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The macroeconomics of radical uncertainty

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Michael W.M. Roos

The Macroeconomics of Radical Uncertainty

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Michael W.M. Roos[1]

The Macroeconomics of Radical Uncertainty

Abstract

Macroeconomics must take radical uncertainty into account, if it aims at contributing to the solution of serious real-world problems such as climate change. Allowing for radical uncertainty must happen at two levels: the level of modeling and the level of the scientific discipline. I argue that the complexity approach which sees the economy as a complex adaptive system is better suited to deal with radical uncertainty than the mainstream DSGE approach. I review a number of agent-based models that are promising starting points to incorporate radical uncertainty into macroeconomics. Discussing the examples of the financial crisis and climate change, I establish why methodological monism is dangerous and why macroeconomics needs more pluralism and openness towards other scientific approaches. Radical uncertainty and the complexity approach have important implications for macroeconomic policy and the advice that economists can give to policy makers. Under radical uncertainty it does not make sense to look for optimal policies.

JEL Classification: B41, B52, B59, C63, E12, E60

Keywords: Complexity economics; agent-based modeling; complex adaptive systems; non-linear dynamics; climate change; pluralism

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1 Introduction

Radical uncertainty in the sense of a fundamental unpredictability of the future was a central topic for John Maynard Keynes. In fact, it was one of the main messages of his General Theory. In Keynes (1937), he summarizes the key points of his new approach: "I accuse the classical economic theory of being itself one of these pretty, polite techniques which tries to deal with the present by abstracting from the fact that we know very little about the future" (p. 215). "The orthodox theory assumes that we have a knowledge of the future of a kind quite different from that which we actually possess. … The hypothesis of a calculable future leads to a wrong interpretation of the principles of behavior which the need for actions compels us to adopt, and to an underestimation of the concealed factors of utter doubt, precariousness, hope, and fear" (p. 222). For Keynes, macroeconomic phenomena cannot not be understood properly, if radical uncertainty and subjects' ways to deal with it are ignored. Post-Keynesian economists (see Davidson 1991) upheld and elaborated on Keynes' emphasis on radical uncertainty for macroeconomics, but their views never made it into macroeconomic mainstream thinking. The so-called Keynesians, who formalized what they saw as Keynes' main idea first in the IS-LM model and later in the neoclassical synthesis of the AD-AS model, shaped the field of macroeconomics for the three decades after Keynes. Castrating Keynes original thoughts, they focused on the equilibrium of aggregate demand and supply and nominal rigidities, because this was possible to formalize with the available methods of the time. The rational expectations revolution of the 1970s, which paved the way to current mainstream macroeconomics, formalized all uncertainty as risk and hence eradicated the last remainders of radical uncertainty. So after about 80 years of macroeconomic research, we are effectively back at square one with respect to the role of radical uncertainty in mainstream macroeconomics.

The main thesis of this essay is that macroeconomics must take radical uncertainty into account, if it aims at contributing to the solution of serious real-world problems such as climate change. Allowing for radical uncertainty must happen at two levels: the level of modeling and the level of the field of macroeconomics as a scientific discipline. Macroeconomics needs models which feature radical uncertainty and which contain agents that have to cope with it. But this change at the technical level will not be possible without a change in the mind-set of the field. Incorporating radical uncertainty into macroeconomic models is only possible if macroeconomists acknowledge that central economic decisions are characterized by the unknowable future and cannot be modeled adequately in the way it is usually done. This will require a change of perspective away from the mechanistic modeling approach in the tradition of Newton and Descartes to a more evolutionary view of the world. In many respects it is more appropriate to think of economies as complex adaptive systems rather than linear general equilibrium systems. It is important to see that such a shift in world view does not only imply the use of different types of models but also a different understanding of what science can do and how

this can be done. The complexity paradigm is holistic as opposed to reductionist, and puts more emphasis on description and understanding than on prediction and the analysis of cause and effect. All this implies that macroeconomics at least needs more pluralism and openness towards other scientific approaches and disciplines, if not a proper paradigm shift.

For many macroeconomic questions radical uncertainty is crucial. Whenever there is an element of true novelty, and whenever behaviors and institutions change, it will be difficult or impossible to predict in a reliable way, how the economy will be affected. This is most certainly the case if we consider long time horizons. Examples of macroeconomic topics that involve radical uncertainty are innovation and the resulting new technologies, products and markets; major changes of the politico-economic system like the transformation of the former Soviet Union and the Eastern-European countries, the formation of the European Union or the evolution of China; the response of the global economy to climate change; and the effects of major financial crises which have lasting impact on the global financial architecture and the global financial system. DSGE models and neoclassical models of economic growth, which are the current standard in macroeconomics, may be useful under certain conditions, but are seriously misleading if radical uncertainty is important. In "normal times", when economic behavior and institutions can be expected to be rather stable and exogenous shocks are rather small, these models might do a decent job. However, they are likely to break down and to provide inaccurate predictions, if there is significant structural change in the economic system. Acknowledging this problem is of prime importance for the derivation of policy conclusions and the provision of economic advice to policy makers. Ignoring the possibility that the economic system might change its structure drastically and that conventional models will not provide any guidance in that case, can be very harmful for society because it leaves policy makers unprepared for such crises. The former President of the European Central Bank Jean-Claude Trichet referred to exactly this point in his opening address at the ECB Central Banking Conference in November 2010[1]: "When the crisis came, the serious limitations of existing economic and financial models immediately became apparent. … Macro models failed to predict the crisis and seemed incapable of explaining what was happening to the economy in a convincing manner. As a policy-maker during the crisis, I found the available models of limited help. In fact, I would go further: in the face of the crisis, we felt abandoned by conventional tools." If macroeconomics does not take radical uncertainty into account, such failure could happen again, for instance in the case of climate change.

