Portfolio management and asset prices when investors have heterogeneous beliefs
A research project for Europlace Institut of Finance

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1 Abstract

Suppose that a group of agents having divergent expectations can share risks efficiently by trading on financial markets and by purchasing insurance. The objective of this research is to examine how the divergence of opinions on the profitability of firms affects

1. the investors' portfolio management and the consumers' insurance demand;
2. the equilibrium asset and insurance prices;
3. the optimal investment strategy by firms.

We will consider an Arrow-Debreu economy which is classical in all directions, except that investors diverge on their subjective probability distribution of the various states of nature. This does not come from any asymmetric information, but rather from a deeper divergence of opinion about how to interpret various signals of the economy. We conjecture the following properties of the competitive equilibrium:

1. As in the standard model, there exists a representative agent, but his beliefs is a complex combinasion of the different investors's beliefs. At the aggregate level, the standard CAPM formula apply, but with a distribution of returns that takes into account of the investors' disagreement.
2. The collective probability distribution is biased in favor of the beliefs of the more risk tolerant agents in the group. Intuitively, if an agent does not participate to the collective investment, either because of his high risk aversion or because of his pessimism, his beliefs will not matter for pricing.
3. From this central result, we want to show how does increasing disagreement on the individual subjective state probability affect the state probability of the representative agent. We want to show that the collective state probability is decreased by the heterogeneity of beliefs, at least when relative risk aversion is larger than unity. When there are only two states of nature, we want to show that the representative agent has a bias towards certainty. This latter result may be useful to understand the insurability problem of catastrophic risks.
4. Moreover, we want to prove that the divergence of opinions about the probability of occurence of a boom may help solving the equity premium puzzle.

2 Description of the project

The preliminary results presented in this section are extracted from some written notes that have been produced by the author during his researches in April and May 2003. Comments welcome.

People have divergent opinions on a wide range of subjects, from the outcome of an election or of a war, the profitability of a new technology to the risk of global warming. Suppose that this heterogeneity of beliefs does not come from asymmetric information but rather from intrinsic differences in how to view the world. People agree to disagree, which implies that prices and observed behaviors of other market participants do not generate any Bayesian updating of individual beliefs. We examine how the group as a whole will behave towards risk. Aggregating beliefs when agents differ on their expectations is useful to solve various economic questions, from asset pricing to cost-benefit analyses of collective risk prevention.

The attitude towards risk of a group of agents depends upon how risk is allocated in the group. For example, if an agent is fully insured by other agents, it is intuitive that this agent's beliefs should not affect the social welfare function. Only those who bear a share of the risk should see their expectations be taken into account on the collective risk decision. In this project, we will assume that risks can be allocated in a Pareto-efficient way in the group. In such a situation, the willingness to take risk is increasing in the Arrow-Pratt index of absolute risk tolerance. It implies that the beliefs of agents with a larger risk tolerance should have a larger impact on how individual expectations are aggregated. At the limit, those with a zero risk tolerance do not influence the group's expectations.

The properties of the socially efficient probability distribution are derived from the characteristics of the efficient allocation of risk in the group, such as the one derived from the competitive allocation with complete Arrow-Debreu markets. Borch (1960,1962), Wilson (1968) and Rubinstein (1974) were the first to characterize the properties of Pareto-efficient risk sharings and of the representative agent when agents have identical beliefs. Calvet, Grandmont and Lemaire (2001) showed that the standard methodology of the representative agent can still be used when agents have heterogeneous beliefs. Leland (1980) examined the competitive equilibrium asset portfolios when agents have different priors on the distribution of state probabilities.

The main comparative static exercise that we consider in this project is to compare two states of nature for which the distribution of individual probabilities are different. Consider for example a situation where all agents believe that state s_2 has the same probability of occurrence than another state s_1, except agent θ. Suppose that this agent has a subjective probability for s_2 that is 1 percent larger than for s_1. By how much should we increase the probability of state s_2 with respect to s_1 in the collective decision making? The central technical result on which this research project is based is that the collective probability should be increased by $x/100$ percents, where x is the share of the aggregate risk that is borne by agent θ, or the agent θ's tolerance to risk ex-

pressed as a share of the group's risk tolerance. More generally, the rate of change of the collective probability is a weighted mean of the rate of change of the individual probabilities. The weights are proportional to the individual risk tolerances. More risk tolerant agents see their beliefs better represented in the collective decision making under uncertainty. This intuitive result has several important consequences.

