

# SAMSI Program on Financial Mathematics Statistics and Econometrics

## FINAL REPORT

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### 1 Introduction and Overview

The goal of the SAMSI Program on Financial Mathematics, Statistics and Econometrics (FMSE) was to identify short and long term research directions deemed necessary to achieve both fundamental and practical advances in this rapidly growing field and to initiate collaborative research programs — between mathematicians, statisticians, and economists — focused on the multi-disciplinary and overlapping set of fields which involves disciplines such as: Applied Mathematics, Economics and Finance, Econometrics and Statistics. A prominent theme throughout both the workshop and program was the necessity of exploiting the natural synergy between areas of financial mathematics, statistics and econometrics. The goal of the SAMSI program in Financial Mathematics and Econometrics was to bring together these disciplines and initiate a discussion regarding what is really important and what is missing in three essential tasks. (1) **Modeling:** Model development was considered in domains ranging from financial and energy derivatives to real options. (2) **Data:** The size of financial data can be considerable when looking at high frequency data for large numbers of stocks for example. (3) **Computation:** Once a model has been written and calibrated to data, it remains necessary to compute quantities of interest. These three key themes transpired through the entire program and all its activities, including workshops, courses and the diversity of visitors and participants. In particular the program included the following components and activities.

- **Opening Workshop** (September 18-21, 2005): The goal of the opening workshop was to initiate discussion focused on identifying avenues of research in financial mathematics, statistics and econometrics, including models of risk and uncertainty, extreme events, equity, credit, and energy markets; computational and practitioners issues, portfolio optimization. Leading researchers from a variety of fields were asked to provide overview presentations and make recommendations concerning research directions deemed necessary to make significant advances in the field. The keynote speaker was Robert F. Engle, Nobel Prize Laureate in 2003, for his contributions in the field of financial econometrics. This provided a framework for the research directions pursued in the program. Over 160 participants were present at the Opening Workshop.
- **Tutorials** SAMSI Fellows Ronnie Sircar, Princeton University, and Bas Werker, Tilburg University, provided tutorials on Financial Mathematics and Econometrics, respectively.
- **Workshop on Credit Risk** (October 31 - November 2, 2005): Chair: Jean-Pierre Fouque (NCSU). The goal of this workshop was to bring together researchers from academia and the financial industry to present and discuss recent developments in the area of credit risk. Modeling default, correlation of defaults and the associated structured products were the main topics of the workshop.
- **Workshop on Model Uncertainty** (January 27, 2006): Chair: Eric Ghysels (UNC). In this workshop, participants focused on how to introduce uncertainty about the data generating process into asset pricing models and financial decision making.

- **Transition Workshop** (February 27-28, 2006): Participants in the program outlined progress made in the different fields covered by the various workgroups; that is (1) Computational Issues, (2) Credit Risk, (3) Lévy Processes, (4) Model Uncertainty and (5) Portfolio Management.
- **Distinguished Lecture:** Professor Robert F. Engle (Stern Business School, New York University) - Nobel Laureate 2003, "The Spline GARCH Model for Unconditional Volatility and its Global Macroeconomic Causes"
- **SAMSI University Fellows:** Ronnie Sircar (Princeton University) and Bas Werker (Tilburg University)
- **SAMSI Postdoctoral Fellows:** Jesus Rodriguez and Moustapha Pemy
- **SAMSI Young Research Fellow:** Mingxin Xu (UNC-Charlotte)
- **SAMSI Graduate Fellows:** John Hyde (Mathematics, Duke), Arthur Sinko (Economics, UNC), Jennifer Sloan (Statistics, NCSU), Chong Tu (Statistics, Duke), Doug Vestal (Mathematics, NCSU), Yichao Wu (Statistics and Operations Research, UNC)
- **SAMSI Graduate Associate:** Stephen Zhou (Mathematics, NCSU)
- **Short and Long-Term Visitors:** Evan Anderson (NIU), Elena Andreou (University of Cyprus), Fousseni Chabi-Yo (Bank of Canada), Rama Cont (Ecole Polytechnique), Yanqin Fan (Vanderbilt), Kenneth Hochbery (Bar-Ilan University), Aytac Ilhan (Oxford), Kasper Larsen (CMU), Jennifer Juergens (ASU), Knut Solna (UC Irvine), Gordan Zitkovic (Austin, Texas)
- **Working Groups:** Five formal working groups were formed to organize, pursue, and communicate research investigated during the program.
  - *Computational Issues:* Led by Paul Fackler (NCSU)
  - *Credit Risk:* Led by Jean-Pierre Fouque (NCSU) and Ronnie Sircar (SAMSI Fellow from Princeton University)
  - *Lévy Processes:* Led by George Tauchen (Duke)
  - *Model Uncertainty:* Led by Eric Ghysels (UNC) and Eric Renault (UNC)
  - *Portfolio Management:* Led by Tao Pang (NCSU) and Mingxin Xu (UNC Charlotte and SAMSI Young Research Fellow)
- **Courses:** Two courses were taught in conjunction with the program.
  - *Advanced Topics in Financial Econometrics*, Cross-listed at NCSU, UNC and Duke and co-taught by Eric Ghysels (UNC) and Bas Werker (Tilburg University and SAMSI Fellow).
  - *Special Topics in Financial Mathematics*, Cross-listed at NCSU, UNC and Duke and co-taught by Jean-Pierre Fouque (NCSU), Paul Fackler (NCSU) and Ronnie Sircar (SAMSI Fellow from Princeton University)
- **Technical Reports, Papers, and Books**
- **Presentations**

Details regarding these activities are provided in subsequent sections.