In the following, I will present the idea of economies as complex adaptive systems and explain why this concept is useful to introduce radical uncertainty into macroeconomics. Then, I discuss how radical uncertainty can be dealt with in economic models based on the complexity-view of the economy.

[1] See: http://www.ecb.europa.eu/press/key/date/2010/html/sp101118.en.html

Agent-based simulation models are a promising tool for this purpose. As already indicated, taking radical uncertainty seriously will require more methodological pluralism in macroeconomics. More pluralism does not only mean working with different kinds of models, but also implies a different notion of the aims and scope of macroeconomic research. In the fourth section of this article, I will elaborate what this means and why this is the case. Radical uncertainty is also important for macroeconomic policy and the advice that economics can give to policy makers. Section 5 discusses some principles for macroeconomic policy under radical uncertainty. I conclude with some further thoughts in Section 6.

2 Economies as complex adaptive systems

Current macroeconomic models have microfoundations which means that all aggregate relationships between variables of interest are derived from the optimization behavior of individual firms and households and are hence functions of the so-called "fundamentals": preferences and technology. These fundamentals are exogenous and constant which leads to fixed functions that describe the behavior of agents, such as consumption Euler equations, labor supply and demand equations, or investment functions. Furthermore, the types of agents in the economy, the kinds of products, the sectorial structure, and the institutional framework are usually fixed. The models are solved by assuming that there is a unique and stable general equilibrium or steady state[2]. Uncertainty (more precisely risk) enters in the form of usually additive exogenous shocks on the endogenous variables. Agents deal with this uncertainty by forming rational expectations about future endogenous variables based on their information set, which includes the complete model and the distributions of all stochastic shocks.

In such a framework radical uncertainty or true novelty cannot exist. "Surprises" can only occur in the form of the random realizations of the shocks whose distribution is assumed to be known. True novelty would mean that new types of goods appear or old ones vanish, different behavior shows up or institutions change in unexpected ways. Typically this would imply some kind of structural change which is reflected in varying function forms in the model. The standard neoclassical framework is inspired by Newtonian mechanics, in which observed natural phenomena can be described by universal, unchanging natural laws. The consumption Euler equation can be seen as a core equation in basically all modern DSGE models and determines much of those models' dynamics. Reading these papers, one often gets the impression that the Euler equation is interpreted as the analog of a natural law in economic models.

[2] There are, of course, models with multiple equilibria and self-fulfilling prophecies. But these are exceptions rather than the normal case.

The models sketched here can only be successful in the scientific community, because most mainstream economists basically accept the view that we can study macroeconomic systems in the same way as one can analyze solid physical bodies which are subject to universal laws of nature such as gravity. The economy is hence seen as a complicated mechanism or machine. However, there are good reasons to view an economy rather as an evolutionary system, which is permanently in flux and is subject to ongoing structural change. An important characteristic of an evolutionary system is that its agents permanently adapt their behavior to changing environmental conditions and thereby trigger new changes by other agents and the environment themselves. Exactly this interaction of adaptive agents generates radical uncertainty, because each decision of an individual agent triggers responses of many others whose aggregate effects in the long run are unforeseeable.

An alternative view on the economy is the complexity view (see Beinhocker 2007, Colander 2000, Colander et al. 2011, Colander and Kupers 2014, Fontana 2008, Kirman 2011, Arthur 2015, Elsner et al. 2014) which sees economies as complex adaptive systems. According to John Holland[3] "a Complex Adaptive System (CAS) is a dynamic network of many agents (which may represent cells, species, individuals, firms, nations) acting in parallel, constantly acting and reacting to what the other agents are doing. The control of a CAS tends to be highly dispersed and decentralized. If there is to be any coherent behavior in the system, it has to arise from competition and cooperation among the agents themselves. The overall behavior of the system is the result of a huge number of decisions made every moment by many individual agents." More concisely, Holland (2006, p. 1) defines: "CAS are systems that have a large number of components, often called agents, that interact and adapt or learn". The central feature of CAS is that agents change their behavior which creates endogenous or behavioral uncertainty, since no agent can assume that other agents will always respond in the same way to his own actions.