Observe first that, as initially observed by Hylland and Zeckhauser (1979), the efficient aggregation of beliefs cannot be disentangled from the risk attitude of the group's members. Except in the case of constant absolute risk aversion, this individual risk attitudes depends upon the allocation of consumption in the group. It implies that the efficient collective probability distribution will be a function of the wealth per capita in the group. The representative agent has state-additive preferences as under the standard expected utility model, but the different terms of the sum cannot be written as a product of a probability that would depend only upon the state by a utility that would depend only upon consumption. Equivalently, this means that the representative agent has a state-dependent utility function, despite the fact that all members of the group have state-independent preferences. Drèze (2001) and Drèze and Rustichini (2001) examine the effect of the state dependency of the utility function for risk management and risk transfers. Another way to interpret this result is that the collective probability distribution depends upon the aggregate wealth level. As proved independently by Clavet, Grandmont and Lemaire (2001), we show that this wealth effect vanishes when agents have an absolute risk tolerance that is linear with the same slope. We also show that this is the only case in which the collective probability distribution is state-independent.

Our aggregation result states that the rate of change of the collective probability across states is a weighted mean of the rate of changes of individual probabilities. This result must be compared to the observation that the state probability used by the representative agent does not need to be in between the smallest and the largest state probabilities of the agents. Notice however that when deciding about transfers of wealth across states, what really matters are relative state prices per unit of probability. Thus the rate of change in the collective probabilities across states is the relevant information for determining the collective risk exposure, and our aggregation formula provides exactly that information.

The main objective of the project is to determine how the divergence of opinions about the true probability distribution of the states of nature affects the optimal collective risk exposure, and the equilibrium asset prices. Let us compare two states of nature such that all individual probabilities for the second state are k percents larger than those of the first state. A direct consequence of our aggregation rule is that the collective probability will also be increased by k percents. Two classical aggregation rules satisfy this necessary condition. Under the geometric (arithmetic) mean approach, the collective state probability is assumed to be proportional to the geometric (arithmetic) Pareto-weighted mean of the individual subjective probabilities for that state.

The geometric mean approach for the aggregation of beliefs is socially effi-

cient only if all members of the group have the same utility function exhibiting constant absolute risk aversion. When this condition is not fulfilled, the rate of change in the collective probability will dependent upon the relative degree of disagreement in the two states under consideration. We say that there is increasing disagreement if those agents with a larger subjective probability for the initial state also have a larger rate of increase of the likelihood of the second state relative to the first. We show that decreasing absolute risk aversion (DARA) implies that the geometric aggregation rule underestimates the effect of an increase in disagreement on the collective probability. To illustrate, suppose that Mrs Jones has a larger subjective probability for a flood to occur this year than Mr Jones. Compared her own beliefs about floods, Mrs Jones has a subjective probability for the risk of an earthquake that is k percents larger, whereas Mr Jones has a subjective earthquake probability that is k percents smaller than his estimate of the probability of a flood. Thus, the geometric mean probability in the couple is the same for the two risks, but there is more disagreement about the likelihood of an earthquake than for a flood. Under DARA, it implies that, when Mr and Mrs Jones decide about their collective prevention efforts and insurance, they should use a larger probability of occurrence for an earthquake than for a flood.

The alternative aggregation rule would be to take the arithmetic (Pareto-weighted) mean of individual probabilities for the collective beliefs. It is easily shown from the efficient aggregation rule that the arithmetic mean approach is efficient if and only if all agents have a logarithmic utility function. We show that this approach overestimates the effect of an increase in disagreement on the collective probability, if the sensitivity of absolute risk tolerance to changes in consumption is smaller than for the log utility function. Under constant relative risk aversion, this means that relative risk aversion is larger than unity, a plausible assumption. Suppose again that Mr and Mrs Jones have a subjective flood probability of respectively p_{Mr} and $p_{Mrs} > p_{Mr}$. Suppose also that for earthquake, Mr Jones has a probability $p_{Mr}-k$, and Mrs Jones has a probability $p_{Mrs}+k$. Here, the arithmetic means of individual probabilities are the same for the two events, and there is more disagreement for an earthquake than for a flood. Then, if relative risk aversion is larger than unity, the collective probability for an earthquake should be smaller than for a flood. This result has first been obtained by Varian (1985) and Ingersoll (1987). We extend it to the comparison of states where the means of individual probabilities are not equal.

