Will Equilibrium-Induced Predictability Survive Undoing By The Uninitiated And Skeptical?

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Contents

1 Abstract

A fundamental debate is taking place in finance academia whether the predictability in securities prices is an equilibrium phenomenon (the neoclassical story, based on Lucas' theory of intertemporal asset pricing) or evidence of market inefficiency (the view of behavioral finance). It is important that some guidance is given as to what side of the debate is right. If predictability reflects market inefficiency, then practitioners are right to exploit it. If not, then exploiting predictability merely amounts to taking on risks without proper evaluation of whether the compensation is sufficient.

The very reason why the debate cannot easily be settled – namely, we do not know much about the structure of the economy – is also a cause to suspect that the equilibrium explanation may not be tenable. Indeed, many practitioners interpret the predictability as a sign of market inefficiency; just like academics, they do not have sufficient structural knowledge of the economy to be convinced otherwise. As a result may attempt to un-do the predictability. It is not known whether equilibrium predictability would survive such attempts.

Financial markets experiments provide a micro-cosmos of the real world. Tension between counter-intuitive equilibrium predictions and common sense have emerged in past experiments before, but the experiments concentrated on simpler, cross-sectional implications of static asset pricing theory. In those cases, neoclassical restrictions do survive attempts by subjects to un-do them even if they are counter-intuitive.

The goal of the proposed research is to run experiments designed so that (Lucas') equilibrium would imply substantial predictability, and to verify whether subjects manage to un-do this predictability.

There are many differences between the field and an experiment. But the lack of structural knowledge of the economy is one aspect in which an experiment can be made to be the same as the field. Like investors in the field, subjects will not be given the information (e.g., aggregate risk) that would allow them to verify whether predictability is an equilibrium phenomenon. As such, the experiment and the field are on an equal footing, and the experimental results should be of interest to anyone studying financial markets, whether in an experimental setting or in the field.

Confidence in neoclassical economic thinking will be substantially enhanced if predictability survives attempts to trade against it. If predictability disappears, one may question neoclassical explanations of predictability in securities markets, and the practitioner would find some justification for trading strategies aimed at exploiting predictability.

2 Research Objectives, Methods, And Anticipated Results

2.1 Introduction

Asset pricing theory sometimes makes predictions that are counter-intuitive. Even the initiated may be surprised to observe particular price configurations, only to be re-assured that nothing is wrong when given more (background) information about the situation.

2.2 An Example

Here is an example. I have been using this setup in my finance classes, because not only does it illustrate the power of asset pricing theory; it also aptly illustrates the point I am trying to make here.

Imagine markets in three one-period securities. Two securities are risky, and are called *Stock A* and *Stock B*, respectively. The third security, called *Bond*, is riskfree. There are three possible, equally likely states, X, Y, and Z, which determine the final payoffs on the two risky securities, as follows:

	State		
	X	Y	Z
Stock A	0.50	0	1
Stock B	0	1	0.50
Bond	1	1	1

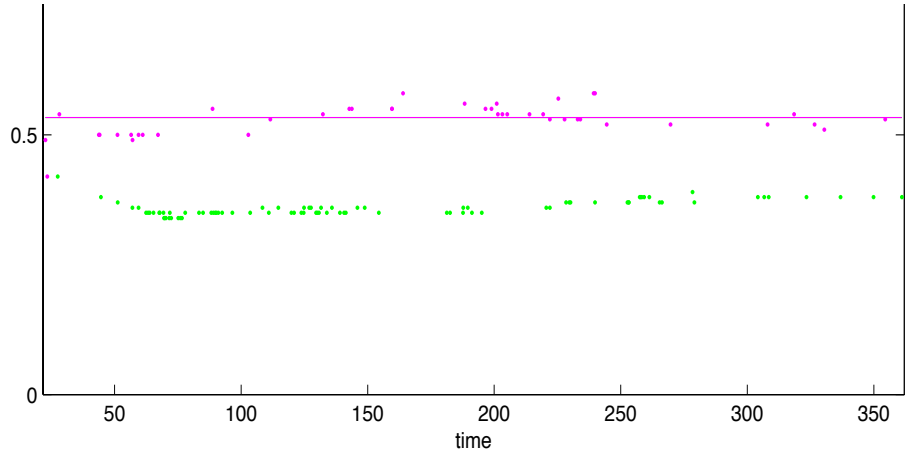
Initial holdings are such that there are more Stock A than Stock B, but nobody in the markets knows this.