CAS typically have non-linear aggregate dynamics that cannot be captured well by linear models. Non-linear systems are very different from the models economists usually use. They can be chaotic or at the edge of chaos. Although they are deterministic, they are unpredictable (see Velupillai 2005) and are extremely sensitive to initial conditions. Positive feedback effects can lead to cumulative causation of very small disturbances giving rise to the so-called "butterfly effect" (see Lorenz 1963). Furthermore, non-linear systems often have bifurcations which means that the system can suddenly change its behavior, when a parameter value passes a tipping point or bifurcation point. Moving to a different attractor after passing a bifurcation point can be surprising from the perspective of the agents in the model since their environment then changes its properties.

[3] John Holland cited in M. Mitchell Waldrop (1992).

Another important property of CAS is self-organization and the emergence of order at the macro level. Complex systems tend to develop a stable structure over time without any centralized or external control. Control over everything that happens is decentralized and exerted by the individual agents. The mutual adaptation of behavior leads to coordination and emergent patterns observable at the macro level. The macro patterns are typically impossible to predict from the characteristics and behaviors of individual agents alone. This also implies that the agents themselves will not be able to predict the macro consequences of their actions and are hence subject to radical uncertainty.

It should have become clear that CAS have very different properties than conventional equilibrium models. The most important difference is that equilibria are not assumed to exist, but can only emerge (or not) as the result of a multitude of individual decisions. This point is absolutely crucial, because economic models are usually judged by their capability of making good predictions (see Friedman 1953). But theoretical predictions in neoclassical economics are always statements about equilibria and if we cannot be sure than an economic system has a unique and stable equilibrium, conventional analysis in the spirit of comparative statics is not possible[4]. Giving up the assumption of stable equilibria, which is mandatory for the complexity view, requires a shift in the economic methodology away from the prediction of outcomes and towards the description and understanding of processes.

3 Models with radical uncertainty

When we talk about macroeconomic models with radical uncertainty, it seems necessary to clarify who is subject to this uncertainty. We could think of the agents within the model to be faced with radical uncertainty, while the researcher as an outside observer of the model has full knowledge of the model and its evolution over time. But we might also imagine models that can also surprise the researcher and generate outcome that he did not expect. Of course, the researcher who designed the model knows all the assumptions and details of the model, but this does not necessarily mean that he can predict its behavior and outcomes ex ante before having analyzed it in depth. While some might argue that a good model should always surprise its creator and generate unanticipated insights, it is common practice in economics that models are mere formalizations of pre-existing insights and often mainly serve as consistency checks and concise representations of the argument. I think that we need more models in economics that also expose the researcher to uncertainty about its outcome. It also seems more convincing to require that it is as difficult for the researcher to predict the aggregate outcomes of the model ex ante as it is for the agents in the model. Otherwise, one can always argue that rational

[4] According to Samuelson's correspondence principle, only models with a unique and stable equilibrium are of interest, because they allow testable predictions about how the equilibrium changes when parameters are changed. It is therefore common practice to rule out unstable equilibria by assumption (see Heijdra 2009).

agents should make use of the researcher's superior knowledge of the social system. This is one of the classical justifications of the rational expectations hypothesis. It will be difficult for the researcher to predict the model's aggregate dynamic behavior if the model has typical features of complex systems such as bifurcations and nonlinear and potentially chaotic dynamics.

A model which credibly exposes its agents to radical uncertainty should satisfy two requirements. First, it must exhibit some sort of true novelty and surprise which lead to some kind of structural change and evolution. Second, it must contain agents whose behavior is modeled quite differently from how this is usually done in neoclassical models. If agents are to be subject to radical uncertainty, we cannot assume that they have full information, form rational expectations and are able to optimize perfectly. This does not imply that agents are irrational or even boundedly rational. Bounded rationality often has the flavor of being some imperfect version of full or "true" rationality[5]. If there is radical uncertainty, neither the probabilities of potential outcomes of decisions nor the complete set of those outcomes are known to the decision maker. But then agents cannot make decisions as prescribed by (subjective) expected utility theory (SEUT), which is the current ideal of rational decision-making in economics. One can debate whether situations of risk or situations of radical uncertainty are more representative for decisions that are relevant from a macroeconomic perspective. However, a key point of this paper is that situations of radical uncertainty are not odd exceptional cases, but rather frequent, so that the rationality of SEUT does not seem to be a natural benchmark for decision-making (let alone its typical rejection in economic experiments, see Starmer 2000).

In line with the quotation of Keynes in the Introduction, models with radical uncertainty must look more closely at the "principles of behavior". With respect to rationality, Herbert Simon's concept of procedural rationality is a good candidate for an appropriate modelling of agents' behavior. Simon (1976, p. 405) defines this type of rationality as "a style of behaviour that is appropriate to the achievement of given goals, within the limits imposed by given conditions and constraints". Gilboa and Schmeidler (2001, p. 17) define such behavior as rational, which does not lead to regret ex post. It is also important to acknowledge that behavior is often determined by affects or "animal spirits", imitation, or the adherence to social norms, which are all sensible ways to come to a decision when it is not possible to calculate an optimal solution of a well-specified decision-problem (see Pech and Milan 2009). Being confronted with radical uncertainty, procedural rationality and the reliance on intuition, imitation, and social norms may be the best way to make decisions that is possible and in this sense fully rational.

