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# Personal Statement

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**Executive summary.** My research explores, challenges, and extends the applicability of auction theory for the analysis and design of real-world market institutions. Auctions have been studied intensively for decades, but my work has pushed the envelope of auction theory in interesting new directions. For example, an important part of my research has added to the foundation for theoretical and empirical studies of “multi-unit auctions”, with recent work applying these new tools to data.

Within the auction paradigm, a fundamental assumption is that players abide by well-understood rules. But how can players credibly commit to abide by rules? My joint work with Michael Schwarz develops a theory of “credible sales mechanisms” that raises the possibility of viewing some negotiation procedures and customs as endogenous.

Finally, in a new vein of work, I examine repeated interactions when stage-game payoffs evolve over time. This research sheds light on how partnerships form, thrive, struggle, and fail in changing environments.

**Outline.** The remainder of this research statement is organized into seven parts:

1. Introduction to auctions.
2. Research on auctions, including work on first-price auctions, multi-unit auctions, and auctions with endogenous information.
3. Research on credible sales mechanisms.
4. Research on changing games.
5. Research on market design-related topics.
6. Teaching innovation.
7. List of papers, with details on current status.

## 1. Introduction to auctions

**Auctions in practice.** Auctions have recently become ubiquitous. Indeed, when Sotheby's and Christie's were sued for price-fixing, the judge auctioned off the right to serve as plaintiffs' lawyer against the renowned auction houses! Furthermore, as auctions have been applied more and more widely, auction theory has left the ivory tower and attracted the attention of business leaders and policy-makers. For example, auction theorists such as Paul Milgrom, Robert Wilson, and Paul Klemperer played central roles designing the recent spectrum auctions in the United States and Europe. These auctions have raised tens of billions of dollars in government revenue and served as a model in many other applications, such as electricity and natural gas procurement.

**Auction theory and the internet.** Less well publicized but no less important is how auction theory is shaping the internet economy. Over \$44 billion worth of merchandise was purchased in eBay auctions in 2005, allowing eBay to collect over \$1.3 billion in fees. Similarly, of Google's \$3.2 billion revenue in 2004, over 98% came from its auctions for search-related advertisements. Bidders in such auctions are strategic and seek out ways to

maximize their winnings at minimal cost. In poorly designed mechanisms, bidders' strategic behavior can undermine the effectiveness of the auction. For instance, the "generalized first-price auction" that Yahoo! used to sell search ads from 1997 to 2002 was substantially more unstable and inefficient than the "generalized second-price auction" that it (and Google) adopted in 2002.<sup>1</sup> Given the centrality of auction theory to their business model, it comes as no surprise that Yahoo! has begun to build an in-house research group focusing on auction design.<sup>2</sup>

**Auctions in disguise.** A search of the literature reveals thousands of economics papers citing auction theory (and tens of thousands of papers across all fields), but most of this work is *not* about "actual auctions" in the literal sense of formally defined mechanisms for the competitive allocation of scarce resources. Auction theory provides a strategic foundation for market microstructure (*i.e.* how prices are determined and goods and assets allocated) beyond the simple picture of supply and demand. More than that, auction theory provides a framework for understanding a wide variety of competitive strategic interactions. Indeed, in the MBA elective that I created, "Game Theory for Strategic Advantage," we spend an entire lecture discussing "auctions in disguise", including (a) getting a job, (b) resolving a dispute, (c) seeking a promotion, (d) competing for a contract, (e) choosing a romantic partner, and so on. Because of this broad applicability to diverse economic phenomena, auction theory has become a mainstay of modern economic theory.

## 2. Auctions

### 2-a. First-price auctions

Although Paul Milgrom and Robert Weber's classic "mineral-rights auction model" has been cited over one thousand times, an open question has remained whether this model has a unique equilibrium.<sup>3</sup> Taken together, my papers "**Uniqueness in Symmetric First-Price Auctions with Affiliation**" and "**Monotonicity in Asymmetric First-Price Auctions with Affiliation**" establish uniqueness. "**Monotonicity ...**" shows that any equilibrium must be in monotone pure strategies (*i.e.* each bidder submits a higher bid when he has a higher value) while "**Uniqueness ...**" shows that there is a unique equilibrium in such strategies.

