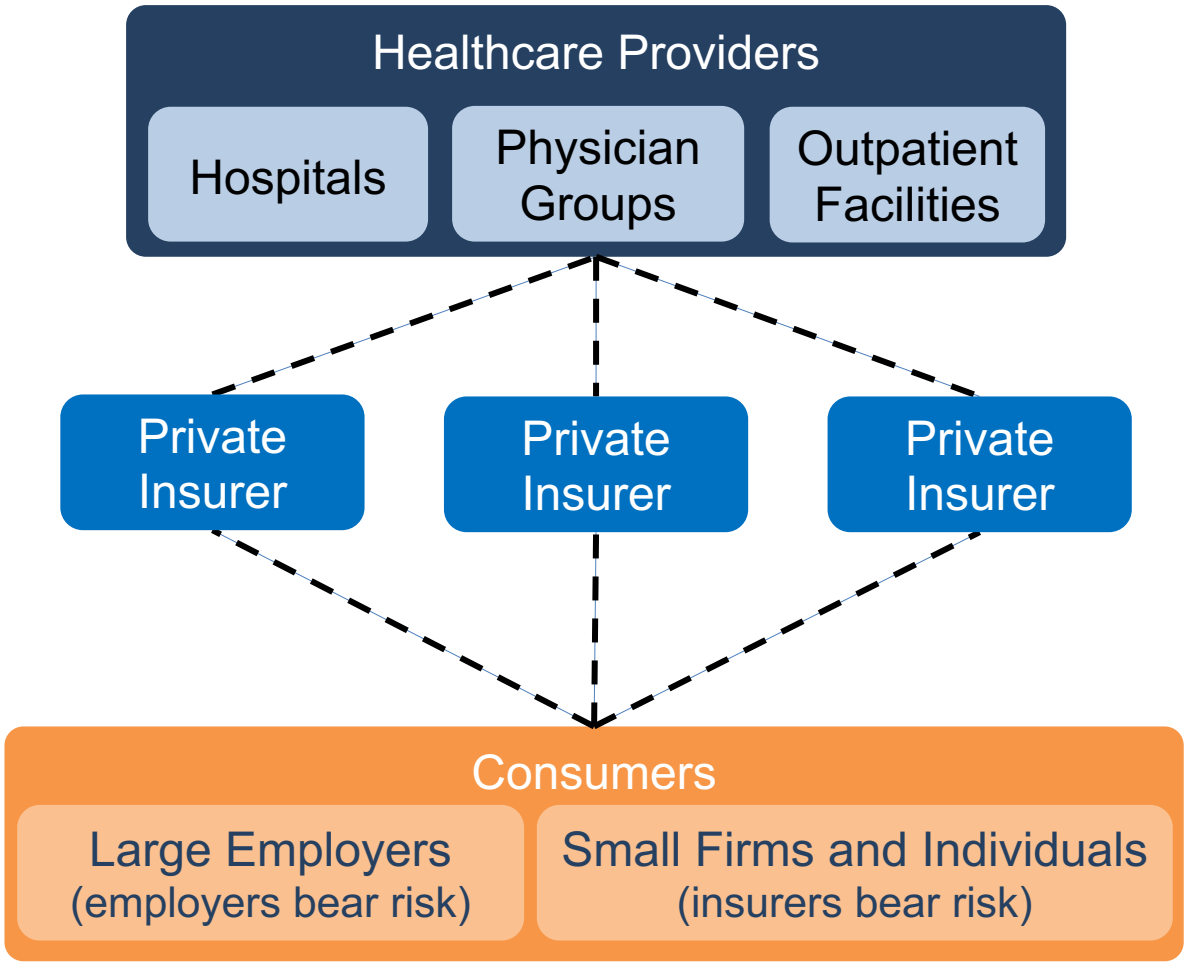
- This is bargaining with externalities; i.e. whether upstream firm A contracts with intermediary B, and the terms of that contract, effects the profits to other upstream and downstream firms.
- The total profits generated by a contract between A & B are the revenues the downstream firm generates minus the costs of production of the upstream firm.
- The bargaining generates contracts which splits those profits between the intermediaries and the producers of the goods.
- The typical solution is a Nash bargaining solution. However this raises the issue of what is the deviation value (what is the value should they not contract).
- Initial theory framework (Nash and Nash, by Horn and Wolinsky, 1988), attempt to generalize (Ho and Lee, 2018; Nash in Nash with threat of replacement)

- Still there is no generally accepted notion of a rest point for these models, because of what is a reasonable notion of a deviation.

Example: what happens when you ignore the Intermediary.