[5] Bounded rationality is often defined as a deviation from the standard economic model reflecting "the limited cognitive abilities that constrain human problem solving" (Mullainathan and Thaler 2000).

Agent-based computational models or simulations are an ideal tool to model and analyze complex adaptive systems which can meet the criteria above. Agent-based computational models typically have the following properties (compare Arthur et al. 1997): 1) control is decentralized and bottom-up, 2) there is no equilibrium assumption, 3) agents feature procedural rationality, 4) agents have limited and local knowledge, 5) agents interact, and 6) agents learn and adapt to their environment.

In the recent past, a growing number of macroeconomic agent-based models have been developed, for instance Assenza und Delli Gatti (2013), Deissenberg et al. (2008), Delli Gatti et al. (2011), Dosi et al. (2010), Dosi et al. (2013), Mandel et al. (2009), Salle et al. (2013). Not all of them explicitly focus on radical uncertainty and its effects, but these models at least satisfy the requirement that agents have limited knowledge and information and are hence not neoclassical maximizers. Lengnick (2013) nicely illustrates the unpredictability in such models due to the butterfly effect. Frank Westerhoff has a number of papers that study the complex behavior of quite simple macroeconomic systems in which agents' boundedly rational behavior and their interactions lead to nonlinear dynamics. Lines and Westerhoff (2006) show that the simple Samuelson multiplier-accelerator model with extrapolative and reverting expectations has a Neimark-Sacker bifurcation. Such a bifurcation is also found in a similar model with income-dependent consumer sentiment in Westerhoff (2008). In this model, countercyclical fiscal policy can lead to chaotic dynamics of national income. Westerhoff (2012) presents another model with complex dynamics, in which the goods market interacts with a stock market with heterogeneous speculators.

Dawid (2005) provides an excellent survey of agent-based models of innovation and technological change. There is a significant literature based in evolutionary economics inspired by the seminal work of Nelson and Winter (1982) studying industry dynamics and the co-evolution of technology and industry structure. Of particular interest is the model by Cooper (2000) in which innovating firms have to deal with substantive or radical uncertainty while searching for new technologies. Another aspect related to radical uncertainty is how innovators predict the market response to their new product. Birchenhall (1995), Yildizoglu (2001), and Natter et al. (2001) are examples of models in which firms develop internal models of the market to assess the profitability of their innovation. Triulzi and Pyka (2011) model university-industry relationships in biopharmaceutical sectors to analyze the interactions and knowledge dynamics between heterogeneous agents involved in research. An important aim of their paper is to discuss how agent-based models can be used through a learning-by-modelling process to better understand innovation processes in complex and uncertain environments. Somewhat closer to the macroeconomic literature is the evolutionary growth model by Silverberg and Verspagen (1994). This agent-based model differs significantly from conventional approaches by taking into account several stylized facts about technological change and growth that are had to incorporate into analytical

model, such as the co-existence of diverse concurrent technologies, the exploration vs. exploitation tradeoff of innovation efforts, the importance of innovation diffusion speed and the characteristics of knowledge. A more recent paper in this tradition with a special focus on the microfoundations of novelty creation is the evolutionary growth model by Beckenbach et al. (2012).

4 Methodological pluralism in macroeconomics

Before the outbreak of the financial crisis of 2007 – 2009, the field of macroeconomics had achieved a widely accepted methodological consensus which was sometimes called the "New Synthesis" (see Arestis 2007, Woodford 2009). This synthesis combined the methodological approach of Real Business Cycle Theory (microfoundations, rational expectations, general equilibrium, shocks as cause of business cycle fluctuations) with price rigidities and imperfect competition from the New Keynesian camp. Mainstream macroeconomics was defined by this unified methodological approach represented by the dynamic stochastic general equilibrium (DSGE) models. Popular macroeconomic textbooks (see Carlin and Soskice 2005, Heijdra 2009, Romer 2011, Wickens 2012) typically present exactly this view of a macroeconomic mainstream. Often, they start with "old-style" Keynesian models to introduce important concepts such as aggregate demand and supply, and then, after criticizing it, move on to the presentation of the Ramsey growth model, New Keynesian models that formalize price rigidities, and the combination in the form of "state-of-the-art" New Keynesian DSGE models. In general, the evolution from "traditional macroeconomics" to modern dynamic general equilibrium modeling is seen as a progress which occurred in an almost linear fashion (see Wickens 2012, ch. 1 for a clear expression of this view).