These results describe how the heterogeneity of beliefs affects the difference in collective probabilities for any pair of states. Going from this partial analysis to a more global one, it is necessary to describe the structure of disagreements across states. This would be useful to determine whether the collective distribution function be stochastically dominated by the mean subjective distribution. Cecchetti, Lam and Mark (2000) and Abel (2002) examine the effect of a change in the beliefs of the representative agent on the equity premium. Contrary to us, they assume that all agents have the same beliefs that deviate from what could be inferred from the existing data. However, their work is

useful to us because once the beliefs of the representative agent is obtained, our model becomes equivalent to an economy with homogeneous beliefs that can differ from a reference probability distribution. It is not true in general that a first-order-stochastically dominated shift in the subjective distribution of aggregate consumption raises the equity premium. Abel (2002) defines the notion of uniform pessimism by a leftward translation of the objective distribution of the aggregate consumption. He shows that uniform pessimism raises the equity premium. We provide another result which states that transferring probability mass from the wealthiest states uniformly to the other states also unambiguously raises the equity premium. Now, if most of the disagreement is concentrated on the likelihood of a boom, and if relative risk aversion is larger than unity, we know that this state should have a collective probability that is less than its mean individual probability. Thus, such concentration of disagreement on the boom state provides exactly the kind of transformation of the collective probability distribution for which we know that it raises the equity premium. We will provide a numerical illustration that shows that a disagreement on the likelihood of a boom may have a sizeable positive effect on the equity premium. In a plausible simulation, it multiplies the equity premium by 4. The bad news is that the equity premium is reduced when most of the disagreement is about the likelihood of a krach.

Practical value

The practical value of the project is multidimensional. As explained above, using the CAPM standard formula for porfolio management and investments by firms can be very misleading and inefficient when not taking into account of the divergence of opinions by investors. This project aims at correcting this bias. Also, we want to use this methodology to try to explain insurability crises in periods of high degree of disagreement among investors - as the one that followed the 9/11 events. This work could generate policy recommandations for the regulation of financial and insurance markets. For example, the observation that some agents do not purchase insurance for some socially diversifiable risks does not mean that insurance markets are inefficient, when people have heterogeneous beliefs. Compulsory insurance would be inefficient in that case.

Output

The proposed output of this research project would take the form of a research paper to be submitted to a scientific journal like *Econometrica* or the *Journal of Finance*. A less technical report would be written for the Europlace Institute of Finance. The paper would be presented in seminars and conferences in Europe and in North America.

Proposed timetable

Assuming that the project is accepted by Europlace Institute of Finance in September 2003, a first draft of the scientific paper would be written before the end of February 2004. The paper would be presented and tested in various places like Wharton, MIT, LSE and Paris before submitting the paper to a scientific journal. A technical final report would be written for the Institute for August 30, 2004.

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CURRICULUM VITAE (05/03)

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Education

a) Docteur en Sciences Economiques at the Catholic University of Louvain, (1984-1988). Dissertation : "Intergenerational Risk Sharing and Unemployment" supervised by J.H. Drèze.

b) M.A., Applied Mathematics at the Catholic University of Louvain, (1979-1984).

Professional Experience

- Professor, Oct 1992-current, University of Toulouse. Director of the FFSA Chair of Insurance at IDEI.
- Associate Professor, Ecole Polytechnique (Paris), Oct 1999-June 2002.
- Visiting researcher, European University Institute (Florence), Oct 1999-current.
- Associate Professor, Oct 1992-Sept 1994, Groupe HEC.
- Assistant Professor, Sept 1989-Sept 1992, Groupe HEC, Paris.
- Visiting Assistant Professor, 1991-1992, University of Louvain.
- Visiting Professor, Sept 1990 and Sept 1991, University of Montréal.
- Visiting Lecturer in Operations Research and Economics, 1988-1989, Dept of Economics, University of California at San Diego.
- Fellow of the Belgian National Science Fund (FNRS), 1985-1989, Center for Operations Research and Econometrics (CORE), University of Louvain.
- Instructor of Statistics, (1984-1985), Dept of Economics, University of Louvain.

Refereed Publications

1. The Design of Optimal Insurance Contracts without the Nonnegativity Constraint on Claims, *Journal of Risk and Insurance*, June 1987, 54, 314-324.
2. Pareto-Optimal Risk Sharing with Fixed Costs per Claim, *Scandinavian Actuarial Journal*, 1987, 62-73.
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5. Unemployment Insurance : Risk-Sharing Versus Efficiency, *The Geneva Papers on Risk and Insurance Theory*, 1991, 16(1), 59-74.
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20. Demand for Risky Assets and the Monotone Probability Ratio Order, with L. Eeckhoudt, *Journal of Risk and Uncertainty*, 1995, 11, 113-122.

