

A Volume in Honor of Hugo F. Sonnenschein:  
Foundations in Microeconomic Theory

Presented to Hugo at his 65th Birthday Celebration

October 7, 2005

## Introduction

What a wonderful occasion it is to be celebrating 65 years of Hugo Sonnenschein! Given his many contributions to economic research and academia more broadly, there is much to celebrate. This volume, presented to Hugo at a conference in his honor at the University of Chicago in October 2005, highlights one of his deepest contributions. It is perhaps the hardest to detect from reading his bios and vita; but something that he is famous for among economists in general and economic theorists in particular. It is his incredible record as a mentor and advisor of students.

In putting this volume together, we have collected papers from Hugo's students with the aim of demonstrating his tremendous impact as an advisor. The papers span decades, with the earliest coming from his advisees in the first years of his career and the most recent coming in the last two years after his return to research and advising that followed his adventures as a university administrator. The contributors include not only his graduate advisees, but also some of his undergraduate advisees and still others who did not have him as an advisor, but nonetheless consider him a primary mentor in their training as economic theorists. Each paper is accompanied with a brief preface by the student that provides background on the paper and indicates Hugo's influence on its genesis. The impressive quality of the contributions is a fitting tribute to the overall impact that Hugo has had through his advice and mentoring. Moreover, the papers highlight the variety of ways in which Hugo has had an influence. Some are papers that came out of theses and show Hugo's central hand as advisor, and some were authored jointly with Hugo years after graduation. In other cases the influence was less direct, being related to Hugo's work or exhibiting some other personal touch that Hugo had, such as introducing the student to someone of similar interests, or posing questions that seemed to lead to nothing but puzzles at the time, but which later blossomed into profound insights. Together, we hope that this volume makes obvious the scope and depth of Hugo's impact and influence in his role as advisor.

An enormous amount has been written about instruction, and about the craft of teaching. University administrations worry about it, and devote time and resources to training their faculty to excel at it. In contrast, the role of the advisor still remains much more elusive and has received much less study, even though the preponderance of scholars, particularly at the highest

levels of academia, would include their thesis supervisors in any list of the most important people in their lives. It is inherently subtle, less a matter of “instructing” the student than of overseeing the final steps on the path to intellectual and scholarly independence. Whether it was helping a student who lacked confidence or experience by guiding them towards questions to cut their teeth on, or having the patience to sit down with a student and paper and go through each word and sentence asking what its purpose was and whether it properly conveyed what the author intended; Hugo excelled at all aspects of guidance. What was most remarkable, was his ability to consistently get his students to perform to the very best of their abilities. As many of us have learned, such advising and mentoring can be much more difficult than it seemed when we were working with Hugo. We believe the reminiscences gathered here combine to give a useful and fascinating picture of how one scholar succeeded brilliantly in this capacity.

### **The Papers**

Much of the work in this volume had its origins in the 1970’s and 80’s, which was a period of upheaval in economic theory. Hugo’s reputation in research was built on important results in the theory of the consumer, general equilibrium theory, and social choice. While some of his students worked in these areas, many of his students followed, and to a large extent led, the newer currents associated with the rapid development of game theory. Often, especially in other disciplines, Ph.D. students are expected to pursue the advisor’s research program, but in many cases Hugo was supervising work that was at least a certain distance from his own specializations. Even though such distance makes the advisor’s role more challenging intellectually, the tendency is for the advisor to receive a smaller share of the credit than he would in connection with theses that are clearly related to the advisor’s own research program. Viewing the work done by Hugo’s students collectively reveals that such an assessment would be mistaken, and the common themes visible in the papers in this volume make very evident the part that Hugo played in the rapid progress of that era. Far from being a bystander at the revolution, he was one of its masterminds. The list of papers included here is impressive:

1. Kevin Sontheimer : “An Existence Theorem for the Second Best,”  
*Journal of Economic Theory*, 3(1), 1-22, 1971.

2. Kunio Kawamata : “Price distortion and Potential Welfare,” *Econometrica*, 1974.
3. John Roberts : “An Equilibrium Model with Involuntary Unemployment at Flexible, Competitive Price and Wages,” *American Economic Review*, 77, 856-874, 1987.
4. Salvador Barberà : “The manipulation of social choice mechanisms that do not leave “too much” to chance,” *Econometrica*, 1977.
5. Javier Ruiz-Castillo : “Residential Land Use. The Continuous Case,” *Economic Letters*, 8: 7-12, 1981.
6. William Novshek : “Cournot Equilibrium with Free Entry,” *Review of Economic Studies*, 47, 473-486, 1980.
7. Richard Peck : “Power, Majority Voting, and Linear Income Tax Schedules,” *Journal of Public Economics*, 36, 53-67, 1988.
8. Andrew McLennan : “Sequential Bargaining as a Non-Cooperative Foundation for Walrasian Equilibrium,” with Hugo Sonnenschein, *Econometrica*, 1991.
9. Dilip Abreu : “Virtual Implementation in Iteratively Undominated Strategies: Complete Information,” with Hitoshi Matsushima, *Econometrica*, 60(5), 993-1008, 1992.
10. Vijay Krishna : “Finitely Repeated Games,” with Jean-Pierre Benoît, *Econometrica*, 53, 905-922, 1985.
11. David Pearce : “Rationalizable Strategic Behavior and the Problem of Perfection,” *Econometrica*, 1984.
12. Matthew Jackson : “Strategy-Proof Exchange,” with Salvador Barberà, *Econometrica*, 63(1), 51-88, 1995.
13. Marc Dudey : “Dynamic Monopoly with Nondurable Goods,” *Journal of Economic Theory*, 1996.
14. In-Koo Cho : “Signaling Games and Stable Equilibria,” with David Kreps, *Quarterly Journal of Economics*, 102, 179-221, 1987.

15. Faruk Gul : “Unobservable Investment and the Hold-Up Problem,” *Econometrica*, 2001.
16. Arunava Sen : “The Implementation of Social Choice Functions via Social Choice Correspondences: A General Formulation and a Limit Result”, *Social Choice and Welfare*, 12, 277-292, 1995.
17. Philip Reny : “On the Existence of Pure and Mixed Strategy Nash Equilibria in Discontinuous Games.” *Econometrica*, 67, 1029-1056, 1999.
18. James Dow : “Learning under Knightian Uncertainty: The Law of Large Numbers for Non-additive Probabilities,” with Sergio Werlang.
19. George Mailath and Jeroen Swinkels : “ Extensive Form Reasoning in Normal Form Games,” with Larry Samuelson, *Econometrica* 61, 273-302, 1993.
20. James Bergin : “Player type distributions as state variables and information revelation in zero sum repeated games with discounting,” *Mathematics of Operations Research*, 17(3), 640-656, 1992.
21. Daniel Vincent : “Repeated Signaling Games and Dynamic Trading Relationships,” *International Economic Review*, 1998.
22. Lin Zhou : “Impossibility of Strategy-Proof Mechanisms in Economies with Pure Public Goods,” *Review of Economic Studies*, 58, 1991.
23. Zachary Cohn : “On Linked Bargaining,” *forthcoming*.

The papers are remarkably coherent in subject matter and style, without being overly narrow in scope. The papers all lie in microeconomic theory, and moreover all make contributions to the foundations of the theory. That is, they are not descriptive in nature, nor positive models of some particular observed stylized fact. They are foundational in nature, building our understanding of the fundamentals of strategic interaction and the behavior of markets. The contributions by Barbera, Abreu, Jackson, Sen, and Zhou, all lie in social choice theory and in particular in the area of strategy-proofness

and implementation. There the issues addressed concern which social decision rules can be achieved, when individuals act in their own self interest in potentially manipulating their private information about their preferences and the state. The papers by Pearce, Krishna, Cho, Reny, Mailath, Swinkels, and Bergin are all in the area of game theory, and all deal with modeling and understanding equilibrium. In a sense, these deal with modeling behavior at an even more fundamental level. Each of these papers is concerned with either defining, proving existence of or analyzing the structure of the set of equilibria; and some of the papers do all three. The remaining papers all deal with market behavior in one way or another. The papers by Sontheimer, Kawamata, Roberts, Ruiz-Castillo, Novshek, and Peck, are all related to understanding whether certain imperfections in markets lead to competitive or non-competitive behavior, and what the resulting welfare implications are. The papers by McLennan, Dudey, Gul, Vincent, Cohn, in one way or another deal with issues of repeated or linked market interactions and the competitiveness or efficiency of the resulting allocations. Together, the papers give us an impression of the magnitude and scope of Hugo's contributions as a mentor, advisor, friend and scholar.

**Matthew O. Jackson and Andrew McLennan, September 2005**

## **A Brief Biographical Sketch of Hugo F. Sonnenschein**

Hugo Sonnenschein was born in 1940. He received his Bachelor's Degree from the University of Rochester in 1961, where he majored in mathematics. He completed his Ph.D. in economics at Purdue University in 1964, writing his thesis under the supervision of Stanley Reiter.

Hugo's first academic appointment was at the University of Minnesota. Subsequently he held positions at the University of Massachusetts at Amherst and Northwestern University, before moving to Princeton University in 1976. Hugo's role as advisor began as soon as his career did. He was an important intellectual influence on students at the University of Minnesota before going to Northwestern University, where he began advising dissertations in earnest. The bulk of the thesis supervision that this volume celebrates took place at Princeton. Remarkably, in addition to his teaching, advising, and research during this period, he was the editor of *Econometrica* from 1977 to 1984.

In 1988 Hugo began a second distinguished career as an academic administrator, serving as Dean of the School of Arts and Sciences at the University of Pennsylvania from 1988 to 1991, and as Provost of Princeton University from 1991 to 1993. He was appointed to the presidency of the University of Chicago in 1993 and held that position until he resigned in 2000. As president he significantly improved the university's finances, and did not shy away from initiating much needed, although controversial changes, to the university's core curriculum and size of the undergraduate body. Supporters and skeptics agree that he succeeded in his main objectives, with important long run benefits for the university and city of Chicago. Since 2000 Hugo has been the Charles L. Hutchinson Distinguished Service Professor and President Emeritus of the University of Chicago.