## 2 Program Objectives, Anticipated Outcomes and Recruitment

### 2.1 Objectives

The following program objectives were identified during the Opening Workshop. Details regarding these activities are provided in the various sections in the context of the working groups.

- **Modeling.** In equity markets there is a profusion of models ranging from local volatility to stochastic volatility, multi factors with and without jumps, based on Brownian motions or Lévy processes. The situation is similar in fixed income markets with short rates models, HJM or BGM models to name only a few. There is also a variety of discrete time models as the ARCH family for example. The scope of the program focused on addressing the fundamental question of relevance of these models as well as links between physical measures and pricing measures through market prices of risks. Closely connected are the problems of hedging and portfolio optimization which will also be addressed.
- **Data.** The size of financial data can be considerable when looking at high frequency data for large numbers of stocks for example. Data is essential in the modeling part in at least two ways: writing models which quantify the main effects seen in the data (for example, “are jumps present?”) and calibrating the models with an assessment of the stability of the parameters. A lot has been done in this direction in Statistics and Econometrics and to a lesser extent in Applied Mathematics. The program brought these disciplines together, presented the state of the art and discussed issues on choosing, preparing and using financial data. The program also ensured that statistical software companies were involved.
- **Computation.** Once a model has been written and calibrated to data, it remains necessary to compute quantities of interest. For instance, in option pricing, one has to compute expected values along the trajectories (time evolution) of multidimensional stochastic processes. These quantities are also often obtained as solutions of partial differential equations (or inequalities) with various boundary conditions. The program addressed the question of choosing the most efficient computational method for classes of problems. In particular Monte Carlo methods and numerical methods were discussed, keeping in mind that the computational difficulty has a feedback effect on the modeling and data calibrating parts.

### 2.2 Anticipated Outcomes

Expected outcomes at the program level were the following. The methods used to document each outcome are indicated in brackets. A number of the outcomes were still in progress at the program conclusion and post-program evaluation will be performed in these cases.

- Significant research accomplishments by the working groups leading to collaborations and interdisciplinary research with the goal of starting to write papers and research proposals by the end of the program. *[Documentation: A fundamental result will consist of documents defining future research directions identified during the program. These documents will be disseminated to program managers at funding agencies and the general research community. The number of papers, proposals, and research visitors for the program are being documented.]*
- Significant educational benefits for mathematics, statistics, finance and econometrics graduate students, postdocs, and faculty through the two semester-long courses. *[Documentation: Formal evaluations and feedback from course participants.]*

- Significant educational experience for SAMSI graduate students and postdocs as well as visiting students and postdocs. This will strongly enhance their perspectives regarding future research directions considered as important by experts in the field. [*Documentation: Formal evaluations and feedback from participants.*]
- Provide a focal point within the mathematics, statistics, finance and econometrics communities for rigorous analysis of financial theory and applications work and advanced materials through the visitor program and program website. [*Documentation: Feedback from visitors.*]
- Dissemination of research directions and results through presentations at international conferences (e.g., NBER/NSF Time Series conference in Montreal September 2006 and Joint Statistical Meetings (JSM) in August 2006), SIAM meetings (Boston, July 2006), AMS meeting (New Orleans, January 2007), articles in society publications (e.g., Journal of Financial Econometrics, Journal of Econometrics, Econometrica, Review of Financial Studies, Mathematical Finance, Applied Mathematical Finance, Finance and Stochastics, SIAM Journals, Wilmott Magazine, Risk Magazine, Quantitative Finance), [*Documentation: A record of all presentations and publications is being maintained.*]

### 2.3 Recruitment and Diversity

Two significant goals of the program were to make it as widely accessible to young people as possible and to recruit a diverse range of participants. Both goals were addressed through aggressive solicitation by the program leaders and committee via personal and research contacts as well as formal symposia and presentations. For example, the majority of participants who attended the Opening Workshop were notified by either the organizers or committee. To illustrate, on the first day of the Opening Workshop there were 78 attendees of whom 20 were women and 2 were African Americans. On the second day, during the inaugural lecture we had approximately 165 attendees with similar proportions of women and minorities. Similar demographics were observed during the remainder of the workshop as well as at the other workshops. For example, the Credit Risk workshop had 27 attendees which included 5 women.

Several formal presentations have also been made by the program chairs, postdoc, and members of the SAMSI directorate. As detailed in Section 3.16, Ghysels gave keynote addresses at the Deutsche Bank Conference in honor of Eugene Fama, at the Second AFF and at the  $EC^2$  conference on Financial Econometrics. He has also discussed aspects of the SAMSI program at seminars and colloquia throughout the last year and similar presentations are being made by other SAMSI participants, chairs and directors.