Notice that the payoff distributions of the Stock A and Stock B are *identical*. The question I pose to my students is: *Which of the two, Stock A or Stock B, will have the highest price?*

Of course, neoclassical asset pricing teaches us that one cannot answer this question without knowing aggregate supplies. If, as is the case here, more units of Stock A are available, it will have the higher covariance with the aggregate payoff (sum of all payoffs on all securities), i.e., it will have a higher "beta," and hence, the price of Stock A will be lower. I ask the above question when students do not know asset pricing yet (and hence, they are unlikely to ask me for the aggregate supplies).

Invariably, a discussion emerges between my students and me which shares in many respects the features of the dispute presently taking place in academia between proponents and opponents of behavioral finance. Most often, students claim that it does not make sense for the prices of Stock A and Stock B to be any different. After all, the two payoff distributions are the same. I counter that it is perfectly possible for the two prices to be different. I add that in this particular case, prices *will* be different.

Figure 1: Trade prices of Stock A and Stock B (in U.S. dollars; vertical axis) as a function of time (in seconds; horizontal axis) in one period in a class experiment (December 1, 2005). Stock A (green prices) is cheaper than Stock B (purple prices; purple line indicates expected payoffs of both Stock A and Stock B), in accordance with asset pricing theory, because Stock A has the higher "beta."



When asked whether they would be willing to trade against any difference in prices, my students often answer affirmatively. They claim that eventually prices will be the same.

I then invite the students to participate in an experiment that is set up exactly as explained above. Students can trade their holdings in fast, web-based markets[1] during a pre-specified time period, after which the state is drawn, securities are liquidated, and subjects are paid depending on their final holdings.

We then reconvene and discuss the results. Figure 1 provides a typical outcome. As one can see, asset pricing theory makes the right prediction.

Evidence like that displayed in Figure 1 settles the issue. To be sure, the issue *can be settled* here because the evidence comes from an *experiment*, where I controlled, and hence, where I knew, the very parameters that determine which side of the debate is right.

[1] See http://jmarkets.ssel.caltech.edu/.

2.3 Experimental *vs.* Field Evidence

In the field, it is rare to have the information required to settle an issue like the one above. We rarely, if ever, have information on the true aggregate supplies (this is reminiscent of the Roll critique; Roll 1977).

The experiment, however, demonstrates that if (neoclassical) finance predicts a counter-intuitive price configuration in a simple static setting, it is neoclassical finance that wins, despite efforts by some to "undo" its prediction (and, I should add, despite ample anomalies in individual behavior, discussed in detail in Bossaerts, Plott and Zame 2005). Not only do opponents of counter-intuitive asset pricing results eventually not affect prices, like in the field, the experiment is populated with plenty of subjects who do not do what neoclassical theory predicts. Yet neoclassical theory wins.

The experiment is designed to be on an equal footing with the field: subjects are not given enough information to figure out what equilibrium should look like (if they care to do so), just like investors lack the knowledge to fully understand why, say, one stock is more expensive than another. In this sense, the experimental results are relevant even for those who are only interested in field markets.

It is often stated that trading sophistication in field markets is higher than in an experimental setting. While this is debatable (and behavioral finance surely indicates that field market participants are particularly bad), increased trading sophistication is actually a double-edged sword in the present context: it may help markets attain the right equilibrium, but it may also precipitate un-doing of equilibrium pricing patterns that investors cannot trace to fundamentals because they don't know those.

2.4 The Debate About Predictability

The above example concerns a simple situation, namely, the prices of a cross-section of assets with a one-period life. Today's debate in finance academia deals with multi-period, even infinite-lived securities.