Hugo is a member of the National Academy of Sciences and the American Philosophical Society and a fellow of the American Academy of Arts and Sciences. He was President of the Econometric Society in 1988, has received honorary doctoral degrees from six colleges and universities including Tel Aviv University and the Universitat Autònoma de Barcelona, and is an honorary member of the Board of Trustees of the University of Rochester. He is a former chairman of the Board of Governors of Argonne National Laboratory, and has served as a Member of the Civic Committee of the City of Chicago and on the Boards of Directors of the National Merit Scholarship Corporation, the Van Kampen Mutual Funds, Winston Laboratories, and

various non-profit organizations.

Hugo is married to Elizabeth ‘Beth’ Gunn Sonnenschein, whom he met in 1957 as a freshman at the University of Rochester. She has a Ph.D. in cancer epidemiology and has held appointments on the medical faculties of the University of Illinois and New York University, and has served as President of the Board of the Chicago Child Care Society. They have three daughters and five grandchildren.

### **Selected Works of Hugo Sonnenschein**

“The Relationship Between Transitive Preferences and the Structure of Choice Space”, *Econometrica*, 1965.

“The Dual of Duopoly Is Complementary Monopoly: or, Two of Cournot’s Theories Are One,” *The Journal of Political Economy*, 1968.

“The Terms of Trade, the Gains from Trade, and Price Divergence,” with Anne O. Krueger, *International Economic Review*, 1967.

“Price Distortion and Economic Welfare,” with Edward Foster, *Econometrica*, 1970.

“Demand Theory without Transitive Preferences,” in Chipman et al., editors, *Preferences, Utility and Demand*, 1971.

“Market Excess Demand Functions,” *Econometrica*, 1972.

“General possibility theorems for group decisions,” with Andreu Mas-Colell, *Review of Economic Studies*, 1972

“Do Walras’ Identity and Continuity Characterize a Class of Community Excess Demand Functions?,” *Journal of Economic Theory*, 1973.

“The Utility Hypothesis and Market Demand Theory,” *Western Economics Journal*, 1973.

“An axiomatic characterization of the price mechanism,” *Econometrica*, 1974.

“Equilibrium in Abstract Economies without Ordered Preferences,” with Wayne Shafer, *Journal of Mathematical Economics*, 1975.

“On the existence of Cournot equilibrium without concave profit functions,” with John Roberts, *Journal of Economic Theory*, 1976.

“The Demand Theory of the Weak Axiom of Revealed Preference,” with Richard Kihlstrom and Andreu Mas-Colell, *Econometrica*, 1976.

“Equilibrium with Externalities, Commodity Taxation and Lump-Sum Transfers,” with Wayne Shafer, 1976, *International Economic Review*, 1976.

“On the Foundations of the Theory of Monopolistic Competition,” with John Roberts, *Econometrica*, 1977.

“Preference Aggregation with Randomized Social Orderings,” with Salvador Barberà, *Journal of Economic Theory*, 1978.

“Cournot and Walras Equilibrium,” with William Novshek, *Journal of Economic Theory*, 1978.

“Two Proofs of the Gibbard-Satterthwaite Theorem on the Possibility of a Strategy-Proof Social Choice Function,” with David Schmeidler, in Gottinger and Leinfellner, editors, *Decision Theory and Social Ethics*, 1978.

“Small Efficient Scale as a Foundation for Walrasian Equilibrium,” with William Novshek, *Journal of Economic Theory*, 1980.

“Strategy-proof allocation mechanisms at differentiable points,” with Mark Satterthwaite, *Review of Economic Studies*, 1981.

“Existence of rational expectations equilibrium.” with Robert Anderson, *Journal of Economic Theory*, 1982.

“Market Demand and Excess Demand Functions,” with Wayne Shafer, in Arrow and Intriligator, *Handbook of Mathematical Economics, Vol. II*, 1982.

“Foundation of Dynamic Monopoly and the Coase Conjecture,” with Faruk Gul and Robert E. Wilson - *Journal of Economic Theory*, 1986.

“On Delay in Bargaining with One-Sided Uncertainty,” - with Faruk Gul - *Econometrica*, 1988.

“Sequential Bargaining as a Non-Cooperative Foundation for Walrasian Equilibrium,” with Andrew McLennan, *Econometrica*, 1991.

“Voting by Committees,” with Salvador Barberà and Lin Zhou, *Econometrica*, 1991.

Editor, *Handbook of Mathematical Economics, Vol. IV*, with Werner Hildenbrand, 1991.

“Understanding When Agents are Fairmen or Gamesmen,” with Matthew Spiegel, Janet Currie, and Arunava Sen - *Games and Economic Behavior*, 1994.

“Overcoming Incentives by Linking Decisions,” with Matthew O. Jackson, *Econometrica*, forthcoming.

# 1 Kevin Sontheimer

Paper to be included: “An Existence Theorem for the Second Best,” *Journal of Economic Theory*, 3(1), 1-22, 1971.

I had my first encounter with Hugo in the fall of 1966. Hugo had joined the Department of Economics after I had finished the microtheory and other courses I needed for the PhD, and so I never had the benefit and pleasure of having him as an instructor. In fact I had not worked for or with him in any capacity, or even had a one-on-one meeting with him before the fall of 1966.

I had spent the summer of 1966 away from the University of Minnesota working on an initial effort to develop a dissertation topic and research plan. I had devoted about three months trying on my own to lay out an analytical method and framework for developing a general model of custom unions. My goal was to develop a model that would allow for the investigation of the existence of equilibrium and potentially some of the welfare properties of equilibrium in a world of multiple custom unions. When I returned to Minnesota I showed the product of my efforts to an appropriate faculty member with whom I had taken several courses. He read the write-up of my efforts and proposal. His response was that he did not think my proposed approach would work, and that he did not have any ideas as to how the problem(s) could be successfully attacked. I then went to a second faculty member, and she offered me some good advice. She suggested that, given the technical complexity of the proposed problem(s), I might try talking with Hugo Sonnenschein. It was excellent advice.

I then met with Hugo. I described what I wanted to try to do, the results of my summer’s work, and my meetings with the other two faculty members. Hugo’s immediate reaction was to suggest that I take on a less complex problem. Instead of trying to deal with a world of custom unions, why not deal with a trade model in which individual (small) countries can employ tariff-subsidy distortions? In particular, since the existence of a competitive international market equilibrium had not been proven in the presence of tariff-subsidy distortions, why not just try to do that? Hugo erased the overly ambitious vision of the inexperienced researcher in two succinct and gently put sentences. His wisdom was obvious. I accepted it immediately. The end result was that, with his subsequent guidance and supervision, my dissertation was completed in reasonable time and was published in *Econometrica*.

The paper I have offered for inclusion in this festschrift is an outgrowth of my dissertation. It is on the existence of competitive equilibrium in a closed economy with tax-subsidy distortions and lump sum transfers. The existence problem in the latter case differs significantly from that in the neoclassical trade model. The latter paper, like my dissertation, would never have been written (by me) had it not been for Hugo's earlier counsel and guidance. I selected it not just because it reflects Hugo's influence, but also for a second reason. The second reason is that Hugo and Wayne Shafer subsequently used my 1971 *Journal of Economic Theory* paper in their paper on "Equilibrium With Externalities, Commodity Taxation, and Lump Sum Transfers" that appeared in the 1976 volume of the *International Economic Review*. So I owe Hugo heartfelt thanks for not only providing invaluable counsel, guidance, and supervision, but also for the great pleasure of having a link to a piece of his work. Hugo is an outstanding scholar, teacher, and advisor. I wish I also had had the benefit of his famously wonderful classroom instruction. Then I could be even more deeply in his debt. Thank you Hugo, and happy birthday!

## 2 Kunio Kawamata

Paper to be included: “Price distortion and Potential Welfare, *Econometrica*, 1974.

The basic idea of the paper is contained in my Ph.D. thesis submitted to the University of Minnesota in 1972. I would like to mention the names of the three professors who helped me to complete the Ph.D. thesis. One is Ed Foster, who was then the chief adviser to the graduate students, and was also the co-author of the *Econometrica* 1970 article with Hugo upon which my paper is based. The second is Marcel Richter, the main adviser of my thesis, who read every part of my paper very carefully and gave me penetrating comments. The third person is the late Hukukane Nikaido who was then visiting Minnesota and pointed out several errors in my original draft. The name Hugo Sonnenschein was not included in the above list because he was at Northwestern when I was writing the thesis. He might not have known that my thesis was based on his paper. Still my indebtedness to him is pervasive. For me he played the role of the King of Denmark in the Shakespeare’s Hamlet; although he did not appear on the stage, the drama would not have concluded without him. I took his course in advanced Microeconomics around 1970, when some students were staging demonstration against the Vietnam War. Hugo’s class was open as scheduled but, instead of requiring us to come to the class, he gave us an option of solving some of the open problems. I do not remember whether he mentioned the problem I worked on, but the Foster and Sonnenschein paper had been published by then, and I read it with great interest. I should also mention that Hugo was then working on the celebrated Sonnenschein theorem on market excess-demand functions.

The fundamental theorem of welfare economics implies that, under standard assumptions, if an allocation is attainable and all consumers are minimizing expenditures given a normalized price vector  $p$  and all producers are maximizing profits given another similarly normalized price vector  $q$ , then the allocation is dominated by a competitive allocation where  $p = q$ . By measuring the price distortion by  $p - q$  (where the difference may be regarded as the specific tax vector), can we say that an allocation with a proportionally smaller distortion is Pareto superior to an allocation with a larger distortion? The Foster and Sonnenschein paper shows that, in particular, this is not necessarily the case even under very restrictive assumptions. They conjectured

that, corresponding to any allocation with a non-zero distortion  $p - q$ , there may exist a better allocation with a proportionally smaller distortion. This was the problem I worked on and I could give fairly general sufficient conditions for this to be true. I presented the main results of the thesis at the 1971 Meeting of Econometric Society. Hugo was the chairperson of my session, and I received encouraging comments from him. A few weeks later, I left the US for Japan. It took almost ten years before I could visit the US again on sabbatical and see Hugo in Princeton. Many happy things have happened since then.

### 3 John Roberts

Paper to be included: “An Equilibrium Model with Involuntary Unemployment at Flexible, Competitive Price and Wages,” *American Economic Review*, 77, 856-874, 1987.

One of Hugo’s most lasting lessons for me was the crucial importance when doing theory of getting the foundations straight and strong. The paper that follows, “An Equilibrium Model with Involuntary Unemployment at Flexible, Competitive Prices and Wages” (Roberts 1987b), is an attempt to be careful about foundations in the context of a model of a whole economy. It grew out of work that Hugo and I had done a decade earlier.