### 2-b. Multi-unit auctions: theory

Most auction theory research has focused on auctions of a single indivisible object such as the first-price auction, building on seminal work by scholars such as Roger Myerson, Paul

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<sup>1</sup> See Edelman, Ostrovsky, and Schwarz, "Internet Advertising and the Generalized Second Price Auction: Selling Billions of Dollars Worth of Keywords", *American Economic Review* (2007).

<sup>2</sup> In an interview with cNet.com, Yahoo! Chief Scientist Prabhakar Raghavan was asked:

*What are some of your major challenges in developing the Internet as a commercial medium?*

*Raghavan:* We show a lot of banner ads. Pricing these banner ads is similar to pricing airline seats. Airlines have this thing called yield management software that's constantly pricing each seat. This yield management software is always trying to figure out the best way of making the most attractive offer to you. The situation in presenting banner ads is not very different. If you're an advertiser and you want to advertise a certain number of impressions before the Super Bowl, you have the same problem. The only difference, which makes our life a little harder, is that we don't have exactly 180 seats on the plane, and that's because we don't know exactly how many users will show up before the Super Bowl. That leads to interesting dimensions of economics and pricing theory that nobody's quite figured out yet.

<sup>3</sup> Multiplicity of equilibrium raises deep conceptual concerns for empirical work. Thus, proving uniqueness is especially important for empirical applications.

Milgrom, and Robert Weber in the 1980s. In multi-unit auctions (also known as “share auctions”), bidders buy, sell, or trade shares of *divisible* objects. Examples include everything from stock exchange trading and web banner ad sales to Treasury bond sales and electricity procurement. Despite its practical importance, the theory of multi-unit auctions was left relatively undeveloped until recently because of its difficulty.<sup>4</sup> Multi-unit auctions are games having multi-dimensional actions (*i.e.* one may bid different prices for different quantities) and multi-dimensional private information (*i.e.* bidders may have different willingness to pay for different quantities), a notoriously challenging combination.

In “**Isotone Equilibrium in Games of Incomplete Information**”, I leverage lattice theory to prove existence of equilibrium and verify certain “monotonicity” properties of equilibrium play in games with multi-dimensional actions and multi-dimensional private information. My work sheds light on games in contexts well beyond auctions, such as oligopolistic competition among firms that compete on several dimensions, allowing one to address questions such as, “Should my firm raise or lower its price when others invest more heavily in research?”

In “**Monotone Equilibrium in Multi-Unit Auctions**”, I applied these new lattice tools to commonly studied multi-unit auction models, proving that equilibrium exists and that every equilibrium must be in monotone pure strategies (*i.e.* each bidder submits a higher bid for every quantity when he has a higher willingness to pay for every quantity). On the other hand, “**On the Failure of Monotonicity in Uniform-Price Auctions**” explores the limits of monotonicity in multi-unit auctions. Surprisingly, for reasons unique to multi-unit auctions with multi-unit demand, *all* equilibria may fail to be monotone if bidders are risk-averse or if bidder values are affiliated.

## **2-c. Multi-unit auctions: evidence**

**Applying auction theory in the field.** Auctions provide unique opportunities for empirical analysis. Most importantly, auctions provide a compelling laboratory in which to examine strategic behavior and make policy-relevant inferences about players. As Susan Athey and Philip Haile explain in their excellent surveys of the field:

“Auctions provide opportunities for economists to examine field data from markets that can involve rich strategic interaction and asymmetric information while nonetheless being simple enough to be convincingly captured by a tractable economic model. The primitives of any strategic model include the set of players, the information structure, the rules of play, and players’ objectives. In auction markets, one can often describe these key elements with an unusually high degree of confidence. Consequently, auctions have been at the center of efforts to combine economic theory with econometric analysis to understand behavior and inform policy.” (Athey and Haile, 2006a, “Nonparametric Approaches to Auctions”, *Handbook of Econometrics*, Volume 6, forthcoming)