At the core of this debate is the level of predictability observed in field data. Since Keim and Stambaugh 1986, evidence has accumulated that returns *are* predictable. Two camps have emerged. There are those, starting with De Bondt and Thaler 1985, who interpret predictability as reflecting the many cognitive biases that have been known to exist at the individual level – the core thesis of behavioral finance. There are those, starting with Bossaerts and Green 1989 and Berk, Green and Naik 1999, who point out that predictability is perfectly consistent with the workhorse of intertemporal asset pricing, namely, Lucas' model (Lucas 1978). What is more, even the most puzzling aspects of predictability can be explained by reasonable – and often simple – assumptions of the structure of the economy, a point made quite convincingly in, e.g., Li, Livdan and Zhang 2006.

Indeed, the Lucas' model of intertemporal asset pricing allows for predictability. This is because the model insists on stationarity: the mapping from the underlying states (defined, e.g., as levels of dividends) to prices is to be time

invariant. As a result, unless this mapping is trivial, predictability in the states will be inherited by prices. The more the state transitions are predictable, the more price changes (returns) will be predictable.

The relative merits of the two sides to the debate (behavioral finance *vs.* neoclassical finance) cannot be settled using field data. This is because we lack the crucial information to determine whether the neoclassical model is right. The information that is missing is the very structure of the economy that theorists need to ensure the right amount of predictability.

Without information on the structure, behavioral finance should win the debate. After all, the premise of behavioral finance, that investors suffer from all kinds of serious cognitive biases, is without doubt. Why would they *not* affect prices?

It is precisely results from experiments such as the one discussed above that ought to make one hesitant to jump to conclusions.

2.5 Proposed Research

I propose to design and run experiments in such a way that neoclassical asset pricing theory (in particular, Lucas' model) would imply substantial predictability. Subjects, who will not know the structure of the economy they are in, and hence, who cannot determine the origin of the predictability, should wonder. Predictability is, after all, counter-intuitive. Some, like the behavioral finance hedge funds in the "real world," will be bold enough to trade against the predictability.

The question is: *Will predictability survive?*

The proposed experiments will be an outgrowth of research I have been involved in with Thorsten Hens of the University of Zürich and Jørgen Haug of the Norwegian School of Economics and Business Administration. The aim of that research was to create, in an experimental setting, the right conditions for Lucas' equilibrium to emerge.

It is not obvious to emulate Lucas-type economies in an experimental setting. Typical experiments are short in duration (2 to at most 4 hours) and what matters to subjects is only the cumulative payoff they receive at the end. Specifically, it should not be relevant that they receive some of this payoff early on rather than later in the experiment. There is no role for payoff *smoothing* – ensuring that payments are fairly steady over time. Yet smoothing ("consumption smoothing") is at the core of the Lucas model.

But the Lucas model is a representative-agent model. It suffices that only the representative agent has a demand for smoothing. Each individual agent in the economy may not need to smooth, as long as the aggregate agent, implied by the preferences of the individual agents and the structure of the economy, does want to smooth.

Thorsten Hens, Jørgen Haug and I were able to come up with a design in which individual subjects have no demand for smoothing, yet, in the aggregate, there is demand for smoothing. The trick is to ensure that the take-home payoff

for different groups of subjects is determined by their securities and cash holdings at different points in time.

Because subjects are to be assigned to groups, yet each group is to have a sufficient number of members (to ensure competition), our experiments are difficult to run. They require flexible software that allows a large number of subjects to participate simultaneously. We have finished development of this software (see footnote 1). The experiments are also expensive - subjects need to be compensated sufficiently to ensure they have the right incentives.

Protocol for the experiments has proven to be successful before, as the above example illustrates. The prototype of the intended type of large-scale financial markets experiment is described in Bossaerts and Plott 2004.[2] Experiments will be web-based, allowing subjects to log in from other places than a traditional laboratory. An example of one of my experiment web sites is

http://clef.caltech.edu/exp/info/

2.6 Results Anticipated

The experiments will be set up in such a way that Lucas' model implies substantial predictability. The observation to be made from the experiments is to what extent subjects, unaware of the equilibrium nature of the predictability, attempt and succeed in reducing or even eliminating it.