In the mid-1970s Hugo and I looked at the then-burgeoning literature that was trying to bring elements of imperfect competition into the Arrow-Debreu model. That model’s foundations were secure in that all the relevant properties of its constructs were obtained from assumptions on the fundamental elements of the model. Thus, for example, the continuity of excess demand that underlay the application of Brouwer’s theorem to establish existence of equilibrium was derived from assumptions on tastes, endowments, technology, maximizing behavior and the structure of markets. The same was not true however, of the imperfectly competitive general equilibrium models. Most of these papers simply assumed that the imperfect competitors’ behavior could be described by continuous reaction functions or convex-valued UHC correspondences. But there was no analysis of what conditions would generate this continuity. So Hugo and I set out to try to find out what assumptions on fundamentals would generate these properties.

What we found was not good for the existing theory (Roberts and Sonnenschein, 1977). Drawing on work initiated by Hugo on what functions could be excess demand functions (Sonnenschein 1973), we easily showed that, in essence, there were no assumptions on the fundamentals that would do the trick. You could not get the foundations right simply by tacking some agents who perceived that they influenced price formation onto the standard Arrow-Debreu model.

In the following years I learned game theory and especially the use of the extensive form. I came thereby to appreciate the importance of specifying carefully and completely the range and timing of actions and the outcomes corresponding to any available set of choices. This of course had not been

done in general equilibrium theory, whether with imperfect competitors or not. There was no modeling of the process of price determination, no specification of what would happen if markets did not clear, and no indication of how the actual transactions would be carried out even if prices would support market clearing. Yet our partial equilibrium models indicated these sorts of specifications could be very important.

Thus I began by constructing a simple example of an economy where the owners of the production technologies (“firms”) set prices and wages, worker-consumers placed orders and offers and the firms decided how much of these to accept (Roberts, 1987a). The set-up was a fully specified extensive form game (including utility functions), and it was reasonably straightforward to compute the subgame perfect Nash equilibrium. This was then truly an imperfectly competitive general equilibrium, and it had some interesting properties. For instance, while the ratio of the output price to the wage announced by any firm was higher than in the Walrasian solution, the prices were actually lower relative to the numeraire than the Walrasian ones. To me this seems to indicate that we really do need to take the analysis of imperfect competition into a general equilibrium context.

Working with the example while varying the institutional arrangements in the model led me to see that it might be possible to have rationing in equilibrium, where of course equilibrium means that no one has any unilateral incentive to change any of his or her choices, whether these be prices, wages, offers to trade or decisions whether to accept offers. This opened the possibility of generating Keynesian involuntary unemployment as an equilibrium phenomenon, something that could never be done in models in the Arrow-Debreu tradition, where equilibrium means market clearing.

The following paper realizes this possibility. It has equilibria with Keynesian unemployment at Walrasian prices and wages, and because the processes of price formation and trade determination are modeled, equilibrium means that no one has an incentive to change prices, wages or offers to trade. Hugo’s lesson proved very important: If you get the foundations right, then you can do things that are otherwise impossible.

John Roberts (1987a), “General Equilibrium Analysis of Imperfect Competition: An Illustrative Example,” in *Arrow and the Ascent of Modern Economic Theory*, G. Feiwel, ed., London: Macmillan and Co., and New York: State University of New York Press, 415-438.

John Roberts (1987b), “An Equilibrium Model with Involuntary Unemployment at Flexible, Competitive Prices and Wages,” *American Economic Review* 77, 856-874.

John Roberts and Hugo Sonnenschein (1977), “On the Foundations of the Theory of Monopolistic Competition,” *Econometrica* 45, 101-113.

Hugo Sonnenschein (1973), “Do Walras’ Identity and Homogeneity Characterize the Class of Community Excess Demand Functions?” *Journal of Economic Theory*, 6, 345-354.

## 4 Salvador Barberà

Paper to be included: “The manipulation of social choice mechanisms that do not leave “too much” to chance,” *Econometrica*, 1977.

June 1975. Hugo had visited Israel for several weeks, during which I had finally got a result that looked good for my dissertation. He returned late in the evening, but I couldn't wait. Contrary to our practices, I called him home. “I think I finally got the right result on extending Gibbard-Satterthwaite to correspondences.” “Well, Salvador, I'm afraid Gibbard has the right result. He just presented it in Jerusalem, and it solves it all.” (He was referring to the first version of Alan Gibbard, “The Manipulation of Schemes that Mix Voting with Chance”, *Econometrica*, 1977.) I could sense how sorry he was for me. But my thesis was at stake. “Cannot be. You should see mine. Can I just come to your home?” I intruded in Hugo's home well past dinner time, and an hour later we were both relieved. Gibbard and I had taken two polar views on the same initial problem, and we had attained different but complementary results. That's how I got approval for the first chapter in my dissertation, which is reprinted here. Chapter 2 followed easily, and everything was finished in a short time, leaving behind five years of learning, but also of risk: results had taken very long to come! Finally, Hugo had triggered them in his very special way.

Northwestern was a very active spot in the development of incentive theory during the early seventies. Mechanism design was a central concern at the Math Center, created by Stan Reiter (Hugo's PhD advisor at Purdue and the best teacher I ever had). Leo Hurwicz, who visited often, was developing an increased interest in incentives, which he extended to everyone with his unbounded energy. Along with Martin Loeb, Ted Groves was developing his schemes. He and John Ledyard also explored different notions of incentive-compatibility. John Roberts and Andy Postlewaite were probing the extent to which large number arguments could sustain price-taking behavior, rather than price manipulation. Mark Satterthwaite, Elisha Pazner and Jean-Marie Blin were examining incentive questions in the framework of social choice, which I had recently learned from Antonio Camacho. Hugo himself had worked in mechanism design. He quickly detected the importance of the Gibbard-Satterthwaite theorem. His presentations all around the country, through seminars on a joint paper with Schmeidler, were crucial

to publicize its content and proofs, to predict its deep impact on economics and to establish the independence among the contributions of the two creators of the result. (David Schmeidler and Hugo Sonnenschein, “Two proofs of the Gibbard-Satterthwaite Theorem on the Possibility of a Strategy-Proof Social Choice Function” in Gottinger and Leinfellner (Eds.), *Decision Theory and Social Ethics*, 1978.)

When Hugo arrived at Northwestern, I was already in my third year, fascinated by these topics but not lucky with my writing. There was a small tribe of Spaniards at Northwestern, and he quickly looked after us. While in Minnesota, he had learned that Spanish students could have bizarre CV’s and yet be able to perform: in fact, he had just written a paper with one of them. (Andreu Mas-Colell and Hugo Sonnenschein, “General possibility theorems for group decisions,” *Review of Economic Studies*, 1972.) He kept a friendly eye on us, providing encouragement and advise.

Then, one day, I bumped into him at the entrance of the Math Center. He simply said: “Do you know whether the Gibbard-Satterthwaite theorem extends to correspondences? Why don’t you take a look?” That was the first and most decisive time, but certainly not the only one, when Hugo led me on a path that was to keep me busy for years, just starting from a simple question. How many people can do that? How many can be so insightful and so generous in sharing ideas?

Some months later, he led me through the final stages of the dissertation. Rather than fighting with my Spanglish all along, we went over and over the same few pages, until he found them satisfactory and I had learned what to do with the rest. The introduction to the paper here was the testing ground.

Two other questions of the same type led to the two papers we have written together, to date. One was posed as we waited to cross Sheridan Road: “What happens with Arrow’s theorem if we allow for lotteries over social preferences?” (Salvador Barberà and Hugo Sonnenschein, “Preference Aggregation with Randomized Social Orderings,” *Journal of Economic Theory*, 1978.) The other question came up in Pisa, during a congress where Aumann had proposed a new voting rule for the Econometric Society and claimed it was strategy-proof. “We know this cannot be in general. But, could he be right for some domain restrictions?” (Salvador Barberà, Hugo Sonnenschein and Lin Zhou, “Voting by Committee,” *Econometrica*, 1991.)

In all cases, these papers generated interest in new topics. The one presented here helped inducing a vast literature on the ranking of sets. The

paper on social lotteries called the attention of different authors toward stochastic preferences and choices. And the results on committees paved the way for many characterizations of specific frameworks and domains admitting the design of non trivial social choice rules.

Most importantly, graduate students benefitted from these questions in all cases. I did from the first, Andy McLennan wrote his first published piece as a reaction to the second, and Lin Zhou became a co-author after the third. In fact, there were many other questions that I couldn't answer, and a crowd of younger students at Princeton could. But I had my share, and I keep looking forward for the next of Hugo's questions that I can handle.

## 5 Javier Ruiz-Castillo

Paper to be included: “Residential Land Use. The Continuous Case,” *Economic Letters*, 8, 7–12, 1981.

The connection between Hugo and Spain started early, when he met a group of outstanding Catalan graduate students at the University of Minnesota in the early 1970s. The bunch of Spanish graduate students at Northwestern University were next in line, around 1975. Fortunately for us, he arrived in Evanston interested in anything Spanish and intrigued by the experience of those foreigners from the 1960s trying to make it in the 1970s as Ph.D.’s in American Universities. Eventually, the four of us at that time—Jordi Andreu, Salvador Barberà, Isabel Fradera, and myself—wrote our dissertations with his help. This was only the beginning. It suffices to check the national origins of his graduate students to appreciate how truly cosmopolitan Hugo’s career as an adviser has been.

Among the brilliant group of theorists that have worked with him over the years, I am a fortunate outsider. My formal skills have been always very limited, but Hugo gave me a problem in spatial economics in search of a General Equilibrium approach that constituted my dissertation at Northwestern. As a matter of fact, what Hugo gave me was a homework from his graduate Micro I class. I do not conserve the original draft, but I can offer the version I have been handing in to various groups of undergraduate and graduate students in Spain.

