NSERC LONG RANGE PLAN: FINANCIAL MATHEMATICS

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1. Science

1.1. **Research Highlights.** It is fair to say that the scope and depth of Financial Mathematics ("FM", also known as Mathematical Finance, Quantitative Finance or Computational Finance) research has exploded in the past decade, partly as a result of the growth in complexity in the financial markets and the resulting need for technical expertise, but also as a result of a dramatic influx of talented mathematicians, statisticians, computer scientists, physicists, engineers and social scientists. On the finance side, we have made inroads into areas poorly understood in 2000 including: credit risk, risk measures, portfolio selection, pricing and hedging in incomplete markets, multi-objective (risk-reward) programming, principal-agent problems (executive compensation), liquidity and systemic risk, market microstructure, algorithmic trading, energy markets, and insurance. The mathematical side has seen tremendous advances in jump processes and semi-martingales, stochastic control and backward stochastic differential equations (BSDEs), utility theory and convex analysis, Monte Carlo methods, statistical inference and filtering. This growth has been officially recognized only to a limited extent. Mathematical finance scarcely existed in the 2000 AMS subject classification, but in 2010 it appears as 91Gxx. NSERC policy has not been updated to recognize these advances. As further evidence of this growth, there has been an explosion in preprints in quantitative finance, now consolidated in the new q-fin sector of arxiv.com that started in 2008 and posts more than 400 papers a year (65% of the total number posted in all of Statistics). This number is far from representing all the contributions to the field, since many FM researchers never post preprints, or post elsewhere (SSRN, defaultrisk.com, etc.).

As well, FM has impacted more traditional areas of research: probability theory, optimization and control theory, statistics and filtering, game theory and economics, actuarial science, applied mathematics and information technology. There are many reasons for this exchange of ideas. There is a tremendous flux of junior researchers who move from academia to industry, carrying their technical skills and relaying back open industrial problems. Problems originating in industry have a new flavour: the need to address high dimensional problems with efficient and fast algorithms, to handle huge databases, to model complex stochastic behaviour and information asymmetries, and recently to incorporate behavioral traits into decision making.

1.2. **Changes Over Next 5 Years.** On a research level, one great success of FM has been the foundational work known as the Fundamental Theorems of Asset Pricing (FTAP), which rely heavily on functional analytic techniques and significantly broadens the scope of traditional general equilibrium economic theory. The field is now expanding even further by considering the foundational implications of market imperfections. Like economics itself, FM is revisiting these foundations, debating the effects on markets of behavioral traits, nonstationary conditions, heterogeneous agents, etc.

As an institutional factor to recognize, we expect to see an increasing urgency in recruiting young talent to focus on quantitative subjects, driven to a large extent by the increasing importance of markets in all areas of enterprise. Finance, energy, commodities, insurance, manufacturing: all are under pressure of competition and regulation and consequently have rapidly growing needs for quantitative methods. Financial Mathematics is a keystone area for young people. It is a diverse multidisciplinary area with a tremendous number of untapped but accessible research topics, and with excellent career options when finished. A critical bottleneck will certainly be a continuing shortage of academic mentors to cope with the demand from students to work in FM.

An important consequence of this HQP pressure is the growth of coursework professional style MSc programs in FM, as exist at the University of Toronto, McMaster, Waterloo and York. While so far successful, and useful for the host university, these programs may run at the expense of graduate research, as FM faculty find increasing pressure on their research time.

1.3. **Advancement Opportunities.** Established researchers in FM benefit from the tremendous interest of prospective graduate students, providing a continuous stream of young talent. In addition, there is wide interest from industry in the type of research we do. Unfortunately, this brings many extra pressures that take time and sap the strength of academics: the pressure to supervise and mentor many students, the pressure to engage practitioners to mentor research projects. In light of these pressures and interest from talented graduate students and post docs it is surprising how little funding support established researchers in FM have received from granting agencies, particularly NSERC, up to now.