If predictability disappears in the experiments, one ought to question the relevance of Lucas' concept of (stationary) equilibrium. The predictability that this notion of equilibrium implies may be the very reason why it is not of practical relevance in a world populated by agents who do not know the structure of the environment. Instead, the random walk theory may be the focal point of market behavior, even if markets exhibit transient predictability. In this case, the results would provide empirical support for a criticism raised long ago by Friedrich Hayek – that sophisticated mathematical equilibrium models of markets assume too much about the structural knowledge of participants, and hence cannot be true (Hayek 1948). If predictability disappears, closer inspection of price behavior may provide ideas about the type of non-stationary equilibrium that theorists may want to focus on in the future.

If predictability remains, the experiments would demonstrate that Lucas' notion of equilibrium is robust: it survives despite the fact that it generates predictability that no subject can trace to fundamentals. Previous experimental evidence has shown that competitive equilibrium is unaffected by attempts to trade against some of the counter-intuitive static pricing patterns it implies. The finding that predictability remains would extend this to inter-temporal pricing patterns.

[2]This paper won the 2004 GSAM Best Research Paper Award of the European Finance Association.

3 Practical Relevance

The academic debate about the relevance of behavioral finance in asset pricing has deep implications for the practice of investments. At the heart of the debate is the issue whether observed predictability is an equilibrium phenomenon, and hence, compensation for risk, or whether it reflects market inefficiencies. If it is the former, then any attempt at exploiting it just amounts to investing without appropriate consideration of the risks. The resulting strategies may prove profitable for a while (this is compensation for the risks), but at one point the risks will be realized and the consequences may be dire. If, however, predictability reflects market inefficiency, then the numerous hedge funds that have been set up to exploit it are right - and will make the market more efficient.

Field data, however, cannot be conclusive, because we lack the structural information to determine which side of the debate is right. Well-designed experiments, however, provide a micro-cosmos of the real world within which the debate becomes alive: subjects have an equal lack of understanding of the structure of the environment and will (and do) wonder about the predictability – oftentimes deciding, like hedge funds, to exploit what they perceive to be market inefficiencies. The experimenter, however, controls the structure. As such, the experimenter can verify to what extent the predictability of equilibrium asset pricing theory comes about in the face of attempts of some subjects to undo it.

If predictability survives such attempts, then the message for practitioners is clear: one ought to be suspicious that predictability observed in field data reflects market inefficiency; instead, predictability may be mere compensation for risk in a more sophisticated setting than the standard one-period CAPM world.

One can easily imagine the opposite outcome, however. For practitioners, it would mean that the simple random walk is the baseline towards which financial markets appear to move. Sophisticated mathematical equilibrium models may not be the right lens through which field data are to be interpreted and investment strategies are to be evaluated.

4 Timetable

Fall 06	Design of experiments; Running of pilot experiments
Winter 07	Main experiments; analysis of data
Spring 07	Writing up of results
Fall 07- Spring 08	Presentation of results - publication.

Note: experiments will be run at the Université de Lausanne. *Inquire Europe* grant money is to be used to cover part of the cost of the experiments. A typical experiment involves 40 subjects, at an expected cost of €50 each (i.e., €2,000 per experiment).

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Berk, J.B., R.C. Green and V. Naik, "Optimal Investment, Growth Options, and Security Returns," *Journal of Finance* 54 (1999) 1553-1607.

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Bossaerts, P. and C. Plott, "Basic Principles of Asset Pricing Theory: Evidence from Large-Scale Experimental Financial Markets," *Review of Finance* 8 (2004), 135-169.

Bossaerts, P., C. Plott and W. Zame, "Prices and Portfolio Choices in Financial Markets: Theory and Experiment," Caltech Working Paper (2005).

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Hayek, F.A., "The Meaning Of Competition," in: F.A. Hayek, ed., *Individualism and Economic Order*, The University of Chicago Press, Chicago (1948).

Keim, Donald B. and Robert F. Stambaugh, "Predicting Returns in the Stock and Bond Markets," *Journal of Financial Economics* 17 (1986), 357-390.

Li, E.X.N., D. Livdan and L. Zhang, "Optimal Market Timing," University of Rochester Working Paper (2006).

Lucas, R.E., "Asset Prices in an Exchange Economy," *Econometrica* 46 (1978), 1429-1445.

Roll, R., "A critique of the asset pricing theorys tests: Part I." *Journal of financial economics* 4 (1977),129-176.

Resume

See next pages.