“There are two commodities: land uniformly distributed over the set  $K$  of available locations; and a homogeneous and mobile commodity, called the consumption good. A consumer’s role is to choose both a location  $k \in K$ , as well as a commodity bundle  $(s, x) \in \mathfrak{R}_+^2$  consisting of a quantity of land,  $s$ , and a quantity of the consumption good,  $x$ . There is a continuum of identical consumers characterized by their preferences over the two commodities, represented by the utility function  $u = sx^2$ , and an initial endowment of the consumption good equal to 100. The set  $K$  can be taken to be a subset  $(0, k^*)$  of  $\mathfrak{R}_+$ , where 0 represents the Central Business District (CBD), and  $k^*$  represents a location beyond which it is not possible to live. Consumers are assumed to make the same number of trips to the CBD where all exchange takes place. Transportation costs in terms of the consumption good depend only (and linearly) on distance from the CBD,  $T = 2k$ . A normalized price

system  $\langle r, 1 \rangle$  consists of a function  $r : K \rightarrow \mathfrak{R}_{++}$  which gives the price of land at every location, and the price of the consumption good that is equal to 1. A consumption budget set at a location  $k$  is the subset

$$B(r, 1, k) = \{ (s, x) \in \mathfrak{R}_+^2 : r(k)s + x \leq 100 - 2k \}.$$

Assume that at location  $k = 2$ ,  $r(2) = 2$ . Solve for the optimal choice of  $(s, x)$  for the consumer living at that location. What is the optimal choice of  $(s, x)$  and the equilibrium  $r(k)$  for the consumer living at location  $k = 4$ ?"

Of course, this is a version of the original Von Thünen (1987) problem, studied in Alonso (1964) in a partial equilibrium context. However, the non-convexity created by the impossibility of multiple human agents living at the same locality at the same time had not been studied in a general equilibrium context. If transportation costs are an increasing function of distance from the CBD in this linear city, then for a consumer in equilibrium to be indifferent between two locations the price of land must be decreasing with distance. Consequently, in equilibrium the demand for land must be increasing with distance. It is shown that the only efficient allocation can be supported as a competitive equilibrium.

This is possibly a relatively straightforward result, but I had to learn how to use Fatou's Lemma and the Lebesgue Convergence Theorem to prove it. Since then, I started an academic career as an applied economist in welfare economics. But I did it after having a wonderful opportunity of directly experiencing economic theory at work. Hugo is so serious an adviser and such a sympathetic person that, as others have said, he really gets the best of everyone.

## 6 William Novshek

Paper to be included: “Cournot Equilibrium with Free Entry,” *Review of Economic Studies*, 47, 473-486, 1980.

I met Hugo when I was in the first year of the economics Ph.D. program at Iowa. The usual instructor for the second semester microeconomics course was on leave and the department had arranged for Hugo, who was at Northwestern, and Rich Kihlstrom, who was at Illinois, to share teaching the course. Each week, one of them would fly in for a day of intensive instruction. It was a memorable course for both the topics and the enthusiasm of the instructors, and it led to my transfer to Northwestern the following fall. After my first year at Northwestern, Hugo moved to Princeton and I followed informally for part of his first summer there and later, after finishing my coursework with a final quarter physically at Northwestern, as a visiting student at Princeton.

It is hard to describe adequately Hugo’s impact as a mentor and friend. Many hours of discussion in his office or while walking about the Princeton area helped to develop not only my research ideas but also my approach to research. Hugo asked the right questions in terms of research topics to pursue. Later, when discussing the tentative results of the research, he again asked the right questions to zero in on the key insights or ideas. Then when discussing written drafts of the work, his questions and comments always brought clarity and precision to the presentation. Hugo treated me not just as a student but as a friend, so I also had the pleasure of interacting frequently with his family.

The topic of my paper, the first chapter of my Ph.D. thesis, evolved out of a series of discussions with Hugo concerning imperfect competition. Hugo’s interest in imperfect competition at this time was evident from his paper with John Roberts on imperfect competition in general equilibrium. At times, Hugo and I discussed and worked with Charles Ellet’s spatial model among others, but two questions, about existence of equilibrium (raised in his paper with Roberts) and free (as opposed to exogenously imposed) entry, made the partial equilibrium Cournot model a natural starting point. As soon as the partial equilibrium results became clear, we began to consider the general equilibrium version. This led to several joint papers that viewed the perfectly competitive general equilibrium model as a limit of imperfectly

competitive economies with small efficient scale and free entry, starting with  
“Cournot and Walras Equilibrium,” *Journal of Economic Theory*, 1978.

## 7 Richard Peck

Paper to be included: “Power, Majority Voting, and Linear Income Tax Schedules,” *Journal of Public Economics*, 36, 53-67, 1988.

My dissertation was an extension of Aumann and Kurz 1977 work on “Power and Taxes.” Hugo and I were initially interested in Coase’s Theorem and the particular angle involved bargaining models. Hugo suggested that I read Aumann and Kurz’s paper 1977 *Econometrica* paper and the Aumann-Shapley book, *Values of Non-Atomic Games*. I became quite intrigued by the Aumann-Kurz model, and an extension, discarding the assumption of inelastic labor supply, became my thesis. Hugo was very supportive and even though this is not quite the original focus, he never tried to dissuade me.

The committee consisted of Hugo, Bob Anderson and Marty Osborne who was then at Columbia. I learned much from Hugo. He taught me how to write (or at least write better). I would give portions of the thesis paper and then we would go through the first several pages, almost line by line. Each line was challenged: Is it clear? Is it in any way misleading? Can the sentence be improved in any way? He was an excellent, gentle critic and mentor. I have tried to emulate this technique with my own students. I don’t really have the patience, insight and ability to guide the student to understanding well the deficiencies of their writing and how to improve it. I usually end up, in effect, just rewriting their material myself. This experience has made me appreciate how rare are Hugo’s particular teaching gifts. Of course, what Hugo was really teaching was intellectual honesty and thinking clearly. Hugo told me that reading other people’s work carefully, in the same way he read my dissertation work, would always generate research topics. This notion of carefully examining and challenging unproved assertions and unarticulated assumptions is a thread that goes through much of Hugo’s own work.

Hugo also has a quirky sense of whimsy and humor. In Hugo’s Princeton office, there hung an oil portrait of a balding middle-aged man. It was always there and after looking at it four years, I finally asked Hugo: “Who is that person?” Hugo explained. The painting was bought at a Chicago garage sale and was reputed to be a life portrait of Al Capone. I always assumed that it was some venerable Princeton professor or a generous alumnus who had endowed a chair. The idea of the editor of *Econometrica* signing accep-

tance and rejection letters under the stern gaze of Al Capone was a little incongruous but also consistent with Hugo's toughness. If the authors only knew.

## 8 Andrew McLennan

Paper to be included: “Sequential Bargaining as a Non-Cooperative Foundation for Walrasian Equilibrium,” with Hugo Sonnenschein, *Econometrica*, 1991.

“Sequential Bargaining as a Non-Cooperative Foundation for Walrasian Equilibrium” was the result of a collaboration that began several years after my thesis research, and which reflected Hugo’s continued interest in and concern for his students. Getting my thesis into decent shape was an agonizing process that took far too long, so I was quite relieved and delighted to get the defense over with, but, in a way that I sensed only dimly at the time, I am pretty sure that he thought of it as an intermediate step in a longer process. Over the years I benefitted repeatedly from the watchful eye he kept on my progress, and in our collaboration I became aware of aspects of his guidance that, due to his gentle and subtle approach, were not so apparent when I was a graduate student.

At various times during the 1980’s I visited Princeton, and of course he was always eager to get together and talk about research, even though the demands on his time were extreme. On one occasion we tried to talk in his office, but every few minutes someone would call about some piece of pending business, he would quickly give his thoughts and advice, pleasantries would be exchanged to conclude the call, we would try to recall where we were, and the phone would ring again. The connections at the phone and the wall socket were old fashioned, and couldn’t be unplugged, but leaving the receiver off the hook resulted in a loud and very annoying sound. Eventually he covered the ear piece with Scotch tape and tried burying the receiver in a desk drawer, which was just barely workable. Subsequently we agreed to meet at a coffee shop in a small town about half way between Cornell and Princeton, and actually managed to find time to do this two or three times. It was a hard day’s drive for each of us, but perhaps he appreciated that as a relatively tranquil respite.

The idea for this paper originated with Hugo. Douglas Gale had recently written a stunning trio of papers (1986a, 1986b, 1987) showing that repeated pairwise bargaining between randomly matched agents could serve as a noncooperative foundation for general equilibrium in an exchange economy. Hugo thought that it was possible to give a clearer explication of the

forces leading to this result, and our paper confirms this insight. It was also his idea that this would be a good project for me, dovetailing with earlier work on bargaining and characterizations of general equilibrium. The phrase “Nash program” refers to a style of modelling in which an idea is described axiomatically, and the axiomatic insights are confirmed by displaying a non-cooperative model that has the predicted outcome. This was a particularly satisfying instance of that program, at least for my tastes, because the proof of the noncooperative result is strongly connected to the axioms.

An aspect of Hugo’s influence reflected here, and in all of the work collected in this volume, is his persistent focus on central and fundamental issues in economics. I remember him describing this project as one manifestation of a continuing interest in the concept of competition, aiming at a richer description than is given by classical economic equilibrium, which describes competition’s shadow but not its substance. A simple and natural theory leads one to expect that the remaining low hanging fruit should be in the distant suburbs and further out, but in his own research Hugo has repeatedly shown that the best opportunities are still in the center of town. Since his advice consists mainly of gentle nudges, this aspect of his influence on me was less apparent during my student days than it is now, and less evident in any particular instance than when I consider his students’ work collectively.

Douglas Gale (1986a) “Bargaining and Competition, Part I: Characterization,” *Econometrica* 54, 785–806.

Douglas Gale (1986b) “Bargaining and Competition, Part II: Existence,” *Econometrica* 54, 807–818.

Douglas Gale (1987) “Limit Theorems for Markets with Sequential Bargaining,” *Journal of Economic Theory* 43, 20–54.

## 9 Dilip Abreu

Paper to be included: “Virtual Implementation in Iteratively Undominated Strategies: Complete Information,” with Hitoshi Matsushima, *Econometrica*, 60(5), 993-1008, 1992.

I came to Princeton in Fall 1980 to begin, as it turned out, three of the most important years of my life. I am, professionally, what was coaxed into shape there. Hugo was a central element of this defining experience.

Hugo’s energy and enthusiasm were infectious and inspiring. He was at the center of a huge theory buzz which he created and orchestrated with astonishing skill. Thanks to him, it was self-evident that theory was important and deeply exciting and one really wanted to be part of the great enterprise. He was already a high priest and elder statesman in the profession—it is hard to imagine that he was only forty then! Although he was phenomenally busy with the editorship of *Econometrica* and the considerable demands placed on a star at the epicenter of the economic theory universe, he found the time to participate in informal evening seminars on some of the most current and intriguing new developments, to be a highly charismatic and brilliant teacher, and to mentor legions of students. He was incredibly open and receptive to stumbling new ideas which he would patiently listen to and probe over the course of long and memorable walks. He made it seem natural to think that anything was possible (his own example made it seem so plausible) and that was an empowering idea even for those of us (like myself) for whom this notion, to put it mildly, stretched credibility. It was an amazing privilege to be guided by such an extraordinary individual and a lifelong gift to be part of the dazzling group which gravitated to him.