### 2.4 Program Conclusions

One of the primary goals of the program was to ascertain the manner through which synergistic mathematical/statistical/econometrics investigations could significantly improve our understanding of financial asset pricing and risk management. A number of different possibilities were explored by the working groups and conclusions can be broadly summarized as follows.

The SAMSI program on FMSE identified a number of key issues of current research in the area. In many regards the program provided the unique platform that started a closer dialogue between mathematicians, statisticians and econometricians on very key topics in financial modeling. Model uncertainty is one such topic. The foundations of probability theory, risk and uncertainty were discussed at length and several key contributions and open questions were identified, notably in a workshop on model uncertainty that included a number of leaders in the field. Another key topic

is the identification of jump processes in financial data. At the opening workshop, experts such as Ole Barndorff-Nielsen (Aarhus, Denmark) made several observations on the topic and a workgroup on the topic identified the recent advances in the area. Credit risk is another theme to which much attention was devoted. The program has given the opportunity to a number of young researchers to enter the field of defaultable instruments and produce significant improvements on the modeling of these instruments. The workgroup on computational issues has concentrated on issues concerning solving stochastic control models in multiple-dimensions. A number of methods were examined and an attempt was made to develop a practical Monte Carlo based approach. The portfolio optimization group met weekly (some times twice a week) at SAMSI to study backward stochastic differential equation and its applications in portfolio management. Stochastic portfolio theory, a new theory about portfolio management, was also studied by the group

### 3 Program Activities

#### 3.1 Program Leadership

Marco Avellaneda (NYU), Jean-Pierre Fouque (NC State; Co-Chair), Eric Ghysels (UNC; Co-Chair), John Lehoczky (Carnegie-Mellon University; National Advisory Committee Liaison), Ronnie Sircar (Princeton), Ralph Smith (SAMSI; Directorate Liaison) Ruey Tsay (University of Chicago), and Thaleia Zariphopoulou (University of Texas Austin).

#### 3.2 Opening Workshop

The SAMSI Opening Workshop for the Program on Financial Mathematics, Statistics and Econometrics was held on September 18–21, 2005. The goal of the workshop was to initiate discussion focused on identifying avenues of research that would run across the entire program. The inaugural lecture of Nobel Laureate Robert Engle touched on the question of how to link stock market volatility to its fundamental sources. This theme resonated through the rest of the program. Another theme was the use of Lévy processes in financial modeling. Neil Shephard in joint work with Ole Barndorff-Nielsen reported on the current state of the art and the outstanding challenges. A prominent theme throughout the workshop and the entire program was the improvement of communication between financial mathematicians, statisticians and econometricians. To that end, there was a panel discussion involving Ole Barndorff-Nielsen (University of Aarhus, leading scholar in the fields of statistics and stochastic process theory) Robert F. Engle (New York University Stern School of Business, 2003 Nobel Laureate for contributions to financial econometrics), Lars Peter Hansen (University of Chicago, leading scholar in the field of financial econometrics and expert on model uncertainty) and Ruey Tsay (University of Chicago, leading scholar in the field of financial statistics).

Tutorials on *Financial Mathematics*, and *Financial Econometrics* were offered on the first day of the workshop with 78 participants in attendance. The program during the remaining three days consisted of six focus sessions on topics pertaining to financial mathematics, statistics and econometrics, and a poster session. Each session consisted of two or three 40 minute overview presentations followed by discussions focused on identifying directions necessary to achieve significant scientific advances in that facet of the field. The open forums were expanded in the final session of the workshop to identify objectives and research directions to be pursued in the program.

A total of 161 individuals registered for the workshop of whom 38 were affiliated with mathematics departments, 34 were in statistics departments, and 33 had affiliations in economics and finance. The demographics for the second day are representative of those for the full workshop and can be

summarized as follows. There were 132 attendees of whom 27 were women and 2 were African American.

During the open forum on the final day of the workshop, five focus areas were identified and suggested as topics for working groups: (i) Computational Issues, (ii) Credit Risk, (iii) Lévy Processes, (iv) Model Uncertainty and (v) Portfolio Management. The first focuses on computational issues including the calculation of complex derivative prices, dynamic portfolio optimization and simulation design and methods. The second topic studied credit risk issues that appear in term structure models, derivative pricing and consumer credit. It was recommended that the third workgroup would study application of Lévy process theory to financial problems. This includes extreme events and jump processes. The fourth group emerged from the presentation of Lars Hansen and Jennifer Juergens at the Opening Workshop, both covering methods to introduce model uncertainty in asset pricing models. Finally, it was recommended that the portfolio management group focuses on optimal portfolio allocation. It was stressed during the forum that groups communicate frequently through joint meetings and overlapping participants and this has been promoted during the program.

Details regarding the working groups are provided in Section 3.12 and a summary of the full program is provided in 2005-2006 Annual Report.