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1. Education

Ph.D. (Management) University of California, 1986.

Coursework in the Master's program (Statistics) Vrije Universiteit Brussel, 1982-1983.

Doctorandus (Applied Economics) Universitaire Faculteiten Sint Ignatius, 1981-1982 (summa cum laude).

Licenciaat (Applied Economics) Universitaire Faculteiten Sint Ignatius, 1977-1981.

2. Appointments

Swiss Finance Institute Visiting Professor, HEC, Université de Lausanne, July 2006-7 (on sabbatical from Caltech)

Chair, Division of The Humanities and Social Sciences, California Institute of Technology, July 2006-

Member of the faculty of the *Computation and Neural Systems* Program, California Institute of Technology, 2006-

Fellow, Center of Excellence, Kobe University (Japan), March 2006.

Guest Professor, University of Zurich, April 2004.

William D. Hacker Professor of Economics and Management, California Institute of Technology, 2003-

Executive Officer, Social Sciences, California Institute of Technology, 2002-2005.

Leif Johansen Distinguished Visiting Scholar, BI, Oslo, Norway, June 1999.

Research Fellow, Centre for Economic Policy Research (CEPR), London, 1999-

Professor of Finance, California Institute of Technology, 1998-

Associate Professor of Finance (with tenure), California Institute of Technology, 1994-1998.

Visiting Associate Professor of Finance, Yale School of Management, Winter 1998.

Research Professor (Center for Economic Research) and Professor of Investments Analysis (Department of Economics) at Tilburg University, The Netherlands, 1994-96.

Assistant Professor of Finance, California Institute of Technology, 1990-1994
Assistant Professor of Finance, Carnegie Mellon University, 1987-1990.

Research Fellow, Carnegie Mellon University, 1986-1987.

3. Grants (Post-doctoral Only)

National Science Foundation, for the project "Experiments on Information and Information Processing in Financial Markets," 2006-9, Grant #SES-.

National Science Foundation, for the project "How Asset Markets Assist Complex Problem Solving: Identifying The Cues Through Neurocorrelates," 2005-2008, Grant #SBE-0527491.

National Science Foundation, for the project "The Evolution of Prices and Allocations in Markets: Theory and Experiment," 2003-2006, Grant #SES-0317715.

National Science Foundation, for the project "Perfectly Rational Markets, Imperfectly Rational Traders: Theory and Experiment," 2000-2003, Grant #SES-0079374

Grant to support research on financial markets from the R.G. Jenkins Family Fund of the Fidelity Investments Charitable Gift Fund.

Research Grant from State Street Bank to Caltech for the Proposal "Assessing The Severity of the Absence of 'Packaging' Possibilities At the NYSE Open," 1999.

Research Grant, "Participation of Boundedly Rational Agents in Financial Markets: Effects on Speculation, Trading Volume and Price Volatility," European Union, Grant #ERB4001GT950936, 1995-6.

Grant, "Local Parametric Analysis of Hedging In Discrete Time," Royal Dutch Academy of Sciences, 1995.

Research Grant from First Quadrant to Caltech for the Proposal "Forecasting Non-Stationary Financial Return Data," August 93-July 94.

Standard Oil Research Chair Award, Summer 1987.

4. Awards

Review of Finance 2004 GSAM Best Research Paper Award for the paper "Basic Principles of Asset Pricing Theory: Evidence From Large-Scale Experimental

Financial Markets."

Journal of Financial Markets 2003 Best Paper Award for the paper "Excess Demand and Equilibration in Multi-Security Financial Markets: The Empirical Evidence."

Mathematical Finance 1993 Best Paper Award (Third Prize) for the paper "A Test of a General Equilibrium Stock Option Pricing Model."