The informal seminars were especially exciting. They were held, as I recall, after dinner, in Dickenson Hall, and amazingly Hugo would make the time to attend and gently preside. The building was deserted and eerily calm, and it was a treat to have the run of the place with one’s small circle of theory enthusiasts. It made us neophytes feel like serious researchers. It was one of the important ways in which students were thrown together intellectually outside the context of a ‘required’ academic task. This mingling of students was enormously fruitful, and led to much cooperative learning, wide ranging and open ended discussions and subsequent collaborations. Each cohort had its own tightly-knit groupings. My own included my old friend from India,

Vijay Krishna, Motty Perry and, of course, David Pearce with whom my collaboration is ongoing.

One of the informal seminars I remember vividly was on implementation and social choice theory. It was fascinating to have an opportunity to delve into this subtle and elegant material. It is where my interest in the topic originates and was the distant starting point for the paper I have chosen for this volume. Needless to say, this is an area to which Hugo has made the deepest contributions, and I offer this paper as a modest homage to his work, his guidance, his inspiration, his wisdom and his friendship.

## 10 Vijay Krishna

Paper to be included: “Finitely Repeated Games,” with Jean-Pierre Benoît, *Econometrica*, 53, 905-922, 1985.

“Who taught you game theory?” was a question Hugo’s students from the early 1980s were often asked. Even though Princeton was the birthplace of game theory, it was a legitimate question. Of the giants of the 1950s, only Harold Kuhn remained, and his research interests had drifted away from game theory to computation. I, for one, had never taken a course in game theory while at Princeton and at first found myself fumbling for an answer. When I arrived there in 1978, Hugo was, of course, renowned for his work in many areas—general equilibrium, social choice, demand theory—but game theory was not one of these. Yet almost all of his students from this time wrote dissertations on various game theoretic topics and went on to specialize in this area.

After some reflection, I came to realize that the correct answer to the question “Who taught you game theory?” was complicated. It was Hugo who taught us all game theory, but not by lecturing. Rather, in his own subtle way he managed to push us to learn the subject ourselves. But push is a strong word—steer is more descriptive of Hugo’s style. And learning was never good enough—we had to be able to teach Hugo what we had learned, usually during walks which ended up at Thomas’ ice cream shop. At one point, a group of us decided to meet late on Wednesday evenings to discuss various papers on game theory, especially the then new work on refinements of Nash equilibrium. When he heard about this, Hugo enthusiastically became a member of the weekly group, learning along with us. So perhaps the correct answer to the question was that we learned game theory together with Hugo rather than from Hugo. And learning with Hugo was as great a privilege as learning from him.

The paper I have chosen to include here was written in my first year out of graduate school. I was still living in Princeton and commuting to my job at Columbia. Whenever Hugo had to make a trip to New York for business or other reasons, he would call and, if convenient, we would travel together on the train. During one of these trips I told him about the work on finitely repeated games I was doing with Benoît. We had obtained some preliminary results but as yet not succeeded obtaining a full “folk theorem.” I was

lamenting the difficulty of the problem and our then inelegant characterization of the set of equilibria. Hugo was very encouraging and after hearing some of the details, said that such a problem must have an elegant solution. Soon after, perhaps that very day, Benoît and I succeeded in completing a key step. Hugo's influence was subtle but, as always, profound.

## 11 David Pearce

Paper to be included: “Rationalizable Strategic Behavior and the Problem of Perfection,” *Econometrica*, 1984.

Hugo Sonnenschein’s accomplishments as an advisor began in the classroom. There, his charismatic personality combined with mastery of the material to produce a compelling educational experience. Along with rigorous, ambitious treatments of the major topics of economic theory, he communicated *values*: the goals of clarity and generality, the importance of acknowledging others’ ideas, and the cooperative nature of learning and research. One of the results was the exceptional sense of rapport among his advisees. That is probably why I learned so much from my fellow students at Princeton, most of all Vijay Krishna and Dilip Abreu.

We all knew that we had a wonderful dissertation advisor. But it was only years later that I understood just how unusual Hugo’s generosity was. Through group meetings after class or in the summertime, parties he and Beth gave, and the long walks during which he brought limitless concentration to bear on an advisee’s ideas, Hugo made himself continuously accessible to us. When Vijay Krishna and I organized a student workshop on the implementation of social choice rules, Hugo turned out enthusiastically every Wednesday night to help us. I guess he had little else to do, apart from editing *Econometrica*, raising his family, teaching, publishing and shepherding the lot of us.

Written in 1983, the paper that follows was the second essay in my doctoral dissertation. At the time the microeconomic literature on time inconsistency pioneered by Strotz was largely forgotten, and the new wave of work by Rabin, Laibson and others was not yet on the horizon. The main essay in the dissertation, on rationalizability, was simple heresy when it was written. Years later, when I tried to thank him for giving me the freedom to pursue such risky topics, Hugo just flashed one of those famous smiles and asked: “Do you actually imagine I had any choice?”

## 12 Matthew Jackson

Paper to be included: “Strategy-Proof Exchange,” with Salvador Barberà, *Econometrica*, 63(1), 51-88, 1995.

This paper was an obvious one to include because it not only ties in with Hugo’s research and interests, but also owes much to his personal side. On the research side, it deals with Hugo’s interests both in strategy-proofness and incentives, as well as foundations of behavior in exchange economies, and it makes use of some key tools from work of his together with Mark Satterthwaite (“Strategy-proof allocation mechanisms at differentiable points,” Mark Satterthwaite and Hugo Sonnenschein, *Review of Economic Studies*, (1981)). But, perhaps most importantly, its genesis owes much to Hugo’s direct and indirect personal touch, which both set me on a path which led to this paper and introduced me to my co-author Salvador Barberà.

There is much to be learned in noting that when Hugo visited the Graduate School of Business at Stanford University in 1984-1985, along came many of his current and former students. Among his doctoral advisees at the time, In-Koo Cho, James Dow, Faruk Gul, George Mailath, and Arunava Sen, all visited for extended periods, and some for the whole year. His former student Salvador Barberà also visited for the year; and I, as a former undergraduate advisee, took up residence as a doctoral student. This not only indicates the enjoyment that others found in being around Hugo, but is also reflective of Hugo sharing of his enthusiasm for what he could see was path-breaking research. He was not afraid to say that he thought the researchers at the GSB were doing the best and most creative micro-economic theory work in the world at that time. When I asked various people for advice about where to go to graduate school, Hugo was the only one who was suggesting the Stanford GSB, and I listened to Hugo not only because I thought highly of his opinion and judgement, but also because I knew that when he answered, he had thought carefully about my personality and interests, and not just some abstract ranking of programs. I guess it also speaks volumes of Hugo, to note that he was the only faculty member whom I ever knew who came to see a (not too exciting) gymnastics meet, because he cared enough to find out what one of his undergraduate advisees did in his spare time.

Hugo not only guided me to graduate school and to Stanford, which were key branches that led to this paper, but he was also was involved in my

getting to know Salvador Barberà. In addition to Hugo's knack for matching people with institutions, he is also an expert at getting to know people and matching them together. I first met Salvador, when a friend and I drove Hugo and Beth's station wagon loaded with their belongings from Chicago to Stanford late in the summer of 1984. We were to deliver it to Salvador Barberà and his family, who were also visiting Stanford from Spain that year, and were going to use the car. Salvador was not only a person whom I should deliver the car to, but also a person whom Hugo suggested that I would enjoy getting to know and talking about social choice with. My first meeting of Salvador was more than a bit rocky, as my friend and I had taken our time and meandered a bit in driving Hugo's car across the country. But I was, perhaps not coincidentally, assigned to be Salvador's research assistant, and within a few months we already had the base for a first paper together. It was the beginning not only of a long and fruitful collaboration between Salvador Barberà and myself, but also of a great friendship.

The paper which follows, "Strategy-Proof Exchange," sits in squarely in one of Hugo's favorite settings, that of classical exchange economies, and involves two of his interests, strategy-proofness and foundations of Walrasian Equilibrium. The paper is easily summarized: we characterize the allocation rules that are strategy-proof under the domain of classical preferences in exchange economies. Our conclusion is that strategy-proof rules, while neither approximately Walrasian nor even Pareto optimal, nonetheless represent an interesting, rich, and special class of social choice functions. Although this paper was written while Hugo was busy provosting, it exudes his influence and never would have been written without him.

So, a big happy birthday and thank you, Hugo, not only for setting us on this path, but also for the many other wondrous things for which you are responsible.

## 13 Marc Dudey

Paper to be included: “Dynamic Monopoly with Nondurable Goods,” *Journal of Economic Theory*, 1996.

I’ve felt Hugo’s influence in so many ways, but here are three examples. First, the way he talked about his subject helped me to believe it was something I could spend my professional life on. Second, when I expressed an interest in writing a Finance dissertation, Hugo introduced me to his friend Rich Kihlstrom, who met with me once a week at Penn and became an unofficial member of my committee. Third, I can’t imagine that I would have studied mathematics (or met my wife, Yan) after leaving Princeton, if not for Hugo.

My paper is a revision of a chapter from my Ph.D. thesis. Although Hugo was not on my committee, his lectures and our conversations contributed greatly to my sense of what to look for in a topic.

The paper asks if there are noncooperative foundations for inefficiency in dynamic monopoly. It studies a seller who can repeatedly post prices before producing to order. An example wherein all buyers have the same quadratic utility function reveals two possibilities. In one double limit (buyers, then periods), buyers act as future price takers, and the outcome is that of static monopoly. In the other double limit (periods, then buyers), the seller earns the static monopoly profit per buyer, but the outcome is efficient. In the second case, buyers do not act as if future prices are beyond their control, but the seller may not care enough about reopening her market.

These possibilities are not related to the “Coase conjecture,” which Hugo, Faruk Gul and Robert Wilson proved in their landmark paper on durable good monopoly. However, there is a literature that studies the effect of relaxing Gul, Sonnenschein, and Wilson’s assumption that buyers form a continuum. This includes my 1995 and 2003 papers, which adapt ideas from the reprinted article to durable good monopoly, in order to illustrate Coase’s intuition for the finite-buyer case.