“Examples [of policy questions that can be addressed by auction analysis] include the division of rents in auctions of public resources, whether reserve prices in government auctions are adequate, the effects of mergers on procurement costs, whether changes in auction rules would produce greater revenues, whether bundling of procurement contracts is efficient, the value of seller reputations, the effect of information acquisition costs on bidder participation and profits, whether bidders’ private information introduces

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<sup>4</sup> Notable exceptions include two classic papers, “Auctions of Shares” (1979) by Robert Wilson and “Supply Function Equilibria in Oligopoly under Uncertainty” (1989) by Paul Klemperer and Margaret Meyer.

adverse selection, and whether firms act as if they are risk averse. Many of these questions have important implications well beyond the scope of auctions themselves.” (Athey and Haile, 2006b, “Empirical Models of Auctions”, Invited lecture, Ninth World Congress of the Econometric Society)

These sorts of policy questions can be addressed only with knowledge of underlying primitives. An auction model is said to be *identified* when observables (e.g. the distribution of bids) correspond to unique primitives (e.g. the distribution of bidder values). An important finding of the existing literature is that most commonly studied single-object auction models are identified, under relatively mild restrictions on observables. The first main contribution of **“Partial Identification and Testable Restrictions in Multi-Unit Auctions”** is to develop the theory of identification in multi-unit auctions. Surprisingly, even the simplest multi-unit auction models (uniform-price and discriminatory auctions with risk-neutral bidders and independent private values) are *not* identified. However, one can still conduct meaningful policy analysis with data from such auctions, since I provide (tight) *upper and lower bounds* on the values that each bidder might have had when making each observed bid.

This research has helped to open multi-unit auctions to the sort of econometric analysis that has flourished in the context of single-object auctions, as evidenced by several recent empirical projects of mine with co-authors.

*Counter-factual policy experiments.* In **“Bounding Revenue Comparisons across Multi-Unit Auction Formats under epsilon-Best Response”** (with James Chapman and Harry Paarsch) we bound the expected revenue that the Bank of Canada could expect were it to switch to a different auction format for its cash reserve auctions. Similarly, in **“Mechanism Choice and Strategic Bidding in Divisible-Good Auctions: An Empirical Analysis of the Turkish Treasury Auction Market”** (with Ali Hortacsu), we bound the expected revenue that the Turkish Treasury could expect were it to switch to a different auction format to sell Treasury bonds. (This paper builds on and replaces Hortacsu’s job-market paper, and as such is revise-and-resubmit at *Econometrica*.)

Perhaps the most exciting innovation in **“Mechanism Choice ...”** is a new set of estimation methods by which one can make meaningful inferences about bidders’ values given data from a *single* multi-unit auction.<sup>5</sup> The standard practice in the literature has been for researchers to pool data from across auctions to estimate the distribution of bids in each auction. Unfortunately, this approach is invalid if the auctions in the sample differ in unobserved ways, or if bidders adopt different strategies in otherwise identical auction environments. Our auction-by-auction approach circumvents these concerns, though at some cost. In particular, the econometrician must be able to control for ex ante differences between bidders (e.g. be willing to assume that bidders are symmetric or belong to one of several “symmetry classes”).

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<sup>5</sup> One of my contributions to this project has been in deriving asymptotic properties of the estimator proposed in Hortacsu (2002). First, as long as asymptotic supply is “diffuse” in the sense of “Efficiency of Large Private Value Auctions” (2001) by Jeroen Swinkels, bidder values are point-identified in the limit as the number of bidders in the auction goes to infinity. On the other hand, if supply is non-random, then bidder values are not point-identified in this limit. However, even in this case, meaningful confidence intervals for bidder values can be derived when there are “many but not too many” bidders. (Our empirical application provides an example in which meaningful confidence intervals can be derived.)

*Estimating participation costs.* Much of the existing literature on auction design has explored the efficiency properties of equilibrium bidding behavior under alternative auction formats. These analyses implicitly assume that it is costless for bidders to “learn how to play” in an auction of a particular format. However, it may be problematic to assume that firms can acquire the strategic sophistication to bid optimally in, say, a uniform-price auction just as easily as in a discriminatory or Vickrey auction. In work-in-progress with Steven Puller, “**The Cost of Strategic Participation in Multi-Unit Auctions: Evidence from the Texas Electricity Market**”, we estimate bounds on the cost of such “strategic participation” by analyzing bidding behavior into the Texas electricity spot market. We also investigate whether mergers between small firms, while increasing market concentration, can increase efficiency if there are scale economies to strategic bidding.