5. Invited Lectures

"Neuro-Finance," Kobe University, March 2006

"Experimental Finance," Kobe University, March 2006

"Are Cognitive Biases Relevant for Asset Pricing?" Hemsedal, Norway, March 2006

"The Paradox of Asset Pricing," Kobe University, March 2006

"The Paradox of Asset Pricing," Stanford-Tsukuba Conference, March 2006

"Experimental Financial Markets," EIASM, Brussels, December 2005

"The Paradox of Asset Pricing," University of Copenhagen, September 2004

"Experimental Financial Markets," University of Zurich, April 2004

"Testing Asset Pricing Theory When Markets Don't Have Unbiased Expectations," Université de Montréal, March 2003

"Nonstationarities In Asset Returns: Nature, Causes and Remedies," CIDE, Italy, June 2002

"Value vs. Growth Investment Strategies: The Academic Viewpoint," FAME, Switzerland, March 2001

"Risk Measures in Applied Finance: Science or Fiction? " Deloitte and Touche Lecture, Belgium, December 1999

"Finance: Is It The Math Or The Science That Attracts The "Rocket Scientists"? Earnest Watson Lecture, Caltech, November 3, 1999

"Statistical Properties Of Securities Prices: Theoretical Predictions And Empirical Evidence," BI, Oslo, Norway, June 1999

"Time in Options Analysis," *Dies Natalis* Lecture, Tilburg University, November 1995
"Perspectives and Prospectives of Experimental Economics," European Summer Meetings of The Econometric Society, August 1994

"The Econometrics of Learning in Financial Markets," Humboldt-Universität zu Berlin, Institut für Statistik und Ökonometrie, March 1994

"The Econometrics of Learning in Financial Markets," Hong Kong University of Science and Technology, January 1994

"The Econometrics of Finance," Universitat Pompeu Fabra, Barcelona, January 1992

"The Econometrics of Finance," The Swedish School of Economics, Helsinki, September 1989

6. Professional Activities

Economic Science Association, Officer (Section Head, Finance; 2004-2005).

American Finance Association, member of the 2002 Nominating Committee.

Co-Editor: Review of Finance (2005-).

Associate Editor: Review of Financial Studies (1994-7), Journal of Financial Markets (1997-), Journal of Financial Econometrics (2001-5), Mathematical Finance (2002-5), Review of Finance (2003-5), Annals of Finance (2004-2007).

Editorial Board: Foundations and Trends in Economic Theory.

Referee: American Economic Review, Econometrica, Economic Journal, Economics Letters, Economic Theory, European Economic Review, Finance, International Economic Review, Journal of The American Statistical Association, Journal of Business, Journal of Business and Economic Statistics, Journal of Econometrics, Journal of Economic Behavior and Organization, Journal of Economic Dynamics and Control, Journal of Empirical Finance, Journal of Finance, Journal of Financial and Quantitative Analysis, Journal of International Money and Finance, Journal of Money, Credit and Banking, Journal of Political Economy, Proceedings of the National Academy of Sciences, Rand Journal of Economics, Review of Economics and Statistics, Review of Economic Studies, Review of Financial Studies.

Member: American Finance Association, Econometric Society, Economic Science Association, European Finance Association, Society for Neuroeconomics, Society for the Promotion of Financial Studies, Western Finance Association.

7. Research: Articles, Books, Papers (Per Topic)

7.1 Asset Pricing Theory

Published

Articles:

"Common Nonstationary Components of Asset Prices," *Journal of Economic Dynamics and Control* 12 (No. 2/3): June/September 1988.

"A General Equilibrium Model of Changing Risk Premia: Theory and Tests," with Richard C. Green, *Review of Financial Studies* 2 (4): 1989.

"Tax-Induced Intertemporal Restrictions on Security Returns," with Robert Dammon, *Journal of Finance* 49, no. 4 (1994): 1347-1372.

"Speculative Behavior and the Functioning of Financial Markets: Discussion," (in Spanish), *Moneda y Credito* 200 (1995): 39-44.

"Expectations and Learning in Iowa," with Oleg Bondarenko, *Journal of Banking and Finance* 24 (2000), 1535-1555.

"An Exploration of Neo-Austrian Theory Applied To Financial Markets," with Harald Benink, *Journal of Finance* 54 (2001), 1011-1028.

"Excess Demand and Equilibration In Multi-Security Financial Markets: The Empirical Evidence," with Elena Asparouhova and Charles Plott, *Journal of Financial Markets* 6 (2003), 1-22.

"Basic Principles of Asset Pricing Theory: Evidence From Large-Scale Experimental Financial Markets," with C. Plott, *Review of Finance* 8 (2004), 135-169.