Structure of Health Care and Telecasting Industries





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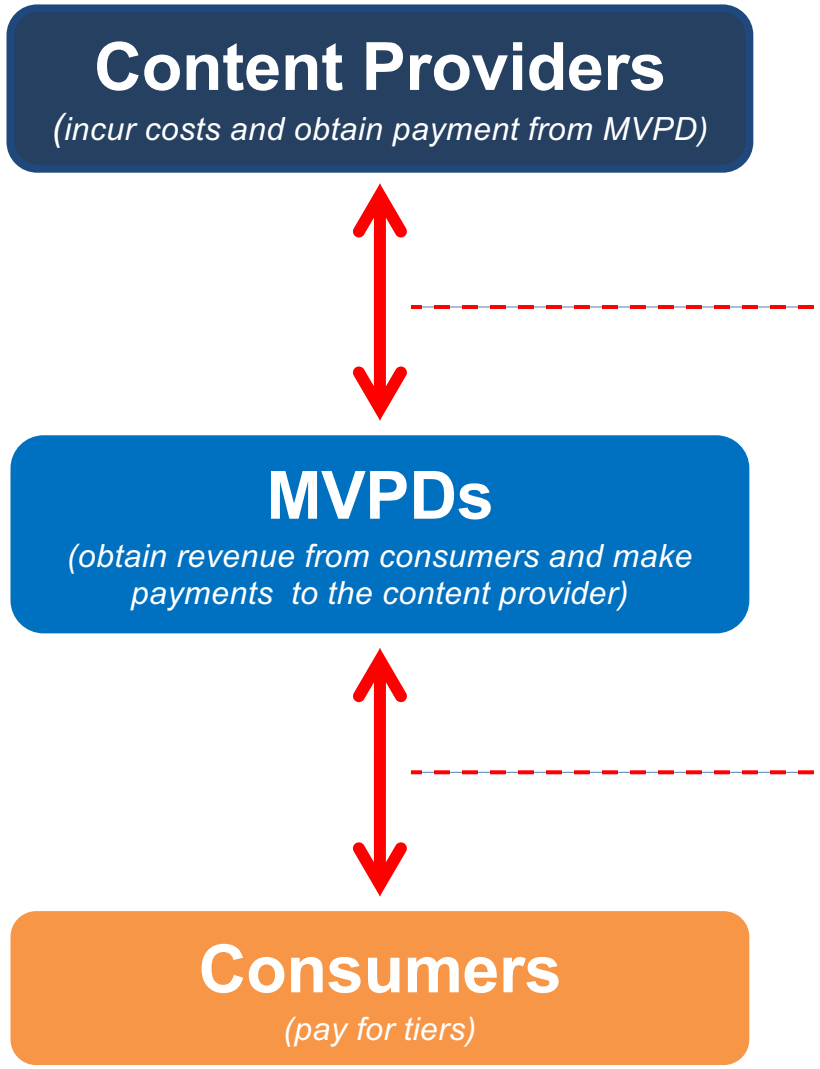
Vertical Interactions



Upstream

- Total profit is MVPD revenue from consumers minus costs of content providers.
- A bargaining process sets a contract which splits these profits between these two.

Downstream

- MVPDs do not bargain with single consumers. Instead consumers given a “take it or leave it” price.
- A “Bertrand” or Nash equilibrium determines prices.

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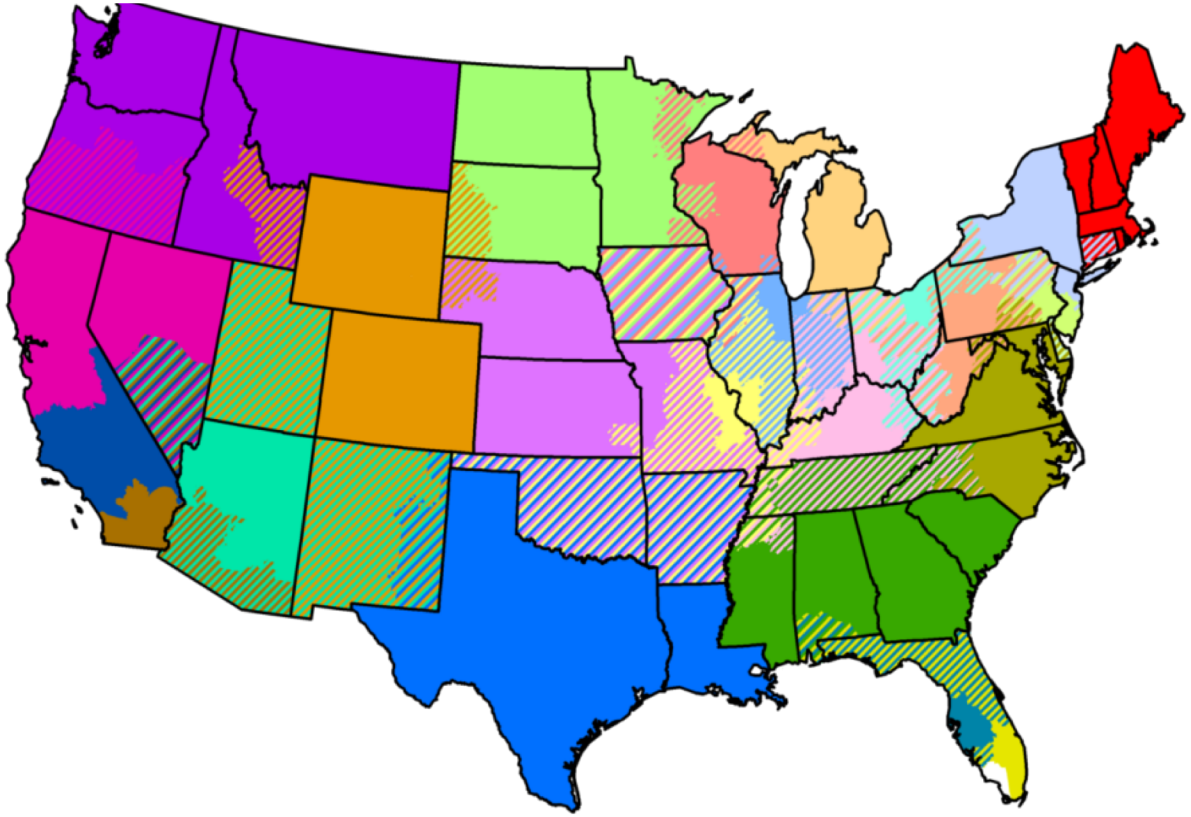
MLB Home Television Territories