*Testing auction theory in the field.* Existing econometric analysis of auctions hinges on the assumption that bidders play equilibrium strategies. But does each bidder actually play a strategy that is a best response to the strategies of others? When field data are used and bidders’ true valuations are unobserved, testing the equilibrium hypothesis can be very difficult in single-object auctions. For example, in the first-price auction, a latent distribution of bidder values exists that rationalizes observed bidding behavior as long as the distribution of bids satisfies the “monotone likelihood ratio property”.<sup>6</sup>

The second main contribution of “**Partial Identification and Testable Restrictions in Multi-Unit Auctions**” is to provide novel testable restrictions of the equilibrium hypothesis, if one is willing to assume that bidders have non-increasing marginal values (NIMV) – that is, each bidder’s value for a first unit is greater than or equal to his value for a second unit and so on. Furthermore, in a significant simplification, I show that testing these restrictions is equivalent to a problem of testing a set of moment inequalities on multinomial probabilities.

For an intuition why one can reject the equilibrium hypothesis without observing bidder values in multi-unit auctions, consider a uniform third-price auction of two units.<sup>7</sup> In any best response, each bidder bids his true value for the first unit but shades his second bid below his true value for the second unit. Suppose now that some bidder  $i$  bids the same price (say \$10) on both units. If this bid is a best response, bidder  $i$ ’s value for the first unit must be \$10 while his value for the second unit must be *greater* than \$10, violating NIMV.

In “**Bounding Best Response Violations in Discriminatory Auctions with Private Values**” (with James Chapman and Harry Paarsch), we apply these new testing techniques to examine data from the Bank of Canada’s twice-daily cash reserve auctions. Bidders in this market are large banks seeking to manage their cash. An advantage of studying auctions of cash is that the NIMV assumption is very natural. Banks use the first dollar that they receive in the highest-value use, the second dollar in the second-highest-value use, and so on. Our main finding is that some bidders frequently fail to play a (static) best response. Yet the “mistakes” that we measure are typically small, often less than the price of a cup of coffee when the implicit values at risk are tens of thousands of dollars. This suggests that equilibrium play may be a good *approximation* of actual bidding behavior and hence that econometric techniques based on the assumption of equilibrium play may be approximately valid.

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<sup>6</sup> In the second-price auction, matters are even worse. Since each bidder has a dominant strategy to bid his own value, all bids can always be rationalized by assuming that each bidder’s value is equal to his bid.

<sup>7</sup> In this auction, the highest two bids win but winners pay a price equal to the third-highest bid.

## 2-d. Auctions with endogenous information

An important implicit assumption of auction theory is that the structure of private information is exogenous.<sup>8</sup> For example, in a private-value auction, each bidder knows his own value while all other players do not *and can not* know that bidder's value. In reality, players expend considerable resources to learn what others know and to share or hide what they know.

Work-in-progress “**Auctions with Information Disclosure**” endogenizes the structure of information in an otherwise standard auction framework. In particular, at a cost, bidders are able to credibly disclose their values (or costs) to the auctioneer.<sup>9</sup> For example, in tight supply chain relationships, large buyers like General Motors routinely work closely with suppliers to identify (and lower) the costs of production. This makes it plausible that a supplier could credibly disclose its true costs to GM, although doing so would be costly for the supplier and/or for GM. In this setting, my analysis implies that the optimal auction for GM takes a simple form: Award the contract to whoever announces the lowest price, but require cost-justification of any winner whose price is above a pre-specified threshold.

Closely related is work-in-progress “**Monopoly Pricing with Imperfect Information Disclosure**”. Here the buyer is able to credibly disclose only an imperfectly informative signal of his willingness to pay, such as age or income. The optimal pricing mechanism in this context is as follows: Allow any buyer to purchase the good at a pre-specified “full price,” but offer a discount to any buyer who can prove that he “qualifies” under certain pre-specified criteria.