Some authors like Simon Wren-Lewis observe a return of schools of thought in macroeconomics after the financial crisis[6]. What he means, however, is simply a division of mainstream macroeconomists into Keynesians and "Anti-Keynesians", where the camps are divided over the belief in the effectiveness of fiscal policy and the desirability of government interventions. This basic divide has always been there in macroeconomics and just reflects opposite ideological positions that become apparent in every major economic crisis. A deeper discussion about methodology is not detectable. Even more, many economists are very reluctant to discuss methodology. As Wren-Lewis writes[7] "you will generally not find economists writing about methodology. One reason for this is … a feeling that the methodology being used is unproblematic, and therefore requires little discussion. … Yet I find many macroeconomists just assume that their methodology is unproblematic, because it is what everyone mainstream *currently* does."

6 http://www.voxeu.org/article/return-schools-thought-macroeconomics

[7] http://mainlymacro.blogspot.co.uk/2014/05/economists-and-methodology.html

This reluctance to discuss methodology and to take criticism seriously is exemplified in a statement in Wickens' (2012) textbook that is worth quoting at some length:

"With the financial crisis in mind, Skidelski [2009] emphasizes that uncertainty cannot be reduced to calculable risk, thereby challenging not just modern macroeconomics but modern finance theory too. How justified are these criticisms? While it is undoubtedly true that the future is uncertain, we still have to take decisions involving the long term, such as those concerning pensions, durable goods like houses and cars, and, for businesses, investment in buildings and machinery. These force us to take a view about the future and hence to make intertemporal decisions under uncertainty – a key feature of modern DSGE macroeconomics that seeks the best way to do this. Although some events may be unpredictable … most shocks to the macroeconomy are open to being modeled as stochastic processes and hence becoming calculable risk. … In this book I have taken the view that, although there may be uncertainty about the stochastic processes affecting the economy, DSGE macroeconomics, in combination with modern financial theory, provides the best means we possess of trying to understand the macroeconomy" (p. 8).

Note that Wickens merely claims that (radical) uncertainty can be transformed into risk without any further argument. He simply asserts that the DSGE methodology is the best available and refuses any serious discussion about potential problems or alternatives.

I argue that methodological blindness is dangerous and misleading. The admissible methodology determines both the questions that can be asked and the potential answers that can be given. In the case of DSGE models, for example, recessions are always the result of some exogenous shock to technology, preferences, price mark-ups etc. Researchers that are deeply rooted in this methodology cannot imagine that recessions could have other reasons as well, although agent-based models such as Westerhoff (2006) or Lengnick (2013) clearly show that it is easy to generate business cycle fluctuations without any exogenous shocks. DSGE researchers treat their shocks as if they were something real rather than a modeling short-cut. This is dangerous because it leads to the conclusion that recessions or economic crises are not predictable as a matter of principle, because their causes – exogenous shocks – are not predictable by definition. But this may be wrong. As Reinhart and Rogoff (2009) have shown with their huge data compilation, financial crises and subsequent recessions occur fairly regularly and often seem to follow certain patterns. This does not imply that anybody can predict the precise date when a crisis will begin. Rather it means that there might be warning signs that a crisis has become more likely. Models with endogenous business cycles can generate patterns which could warn researchers that a crisis or a turning point might be approaching. The researchers still cannot predict the crisis, but they can anticipate that it might happen soon.

Of course, the existence of endogenous cycles is not really a new insight. Non-mainstream authors such as Charles Kindleberger (1978) or Hyman Minsky (1986) described endogenous financial and economic cycles long before. Yet they did not do so using formal mathematical models, but presented their theories in prose, which was and is not acceptable in mainstream economics. But even rather mainstream economists had a hard time advancing unconventional ideas about endogenous financial crises before the global financial crisis actually happened as the examples of Robert Shiller and Raghuram Rajan show. At the now infamous Jackson Hole meeting in 2005, Rajan presented a paper warning that financial development had made the world riskier. Harvard professor and former Treasury Secretary Lawrence Summers dismissed Rajan's warning finding "the basic, slightly Luddite premise of this paper to be largely misguided"[8].

It is revealing what Nobel laureate Robert Shiller writes about his experience being a maverick who questioned the group consensus on panels of economic experts[9]. As a member of the economic advisory panel of the Federal Reserve Bank of New York, he "felt the need to use restraint. While I warned about the bubbles I believed were developing in the stock and housing markets, I did so very gently, and felt vulnerable expressing such quirky views. Deviating too far from consensus leaves one feeling potentially ostracized from the group, with the risk that one may be terminated." Wondering why it is so difficult to convince economists that price bubbles exists, he reckons that "it must have something to do with the tool kit given to economists (as opposed to psychologists) and perhaps even with the self-selection of those attracted to the technical, mathematical field of economics. Economists aren't generally trained in psychology, and so want to divert the subject of discussion to things they understand well. They pride themselves on being rational. The notion that people are making huge errors in judgment is not appealing. In addition, it seems that concerns about professional stature may blind us to the possibility that we are witnessing a market bubble. We all want to associate ourselves with dignified people and dignified ideas. Speculative bubbles, and those who study them, have been deemed undignified."