### **3.3 Workshop on Credit Risk (Jean-Pierre Fouque, Organizer)**

The workshop started on Monday, October 31st, with a combination of talks from a leader in the industry (Randy Miller from bank of America) to three young researchers in the field of credit risk: Mirela Predescu from Toronto working with John Hull, Kiseop Lee from Louisville, and Nan Chen from Columbia working with Steve Kou. During the second day, leaders in the the field from both academia (René Carmona from Princeton, David Lando from Copenhagen, JP Fouque from NC State, Mirela Predescu for a second talk, and Ulrich Horst from UBC) and industry (Pierre Collin-Dufresne from Goldman Sachs), presented various ways to attack the problem of modeling default and correlation of defaults. The structural approach and intensity based models were discussed and compared. Some of the talks were data oriented which gave a good opportunity to the young participants to appreciate the role of data and the real difficulties in handling data. On Wednesday morning a new class of models, “top-down” approach was presented by Lisa Goldberg, senior researcher at Barra. A discussion on credit ratings was led by Peter Bloomfield. The last speaker, Thaleia Zariphopoulou (from Austin Texas) presented recent results on dynamic risk measures.

The meeting was a great success and unique in quality of the talks and discussions.

### **3.4 Workshop on Model Uncertainty (Eric Ghysels, Organizer)**

The meeting was a great success scientifically. It brought together the top two scholars in the field — Lars Peter Hansen from the University of Chicago and Thomas J. Sargent from New York University and Hoover Institute at Stanford. They helped to put a program together that put emphasis not only on the various aspects of the topic but also gather a group of young scholars in the field.

The main issue is how does one account for uncertainty regarding the data generating process in pricing asset, portfolio choice, statistical decision making, hypothesis testing pertaining to financial monitoring. The variety of topics touches on the foundations of decision making under uncertainty. This problem is, of course, far from solved and there was a stimulating variety of viewpoints.

The presentations covered a variety of topics, including how to conduct economic policy, like monetary policy, when policy makers do not know the true model, how can learning be used to address model uncertainty, how do we assess the skills of a fund manager, how can we empirically measure the impact of model uncertainty on asset prices, how do we distinguish risk from uncertainty and

measure its impact on expected returns. There was much discussion about the notion of ‘ambiguity’. This concept relates to environments where one does not know probability laws. One approach relates to robust control with hidden states, the topic of a presentation by Thomas Sargent. Martin Schneider, a young scholar from New York University, presented related research on asset pricing with ambiguity. Computational aspects were covered by Evan Anderson, a young scholar from Northern Illinois University. Laura Veldkamp, also a young scholar from New York University, talked about how one would adopt investment strategies when assets were included with unknown or ambiguous return processes. Jennifer Juergens, a young scholar from Arizona State University, presented empirical work on model uncertainty using disagreement among financial analysts.

Yossi Feinberg and Mark Henry, both young scholars at respectively Stanford and Columbia, presented work on statistical decision making with uncertainty.

Each presentation, 25 minutes long, was followed by lengthy and penetrating discussions. The workshop was hailed by many participants as an enormous success. One of its key features was the young scholars had the opportunity to present their work with some of the most senior and leading scholars present and commenting on their work.

### **3.5 Transition Workshop**

The SAMSI Transition Workshop for the Program on Financial Mathematics, Statistics and Econometrics was held on February 27-28, 2006. Participants in the program outlined progress made in the different fields covered by the various workgroups, that is (1) Computational Issues, (2) Credit Risk, (3) Lévy Processes, (4) Model Uncertainty and (5) Portfolio Management. A total of 70 applicants registered for the workshop of whom 18 were affiliated with mathematics departments, 17 were in statistics and 6 had affiliations in mechanical engineering, materials science or engineering. Of the participants, 14 were female and 1 was African-American.

To keep the spirit of the SAMSI program of enhancing discussions between mathematicians, statisticians and econometricians, the transition workshop was structured in morning sessions devoted to financial mathematics and afternoon sessions devoted to financial econometrics and statistics. During the first day of the workshop, participants had the opportunity to hear Nicole El-Karoui, a leading female scholar in the field of financial mathematics. She presented material that was linked to the workgroup on portfolio choice and the general theme of the FMSE program. Her talk was followed by a presentation of a well-known practitioner (Bruno Dupire from Bloomberg, Inc.) who discussed volatility models, a topic that was also the topic of the inaugural lecture of Robert Engle. The last talk of the morning was on the topic of “Executive Stock Options” presented by a young female researcher from Princeton. In the afternoon we had several presentations related to three of the workgroups, namely Lévy processes, model uncertainty and portfolio choice. Two of those presentations were by female young scholars.

During the second day of the workshop, one of the leading scholars in financial mathematics covered progress on stochastic control theory, and touched on progress that was discussed in the computational and portfolio choice workgroups. The afternoon contained three presentations, all pertaining to progress made in the areas of computational issues.

A summary of the full program is provided in 2005-2006 Annual Report.