- League defines each team's "home television territory."
- In-market telecast rights are assigned to the teams.
- Out-of-market ("OOM") telecast rights are held by the League.
- OOM telecasts are sold as part of an OOM Bundle ("OMB").

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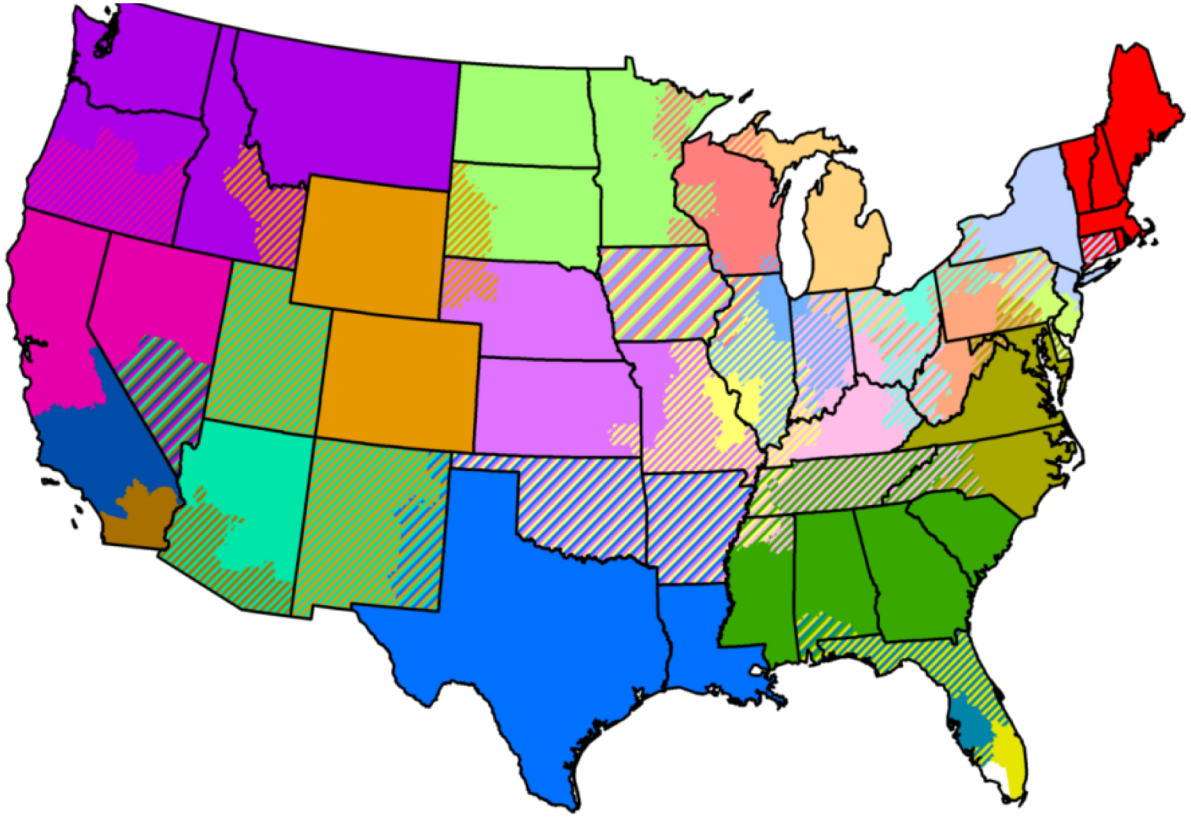
Garber v. MLB et al.



- Plaintiffs characterize the rights arrangements as a conspiracy to divide the "MLB Video Distribution Market."
- Plaintiffs claim this conspiracy harmed all consumers that purchased the OMB.