1.4. **Importance of Cross-Disciplinary Work.** The wording of this question highlights the degree to which FM is interdisciplinary: FM embraces not just science, but social science (economics, human psychology, social networks) and engineering (software, high performance computing, energy and emissions) as well, making it intrinsically cross-disciplinary. Active Canadian researchers in FM must have a high capability in as many of the following areas as possible: applied mathematics, theoretical probability, theoretical statistics, numerical analysis and optimization. They should also be aware of the broad issues of corporate finance and theoretical financial economics. Foundational work in FM requires real and complex analysis, differential equations, and stochastic processes. A consequence of this broad domain is the need for research in teams, reflected in the fact that so much of our published work is multi-authored.

1.5. **Barriers at Granting Agencies.** A critical factor that undermines interdisciplinary research is the contradictory traditions in different subjects. It is amusing to observe that mathematicians happily post all their unpublished preprints while computer scientists zealously protect their work until it is accepted for publication. However, the researcher who crosses such boundaries is likely to be bruised and damaged. Equally important is to recognize that referees of interdisciplinary work may come from anywhere, and bring the biases and prejudices of their own area of specialization. Grant committees and journal editors must be aware of such biases and compensate for them. Finally, interdisciplinary research papers must tread delicately: it is common for one referee to damn a paper for inadequate statistical validation while a second referee dislikes the same paper because proofs were banished to an appendix.

The nature of FM research is so interdisciplinary that it ought to qualify for funding by SSHRC as well as NSERC. However, institutional biases have prevented this from happening. The same type of biases within NSERC certainly damage our subject. Recent NSERC Discovery Grant committees have clearly had difficulties with where to place FM research. We have seen computer scientists in FM moved to mathematics GSC, FM mathematicians moved to statistics, etc. It is now the case that one submits a Discovery Grant application with little guidance about which committee might review it. Recent grant competition results seem to bear out the conclusion that FM research has not been awarded fairly, especially taking into account the above average HQP in the area.

Many academic researchers in FM moved into the area from other established areas of research and very commonly their research funding dropped as a consequence, sometimes despite having an increased number of students. There needs to be full recognition of the difficulties researchers face in making such transitions: the inevitable temporary lag in research output, the difficulties in addressing new audiences, the unfamiliarity with new journals and academic traditions. Grant committees need to be alert to indirect evidence that the researcher is making good progress: for example, if the shift in research comes with an increase in graduate supervision, this should be taken as a strong positive indicator.

2. Research Funding

2.1. **Research Funds Use.** A large fraction (perhaps higher than in other areas of mathematics) of research funds in our field goes to support graduate students and postdocs. As mentioned before, the strong interest in the area from young people is both a source of vigor and pressure for established researchers. The ability to provide stable funding for a steady number of graduate students and postdocs is of vital importance to fulfil the high expectations placed on the subject. In addition, many aspects of research in FM are computationally oriented and benefits tremendously from high performance computing facilities located at individual departments and consortia across the country.

2.2. **Additional Infrastructure.** Additional infrastructure fostering long-term collaboration between industry and academics is paramount for further developments in FM. This needs to take into account the specific nature of relationships with the financial industry. Traditionally, banks and large financial institutions put a high value on graduate students and postdocs as potential future employees, whereas the actual research output is viewed primarily as a "public good", with no need for additional funding. The natural way to address this is through shared funding of graduate students and postdocs, and to some extent this was accomplished in the past by MITACS. Consequently, the termination of MITACS leaves a large gap in funding young researchers, and it is not clear at this point how this gap will be filled. Any similar new programs would need to address some deficiencies that made MITACS less successful in the area of FM, where there was a notable difficulty in engaging the big banks in research.

2.3. **Future Activities that Impact Research.** As a research field, FM is very dynamic and responsive to the changes in the global economy. We are working hard to understand the implications of the Great Recession, and generating new avenues of research from this. It is highly likely that unanticipated world events will cause further major shifts in the field. But the larger trends will continue: markets will become more, not less, sophisticated and algorithmic. The need for quantitative people and methods will continue to increase. Feedback and human behaviour will continue to clash with rational expectations. The complex and adaptive nature of the financial system will become harder to predict. The new motto of the field now seems to be "Next time will be different", but some trends seem to be clear.