## 3. Credible sales mechanisms

The auction paradigm has dominated the academic analysis of real-world sales mechanisms for over twenty years, despite the fact that buyers and sellers in many transactions conspicuously lack the ability to commit to an orderly sales process. This observation has led Paul Klemperer to emphasize the importance of “credibility of the rules” in auction design:

“Sealed-bid auctions [may be] vulnerable to rule-changing by the auctioneer. For example, excuses for not accepting a winning bid can often be found if losing bidders are willing to bid higher. The famous RJR-Nabisco sale went through several supposedly final sealed-bid auctions.” (Klemperer, 2002, “What Really Matters in Auction Design”, *Journal of Economic Perspectives*.)

Even in internet auctions, in which a credible intermediary such as eBay can commit to auction rules, buyers and sellers often have an incentive to expend considerable resources *outside of the auction* to gain an advantage. This is important since, as I show with Michael Schwarz in “**Who Pays When Auction Rules are Bent?**” all such spending translates into lost seller profits. For example, Edelman, Ostrovsky, and Schwarz present evidence that bidders in Yahoo!'s search-advertisement auctions gained a substantial advantage by using bidding software that adjusted their bids more quickly than others' software. As a result, a cottage industry providing fast bidding software emerged, ultimately leaching Yahoo!'s profits (and creating inefficiencies as faster bidders outbid others even when they did not have the

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<sup>8</sup> A large literature considers auctions in which players' values are revealed after the auction (e.g. “auctions with royalty payments”). Separately, Hanming Fang and Stephen Morris have recently examined an auction model in which players receive signals about others' values, but the structure of information is still exogenous.

<sup>9</sup> The important problem of endogenizing bidders' information about other bidders must await future research.

highest value). When Yahoo! switched to the more stable “generalized second-price auction”, bidders had much less incentive to invest in speed. In eBay auctions, similarly, bidders try to gain an advantage by bidding in the last minute, typically paying a third-party service a commission when they win. All money spent in this way also ultimately translates into lower bids, lower seller profit, and lower eBay commissions. These examples illustrate that there can be an important difference between an *announced* sales mechanism and an *actual* sales mechanism, if either the seller or the buyers have an incentive to act outside of the announced game. When designing or studying an auction, therefore, we must consider whether the rules are credible.

In our joint work on “credible sales mechanisms”, Michael Schwarz and I have begun to expand the auction paradigm to account for players’ limited ability to commit to rules. This research was inspired by a negotiation between the Spanish airline Iberia and the airplane manufacturers Boeing and Airbus that students in my game theory class analyze through the lens of auction theory.<sup>10</sup> A notable feature of this example is how messy and difficult it was for Iberia’s CFO Enrique Dupuy de Lome to conduct the negotiation. The bidders were cagey and reluctant to make offers, and the process of concluding the deal took months longer than expected. Fundamentally, Mr. Dupuy’s problem was that he lacked the ability to credibly close the sale. Boeing and Airbus dragged their feet because they knew that any bid would be followed by a demand for yet another bid. Finally, Mr. Dupuy found a way to commit to a *deadline*. He called a special board meeting at which he promised to announce the winner, prepared separate Powerpoint presentations announcing a deal with each supplier, and waited. Just hours before the meeting, Airbus and Boeing presented new offers at significantly lower prices. With no time to bargain further, Mr. Dupuy compared the offers, chose Airbus, and closed the deal.

**“Credible Sales Mechanisms and Intermediaries”** proposes a framework in which to view some negotiation procedures and customs as endogenous. In particular, we consider a rich though tractable model in which a seller interacts with several buyers but can not commit to an auction since the seller lacks access to an institution to credibly close the sale (*i.e.* the seller can not resist the temptation to “haggle” with buyers when doing so is likely to lead to a higher price). The first-price auction emerges as a “credible sales mechanism” when the cost of haggling is very high, while an open ascending-price auction – similar to the well-studied English auction but with an endogenous pace of offers – is credible when the cost of haggling is very low. However, in the intermediate case, expected seller losses due to haggling can be quite large, on the same order of magnitude as the gains from being able to commit to an optimal reserve price. In such settings, a reputable intermediary can create substantial value by helping the seller commit to hard rules.