Books:

The Paradox of Asset Pricing (Princeton: Princeton University Press, 2002; Paperback version appeared 2005).

Unpublished

"Learning-Induced Securities Price Volatility," December 1998.

"Has the Cross-Section of Average Returns Always Been The Same? Evidence from Germany, 1881-1913," with Caroline Fohlin, Caltech Social Science Working Paper 1084: 2000.

"Modeling Price Pressure in Financial Markets," with Elena Asparouhova, 2006.

"Equilibration under Competition in Smalls: Theory and Experimental Evidence," 2006.

"Prices and Allocations in Financial Markets: Theory, Econometrics, and Experiments," with Charles Plott and William Zame, 2006.

"Equilibrium Asset Pricing Under Heterogeneous Information," with Bruno Biais and Chester Spatt, 2006.

"The Impact Of Ambiguity On Prices And Allocations In Competitive Financial Markets," with Paolo Ghirardato, Serena Guarnaschelli and William Zame, 2006.

"Why Cognitive Biases May Not Always Be Relevant For Asset Prices," with Elena Asparouhova, Jon Eguia and William Zame, 2006.

7.2 Experimental Finance

Published

"Experiments With Financial Markets: Implications For Asset Pricing Theory," *The American Economist,* Spring 2001. Reprint in *Shifting Paradigms, New Directions in Economics*, Cambridge, UK: Cambridge University Press (2004).

"Price Discovery in Financial Markets: The Case of the CAPM," Bossaerts, P., D. Kleiman, and C. Plott [2000], in Charles R. Plott*, Collected papers on the Foundations of Experimental Economics and Political Science: Information, Finance and General Equilibrium*, vol. 3, Edwin Elgar Publishers, 2004.

"The CAPM in Thin Experimental Financial Markets," with Charles Plott, *Journal of Economic Dynamics and Control* , 26 (2002), 1093-1112.

"Asset Pricing," in *Handbook of Experimental Economics Results*, Charles R. Plott and Vernon L. Smith, eds., New York: Elsevier (2004).

"Inducing Liquidity in Thin Financial Markets Through Combined-Value Trading Mechanisms," with Leslie Fine and John Ledyard , *European Economic Review,* 46 (2002), 1671-95.

Unpublished

"Risk Aversion in Laboratory Asset Markets," with William Zame, 2006.

"Executing Complex Cognitive Tasks: Prizes vs. Markets," with Jernej Copic and Debrah Meloso, 2006.

"Rational Price Discovery in Experimental and Field Data," 1995 (presented at an invited lecture, European Summer Meetings of the Econometric Society, 1994).

7.3 Cognitive Neuroscience

Published

"Neural Differentiation of Expected Reward and Risk in Human Subcortical Structures," with Kerstin Preuschoff and Steve Quartz, *Neuron* 51, 381-390.

"The Role of Ventromedial Prefrontal Cortex in Abstract State-Based Inference During Decision Making in Humans," with Alan Hampton and John O'Doherty, *The Journal of Neuroscience* 26, 8360-8367.

Unpublished

"Attribution of Mental States to Financial Markets with Insiders: fMRI Evidence," with Tony Bruguier and Steve Quartz, 2006.

"Human Insula Activation in a Monetary Gambling Task Reflects Uncertainty Predictions Errors As Well As Uncertainty Level," with Kerstin Preuschoff and Steve Quartz, 2006.

"Risk and Expected Reward Signals are Added to Form a Conflict or Inconsistency

Metric in the Anterior Cingulate Cortex," with Tony Bruguier and Steve Quartz, 2006.

"Markowitz in the Brain?" with Kerstin Preuschoff and Steve Quartz, 2006.

7.4 Econometric Theory

Published

"The Econometrics of Learning in Financial Markets," *Econometric Theory* 11, no. 1 (1995): 151-189.

"Testing the Mean Variance Efficiency of Well-Diversified Portfolios in Very Large Cross-Sections," with Pierre Hillion, *Annales d'Economie et Statistique* 40 (1995).

"Filtering Returns for Unspecified Biases in Priors when Testing Asset Pricing Theory," *Review of Economic Studies* 70 (2003), 1-24.