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## 14 In-Koo Cho

Paper to be included: “Signaling Games and Stable Equilibria,” with David Kreps, *Quarterly Journal of Economics*, 102, 179-221, 1987.

While struggling as a third year graduate student to begin my thesis work in the spring of 1984, Hugo advised me to look into the possibility of refining sequential equilibrium by exploiting the implicit communication between the sender and the receiver. After working for a few additional months, I was able to produce an example in early July. I used it to explain to Hugo that the implicit communication can refine sequential equilibrium further than David Kreps had proposed. At the end of the discussion, Hugo said “In-Koo, you have come a long way.” He asked me to polish the example so that he could send it to David.

It took another few weeks to polish the example (which later appeared in my paper “Refinement of Sequential Equilibrium”). After dropping off the manuscript in Hugo’s mailbox in the department office around midnight, I pack up to drive to Stanford the next morning to spend a year there with Hugo (along with Faruk Gul and George Mailath).

It was a long and difficult trip to drive my small Volkswagen from Princeton, NJ to Palo Alto, CA. After being separated from my co-driver in Chicago, I drive the remaining 2000 miles alone. My car had a mechanical problem in Wyoming while passing through the Rockies. By the time when I was crossing the Bay Bridge, the car and the driver were about to break down. Immediately after arriving at Stanford, I went to see David to introduce myself. Watching an exhausted, somewhat awed, student standing awkwardly at the door of his office, David said “Let me guess who you are. I think you are a student of Hugo. I got it, read it and liked it.” It was an end of a long journey, but also the beginning of my collaboration with David.

## 15 Faruk Gul

Paper to be included: “Unobservable Investment and the Hold-Up Problem,” *Econometrica*, March 2001.

During 1984-1985, Hugo Sonnenschein, Robert Wilson, and I wrote a paper entitled “Foundations of Dynamic Monopoly and the Coase Conjecture,” (*Journal of Economic Theory*, 1986. Henceforth “DMCC”) This paper offers a game-theoretic analysis of Ronald Coase’s idea that a monopolist provider of a durable good would be forced to sell at the competitive price. Coase’s reasoning was as follows: as soon as the consumers who are willing to pay the monopoly price make their purchases, the monopolist has an incentive to lower his price and sell to some of the remaining consumers. Immediately after the next round of sales, the monopolist would find it worthwhile to lower his price yet again. This process would continue until all buyers with reservation prices above marginal cost are served. But rational consumers would anticipate this rapid fall of prices and wait until the market price reaches its ultimate level before making any purchases. Thus, Coase’s argument asserts that the durable goods monopolist incurs competition from an unexpected source: his future self. The time between subsequent market periods (i.e., offers) determines the extent of this competition.

Let  $D(v)$  denote the fraction of consumers with valuation at least  $v$ . Define the competitive price as the largest  $p$  such that  $D(p) = D(c)$ , where  $c$  denotes the constant unit cost of production. Hence, the competitive price is the largest price at which all consumers who would be served under perfect competition are willing to purchase the good. The case where  $p > c$  is called the gap case, while  $p = c$  is referred to as the no gap case. DMCC shows that  $D$  can be interpreted either as the distribution of valuations in a large market or the probability distribution of the single buyer’s valuation in a bilateral bargaining problem. The main results of DMCC establish that equilibrium exists for any market demand (buyer valuation distribution), that the buyers’ equilibrium strategy is stationary (i.e., time-invariant) in the gap case, and that after the initial period, the sequence of observed prices is deterministic. DMCC also shows that as the time between offers becomes arbitrarily small, the entire market is served immediately at the competitive price in the gap case, and in all stationary equilibria of the no gap case. Hence, DMCC provides a proof of the Coase Conjecture.

The intuition behind this result matches Coase’s argument. Consider the bargaining interpretation of the model. Suppose that buyer behavior is described by a fixed acceptance function that doesn’t depend on the time between offers. Then, as the time between offers becomes arbitrarily small, in any interval of real time, the seller can make arbitrarily many offers. This means that he can achieve as much price discrimination as he wants without incurring any delay. But this means that prices must fall to the competitive level immediately, which means that no sales will be made until they fall to that level. The main proof in DMCC shows that this argument is valid even though the equilibrium buyer acceptance function changes as the time between offers changes.

“Unobservable Investment and the Hold-Up Problem,” extends the analysis of DMCC to a setting where valuations are not exogenous but are determined by the buyer’s unobservable investment. In the new framework, before the bargaining begins, the buyer may invest in relationship-specific capital to increase his valuation of the good. The seller observes neither the level of the buyer’s investment nor the buyer’s resulting valuation. Hence, whenever the buyer uses a mixed strategy, the bargaining stage is exactly like the bargaining game studied in DMCC.

To see how the hold-up model relates to DMCC, consider the case where there are two possible investment levels, 0 and 1, leading to valuations 2 and 5 respectively. Since  $2 - 0 < 5 - 1$ , the efficient decision is for the buyer to invest 1. However, if the buyer invests 1 for sure, then the seller will never charge a price below 5. Hence, the buyer will be held-up and regret making the investment. On the other hand, if the buyer invests 0 for sure, then the seller will charge 2. But this means that the buyer could have earned  $5 - 2 - 1 = 2$  by deviating and investing 1. Hence, in equilibrium, the buyer must use a randomized investment strategy. Part of the argument of DMCC extends to this new case with endogenously determined valuations: as the time between offers becomes arbitrarily small, the probability that the bargaining game ends (almost) immediately approaches 1.

This is true, regardless of the buyer’s investment strategy. But as the time between offers goes to 0, if the probability that the buyer invests 0 stays bounded away from 0, then the fact that the game ends arbitrarily quickly means that the price must converge to 2 arbitrarily quickly. But, as argued above, this would destroy the buyer’s incentive to invest 0, which must happen with positive probability. So, the probability that the buyer

invests 0 must stay positive but go to 0 as the time between offers goes to 0. Since a price below 2 will never be charged, and the buyer invests 0 with positive probability, his payoff must be 0. We conclude that as the time between offers becomes arbitrarily small, the buyer must invest 1 almost surely and purchase the good at price 4 almost immediately so that his payoff is  $5 - 4 - 1 = 0$ .

Thus, the fact that valuations are determined endogenously enables one of the DMCC conclusions to survive without implying the other: agreement is reached almost immediately but prices do not converge to the competitive level. The main result of the hold-up paper establishes that unobservable investment and dynamic bargaining resolve the hold-up problem and restore efficiency. The key steps of the proofs resemble the corresponding arguments in DMCC. The novel argument is a formal and more general statement of the intuition of the preceding paragraph.

## 16 Arunava Sen

Paper to be included: “The Implementation of Social Choice Functions via Social Choice Correspondences: A General Formulation and a Limit Result”, *Social Choice and Welfare*, 12, 277-292, 1995.

I applied to Princeton’s graduate program in economics in 1982. The main reason I applied was that Vijay Krishna and Dilip Abreu were both at Princeton. They had been a couple of years ahead of me at the Delhi School of Economics and already had legendary status there. Both were students of Hugo and word of his qualities as an advisor had spread on the grapevine. I was both astounded and petrified when I received word that Hugo wanted me to call him (collect). I had no idea that famous professors spoke to prospective graduate students. In fact, I was sure that I would be asked some tricky technical questions and had half a mind to keep my notes and textbooks within easy reach when I called. Instead, Hugo informed me that the department wanted to offer me a fellowship and urged me to accept. It is one of the most serendipitous moments of my life. Hugo could have let the office send me a letter but it was typical of him to take the time out to make a personal connection. At Princeton I attended Hugo’s famous micro theory course in my first year. These lectures were so polished that they had an amazing clarity. Later I attended the Advanced Theory course that he offered which involved reading current research. I confess that I didn’t understand everything but it was wonderfully exciting and stimulating. Soon it was time for my second year research paper. After discussions with Vijay and Faruk Gul, I decided to work on implementation theory. I made this announcement to Hugo and he agreed to supervise me. I remember the first step in this endeavor clearly to this day. On a wintry weekend morning in late ’83, Hugo made me present, in the greatest possible detail, Maskin’s classic result on implementation. One aspect of the result which was disappointing to him was that in the natural case where the planner’s objectives are single-valued, implementability implied dictatorship. This led to the question that I tried to address in the second-year paper which later evolved into the first chapter of my thesis and which I have selected for inclusion in this volume. Suppose that the planner’s objectives are single-valued but non-dictatorial. What is the way to implement it “as best as possible?” The proposal was to embed it “minimally” in an implementable social choice correspondence and then

examine the distance between the two as in the limit the number of voters increases without bound. The thesis progressed in fits and starts. Hugo was always at hand to offer insight and encouragement. He had high standards and he emphasized rigor, clarity and depth. I have learnt enormously from him, and I feel both proud and privileged to have been his student.

## 17 Philip Reny

Paper to be included: “On the Existence of Pure and Mixed Strategy Nash Equilibria in Discontinuous Games.” *Econometrica*, 67, 1029-1056, 1999.

From down the hall I hear a familiar greeting: “Helloooo Renyyyy!” The signature “hello” is as well-known to a Sonnenschein student as the theorem that bears his name. By welcoming us in this delightful manner, Hugo immediately puts us at ease, makes us feel welcome, and eliminates any notion that there might be a barrier of formality between professor and student. All of this from a simple greeting; it’s vintage Hugo.

Part of what makes Hugo such a great adviser, and now colleague, is his ability to listen to what one has to say, to isolate the essence of the idea, and to ask just the “right” question. “What’s your best example?” is a classic Hugo question that one eventually becomes prepared to answer prior to visiting his office. Looking back on my thesis (a bit scary, I must say), I now recognize that some of the better parts of it are the examples that were the result of Hugo’s challenges.

Meetings to discuss my thesis with Hugo often began the same way. I would knock on the half-open door, Hugo would look up and say “Helloooo Renyyyy” and then suggest a change of venue with the phrase “Let’s walk!” I thought that this was so very nice, strolling through the grounds of Princeton University, where such great minds had walked and thought before, discussing my research with a famously important microeconomic theorist. It was such a privilege. I now realize of course that, in addition to being intellectually fruitful, our walks served a more practical purpose. As a professor with students of my own, I know how important it can be to keep one’s students away from one’s blackboard! “Let’s walk” indeed! All jokes aside, these were very special experiences.