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<sup>10</sup> Students apply the Revenue Equivalence Theorem to develop strategic advice for Iberia’s CFO on how best to conduct the negotiation. Most students conclude that Iberia should *not* maintain a veil of secrecy and should conduct several rounds of offers until one of the suppliers drops out. This is remarkably similar to the actual negotiation, described in detail in “Airbus and Boeing duke it out to win lucrative Iberia deal” by Daniel Michaels, Wall Street Journal, March 10, 2003.

## 4. Changing games

Uncertainty about future payoffs is an important element in many ongoing relationships. For example, competing firms may view future market demand as being somewhat random and partners may not be able to predict future outside opportunities or the future value from working together. My work on repeated games in changing environments (“changing games”) shows that such uncertainty can have important and surprising implications regarding the dynamic process by which partnerships form, thrive, struggle, and fail.

For concreteness, consider a repeated game in which period- $t$  payoffs take the form

	Cooperate	Defect
Cooperate	1,1	$-1-d_t, 1+d_t$
Defect	$1+d_t, -1-d_t$	0,0

where each player’s incentive to defect  $d_t$  follows a stochastic process. (The stage-game is a Prisoners’ Dilemma if  $d_t > 0$  and a Coordination game if  $d_t < 0$ .) Suppose further that each player can end the relationship at any time and, if so, each player gets outside option flow payoff  $0 < v < 1$  in every subsequent period.

Cooperation is harder. When players discount payoffs by factor  $\delta < 1$  and the incentive to defect is unchanging, it is straightforward to derive that mutual cooperation at time  $t$  is possible if and only if  $d_t \leq (1-v)*\delta / (1-\delta)$ . On the other hand, suppose that  $d_t$  evolves according to any Markov process such that  $\Pr(d_{t'} > d_t | d_t) = \frac{1}{2}$  for all  $t' > t$  and all  $d_t$ , including random walks that move arbitrarily slowly. Then, in the subgame-perfect equilibrium that maximizes the players’ joint payoff, both players defect at time  $t$  whenever  $d_t > \frac{1}{2} * (1-v)*\delta / (1-\delta)$ . Players must defect in a larger set of payoff-states since they can not credibly commit today to cooperate in future periods when the incentive to defect will be higher. Consequently, players have less incentive to cooperate today, since they can not be “punished” as effectively later.

Equilibrium dynamics. Several other interesting phenomena emerge in the subgame-perfect equilibrium that maximizes players’ joint payoff, when entry and exit are endogenous. Among them: “*Honeymoon*” (players are likely to cooperate during the first several periods after partnership formation), “*Golden years*” (players whose relationship has lasted longer are more likely to remain together and cooperate in the future), “*Hard times before divorce*” (players typically endure periods of mutual defection before either ends the relationship).

The optimal cost of exit. Contracts and/or laws can affect the cost of exiting from a relationship (e.g. “no-fault” divorce laws). While players always prefer for entry to be less costly in my model, they sometimes prefer for exit to be more costly. Such considerations can provide an equilibrium rationale for why players sign contracts that make it difficult to leave a relationship, but nonetheless leave those relationships with positive probability.

## 5. Market design

I am interested in diverse applications of market-design principles to real-world problems.

**Medicare’s drug benefit.** In January 2006, Medicare rolled out an unprecedented and massive program to provide seniors with stand-alone prescription drug coverage. In this

program, prescription drug providers (PDP) are free to design their own formularies (*i.e.* lists of drug that are covered) and set their prices, with seniors free to choose among all plans offered in their region. Subsidized by Medicare and “risk-adjusted” to control for the effects of adverse selection, this design is intended to create a self-regulating market. However, as Michael Schwarz and I argue in “**Perverse Incentives in the Medicare Prescription Drug Benefit**”, Medicare regulators are likely to continue to heavily regulate formularies as they have done in 2006, requiring that “unique” and “commonly used” drugs be covered by all PDPs.<sup>11</sup> Of course, making coverage mandatory weakens PDPs’ bargaining strength with drug manufacturers, raising drug prices and the cost of the benefit to the federal government. As an alternative, we argue that the program could ultimately deliver a higher-quality benefit to seniors if PDPs were not allowed to compete on price but only on the extensiveness of their formularies (and other factors such as pharmacy network, etc). See the *NBER Bulletin on Aging and Health*, “Incentives in the Medicare Prescription Drug Benefit”, Spring 2006, for an excellent summary of our work.