### 3.6 Distinguished Lecture

**Speaker:** Robert F. Engle, 2003 Nobel Laureate, New York University

**Date:** September 19, 2005

**Title:** “The Spline GARCH Model for Unconditional Volatility and its Global Macroeconomic Causes”

### 3.7 SAMSI University Fellows

**Ronnie Sircar** (09/01 - 12/15): Sircar taught half of a weekly class based on research pertaining to the SAMSI program. Preparing this class was integral to a book in preparation (with Jean-Pierre Fouque and others) to be finished in 2006. He also worked directly on research papers with Jean-Pierre Fouque, Aytac Ilhan, Erhan Bayraktar and Knut Solna, who also visited at various times. He had many research-related discussions with Jesus Rodriguez, Doug Vestal, Randy Miller and Peter Bloomfield.

**Bas Werker** (09/17 - 11/25): Werker worked on market microstructure econometrics with E. Renault and SAMSI visitors. He also worked with SAMSI visitor E. Andreou on residual based testing. Finally, a new research project in the area of structural break testing was started with E. Andreou and E. Ghysels. He also continued his work with M.J. Boes and F. Drost on overnight closure periods of financial markets and its impact on option pricing and another project on risk-neutral volatility distribution estimation. Additionally, he taught half a PhD level course in Financial Econometrics.

### 3.8 SAMSI Postdoctoral Fellows

#### Jesus Rodriguez

##### *Working Groups*

*Credit Risk:* I have presented papers and current research on modeling credit risk during the working group meetings. I led several discussions on topics of interest, and I am now focusing on modeling correlated multiple default derivatives with Jean-Pierre Fouque. In March I was invited to present some of our results at the Mathematics Department Seminar Series at Oregon State University.

*Portfolio Management:* I led several discussions in the Portfolio Management working group, mainly focused on a new area called Stochastic Portfolio Theory. One of the chief contributors to the theory, Adrian Banner from INTECH, attended the Opening Workshop, and I have remained in contact with him throughout the year. I am currently working with Tao Pang on investigating the behavior of stochastic differential equations in this area.

##### *Current Projects*

*Multiple Default Derivatives:* We are considering modeling correlated multiple default derivatives using structural models which are consistent with short maturity yield spreads. We built on ideas from Stochastic Volatility popularized by Fouque, Sircar, and Papanicolaou, and show how it can be incorporated into complex derivatives in the bond market.

*Stochastic Portfolio Theory:* I am working with Tao Pang on studying the asymptotic behavior of stochastic differential equations with double reflecting boundaries. We are building on the seminal work done by Banner, Fernholz, and Karatzas on ranked capitalization based portfolios, and removing assumptions in order to work apply the ideas in more generality.

*Pricing Issues in Energy Markets:* We study models for electricity pricing and derivatives in today's deregulated markets. We find a class of forward price processes that are consistent with the spot price and use these forwards to value options on the spot. We first suppose the forward price follows a quite general diffusion process and show a necessary and sufficient condition on the drift term, which is perfectly analogous to the Heath-Jarrow-Morton condition. Using the forwards, we then show how to price European call options with a portfolio that has holdings in forward contracts and bonds. In addition to standard derivatives, we also consider a "swing" or "take-or-pay" option which is particular to energy markets. It is these swing options that attract the most interest from market participants, as well as the academic literature since the work of Jaillet, Ronn, and Tompaidis. We show how European calls, along with forward contracts, are used to hedge swing options. We devote special attention to the spot model proposed by M. Barlow, and modify it to prevent arbitrage in our context. A paper based on this work was submitted to Mathematical Finance.

## **Moustapha Pemy**

### *Working Groups*

*Computational Issues:* I was very active in this working group, led by Paul Fackler, and I presented one of my working papers entitled "Quadratically convergent method." I received a lot of useful feedbacks and ideas about how to finish the paper since I still have to figure out how to complete the proof of the main results in this paper. Overall during the semester, we went over different methods to solve problems in Financial Mathematics. I have particularly learned a lot about Monte Carlo methods and how they can be used in a nontraditional way.

*Portfolio Management:* During the group meetings, we devoted significant time to study the theory of Backward Stochastic Differential Equations and how they applied to various problems in finance and stochastic control. This is a new area for me and I will try to incorporate some the ideas I learned in my future research.

*Model Uncertainty:* This group was led by econometricians, Prof Eric Ghysels and Eric Renault, and the approach they presented to solve various problems in Asset Pricing and Modeling the Volatility was different from what I have learned in the past. This caused me to think how I can use those ideals together with my functional analysis background to generalize some of their discrete models to continuous functional depending models to forecast the volatility and the asset price. I know this approach may be quite involved and may require a good deal of challenging results in Stochastic Functional Analysis.

*Personal Research:* My postdoctoral experience has been very positive in the sense that it has put in contact with very motivated researchers. My supervisors Tao Pang and Harry Chang have introduced me to the area Stochastic Functional Equations and we have studied various control problems in this field. Bringing into play the theory of Viscosity Solution, so far we have submitted in this period of time four papers for publication and right now we are working on follow-up papers. In addition, I have continued working with Ph.D. advisor on various Selling Rule problems. We have submitted one paper about the liquidation of a large block of stock when the stock price follows the Geometric Brownian Motion to the Journal of Banking and Finance and right now, we are working on the follow-up paper where we generalize the result to include the case where the underlying model is the Regime Switching Model.