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Dr. Noll's Assumptions Ignore the MPVDs

	Dr. Noll's Assumptions	Market Reality
Cost to Marketer	Cost = telecast costs	RSN/MVPD negotiation sets cost Cost = telecast cost + RSN markup
Who Sets Prices	Each RSN sets the price to consumers for its own product	MVPDs set prices to consumers for all products it markets (includes all RSN's)
Pricing Incentives	Each RSN sets its price independently to maximize its own revenue minus the telecast cost	An MVPD sets prices to maximize revenue from all products it markets minus the sum of their fees

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Assumptions vs. Likely Reality

- Dr. Noll's BFW pricing assumptions.
  - MVPDs face higher cost than Dr. Noll assumes.
  - MVPDs prices multiple products, but Dr. Noll assumes RSNs set prices "independently."

  Implication: Consumers face higher prices than Dr. Noll assumes.

- Dr. Noll did not check equilibrium conditions.
  - Dr. Noll assumes there still exists an OMB including all teams. However, the Yankees would make more money if they drop out and increase price.

  Implication: Both Yankee and OMB consumers lose.

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Extension 3: Non-price centralized allocation frameworks.

In markets where prices are used, allocations are determined by tastes, the prices of the goods marketed, and endowments. There are many circumstances in which society (or a relevant subset therein, like a sports league) does not want to allow endowments to overly impact allocations (the NBA conducts a draft rather than letting wage offers clear the entering cohort's market). The three of these that have been empirically analyzed recently are;

- the medical residency match,
- school assignment mechanisms, and
- the kidneys match

(Roth, Pathak, Sonmez, Abdulkadirouglu, Somaini, Agarwal.).

Analysis.

- Framework: Deferred Acceptance Algorithm, Top trading cycles (Gale, Shapley), and forms of serial dictatorship (test scores). These are mechanisms which take a set of preferences and generate an allocation from them, that satisfy some desirable criteria.
- Theory Issues: the mechanisms that these replaced had undesirable properties (unravelling, fairness considerations).
- These mechanisms are improvements, but due to administrative, cognitive, and institutional constraints, often are not guaranteed to produce desired allocation.
- E.g.'s include; incomplete application lists, ties in ordering , interdependent preferences (couples or siblings), institutional constraints (walk zones), lack of knowledge among participants.
- There s an active area of research directed at trying to mitigate these problems, part applied theory and part empirical.

Empirical work.

- Evaluation of outcomes.
  - For medical and school match requires estimates of utility functions. Data: for schools from ordered lists submitted by participants.
    For medical match only final allocations and characteristics of the participants on the two sides has been made available.
  - To compare to prior mechanisms; requires an ability to estimate preferences when lists are, and are not, truthful (incentive incompatibility) which requires perceptions of how others make decisions.
  - To formulate a new allocation mechanism: what aspects of allocation mechanisms are central to good performance?
- The kidney match is more complex as applicants offered a kidney can reject it and wait for a "better" kidney. This leads to a need to study
  - dynamic choices by individuals when the appearance of kidneys is random; and there are match specific complementarities that must be incorporated in the model

Production Functions and Productivity.

Productivity is defined as the ratio of outputs to inputs. Interested because

- Regulation: the major justification for "regulated" monopolies and for mergers (i.e. that they will generate some form of efficiency).
- More generally the relationship between market structure and the efficiency of the allocation of output among firms is a classic I.O. question.
- Evaluate policies for; infrastructure, public R&D, intellectual property laws, ...; many of which are justified by increasing productivity

Analysis: requires estimation of the index of inputs or the "production function".

- Productivity is the "residual", the output differences that inputs do not account for.
- Environmental changes change relative productivities; leads to entry, exit, and changes in size of continuing establishments. $\Rightarrow$ estimation needs to
  1. correct for entry and exit (else there will be a selection when you look at how events change productivity as large and small firms exit at different productivity levels)
  2. a way of separating out input growth from productivity growth (since input choices depend on productivity and productivity is a residual) .

Analysis.

- Economic theory provides the relationship between input demand and exit decisions to productivity (Maskin and Tirole, 1987; Ericson and Pakes, 1995).
- Olley and Pakes (1996) use this to correct for the relationship between productivity and i) input demands, ii) exit in their analysis of the breakup of A.T. &T.

The breakup of A.T. & T (1982-84)

- Had been a legally protected monopolist in telephone services, and only purchased equipment from its wholly owned subsiduary, Western Electric.
- Judge Green. Breaks it into 7 Regional Bell Operating Companies and makes it illegal for any of them to operate an equipment manufacturer.
- Huge change in structure of industry; immediate entry by Ericson, Northern Telecom, Hitachi,...)
- Question: how did deregulation impact productivity, welfare....

Correcting for exit and simultanaeity in production function estimates

- Note the difference between the balanced panel estimates and the full sample. in sample size
- Full sample Total and Kernel columns correct for the input and exit decisions; Note the difference in capital and labor coefficients.