**Electricity procurement.** In the late 1990s and early 2000s, electricity prices in California and other states skyrocketed more than ten-fold. A major concern during this period was that electricity generators were strategically withholding quantity from the uniform-price auction market to raise the price and, indeed, theoretical models by Robert Wilson and others suggested that this was possible. In “**Adjustable Supply in Uniform Price Auctions: Non-Commitment as a Strategic Tool**”, I propose a way to change the design of uniform-price procurement auctions to limit the strategic exercise of market power. Rather than pre-specifying the total quantity to be bought, the auctioneer can simply wait until after the bidding to decide how much to buy. This approach rewards aggressive bidders with the “carrot” of extra quantity and leads to lower prices in equilibrium.

**Supply chain management.** In most large companies today, supply chain capacity allocation problems are “solved” by time-consuming, complex, and expensive hierarchical processes involving plant managers, factory schedulers, strategic planners, product managers, marketing analysts, sales managers, and others. In “**Internal Markets for Capacity Allocation**”, Thomas Malone and I show how “internal markets” can be employed to help solve such problems, even in environments in which we would expect “external markets” to fail, *e.g.* in the presence of market power, collusion, or production externalities.

**Speedier internet auctions.** Auction theory presents an idealization in which all bidders are “present” to bid. When open auctions are conducted over the internet, however, network communication costs can be an important factor, especially when using auctions to allocate time-shared resources (such as bandwidth or computing power) in real-time environments. In “**Speeding-Up the Ascending-Bid Auction**”, Yoav Shoham, Yuzo Fujishima and I devise a new class of auctions (called “survival auctions”) which combine the speed and predictability of sealed-bid auctions with the desirable properties of open auctions.

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<sup>11</sup> For conditions that are associated with particular drugs, *e.g.* Novartis’ Gleevec and chronic myeloid leukemia (CML), the cost of drugs is endogenous since it is *chosen* by drug manufacturers. Under a risk-adjustment scheme that reimburses PDPs more for patients with CML, PDPs have little incentive to control the cost of Gleevec since an extra dollar paid to Novartis will ultimately be reimbursed by Medicare via risk-adjustment. Thus, any sensible risk-adjustment scheme will need to be “coarse”, in the sense of lumping together patients having different medical conditions. However, under any coarse risk-adjustment rule, some groups of patients will inevitably be less profitable than others. Given PDPs’ ability to preferentially attract certain groups of patients in very fine-tuned ways (by moving a drug onto a different co-pay tier, by requiring pre-approval, etc), we may therefore expect systematic discrimination against certain groups of patients, unless Medicare regulates formularies directly.

## 6. Teaching Innovation

In a press release in November 2000, the Stanford Graduate School of Business emphasized the importance of game theory in the business school curriculum.<sup>12</sup>

“In the last 25 years, many and perhaps most significant innovations in economics have been driven by the use of game theory, which provides economists with a language and analytical tools to study many economic interactions that older tools, such as price theory, couldn't touch. These interactions involve dynamics, private information, small numbers, and non-market institutions. ‘The impact on economics has been very dramatic,’ says David Kreps, the Paul E. Holden Professor of Economics ... Today, these ideas permeate the curriculum of business schools: Subjects that were dramatically changed by these innovations include strategic management, human resource management, managerial accounting, and business and the environment.”

As a core discipline of economics, game theory is applied in many courses offered at Sloan.<sup>13</sup> Yet until I created “Game Theory for Strategic Advantage” (15.025), we did not have a stand-alone course in game theory. When first offered in Spring 2004, the course attracted 30 students. Word quickly spread, and in Spring 2006 I attracted two sections of 70+ students. What makes this course unique and valuable to MBA students is, interestingly, that we take the *theory* in game theory very seriously. Most other schools will teach game theory techniques, such as how to analyze a game tree, but few (if any) push students to think like game theorists as much as 15.025 does.<sup>14</sup>

The theoretical depth of 15.025 is what most attracts students. We cover a variety of topics that are often reserved for PhD students, from information cascades to the Revenue Equivalence Theorem to sequential equilibrium. Indeed, students are amazed when they discover that the unifying concept of the course – strategic complements – is not even listed in the index of the textbook. They are even more surprised when they learn that (as far as I know) they are the only MBA students, anywhere, learning how to apply tools from the theory of strategic complementarity to problems of business strategy.