This example shows that groupthink and being imprisoned in narrow methodological paradigms can generate a blindness towards possible, extraordinary states of the world. This is nicely summarized in the response letter[10] that British economists sent to the Queen of England answering her question, why nobody saw the crisis coming: "So in summary, Your Majesty, the failure to foresee the timing, extent and severity of the crisis and to head it off, while it had many causes, was principally a failure

[8] http://www.kansascityfed.org/publicat/sympos/2005/pdf/GD5_2005.pdf
[9] http://www.nytimes.com/2008/11/02/business/02view.html
[10] http://www.britac.ac.uk/templates/asset-relay.cfm?frmAssetFileID=8285

of the collective imagination of many bright people, both in this country and internationally, to understand the risks to the system as a whole."

It is exactly to avoid this failure of collective imagination why macroeconomics needs more pluralism. If we only use a restricted set of model classes or theories, we will always get similar kinds of results. A greater diversity of economic models and research approaches will deliver a broader set of insights and potential outcomes. Lee et al. (2015) show in a study with bibliometric and survey data that research teams are more creative and produce more novelty if the composition of team members is more diverse with respect to disciplinary background. What is true for the research of interdisciplinary teams most likely also translates to methodological diversity within a discipline. One might expect that even approaches that are incompatible with one another can be fruitful for a discipline as a whole, as it is the case with quantum theory and general relativity theory in physics. To date most physicist consider these theories as incompatible, but there can be no doubt that both have an important place in physics and are indispensable to understand important phenomena of our world. My expectation is that the more we can imagine to happen in our models of the world, the less likely it is that the world will surprise us.

Many macroeconomists might argue that the field has changed a lot as a consequence of the financial crisis. Indeed, there is now plenty of research studying financial markets and its interactions with the real economy that hardly existed before the crisis (see Brazdik et al. 2012). Incorporating banks and realistic financial markets also required some modifications of the basic set-up of macroeconomic models. But most of this research is not very different from the standard DSGE paradigm. Palley (2013) goes as far as saying that from an old Keynesian's perspective nothing substantial has changed in macroeconomics. After the famous movie "Il Gattopardo (The Leopard)", in which the main character's motto is that things must change if they are to remain the same, Palley calls the apparently new macroeconomics "gattopardo economics". Referring to topics such as income distribution or non-standard consumption theories, he states that "gattopardo economics takes on board ideas developed by critics of mainstream economics, but does so in a way that ignores the thrust of the original critique and leaves mainstream analysis unchanged" (p. 193). But even if one is willing to concede that there has been a real change in macroeconomics regarding financial markets, it seems fair to say that the discipline as a whole has not really changed significantly.

Some topics are still fringe topics and not seen as belonging to the core of macroeconomics. Incorporating them will require a change of macroeconomics. A particularly important example is climate change which is rarely considered a macroeconomic problem though it clearly is one. Economic growth is a cause of climate change and climate change is likely to have growth effects. And severe weather events such as storms, droughts or floods affect production and employment in the short-

run. There are some calls to incorporate a macroeconomic perspective into ecological or environmental economics (Rezai et al. 2013), but I argue that in the medium to long term climate change is likely to be one of the most important factors of economic well-being at the macroeconomic level. Hence climate change should also be discussed in macroeconomics classes and macroeconomic journals.

Of course, well-known models used to analyze the effects of climate change such as the DICE model (Nordhaus and Sztorc 2013) or the FUND model (see Anthoff and Tol 2013) can be seen as macroeconomic models, but they are rarely seen as such an typically not known by macroeconomists. In growth theory, there is a branch of the literature that looks at the interaction between the environment and economic growth (see Xepapadeas 2005, Brock and Taylor 2005). Furthermore, in the recent past, a couple of papers have been published that Fischer and Heutel (2013) consider a potential nucleus for an emerging field of environmental macroeconomics. While this is in principle a positive evolution, the way in which this is done only reinforces my call for more pluralism in macroeconomics. The models surveyed in Fischer and Heutel (2013) are either standard DSGE models featuring pollution or endogenous growth models with directed technological change which can help to make growth sustainable. They are just applications of the typical neoclassical equilibrium framework with optimizing agents to environmental issues. As standard models they have all the weaknesses criticized in Section 2, such as the treatment of uncertainty as risk and always optimal adjustments to shocks. As Rezai et al. (2013) argue, one of the problems of this conventional approach is that all adjustments to climate change are optimal and occur smoothly.