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33. A Note on Portfolio Dominance, Review of Economic Studies, 1997, 64, 147-150.

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51. Analyse quantitative de la réversibilité du stockage des déchets nucléaires: Valorisation des déchets, in *Economie et Prévision*, 149, avec J.-G. Devezeaux, juillet 2001.

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54. Time horizon and portfolio risk, with R.J. Zeckhauser, *Journal of Risk and Uncertainty*, 2002, 24 (3), 195-212.

55. Discounting an uncertain future, *Journal of Public Economics*, 2002, 85, 149-166.

56. Quel taux d'actualisation pour le long terme?, *Revue d'Economie Financière*, 2002, 66, 253-267.

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59. To insure or not to insure: An insurance puzzle, *Geneva Papers on Risk and Insurance*, 2003, 28, 5-24.

60. Decision-making under scientific uncertainty: The economics of the Precautionary Principle, with N. Treich, *Journal of Risk and Uncertainty*, forthcoming.

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9. Actualisation du long terme, in *Revue de l'Energie*, n°496, mars-avril 1998, 157-159.

10. Assurance et solidarité, *Le Monde*, 29 février 2000, page 20.

11. Towards an economic theory of the limits of insurability, Assurances, Janvier 2000, 453-474.

12. Alerte au risque zéro, *L'Expansion*, 26 Avril 2001, page 126.

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14. Which risks for which future?, *European Business Forum*, Spring 2003, page 13.

Working papers

- Are independent optimal risks substitutes?, with L. Eeckhoudt.
- Increased Risk Taking with Multiple Risks, with E.E. Schlee.
- Equilibrium Portfolios with Heterogeneous Consumption Externalities.
- Optimal Portfolio Risk with First-Order and Second -Order Predictability.
- Maximizing the expected net future value as an alternative strategy to gamma discounting.
- Transitory shocks to GNP and the term structure of interest rates.
- The effect of information on unconditional asset prices, with E.E. Schlee.
- New Methods in the Classical Economics of Uncertainty: Comparing Risks, with M.S. Kimball.
- Toward a systematic approach to the economic effects of uncertainty II: characterizing utility functions, with M.S. Kimball.
- Analyse quantitative de la réversibilité du stockage des déchets nucléaires: une approche de sûreté, avec J.-G. Devezeaux.

- Optimal prevention of unknown risks: A dynamic approach with learning.
- Collective investment decision making with heterogeneous time preferences, with R. Zeckhauser.
- Risk aversion with non-exponential discounting, with F. Salanié.

Book

- *Les risques financiers : évaluation, gestion et partage*, with L. Eeckhoudt, McGraw Hill (Paris), 1993, 328 pages.
- *Risk: Evaluation, management and sharing*, with L. Eeckhoudt, Harvester Wheatsheaf (New York), 1995, 347 pages.
- *Non-expected utility and risk management*, edited by C. Gollier and Mark Machina, Kluwer Academic Press, Norwell (Ma), 1995, 150 pages.
- *The economics of risk and time*, MIT Press, June 2001, 450 pages. Winner of the "2001 Paul A. Samuelson Award", and of the "2002 Prix Risques-Les Echos".
- Le principe de précaution, avec F. Ewald et N. de Sadeleer, Presses Universitaire de France, Que sais-je? 3596, 2001.

Editing responsibilities

- Associate Editor, *The Geneva Papers on Risk and Insurance Theory* , (since 1990), *The Journal of Risk and Uncertainty,* (since 1994), *The Journal of Risk and Insurance,* (since 1996), *Management Science,* (since 1999), and *Finance Letters* (since 2003).
- Editor, *The Geneva Papers on Risk and Insurance Theory* (1995-2000).
- Member of the editorial board of *Risques.*

Scientific prices, awards

- Junior member of the Institut Universitaire de France (1997-2002).
- Winner of the "Prix Triennal Royale Belge", 1988.
- Winner of the "Prix Ernt Meyer", Prix de la meilleure thèse européenne en Economie de l'Assurance, 1989.
- Robert C. Witt Research Award for Outstanding Feature Article by the American Risk and Insurance Association, 1995.
- President of the Risk Theory Society, 1996.
- 2001 Paul A. Samuelson Award.
- Prix "Risques-Les Echos" 2002.