### 3.9 SAMSI Young Research Fellow

**Mingxin Xu** (09/01 – 12/15): Mingxin Xu gave a talk at the opening workshop and another one at the two-day undergraduate workshop (November 19, 2005). She attended the transition workshop and gave presentations and shared the group-leadership of portfolio management. She studied in the new research area of backward stochastic differential equations and stochastic portfolio theory during this period.

### 3.10 SAMSI Graduate Fellows

**John Hyde** (Mathematics, Duke) John was a second year graduate student. In collaboration with J.P. Fouque and Jonathan Mattingly, he explored models of company default. This became one of the major topics in Hyde's preliminary exam to move in to PhD candidacy. John made progress in his understanding of credit risk modeling. He presented and critiqued a number of models to Mattingly. He also explored the model with simulations. We were trying to develop new models of corporate default which would give insight into how correlations in default times arise. John passed his Exams at the end of the fall. Unfortunately he chose to stop his pursuit of a PhD after passing his exams. Though he has left academic research, he is now pursuing employment in the financial industry. His departure has terminated this particular research project, though he hopes to apply what he learned at SAMSI to others in the near future.

**Arthur Sinko** (Economics, UNC) Eric participated in the activities of the model uncertainty and Lévy processes workgroups. During the semester he continued his research under Eric Ghysels. He started to work on three papers and has greatly benefited from the workgroup and the workshops at SAMSI. His research is about MIDAS regressions, and how it relates to volatility modeling. This topic touches on both of the workgroups he attended.

**Jennifer Sloan** (Statistics, North Carolina State University) Jennifer was mentored by Peter Bloomfield, who led the discussion in a Working Group session on "Credit Ratings." Sloan jointly led the discussion at another session of the Credit Risk Working Group and participated in the "Special Topics in Financial Math" Course. She actively researched Credit Rating Transition and Credit Risk problems, and helped SAMSI in educational outreach activities.

**Chong Tu** (Statistics, Duke) I helped and took part in the Opening Workshop for Financial Mathematics, Statistics and Econometrics from September 18-21, 2005. I also took part in the transition workshop from February 27-28, 2006 and the Model Uncertainty Workshop. I attended the program courses "Advanced Topics in Financial Econometrics" and "Special Topics in Financial Mathematics." I also joined the Model Uncertainty working group which had weekly meetings to discuss frontier papers.

**Doug Vestal** (Mathematics, North Carolina State University) Doug participated in a wide range of activities. In the Fall 2005, he took a special topics course in Financial Mathematics that emphasized the growing field of stochastic volatility models, credit risk, and the evaluation of real options. The course placed special emphasis on the current state of research in these fields. In this course, he was also exposed to the ideas that motivated the need for current research in these areas and some of the problems that remained to be solved. He was also a member of the SAMSI Credit Risk working group. In this group, various members presented current research trends in credit risk. He presented a model of recovery rates in a reduced form model along with some of my SAMSI colleagues. Other members gave presentations on the top down approach to credit risk, stochastic volatility and default correlation, credit ratings

models, and a model for the unified valuation of equity and credit derivatives. As Doug will be doing his dissertation in credit risk, this working group was very helpful. In addition to a thorough review of the literature, he was able to see the current gaps in research to help develop ideas for his own research. In fact, because of the credit risk workshop, he is working on research to develop a new model of recovery rates. This is in addition to the research he started working on (along with Dr. Fouque and Dr. Carmona, two SAMSI participants) to develop an algorithm that enables the computation of extremely rare events with applications towards intensity based models in credit risk.

For the two-day Undergraduate Workshop in Financial Mathematics at SAMSI in October 2005, Doug wrote a document explaining various types of derivative contracts for the undergraduates. In addition, he explained how to implement, in Matlab, the first passage approach to the pricing of risky bonds. Among other things, this entailed teaching the students about yield curves and how to generate random variables. Dr. Fouque presented the binomial tree method to option evaluation and he showed the undergraduates how to implement it in Matlab to value an Asian option. At the SAMSI Undergraduate Workshop coming up in May 2006, he will be helping to teach, organize and execute a five-day workshop on inverse problems along with the other SAMSI Graduate Fellows and Postdocs. This workshop will place particular emphasis on developing the intuition behind modeling physical processes mathematically, the process of data collection, and the statistical analysis of the data collected for parameter estimation.

**Yichao Wu** (Statistics and Operations Research, UNC) From August 2005 to Dec 2005, I was a graduate student fellow associated with the SAMSI program in Financial Mathematics, Statistics, and Econometrics (FMSE). Throughout the program, I attended the opening workshop and the transition workshop of FMSE in addition to the opening workshop in the program of National Defense and Homeland Security and one tutorial in the Astro Statistics program. These workshops brought me to the frontiers in the corresponding assorted areas and brought me to a lot of interesting problems in interdisciplinary study. Additionally, I joined the working group on Levy Process led by Prof. George Tauchen. He invited experts on this area to present their recent work and lead discussion. In particular, he invited Prof. Torben Andersen to present “Jump detection in Finance”. I found this is really interesting and try to work on some related problems. Also Prof. Enrique Figueroa led a discussion on “An Overview of a Nonparametric Estimation Method for Levy Processes”. All of these activities improved my understanding how statistics can be applied to other areas and help them, which I think is very important for a graduate student majoring in statistics.