2.4. **Opportunities to Enhance Research.** Proper recognition of the importance of FM would lead to greater funding of the active researchers in the area. This seems fair, in view of the strategic importance of the subject, the exciting research, and the special circumstances FM researchers have to contend with. This is the greatest single need. FM academics are already expending a great deal of effort in expanding their range of activities and contacts, while monitoring the rapid developments in the field. Adding more types of activities, and expecting the researchers to organize them, might be counterproductive.

2.5. **Areas 'Falling Between the Cracks'.** As a relatively new discipline, it is clear that FM often falls between the cracks. For example, the leading researchers in Canada have been treated differently as soon as they mention FM as an area of specialization. Typically, they are removed from their usual NSERC GSC, to another GSC, where not surprisingly their research is less recognized.

In addition, there is a dangerous perception that FM researchers are "rich", since they are so useful to the financial industry. This has been used as a reason to direct funding from granting agencies elsewhere. A concrete example of this: the NSF traditionally lends strong financial support for US students and academics to attend thematic programs at the Fields Institute. However, in the case of the thematic program on Quantitative Finance, an NSF grant was denied, despite unanimously positive reviews, because the support was deemed to be in an area with access to funds from the private sector.

The perception is false partly because academics have so far not persuaded their industry partners to support long range research. Financiers are by their nature accomplished 'freeriders" and short-term thinkers. They are consequently even less inclined to indulge in long-range research than some other quantitative industries. We are working to change this attitude, but it is fair to say, so far without tremendous success.

3. Institutes

3.1. **Role of Institutes.** In general, all institutes focus mostly on research and less on training. In FM, the two go hand-in-hand, and consequently the fit with Institutes is less than perfect. It is clear that "the community at large" needs HQP as much as cutting-edge research, and it makes sense to ask Institutes to do more on the HQP side.

3.2. **Relevant Institute Activities.** All Institutes have recognized FM research, and have offered conferences, workshops, even a thematic program (at the Fields Institute), in the area. Fields particularly works hard at creating links with industry, notably with its Commercial and Industrial Program that includes regular finance seminar series and events. Also important to FM are the Job Fairs held at Fields and PIMS, as well as the PIMS Industrial Problem Solving Workshops. Fields also regularly hosts industry meetings, such as PRMIA events.

3.3. **New Institute Activities.** In general, Institutes need to put in place more regular graduate level training (as opposed to research) events. In FM, these include special topics difficult to offer (C++ training, corporate finance, finance regulation, etc) and taught by industry practitioners or academics. These would bring together graduate students from different universities and strengthen their network. It is important that most of the burden be taken off the shoulders of academics and that pay to instructors should reflect industry compensation rates.

Institutes should investigate offering training events to executives in quantitative areas. Such people are regular attendees of academic activities, such as the Fields Quantitative Finance research seminars and we can expect they would pay to attend occasional one-day workshops in special topics at critical moments. PRMIA (a professional risk management organization) could help to organize and promote these events.

3.4. **Role of Institutes in training HQP.** Institutes have great difficulty in addressing special needs of the finance sector, and have been by and large unsuccessful in obtaining from them any substantial funding support. Institutes need staff members dedicated to understanding these special needs and able to extract funding in support for research and recruitment of HQP. This should be tied to initiatives to offer more events targeting industry participants. They hire our people, and pay nothing to us: this must change. In general, Institutes do a good job in including graduate-level material in their thematic programs, but this occurs only infrequently in our area. Institute-run Job Fairs have been extremely important and need to grow.