I believe that it was in 1986, my fourth and final year at Princeton, when I was introduced to Hugo’s paper (co-authored with Wayne Shafer) entitled “Equilibrium in Abstract Economies without Ordered Preferences” (*Journal of Mathematical Economics* (1975)). The question at hand was the existence of Nash equilibrium in very general settings. Like all of Hugo’s work, the paper is beautifully written, the proofs are so very elegant, and the results are remarkably general, combining and extending, using novel techniques, a variety of classic and significant results from the literature. It made a lasting

impression upon me.

The paper I have chosen to include in this volume deals with the same question of existence of Nash equilibrium, but it explores a different generalization, namely the extent to which one can relax the assumption of continuous payoff functions. It's fair to say that my interest in fixed point theory and the existence of equilibria in games began with Arrow-Debreu-McKenzie, took hold with Nash, and was permanently established with Shafer and Sonnenschein; Hugo gave our class, and others I am certain, masterful lectures on each topic. I remain actively engaged in this area of research to this day.

## 18 James Dow

Paper to be included: “Learning under Knightian Uncertainty: The Law of Large Numbers for Non-additive Probabilities,” with Sergio Werlang.

As an undergraduate I was mad keen on mathematical economics and microeconomics. I liked the idea of doing something very pure, logical and clever. A PhD in the US was the obvious next step. I had the good fortune to be admitted to several graduate schools, and to be advised by Frank Hahn on which to choose. After pointing out the advantages of the other schools, his comment on Princeton was: “If you’re interested in theory, Hugo is your man.” Of course, this was irresistible to me.

Hugo Sonnenschein’s course was inspirational. Apart from the emphasis on clarity, rigour, and logic there were two distinctive features, both highly characteristic of Hugo’s scholarly personality.

The first was his constant use of encouragement. Hugo praised us both as a cohort of students and as individuals. I believe his praise was sincere. By telling us all the time how exceptionally talented we were, Hugo unleashed a huge wave of creativity and energy. Now that I’m a teacher myself I find I have keep reminding myself to praise my students and to genuinely recognise their talents. It’s too easy to fall back on the comfortable notion that the professor is better than the student. (As a parent too, I’ve realised that there are very similar, perhaps even more important, insights about relationships with children). The fact is that the student tends to assume that the professor’s talents are far superior. This assumption can drastically limit the student’s learning and achievement. The lesson to be learned from this seems very simple, but Hugo is the only professor I’ve known who is able (and willing) to put it into practice so consistently.

The second key feature of Hugo’s personality that I discovered in the course was his occasionally severe assessment of established professors on their merits. I suppose this second characteristic is just the flip side of the first. Hugo was frank and critical in his assessment of other professors, and professional or worldly success was certainly not enough to qualify them for his esteem. To be honest, I like this second characteristic of Hugo’s just as much as the first.

I found it was much, much harder to write papers than to pass exams. My doctoral thesis was the hardest thing I’ve ever done in my professional

life. Although he was encouraging, Hugo set high standards. These high standards were reinforced by own high standards and my ambitions, and by the examples set by previous students of Hugo. It's interesting that the best paper in my thesis is not a project that most professors would have encouraged at all (Search Decisions with Limited Memory, Review of Economic Studies 1992). Indeed the explicit advice I got from another faculty member was to try to start by extending existing models in minor ways (starting with the appendix to one of his own papers, of course!). Fortunately, Hugo gave me the opposite advice in no uncertain terms - the advice came in the form of polite but unmistakable hints, sometimes just in his tone of voice.

I had some good friends at Princeton, especially Sergio Werlang. Our friendship developed during Hugo's course, as we were both so enthusiastic about it and the style of economics that Hugo promoted. It's actually only after our time at Princeton that Sergio and I started to write papers together and the enclosed paper is one of that series. It's a previously unpublished paper, as Sergio was not working in academia at that time and some of our projects fell by the wayside. We have made some changes to the paper to reflect the fact that since we wrote it, it has been partially superseded by the papers published by other researchers. The field of research that Sergio and I worked on together, Knightian uncertainty, was really a wide open area for research and hardly anybody else was interested in it at the time, although it's recently become quite fashionable. This paper discusses the circumstances under which people will learn or not learn about their uncertain environment as time goes by.

Like the other contributors to this volume, I must express my gratitude for the enormous amount of time Hugo spent talking to me, often while walking around the campus or getting a ridiculously large ice cream (I've forgotten the name of the ice-cream place, but I think Hugo said he owned a small share of the business). I well remember the look on the face of one of my best friends, an engineering student, when he asked how long I'd spent with my advisor that day and I casually replied "Oh, six hours."

## 19 George Mailath

Paper to be included: “Extensive Form Reasoning in Normal Form Games,” with L. Samuelson and Jeroen Swinkels, *Econometrica* 61, 273-302, 1993.

My intention, when I first went to Princeton as a graduate student, was to write a dissertation in econometrics. That first year was a revelation. In the first semester, after learning choice theory from Mark Machina, we were taught the failings of the welfare theorems by Joe Stiglitz. Then, finally, Hugo taught us the welfare theorems in the second semester, and there was no going back. Hugo is an inspiring teacher; my thoughts of becoming an econometrician disappeared that year.

Hugo’s track record as an advisor speaks for itself. Hugo’s ability to ask just the right question was invaluable. At one point, I was discussing what I thought was a complete paper with Hugo. The model in the paper was a parametric example of simultaneous signaling in an oligopoly model, and I had explored various questions in that model concerning existence of equilibria and the relationship between finite number and a continuum of types. Hugo asked just the right question: “How important were the parametric assumptions to the results?” Answering that question did take a little time, but I hope Hugo was not disappointed in the results.

Many people have commented over the years on Hugo’s ability to create an exceptional intellectual environment among the theory students at Princeton. Since many of us were fascinated by game theory at the time, an area not at the center of Hugo’s own areas of research, this is even more noteworthy. His ability to always ask the “right” question was critical.

Hugo then became Dean of the School of Arts and Sciences at the University of Pennsylvania, and so Hugo was again my “boss.” We spent an enjoyable semester co-teaching a section of the introductory microeconomics course. Hugo also convinced me to participate in undergraduate college life (at least to the extent of having dinner one night at the undergraduate college he was living in at the time). It was at that dinner that I learned from Hugo of the overlap between the current research of a graduate student at Princeton (Jeroen Swinkels) and a project that I was working on with Larry Samuelson. I can think of no more fitting testimony to his influence on me than the resulting series of papers.

## 20 Jeroen Swinkels

Paper to be included (this preface will go with the previous chapter): “Extensive Form Reasoning in Normal Form Games,” with G. Mailath and L. Samuelson, *Econometrica* 61, 273-302, 1993.

It is a pleasure to participate in this volume, because, unlike the other contributors, I cannot claim Hugo for my main advisor; he left for Penn at the end of my second year at Princeton. (Avinash Dixit gracefully stepped in as my advisor.) Hugo played three distinct and key roles in this paper. First, he supervised my second year paper, which is when I began exploring this topic. Hugo was, of course, also George’s advisor. Finally, it is through Hugo that George and Larry on the one side, and I, on the other, learned that we had been pursuing parallel tracks of research. Thus, we learned of each other’s work early enough to have a very rewarding coauthorship. The multiple ways in which Hugo is connected to this paper are, I think, symptomatic of how deeply Hugo was involved in a huge amount of what was going on in game theory at that time. There are so many papers from that period without Hugo’s name on them but where his hand can be clearly seen.

Hugo’s role in my development became more limited after his move to Penn. But, this paper was my first real research effort, and it’s when I began to learn how to write. I remember the writing critiques particularly well: at our first meeting after I’d turned in a draft, I thought maybe Hugo had been busy, because we spent 45 minutes talking mostly about the first two paragraphs. The real point, of course, was the degree of precision and effort that good writing requires. The other thing I remember most about this period is Hugo’s exceptional patience and generosity. It’s not just that he made the time and emotional energy for his students, but that he made it seem easy. Given the number of other things he was up to, one would suspect that this seeming effortlessness wasn’t.

## 21 James Bergin

Paper to be included: “Player type distributions as state variables and information revelation in zero sum repeated games with discounting,” *Mathematics of Operations Research*, 17(3), 640-656, 1992.

I ended up in academe, working in the field of economic theory by accident. I came to Princeton from LSE where I had obtained an MSc., with primary focus on Econometrics. While at LSE I took one course in theory—with Douglas Gale who was then starting his academic career. I had not intended continuing study further than that, but a friend in London recommended pursuing a PhD: I asked Steve Nickell at LSE for some advice. He had just returned from a visit to Princeton and suggested applying there. I applied and was delighted to be accepted.

At Princeton, continuing in econometrics was a possibility, but, as this volume testifies, there was great energy and enthusiasm surrounding theory at the time—to the extent that students organized an independent theory seminar at one point. I was caught up in that enthusiasm, but after completing the comprehensive exams, was short of a thesis topic. Around that time I encountered the ACDA (Arms Control and Disarmament Agency) papers on games of strategy with asymmetric information and decided to pursue research in that area. I’m not sure of the practical relevance of that literature, at least in terms of clear or direct application. But, there is no doubt as to the elegance and beauty of those papers—hardly a surprising observation given that the group of authors included Aumann, Nash, Selten, and many other legendary names.

With a project under way, I “signed up” Hugo and Joe (Stiglitz) as joint supervisors, and worked for Joe as a research assistant. Because the work was on a tightly articulated model, there was little room for reflection on issues of modeling: the focus was on developing results within the existing framework. This has advantages and disadvantages: the direction is relatively clear, which is good, but modeling flexibility is limited and this restricts the scope for maneuver in obtaining results.

For me, the presence of Hugo and Joe electrified the academic life of the would-be theorist on campus, attracting enthusiastic students from all over, and creating an environment of learning and academic excellence second to none. It was my good fortune to arrive there at the time. It was a wonderful

experience—thanks to Princeton for making it possible, and to Hugo, Joe and many others, such as Ed. Mills, for enriching the experience during my time there.