**Stephen Zhou** (Mathematics, North Carolina State University) Stephen participated in the activities of the credit risk workgroup. During the semester he continued his research under J.P. Fouque and defended his dissertation in February 2006. He has greatly benefited from the workgroup and the workshops at SAMSI. His research focuses on modeling the correlation of defaults which is one of the main issues in credit markets.

### 3.11 Short and Long-Term Visitors

Evan Anderson (NIU), Elena Andreou (University of Cyprus), Fousseni Chabi-Yo (Bank of Canada), Rama Cont (Ecole Polytechnique), Yanqin Fan (Vanderbilt), Kenneth Hochbery (Bar-Ilan University), Aytac Ilhan (Oxford), Kasper Larsen (CMU), Jennifer Juergens (ASU), Knut Solna (UC Irvine), Gordan Zitkovic (Austin, Texas).

## 3.12 Working Groups

### Credit Risk

This group identified the following high level objectives: CDO/Copula/Computational, Recovery Rate, Top down approach, Hybrid Models, Stochastic Volatility Structural Models, Dynamic Copulas. These are also the areas that the group will focus on in the upcoming year (future research). The activities of the group during the program are summarized in the 2005-2006 Annual Report.

### Computational Issues

This group concentrated on issues concerning solving stochastic control models in multiple-dimensions. A number of methods were examined and an attempt was made to develop a practical Monte Carlo based approach. The group activities are summarized in the 2005-2006 Annual Report.

### Lévy Processes

- The Lévy process group was comprised of more than twenty senior and junior researchers from all over the world. Their areas of expertise were probability, statistics, and econometrics. In view of the vast distances separating us, and the scheduling issues, we felt that long distance/electronic presentations were the only practical way to communicate. Scheduling (and financing) a common group meeting was considered infeasible.
- The group held five formal presentations (talks), plus extensive and elaborate e-mail exchanges. The topics covered a wide range of important issues from jump-driven stochastic volatility, hedging jump risk, time changed Lévy processes, and practical jump detection issues in observed market indices. The unifying theme, of course, was the role of the jump portion of a Lévy process in modeling financial time series.
- There was the usual, and expected, outward export flow of information from field experts to others, but there was also some intriguing and very stimulating back flows as well. To cite an example, a probabilist provided the economists with some very useful insights in the complications of hedging jump risk. Sometimes one can gain insights into a topic of one's own domain from others who view that topic from a completely different angle.
- The technology was a bit limited, in that we used a common phone hub and viewed the slides on own computers. It worked alright, except that the speaker never received continuous visual feedback regarding the audiences understanding. Speaking into a phone is far different than lecturing to an audience, so speakers were at times unsure of the audience's level of understanding. The group leader (George Tauchen, Duke Economics) kept everyone on the same page of the set of slides, but the lack of video interaction made for limitations.
- From an intellectual standpoint, the group appeared to be very successful. The communications issues were surmountable, and certainly will become much better as technology progresses. Based on the experience, the workshop leader strongly urged SAMSI and NISS to investigate electronic distance conferencing very intensively.

### *Present and Future Research*

This area continues to be a pole of attraction in the field of finance. Practitioners and theorists regularly meet to discuss how to model, hedge and identify jumps. The workgroup was instrumental in moving the topic ahead.

## Model Uncertainty

The model uncertainty working group consisted of Eric Ghysels, Eric Renault, Moustapha Pemy (SAMSI), Arthur Sinko (UNC), and various graduate students from UNC, Duke and NCSU. This group investigated various aspects of model uncertainty. The highlight was the highly successful workshop held at the end of January 2006. Other than that, the group met regularly to discuss current research in this field.

### *Present and Future Research*

The SAMSI program left its mark on the field by its January 2006 workshop on the topic. It is probably the single most important workshop on the topic that took place recently.

## Portfolio Management

The activities of this group during the workshop are detailed in the SAMSI 2005-2006 Annual Report.

### 3.13 Courses

#### *1. Special Topics in Financial Mathematics*

**Course Listing:** ECG 790M.001, MA 797M.001, ST 810M.001 at NCSU, MATH 390.55 at UNC, STA 294.02 at Duke

**Time and Place:** Wednesdays, 4:30-7:00 pm, SAMSI/NISS

**Instructors:** Jean-Pierre Fouque (NCSU), Paul Fackler (NCSU), and Ronnie Sircar (Princeton)

**Prerequisites:** A first graduate course in financial mathematics such as MA 547 offered at NCSU (or equivalent).

**Average Attendance:** 20 graduate students, postdocs and visitors

#### **General Description:**

The course started with a review of no-arbitrage pricing in complete and incomplete markets in continuous time in the context of equity, fixed income, and credits markets. Stochastic volatility models and implied volatility smiles and skews were introduced. Derivative pricing and hedging when volatility is uncertain were treated in the context of multiscale modeling with asymptotic methods.