3.5. **Long-Term Impact Assessment of Institutes.** PIMS' ongoing industrial problem solving workshops have had great impact on influencing young people to address finance related research problems. Fields long-running Quantitative Finance Seminar Series on a monthly basis brings a practitioner audience that otherwise would never visit, with a marked impacted the type of FM research done in Canada. The recent Quantitative Finance Thematic Program at Fields was a big success, but in hindsight the extended six month format proved to be less than ideal for our subject. In general, senior researchers were eager to come for short highly focused events, but less eager to hang around for quiet work afterwards. The natural rhythm was episodic rather than long-term quiet research. This suggests future institute-sponsored programs in FM be more flexible, concentrating on frequent, short, intense events. This observation is likely applicable to other true interdisciplinary subjects. Finally, for some reason, BIRS has run relatively few programs in FM (and has even denied funding for previous applications). One potential reason is "organization fatigue" in the community despite the great support BIRS supplies.

4. Training

4.1. **Required Support Structures.** As mentioned before, an important aspect permeating FM is interaction with industry at some level. The MITACS accelerate programme has had some success in this direction. When graduate students have the chance to work with industry as part of their programme, the impact on their training can be very positive. However, as already noted, the specific concerns of the finance sector need to be addressed in order to reduce the obstacles that stand in the way – one of which is that the sector is notoriously short-term in its thinking. When a window of opportunity opens, whether for industry support in the form of a research grant, or support for an internship, structures need to be in place to be able to take advantage of this window very quickly. The MITACS programmes have been a step in the right direction in this regard.

One structure that might support training specifically is to provide a mechanism for funding graduate studentships – grants dedicated to specific PhD proposal providing complete support for a single student or postdoc.

4.2. **Expanding Pipeline of Advanced Trainees.** In the FM area, there is no shortage of applicants for training; the bottleneck is in the availability of academic mentors. Better support of existing mentors is needed.

4.3. **Resources.** We have already mentioned the existence of course-based MSc programmes at several universities in Canada. One structure that might help to expand the pipeline without adding an excessive burden to one university might be to encourage groups of institutions to offer a shared programme, perhaps facilitated by remote lecture delivery. For example, PIMS has just started to support the delivery of some specific graduate courses across the PIMS institutions, and similar facilities are being tested at Fields.

5. International

5.1. **What types of research support is available to your international colleagues, that could benefit research in Canada?** We are aware of programs in Europe that fund graduate students to undergo parts of their studies abroad under the supervision of researchers in different universities. This co-supervision model is likely to work well in FM, where the mathematical methods are similar but the market realities vary in different countries, therefore providing a more thorough graduate training.

5.2. **Would it be advisable to fund these types of programs in preference to currently available programs?** We do not believe that funding in current programs should be redirected to international collaborations, but rather additional sources of funding should be made available. For example, through the framework of the European Union - Canada Framework for Co-operation in Higher Education, Training and Youth (EU-Canada Programme)

5.3. **What types of structures would support international collaboration.** There could be agreements between individual departments within Canadian Universities and their counterparts abroad. One such example is the Memoranda of Understanding between the Math & Computational Finance Lab at U. Calgary and the 'Finance & Information Management' graduate program jointly run by the U. of Augsburg and the Technical U. of Munich (Germany) and between McMaster University and IMPA in Rio de Janeiro (Brazil).

Another approach could be to attempt to create a formal structure within novel international institutions. For example, an initiative the FM and science communities must both try to grasp hold of is the Global Risk Institute that aims to make Toronto and Ontario a Top 10 global finance centre, with public funding in excess of $20M announced Sept 2010. There is little scientific representation on this initiative, partly our failure to link with the corporate culture that is driving the GRI, but effort and resources should be directed in making research funding an important part of their agenda. Part of the mandate of the Global Risk Institute should to foster international collaboration in the form of funding support for research visits from foreign graduate students, post docs and faculty members.

5.4. **Is international funding available in your area?; are there structures that could enhance your ability to obtain international funding.** There is a recent venture between NSERC and the Deutsche Forschungsgemeinschaft (DFG, the German Research Foundation) to strengthen collaboration between Canadian and German research communities.

On August 30, 2010, a second joint venture was recently launched in which a Memorandum of Understanding (MoU) was signed between Foreign Affairs and International Trade Canada (DFAIT) and the Federal Agency for Support and Evaluation of Graduate Education (CAPES) of Brazil. The purpose is to enhance academic mobility and scientific cooperation.

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