The paper selected, a chapter from my dissertation, addresses two questions: the structure of behavior in dynamic models, and the strategic use and revelation of information over time. The paper considers these two issues in the context of infinitely repeated games of complete information. These are briefly discussed in turn in the next two paragraphs. In multi-period models, the study of behavior is greatly simplified when the actions can be conditioned on a suitable summary statistic of the past, rather than on the entire history. In dynamic programming, this is both natural and taken for granted: a history of investment can be summarized by current capital stock or asset portfolio, optimal depletion of a nonrenewable resource depends not on the history of depletion, but on the remaining stock. And so on. However, in problems with more than one decision maker where other strategic issues arise, the availability and sufficiency of a summary variable is less clear. In stochastic games with finite action and state spaces an old result confirms that there are equilibria with actions at any point in time depending only on the current state, previous actions and states don't affect current behavior. However, this result doesn't extend in general where the state space is continuous. In the incomplete information game, the natural state variable is the player type distribution, which belongs in a continuous state space. With this in mind, the paper shows that for zero sum games (where players interests are opposed), if the value function is differentiable, then the posterior distribution is a sufficient statistic for the history of behavior, and equilibrium actions may be conditioned solely on the posterior distribution.

The second part of the paper considered the nature of information revelation over time in this class of game. The earlier literature had focused on games where the payoff flow was averaged over time, and in that context, a common pattern of play for an informed player is to strategically reveal some information initially, dispersing the posterior distribution relative to the prior, and then subsequently make no further use of information. With discounting, this is generally not an optimal strategy: for many games optimal behavior requires the strategic use (and hence revelation) of information over time, so that it takes infinitely many periods for information to be fully revealed. In the discounted case, it turns out that on the space of distributions over characteristics, computation of the gain for use of information is

a larger order of magnitude that the resulting loss from facing a now better informed opponent. This leads to slow revelation of information over time in many games, with the informed player exploiting information period by period.

I will end with a poem, “Pangur Bán”, due to an 8th or 9th century anonymous Irish academic which describes the research process by analogy with the task of a cat, Pangur Bán, (for the record, the stroke called a “fada” in Irish Gaelic, lengthens the sound and Bán is pronounced “Bawn”). I think it captures many of the important features of the research endeavor. The translation is by Robin Flower and is taken from *1000 Years of Irish Poetry*, ed. by Kathleen Hoagland.

## PANGUR BÁN

I and Pangur Bán my cat,  
'Tis a like task we are at:  
Hunting mice is his delight,  
Hunting words I sit all night.

Better far than praise of men  
'Tis to sit with book and pen;  
Pangur bears me no ill-will,  
He too plies his simple skill.

'Tis a merry task to see  
At our tasks how glad are we,  
When at home we sit and find  
Entertainment to our mind.

Oftentimes a mouse will stray  
In the hero Pangur's way;  
Oftentimes my keen thought set  
Takes a meaning in its net.

'Gainst the wall he sets his eye  
Full and fierce and sharp and sly;  
'Gainst the wall of knowledge I  
All my little wisdom try.

When a mouse darts from its den,  
O how glad is Pangur then!  
O what gladness do I prove  
When I solve the doubts I love!

So in peace our task we ply,  
Pangur Bán, my cat, and I;  
In our arts we find our bliss,  
I have mine and he has his.

Practice every day has made  
Pangur perfect in his trade;  
I get wisdom day and night  
Turning darkness into light.

## 22 Daniel Vincent

Paper to be included: “Repeated Signaling Games and Dynamic Trading Relationships,” *International Economic Review*, 1998.

“Repeated Signalling Games and Dynamic Trading Relationships” was the first paper I wrote after leaving Princeton and becoming an academic economist. For me, it was a natural successor to the three papers in my thesis, papers which marked me clearly as a student of Hugo Sonnenschein. My thesis treated dynamic trading games where two or three agents attempted to determine a price and time of trade for a single indivisible, durable good. The thesis papers owed a great deal to Hugo’s well-known paper with Robert Wilson and Faruk Gul [2], insofar as they employed a similar model and even used much the same strategy of proof. Indeed, the first paper of my thesis [4] owed its primary significance to the fact that it was able to reverse a famous prediction about durable goods monopoly offered in Gul, Sonnenschein and Wilson [2]. One interpretation of the model in their paper implies that when a bargainer is uncertain solely about the private valuation of her rival, then bargaining will only take a significant time to complete if the technology of making offers requires it. In contrast, I demonstrated that when the uncertainty is over the quality of the good to be traded, often bargaining games had to last a significant time to ensure trade.

In “Repeated Signalling Games” I wanted to extend the class of games in this literature to enable an examination of the effects of allowing players a far richer signalling space. This goal was accomplished by introducing trade in nondurable goods (so buyers could return after consummating a trade) and divisibility (so buyers could signal by consuming different quantities). A consequence of this extension, as many contributors to this volume would have known, was to introduce a large multiplicity of equilibria. The equilibrium I focused on in the paper derived its justification indirectly from Hugo’s contribution as well. Solving the game by a type of backward induction generated an iterated two stage signalling game. In the final stage of a given period, an informed buyer selected a quantity that served as a ‘signal’ to the uninformed seller about his type, a signal that (because of iteration) determined a subsequent continuation utility for the game. To address the multiplicity, I adopted the spirit of the refinement suggested by Hugo’s student, In-Koo Cho (along with David Kreps) [1]. The striking feature of the equilibrium

that I identify is that even in multi-period games, players typically reveal their types immediately and yet continue to incur separation costs throughout the game. This behavior can only be supported by a belief system of the seller that allows her to move from a conviction that no high demand buyer is present to one that such a buyer may well be present. Ordinarily such a reversion of beliefs may have been unacceptable in the literature. However, previous work by other students of Hugo, (Madrigal, Tan and Werlang) [3] showed that not only were such belief systems reasonable, they were often necessary in order for perfect Bayesian equilibria to exist.

This paper thus reflects the enormous contribution Hugo has made to my professional life. It exploits on the training I gained as a student of Hugo at Princeton, it builds on a body of literature in which Hugo was a major player, and it draws on the results of many of Hugo's students as well.

[1] Cho, In Koo and David Kreps, "Signaling Games and Stable Equilibria," *QJE*, 102, (1987): 179–221.

[2] Gul, F., H. Sonnenschein, and R. Wilson. "Foundations of Dynamic Monopoly and the Coase Conjecture," *Journal of Economic Theory* 39,1 (1986): 155–190.

[3] Madrigal, V., T. Tan, and S. R. de Costa Werlang, "Support Restrictions and Sequential Equilibria," *Journal of Economic Theory* 43 (1987): 329–334.

[4] Vincent, Daniel R., "Bargaining With Common Values," *Journal of Economic Theory* 48, 1 (1989): 47–62.

## 23 Lin Zhou

Paper to be included: “Impossibility of Strategy-Proof Mechanisms in Economies with Pure Public Goods,” *Review of Economic Studies*, 58, 1991.

In 1985 I was brought to Princeton by Gregory Chow, hugely famous in China for two tests named after him. The first was a test used to select young people to study economics in US, and the second was the popular Chow test in econometrics. Although I passed the first test with flying color, I never really wanted to become an expert of the second test—an econometrician, that is. At the reception for the new graduate students, Gregory introduced me to Hugo, who just came from Stanford with his troops. I naturally thought that I might be able to work under Hugo’s guidance. Little did I know then how lucky I would be. As it turned out, I was the last student Hugo officially supervised during his tenure at Princeton.

Hugo did not take many new students after he returned from Stanford. This allowed me to have easy access to him. Looking back, I probably have taxed much more valuable time of his than I should, but I have certainly taken full advantages of such opportunities.

During my third year, Hugo presented his work with Salvador Barberà on voting by quotas, which grabbed my attention. After working on the problem for weeks, I realized that their main result could be extended considerably. As I reported the news to Hugo, he was very pleased and graciously invited me to be co-author of the paper. I was honored and excited at the same time. While I was dreaming of more work with Hugo or under Hugo, I was shaken as he announced that he would leave Princeton to become the dean at Penn. Sensing my uneasiness with the situation, he sent me to Salvador, first to finish our joint paper, and second, to learn more from Salvador. Again, little did I know how much I would learn on this trip.

A few days after I arrived in Barcelona Salvador broke his leg. Although it was by no means a direct fault of mine, I felt awful. Like most Chinese, I would believe everything was connected. As a result, I paid frequent visits to Salvador’s house to work with him. But it was really a blessing in disguise. While he was in the office, Salvador was always busy with either meetings or people, but now he was at home, and he was with me alone. As we took time to complete our paper on voting by committees, Salvador also told me about his then current work, including his work with Peleg on the Gibbard-

Satterthwaite theorem with continuous preferences. Prior to that, I had thought about the problem of extending the Gibbard-Satterthwaite theorem to economic models, where preferences are both continuous and convex. When the commodity space is a straight line, the median voter scheme is both strategy-proof and non-dictatorial. But if the commodity space is of multidimensional, there was no general result at the time. (The Groves mechanisms work only when preferences are quasi-additive.) I had not had any success up to that point. I immediately revisited the problem in light of Barberà and Peleg's work. By refining their technique to deal with the additional structure of convexity, I managed to prove the Gibbard-Satterthwaite theorem in the economic environment: any strategy-proof mechanism whose range is not contained in a straight line must be dictatorial even when preferences are both continuous and convex. For this result I am mostly indebted to Salvador. But I also owed it to Hugo since it was Hugo who arranged my trip in the first place! I am happy to include it in this volume to honor Hugo, as well as Salvador.

## 24 Zachary Cohn

Paper to be included: “On Linked Bargaining,”

I met Hugo as a mathematics undergraduate at the University of Chicago, when I took a game theory course he was teaching the fall of my junior year. I greatly enjoyed the class, though my background in economics at the time was limited to whatever he had done the previous day. After the midterm exam, Hugo invited me to his to his office to chat, which started a wonderful conversation that continued each week for the next two years.

Though simple, I am still struck by how welcoming Hugo was; I cannot recall another time when a professor was as inviting, or as genuinely interested and excited in talking with a student. I can no longer recall what grand plans I had for our meetings, but Hugo mentioned his work with Matt Jackson and soon I was trying to work out some details about the efficiency when applied to linked bargaining. After a few diversions, that work eventually evolved into the paper here.

My meetings with Hugo would always start with a trip to the Divinity School Coffee Shop, where he would get a cup of coffee and I some tea (evidence, he would say, that I was a mathematician), and often wind up some time later when his office phone would ring, wondering when he would be coming home for dinner. The meetings were always engaging, and were a defining point of my undergraduate career. I can only hope to one day repay him by trying to be as patient and capable with my own students.

To a great friend and educator, happy birthday!