Our MBA students are hungry for a substantive game theory course, since the theory opens their eyes to new and powerful ways of thinking about old problems. What pleases me most about my course is that my students really are acquiring the mind-set of a game theorist, and applying the ideas of game theory in creative ways. I believe this will give them a real advantage in the business world. As one student recently wrote to me on a postcard, “I’m sure the tools that I acquired will prove valuable for years to come”.

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<sup>12</sup> See “Game Theory: A New Tool for Economists” by Barbara Buell, available at [http://www.gsb.stanford.edu/news/research/econ\\_gametheory.shtml](http://www.gsb.stanford.edu/news/research/econ_gametheory.shtml)

<sup>13</sup> These applications are wide-ranging: games played between competitors in 15.013 (Industrial Econ); games played between firms and their suppliers and between managers and their employees in 15.903 (Strategy & Org.); not to mention applications in negotiations, international macroeconomics, corporate finance, etc...

<sup>14</sup> Materials from the Spring 2004 version of the course are available on MIT’s OpenCourseWare website, <http://ocw.mit.edu/OcwWeb/Sloan-School-of-Management/15-040Spring2004/CourseHome>.

## 7. Status of Papers

\*\* **Bolded** articles are representative examples of my work.

### PUBLISHED or FORTHCOMING Journal Articles

1. **“Isotone Equilibrium in Games of Incomplete Information”**, *Econometrica*, August 2003.
2. **“Monotone Equilibrium in Multi-Unit Auctions”**, *Review of Economic Studies*, October 2006.
3. “Monotonicity in Asymmetric First-Price Auctions with Affiliation”, *International Journal of Game Theory*, February 2007.
4. **“Credible Sales Mechanisms and Intermediaries”** (with Michael Schwarz), *American Economic Review*, March 2007.
5. “Adjustable Supply in Uniform Price Auctions: Non-Commitment as a Strategic Tool”, *Economics Letters*, April 2007.
6. “Perverse Incentives in the Medicare Prescription Drug Benefit” (with Michael Schwarz), *Inquiry*, Summer 2007. NBER Working Paper 12008.
7. “Uniqueness in First-Price Auctions with Affiliation”, *Journal of Economic Theory*, September 2007.
8. “Who Pays When Auction Rules are Bent?” (with Michael Schwarz), *International Journal of Industrial Organization*, October 2007.
9. “On the Failure of Monotonicity in Uniform-Price Auctions”, *Journal of Economic Theory*, forthcoming. (Available online since March 2007.)

### PUBLISHED Conference Proceedings

10. “Speeding-Up the Ascending-Bid Auction” (with Yoav Shoham and Yuzo Fujishima), *1999 Proceedings of the Int. Journal Conference in Artificial Intelligence*.
11. “Bounding Revenue Comparisons across Multi-Unit Auction Formats under epsilon-Best Response” (with James Chapman and Harry Paarsch), *American Economic Review, Papers & Proceedings*, May 2007.

### REVISE and RESUBMIT

12. **“Mechanism Choice and Strategic Bidding in Divisible-Good Auctions: An Empirical Analysis of the Turkish Treasury Auction Market”** (with Ali Hortacsu), revision requested at *Econometrica*.

## **SUBMITTED**

13. **“Partial Identification and Testable Restrictions in Multi-Unit Auctions”**, submitted to *Journal of Econometrics*.

## **IN PREPARATION**

14. "Bounding Best Response Violations in Discriminatory Auctions with Private Values" (with James Chapman and Harry Paarsch).

15. **“Dynamics in an Evolving Partnership”**

“The Cost of Strategic Participation in Multi-Unit Auctions: Evidence from the Texas Electricity Market” (with Steven Puller)

“Auctions with Information Disclosure”

“Monopoly Pricing with Imperfect Information Disclosure”