The second part of the course was devoted to real option modeling. Real options arise when decision makers can choose among a set of mutually exclusive activities. The option to switch out of a current activity can be valued by solving an optimal switching problem. Such models arise in numerous situations, including American option pricing problems, entry/exit problems, sequential choice problems, job change problems and many more. This course discusses the general decision problem in which real options arise and computational techniques for solving such problems. Examples from the literature were used to illustrate and motivate the discussion. In addition to covering the one-state models that represent the bulk of current applications, recent innovations in formulating and solving multi-state problems were discussed.

In the last part of the course optimal hedging and risk management problems involving derivatives were studied.

## 2. Advanced Topics in Financial Econometrics

**Course Listing:** ECG 7900.002, MA7970.002, ST 8100.002 at NCSU, ECON 388.001 at UNC, STA 294.01 at Duke

**Time and Place:** Tuesdays, 4:30-7:00 pm, SAMSI/NISS

**Instructors:** Eric Ghysels (UNC) and Bas Werker, SAMSI University Fellow from Tilburg Univ.

**Prerequisites:** Graduate Time Series, Econometrics, Empirical Finance and Asset Pricing theory.

**Average Attendance:** 12-15 attendees including 1 faculty member, 1 SAS employee and graduate students.

**General Description:** This course covered a selected list of current empirical research topics in finance and related econometric methods. A list of the topics that were covered includes estimation of continuous time processes, MIDAS regressions, stochastic volatility models and term structure models. The coverage of the different topics depended in part on the interest of the students. The purpose of the course was to overview the current developments and to prepare students for research in the areas.

### 3.14 Technical Reports and Papers

The following technical reports and papers have been produced during the program.

1. Fouque, JP, Sircar, R., and Solna, K., "Stochastic Volatility Effects on Defaultable Bonds," *Applied Mathematical Finance*, to appear, 2006.
2. Fouque, JP and Zhou, X., "Modeling Correlated Defaults: First Passage Model under Stochastic Volatility," to be submitted (April 2006).
3. Pang, T., Pemy, M. and Chang, M-H., "Optimal Stopping for Stochastic Functional Differential Equations," *SIAM Journal of Optimization and Control*, submitted.
4. Pemy, M., Yin, G. and Zhang, Q., "Liquidation of a Large Block of Stocks," *Journal of Banking and Finance*, submitted.
5. Pang, T., Pemy, M. and Chang, M-H., "Optimal Control of Functional Stochastic Differential Equations with Bounded Memory," *International Journal of Probability and Stochastic Processes*, submitted.
6. Pang, T., Pemy, M. and Chang, M-H., "Viscosity Solutions of Infinite Dimensional Black-Scholes Equation and Numerical Approximations," submitted.
7. Engle, R., E. Ghysels and B. Sohn, "On the Economic Sources of Stock Market Volatility," Discussion paper NYU and UNC.
8. Chabi-Yo, F., E. Ghysels and E. Renault "Disentangling the Effect of Heterogeneous Beliefs and Preferences on Asset Prices," Discussion paper UNC.
9. Chen, X. and E. Ghysels "Intra-day News Impact Curves and Realized Volatility," Discussion paper UNC.
10. Anderson, E., E. Ghysels and J. Juergens "The impact of risk and uncertainty on expected return," Discussion paper ASU and UNC.

11. Boes, M.-J., F.C. Drost and Bas Werker, “The Impact of Overnight Periods on Option Pricing,” *Journal of Financial and Quantitative Analysis*, to appear.
12. Renault, E. and B. Werker, “Causality Effects in Return Volatility Measures with Random Times,” Discussion paper Tilburg University.
13. Koijen, R.S.J., T. Nijman and B. Werker, “C“Labor Income and the Demand for Long-Term Bonds,” Discussion paper Tilburg University.
14. Boes, M.-J., F.C. Drost and Bas Werker, “Nonparametric risk-neutral return and volatility distributions,” Discussion paper Tilburg University.
15. Andreou, E. and B. Werker, “An Alternative Asymptotic Analysis of Residual-Based Statistics,” Discussion paper Tilburg University.
16. Fouque, JP and Zhou, X., “Perturbed Gaussian Copulas,” in preparation.
17. Fouque, JP and Rodriguez, J., “Singular Perturbations for SPDEs,” in preparation.

### 3.15 Books

The following book was written in part during the FMSE program.

1. Fouque, JP, Papanicolaou, G., Sircar, R., and Solna, K., *Volatility Perturbations in Financial Market*, Cambridge University Press, in preparation.

### 3.16 Presentations

The following presentations pertained to the FMSE program.

1. Eric Ghysels, “Efficient Markets - Empirical Evidence,” Deutsche Bank Symposium in Honor of Eugene Fama, Frankfurt.
2. Eric Ghysels, “Mixed Data Sampling with Applications in Finance and Economics,” Keynote Speaker, International Symposium on Advances in Financial Forecasting, Greece.
3. Eric Ghysels, “Mixed Data Sampling with Applications in Finance and Economics,” Keynote address *EC<sup>2</sup>* Conference on Financial Econometrics, Istanbul, December 2006.