Productivity growth

- Analysis finds productivity growth after deregulation.
- Prior analysis of productivity just had aggregate data.
- With micro data can we delve deeper into the causes of productivity growth?

Table VI
Alternative Estimates of Production Function Parameters[a]
(Standard Errors in Parentheses)

Sample:	Balanced Panel		Full Sample[c,d]			
						Nonparametric F_ω
	(1)	(2)	(3)	(4)	(5)	(6)
Estimation Procedure	Total	Within	Total	Within	OLS	Kernal
Labor	.851	.728	.693	.629	.628	.608
	(.039)	(.049)	(.019)	(.026)	(.020)	(.027)
Capital	.173	.067	.304	.150	.219	.355
	(.034)	(.049)	(.018)	(.026)	(.018)	(.058)
Age	.002	-.006	-.0046	-.008	-.001	.010
	(.003)	(.016)	(.0026)	(.017)	(.002)	(.013)
Time	.024	.042	.016	.026	.012	.020
	(.006)	(.017)	(.004)	(.017)	(.004)	(.046)
Investment	—	—	—	—	.13	—
					(.01)	—
Other Variables	—	—	—	—	—	Kernel in P and h
# Obs.[b]	896	896	2592	2592	2592	1758

a. The dependent variable is the log of value added.

Decomposing Productivity Growth

- If $p_{i,t}$ is measured productivity p_t is aggregate productivity for the industry, $s_{i,t}$ is the share of the plant in industry sales, and $\overline{p}_t$ is the (unweighted) average productivity among plants

$$p_{i,t} = \sum_i s_{i,t} p_{i,t} \quad \Rightarrow \quad p_t = \overline{p}_t + \sum_i \Delta s_{i,t} \Delta p_{i,t},$$

  where $\Delta p_{i,t} = p_{i,t} - \overline{p}_t$, etc.

- This divides productivity changes into

  1. allocation of output effect,

  2. general productivity improvement.

- The productivity improvements we see after 1984 are totally in the distribution of output among plants (Table 11)

- What is clear is that the covariance of capital and productivity is improving. Under regulation the capital allocation seems inefficient and de-regulation improves it.

Table XI
Decomposition of Productivity[a]
(Equation (16))

Year	p_i	$\overline{p}_i$	$\Sigma_i \Delta s_{it} \Delta p_{it}$	$\rho(p_t, k_t)$
1975	0.72	0.66	0.06	-0.11
1976	0.77	0.69	0.07	-0.12
1977	0.75	0.72	0.03	-0.09
1978	0.92	0.80	0.12	-0.05
1979	0.95	0.84	0.12	-0.05
1980	1.12	0.84	0.28	-0.02
1981	1.11	0.76	0.35	0.02
1982	1.08	0.77	0.31	-0.01
1983	0.84	0.76	0.08	-0.07
1984	0.90	0.83	0.07	-0.09
1985	0.99	0.72	0.26	0.02
1986	0.92	0.72	0.20	0.03
1987	0.97	0.66	0.32	0.10

[a] See text for details.

What are we missing and why is it important?

Revenue vs Quantity.

- Most data sets (including the O-P data) have revenue, but not quantity.
- For many issues it will be important to separate them out; if revenue goes up because price goes up, it need not be a good thing. Indeed in the last example it is strange to see no average productivity increase in such a high-tech industry. It could be that whatever increase is actually occurring generates price falls that bring "revenue" productivity down.
- New work by De Loecker and co-authors (E.g. De Loecker, Goldberg, Khandelwal, Pavnick 2015): makes progress in separating revenue from output productivity.
  - Puts more structure on input decisions; cost minimization plus a "perfectly" variable input generate markup=price/marginal cost.

Multiproduct Firms.

- We need an Analytic framework for multi-product firms.
  - Data limitations make it hard to estimate a cost function; $\Rightarrow$ we need a production possibility frontier (allow for common costs).
  - Regulatory issues: economies of scope, vertical integration,...

R & D

- Impact of R&D on productivity and of market structure on R&D is at the heart of
  - many merger cases (recently Dow/Dupont; Monsanto/Bayer),
  - the current debate on the impacts of increases in concentration on inequality.
  - Much of the argument is based on labor share going down and variable profits going up. **There is a question of (i) measurement (where are markups going), (ii) how is it related to various factors of production (including R&D), and (iii) how is it related to inequality.**

- There are many difficulties in pursuing these issues.
  - All the issues that have been hampering dynamic analysis (second semester),
  - direct measures of research output (often also research inputs) are hard to find and those we do have a lot of imperfections

A Start on Product Development: Product Repositioning and Merger Analysis.

Background: Horizontal merger analysis.

- Focuses on predicting price changes resulting from the merger holding the set of products and their characteristics constant. If their are no "cost synergies" the merger will increase price.
- However this does not take into account product repositioning: a change in the characteristics of the products marketed by an incumbent firm.
- Recent work: shows that in a number of industries an analysis that does not take repositioning into account is likely to be misleading, even in the very short run.