Climate change is a situation of radical uncertainty par excellence. It is characterized by scientific uncertainty and by uncertainty about the economic and social impact of any climate forecast and subsequent action (see Aldred 2012). But as argued above, under radical uncertainty optimization and the formation of rational expectations are not possible and models with these features are problematic for several reasons. First, these models force researchers to ask questions of minor importance, such as what are optimal abatement policies instead of asking what are politically feasible or likely policies. Second, they leave out important factors that influence the response of the socio-economic system to climate change like the power of interest groups, ideology, or the multiple feedbacks between economic and societal variables. Third, by construction they neither represent not predict possible consequence of either slow or negative growth or global warming, which are of enormous political and societal importance. Climate change can have dramatic effects on our natural environment, for instance droughts and water scarcely, crop failure and general decline in food production. These in turn can lead to starvation and misery, wars and social unrest. On the other hand, policies that bring greenhouse gas emissions under control might require a century-long recession with aggregate output

and consumption shrinking over many decades (see Nordhaus 2008). While such a de-growth scenario appears necessary, standard models hide what this might mean for the affected societies. De-growth will definitely dramatically change the social world we know institutionally and politically. How this might happen and what it implies cannot be answered in conventional models. Finally, conventional macroeconomic models may shape the political discourse in a dangerous way. They give both researchers and politicians a treacherous feeling of having control. And they might divert political efforts away from potentially required drastic measures towards some illusionary optimal policies.

Unhalted global warming is likely to change of the world and the economic system drastically in the not too far future. Similar to the global financial crisis, a climate crisis may occur abruptly and may take us all by surprise. However, the effects of a true climate crisis will be more severe than the financial crisis, which is already seen as an economic tsunami, by an order of magnitude. Having a large variety of different models might help keeping the surprise about the effects of climate change small. It is important to imagine and to represent the potential effects in our models in order to be prepared and to be able to cope with them. Furthermore, more vivid scientific imagination might stimulate a broader search for solutions to avoid the most drastic outcomes.

How do we achieve more pluralism in macroeconomics? I hope that I was able to make the case why more methodological pluralism is helpful in a world characterized by radical uncertainty and potentially very undesirable states. Maybe the young generation of researchers has the courage to experiment with new approaches that are different from what is currently seen as “good” or “modern” macroeconomics. And maybe there are enough senior macroeconomists who are open enough to allow the juniors to proceed and to publish their results in good journals.

5 Guidance for policy makers

Accepting that many macroeconomic processes are fundamentally unpredictable has far-reaching implications for macroeconomic policy and the advice that economists can give to policy-makers. This message is probably much more relevant for economists than for politicians and other policy-makers who are most likely to be aware of the radical uncertainty they face in their daily work. Macroeconomics has always been a field with a strong focus on economic policy, probably more so than microeconomics, and the analysis of fiscal and monetary policy is a core topic of macroeconomics. The macroeconomic literature is full of policy recommendations and analyses of policy designs. Given the approach of mainstream macroeconomics, it is not surprising that many papers are concerned with the derivation of optimal policies: optimal monetary policy (e.g. Ravenna and Walsh 2011, Gali 2014, Fendoglu 2014), optimal fiscal policy (e.g. Burgert and Schmidt 2014, Gervais and Mennuni 2015), optimal growth and R&D policy (e.g. Grossmann et al. 2013), optimal climate change policy (e.g. Ulph and Ulph 2013), optimal macroprudential regulation (Quint and Rabanal 2014) and so forth. In fact,

welfare analysis and the derivation of optimal policies are seen as major benefits of the microfounded macroeconomic modeling approach (see Blanchard 2009). Yet searching for optimal policies does not take radical uncertainty seriously. Optimal or welfare-maximizing policies can only be derived in models that make strong assumptions and that model uncertainty as risk. And even if optimal policies derived from unrealistic models were somehow generalizable to more realistic settings, it would be impossible to implement them in most cases since neither economists nor policy makers know the precise parameter values needed to determine the optimal level of policy instruments.

Colander and Kupers (2014) nicely explain what the inherent difficulty to make predictions of complex systems implies for “the art of public policy”. They strongly advocate a much more humble approach to policy than the usual control paradigm based on the fiction of social planners. Their argument is mainly based on two pillars. Firstly, in complex systems it is impossible for individual agents including the government to determine optimal or even good policies. Instead Colander and Kupers have a lot of confidence in the ability of the decentralized individual agents to find good local solutions to their individual problems which might lead to socially beneficial outcomes. Secondly, they emphasize that due to multiple feedback effects and the property of complex system to self-organize, they are very difficult to control by individual agents once they have reached an attractor. It follows that the government or institutions such as the central cannot hope to steer the economy, but at best have a trigger function and try to move the system from on basin of attraction into another.