Unpublished

"A Theorem On (Certain Kinds Of) Out-of-Sample Prediction Tests in Finance," 1996.

"On the Power of the Gibbons-Ross-Shanken Test of Optimality of a Portfolio," with Debrah Meloso, 2004.

7.5 General Equilibrium Theory

Published

"Asset Trading Volume in Infinite-Horizon Economies with Dynamically Complete Markets and Heterogeneous Agents: Comment," with William Zame, 2006, *Finance Research Letters*, forthcoming.

Unpublished

"Rational Expectations Equilibria When Priors are Inconsistent," 1998.

7.6 Game Theory

Published

"Asset Prices and Volume in a Beauty Contest," with Bruno Biais, *Review of Economic Studies* 65 (1998): 307-340; *Summary* appeared in *Journal of Finance* 49, no. 3 (1994), reprinted in *Advances in Financial Modeling*, B. Biais and M. Pagano, eds., Oxford University Prees, 2001.

7.7 Mechanism Design

Published

"An Optimal IPO Mechanism," with Bruno Biais and Jean-Charles Rochet, *Review of Economic Studies* 69 (2002) 117-146.

7.8 Mathematical Finance

Published

"A Test of a General Equilibrium Stock Option Pricing Model," with Pierre Hillion, *Mathematical Finance* 3 (4): 1993.

"Local Parametric Analysis of Hedging in Discrete Time," with Pierre Hillion, *Journal of Econometrics* 81 (1997).

"Martingale-Based Hedge Error Control," with Bas Werker, in *Numerical Methods in Financial Mathematics*, C. Rogers and D. Talay, eds., Cambridge University Press, 1996.

"Local Parametric Analysis of Derivatives Pricing," with Pierre Hillion, *Journal of Financial Markets* 6 (2003) 573-605.

Unpublished

"Arbitrage-Based Pricing When Volatility is Stochastic," with Eric Ghysels and Christian Gouriéroux, October 1997.

7.9 Applied Econometrics

Published

"A New Method for Volatility Estimation with Applications in Foreign Exchange Rate Series," with Wolfgang Härdle and Christian Hafner, in *Finanzmarktanalyse und -prognose mit innovativen quantitativen Verfahren*, G. Bol, G. Nakhaeizadeh and K.-H. Vollmer, eds., 71-84, Physica Verlag, 1996.

"Exchange Rates Have Surprising Volatility," with Christian Hafner and Wolfgang Härdle, in *Time Series Analysis,* in memory of Ted Hannan, P.M. Robinson and M. Rosenblatt, eds., 2:55-72, Springer Verlag, 1996.
"Implementing Statistical Criteria to Select Return Forecasting Models: What Do We Learn?" with Pierre Hillion, *Review of Financial Studies* 12 (1999): 405-428.

7.10 Market Microstructure Analysis

Published

"Market Microstructure Effects of Government Intervention in the Foreign Exchange Market," with Pierrre Hillion, *Review of Financial Studies* 4 (3): 1991.

"Transaction Prices When Insiders Trade Portfolios," *Finance* 14 (2), 1993; *Summary* appeared in *Journal of Finance* 48 (3): 1993.

7.11 Corporate Finance

Published

Articles:

"IPO Post-Issue Markets: Questionable Predilections But Diligent Learners?" with Pierre Hillion, *Review of Economics and Statistics* 83, no. 2 (2001): 1-15.

Books:

Lecture Notes in Corporate Finance, with Bernt Arne Ødegaard (Singapore: World Scientific Publishing, 2001; Second Edition Forthcoming 2006).

8. Research: Development of Instruments

jMarkets 1.0 (2005), 1.5 (2006), 2.0 (2006): scientific project supervisor; jMarkets is a pure-Java, J2EE-compliant open-source software tool to run large-scale internet-based experiments with multiple interconnected markets (source and binary code published at http://jmarkets.ssel.caltech.edu); joint with Walter Yuan, Raj Advani and William Zame.

9. PhD Advisees

Past students: Kaoru Kato, Olin Bondarenko, Serena Guarnaschelli, Elena Asparouhova (All from HSS)

Present students: Debrah Meloso (HSS), Kerstin Preuschoff (CNS), Tony Bruguier (CNS)

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