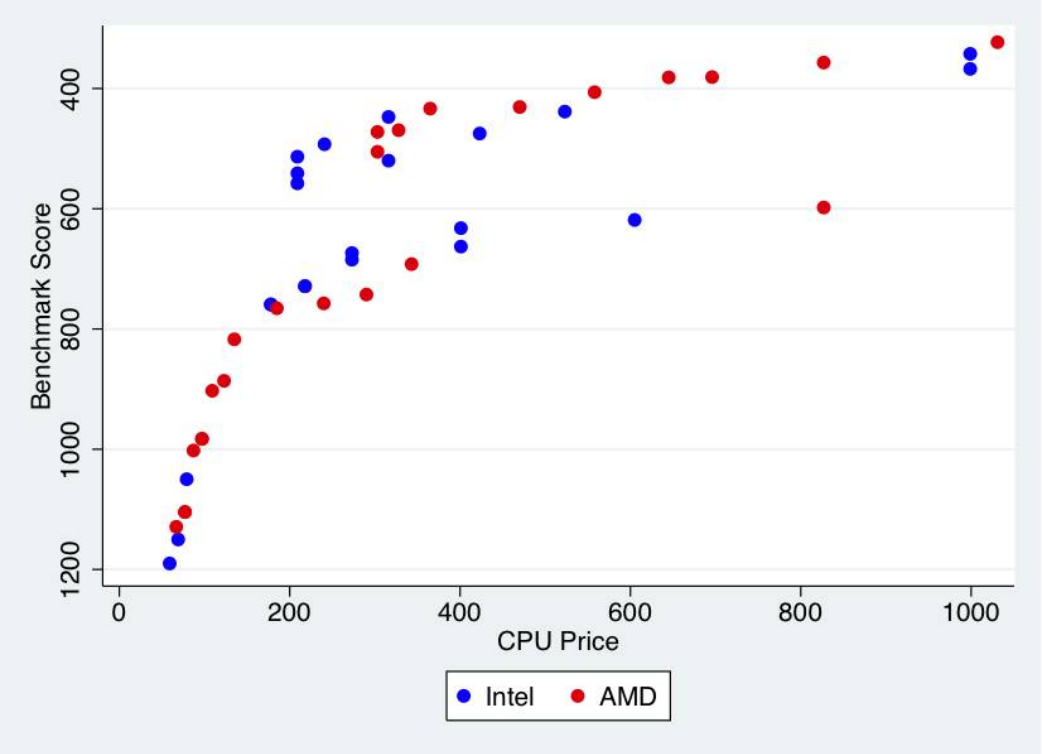
The product repositioning literature

- In addition to demand systems and pricing equations it requires estimates of the fixed cost of marketing a new variant of a product.
- Use the literature on profit inequalities (Pakes, Porter, Ho, and Ishii, 2012). Requires different econometric tools: and we will provide some background on this.
- Since prior work enables us to calculate profits from a counterfactual, we can calculate
  - the incremental profits a firm makes from marketing a product which are expected to be greater than the fixed cost; generates a lower bound to fixed costs and
  - if a firm could have marketed a product but decided not to, the change in profits that it expected to earn from marketing the new product must be less than the fixed costs.; generates an upper bound.

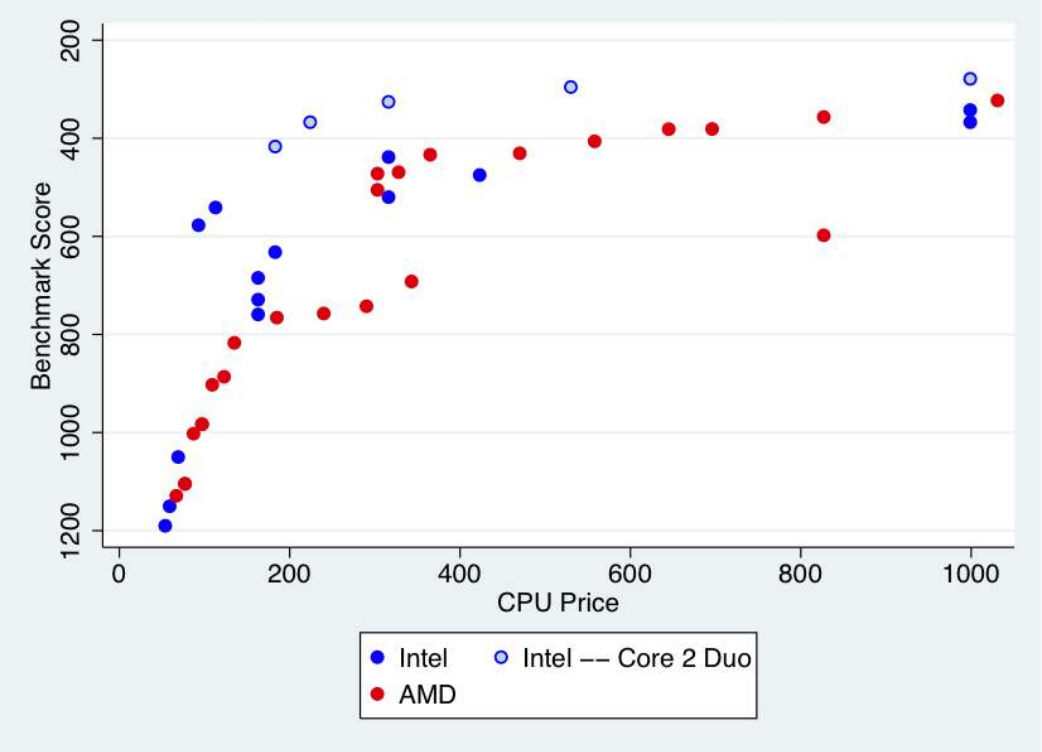
Example: Nosko: Intels' Introduction of The Core 2 Duo Generation in Desktops.