Colander and Kupers conclude that instead of using direct interventions to achieve a certain goals, the government should rather try to influence the rules of the game or the ecostructure of the agents in a way that seems socially desirable. The rules of the game are the institutions that define the individual agents’ action sets. Instead of solving problems for the agents, the government should create institutions that make it easy for agents to solve problems themselves. These rules of the game influence the market dynamics of the complex system in a desired way. But Colander and Kupers even go a step further by proposing that the government should apply “supernudges” (p. 184) that have an effect on agents’ preferences and norms. These institutional changes aim at influencing subjects at a more fundamental level than the usual instruments such as taxes and subsidies which change incentives for given preferences. According to Colander and Kupers, “"the government [in the complexity frame] does not impose norms, or even force individuals to self-regulate. Instead it attempts to encourage the development of an ecostructure that encourages self-reliance and concern about others" (p. 9). In the complexity framework, it is hence crucial for policy makers to know how tastes evolve, change and can be influenced. Given the difficulty of predicting agents’ and the systems behavior, Colander and Kupers also call of experimentation by policy makers which is in clear contrast to mainstream economists desire to derive theoretically optimal policies. This experimentation should

be guided by “educated common sense”, which “involves an awareness of the limitations of our knowledge that is inherent in the complexity frame” (Colander and Kupers 2014, p. 174).

Colander and Kupers (2014) present a modern version of older thoughts that have found their way into the complexity approach to economics. According to them, John Maynard Keynes and Friedrich August von Hayek had a remarkable consensus with respect to the significance of uncertainty, although they are often seen as antagonists and indeed came to different policy conclusions on some political issues. The conclusion that economic policy should abstain from exerting direct control over the economy is very similar to Hayek’s (1945) rejection of neoclassical theory and its attempts to derive optimal policies. Hayek emphasized that nobody can have the knowledge of a complex system required to do social planning. He wrote: "What is the problem we wish to solve when we try to construct a rational economic order? ... If we possess all the relevant information, … the problem which remains is purely one of logic. … This, however, is emphatically not the economic problem which society faces. … The problem of a rational economic order is determined precisely by the fact that the knowledge of the circumstances of which we must make use never exists in concentrated or integrated form, but solely as the dispersed bits of incomplete and frequently contradictory knowledge which all the separate individuals possess" (p. 519).

6 Concluding remarks

Radical uncertainty and ignorance are pervasive in economic systems with complex decentralized interactions of many agents. Mainstream macroeconomists have ignored this fact for too long which led to a severe loss of public trust in the field (see Buiter 2009, Economist 2009) as a consequence of its fundamental failure to anticipate the Great Financial Crisis. The neglect of radical uncertainty happened at two levels which are interrelated. On their quest to building quantifiable, scientific models, macroeconomists treated uncertainty as risk in their models which allowed the use of expected utility theory and rational expectations. The resulting DSGE models are very elegant, logically consistent and powerful in quantitative applications. This inadequate treatment of uncertainty in macroeconomic models caused to the field of macroeconomics to “become so mesmerized with its own internal logic that it has begun to confuse the precision it has achieved about its own world with the precision that it has about the real one” (Caballero 2010, p. 85). Following Hayek, Caballero (2010) calls this the “pretense-of-knowledge syndrome” in academic macroeconomics, which is nothing else than the failure to acknowledge radical uncertainty a second time, now at the level of the discipline. He observes that “on the methodology front, macroeconomic research has been in `fine-tuning´ mode within the local-maximum of the dynamic stochastic general equilibrium world, when we should be in `broad-exploration´ mode. We are too far from absolute truth to be so specialized and to make the kind of confident quantitative claims that often emerge from the core. On the policy front, this

confused precision creates the illusion that a minor adjustment in the standard policy framework will prevent future crises, and by doing so it leaves us overly exposed to the new and unexpected" (p. 85 - 86).

Despite severe criticism and also some compunctious confessions by prominent macroeconomists that the state of macro is not as fine as believed before the crisis[11], it is fair to say that methodologically there is much business as usual in macroeconomics. Of course, many researchers work on incorporating financial frictions into their models, but this work is basically an extension of the otherwise unchallenged DSGE approach (see Chatelain 2012, Ragot 2012). To some extent there is a circle-of-wagons mentality, with mainstream macroeconomists standing closely together to defend themselves against the perceived unfair and unqualified attacks of non-economist critics and dissenters from inside the profession. A good example for this attitudes is Stephen Williamson's (2011) "Defence of Contemporaneous Economics".

While one might wish that the defenders of the orthodoxy demonstrated some openness towards the criticisms and alternative models, and a willingness to engage in a serious methodological discussion instead of stubborn defensive battles, this is unlikely to happen. But this should not discourage dissenters who have good arguments to believe in the fundamental role of radical uncertainty in macroeconomics. There is a growing community of researchers currently labeled as heterodox who are convinced that they have tools available to do rigorous macroeconomic research with models featuring radical uncertainty. They already started fruitful alternative research programs and will continue doing so. Time will show that these approaches, which put more emphasis on accurate descriptions of behavior and institutions than on elegant abstractions, on the understanding of social processes and dynamics than on prediction, generate useful insights for science and policy. These researchers are aware of the dangers of a pretense of knowledge and know that their models only can suggest possible outcomes in a highly uncertain world. This sounds like a very humble aspiration, but knowing one's limitations is a prerequisite for wisdom.

[11] See Olivier Blanchard 2014, http://www.voxeu.org/article/where-danger-lurks

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