Figures: benchmark scores and prices for the products offered at different times.

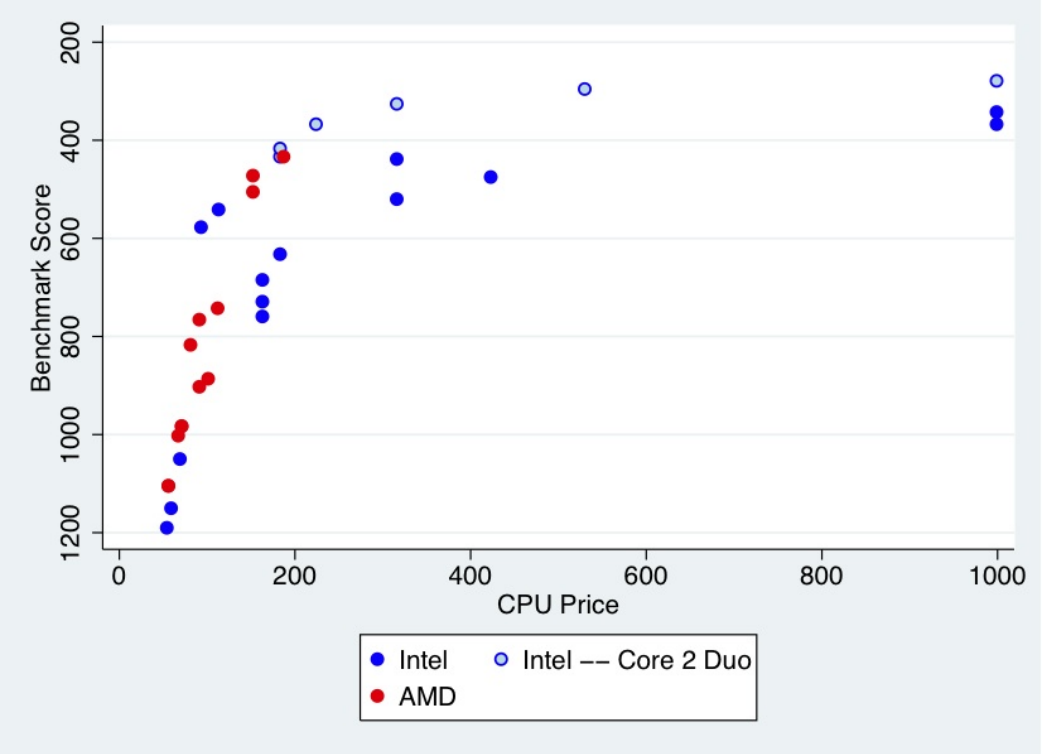
- June 2006: just prior to the introduction of the Core 2 Duo. The red and blue dots represent AMD's and Intel's offerings. Intense competition for high performance chips with AMD selling the highest priced product at just over $1000: seven sold at prices between $1000 and $600.
- Core 2 Duo introduced in July. By October; (i) AMD no longer markets any high priced chips (ii) there are no chips offered between $1000 and $600 dollars.
- November 2006: Only Core 2 Duo's at the high end.
- Nosko goes on to explain
  - that the returns from the research that went into the Core 2 Duo came primarily from the markups Intel was able to earn as a result of emptying



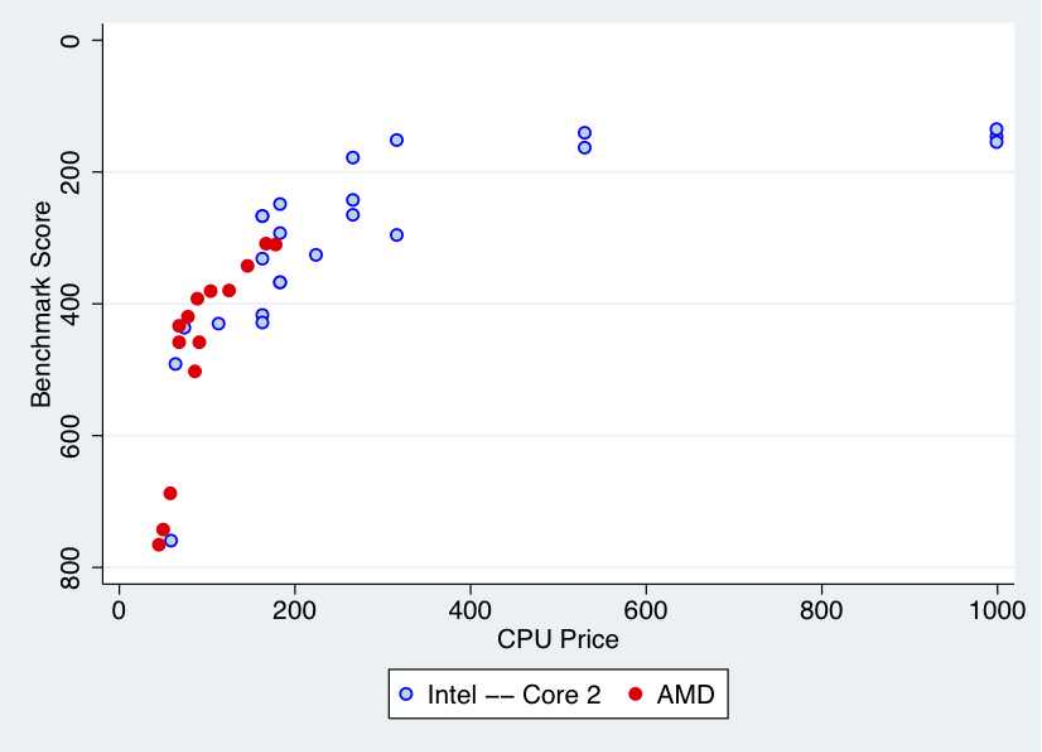
Price/Performance – June 2006



Price/Performance – July 2006



Price/Performance – Oct 2006



Price/Performance – January 2008

out the space of middle priced chips and dominating the high priced end of the spectrum.

– how a similar phenomena would likely occur if AMD were to merge with Intel. So one would get the wrong results if one ignored product repositioning in analyzing the potential merger.

Dynamics.

(This, will be the focus of the second semester, so I will be brief here)

- We need an empirically useable model for investments in physical assets and in product development.
- We started with Markov Perfect models (Maskin and Tirole, 1987, for the theory and Ericson and Pakes, 1995, for the applied framework). These models are based on two behavioral assumptions;
  - firms make choices to maximize their perceptions of the expected discounted value of future net cash flows, and
  - their perceptions are consistent with both the play of competitors and the processes generating any exogenous factors that affect profits.
- The basic model lead to computational explorations of theoretical issues learning by doing (Besanko et. al.), the impacts of collusion (Fershtman and Pakes), mergers impact on investments, (Gowrisankaran, Mermelstein Nocke Satterthwaite and Whinston) & some empirical work (Benkard on aircraft, Goettler and Gordon on computer chips).

What seemed like realistic assumptions lead to the need for

- large state space, and/or
- asymmetric information.

Once we took either into account the cognitive and memory requirements to formulating policies for these models were such that it was difficult

- for the researcher to use these models (computation, estimation...), and
- to believe management made decisions in this way.

So though many thought that these models were the best available, it seemed worth investigating assumptions that might both

- better approximate firm behavior, and
- be easier for the empirical researcher to use.

Attempts to do so

1. Based on approximating equilibria. Benkard, Weintraub, and Van Roy, (2008) operationalized a computational technique based on a limiting (or invariant) distribution over states in "Oblivious Equilibrium" .
   (Related work includes the "mean field" literature in Operations Research and the anonymous sequential games literature in economic theory.)
2. A behavioral approach to simplifying the problem was developed by Fershtman and Pakes, (2012) and labelled "Experience Based Equilibrium". It assumes that given their information sets, firms do not err on average. With appropriate information sets it nests Oblivious Equilibrium
   (For related work in the theory literature see Fudenberg and Levine, 1993, on "self-confirming equilibrium".)
3. Empirical work is just beginning. Perhaps the most striking example is on the bulk shipping industry where Kalouptsidi et. al. combine the above approaches in a setting with search, and endogenously determine trade costs, how they would change with particular environmental changes, and the impact of those changes on trade.

Where are we with applied work on dynamics?

- Computational theory is well underway. In many ways it mimics what happened in applied theory in the 1980's; i.e. we compute examples of what can happen, and they are often illuminating.
- Empirical work; though computational and data constraints are less than they used to be, they are typically still a problem. Work is just starting using the new frameworks. A good example is Brancacio, Kaloupstidi, and Papageorgio (2017).
- There is a need for work on transitions to equilibrium behavior as distinct from equilibrium behavior per se; for a start see (Doraszelski, Lewis and Pakes, 2017)

Like most prior problems in applied work, these are likely to be solved in the context of actually doing empirical work on particular industries.