Essays in nonlinear dynamics in economics and econometrics with applications to monetary policy and banking

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Chapter 1

General Introduction and Thesis Outline

> "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."
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> — Jean-Claude Trichet, President of the ECB, 18 November 2010

As pointed out by Jean-Claude Trichet, the financial crisis from the years 2007-2009 revealed imperfections in existing economic modeling techniques. The standard Dynamic Stochastic General Equilibrium (DSGE) models, widely used by central bankers and policy makers around the world, proved not to capture the intriguing complexity of the global financial sector nor could they have reproduced the boom and bust scenarios which are observed in the real world (Buiter, 2009). In fact, paraphrasing Charles Goodhart from the Bank of England, the standard central banking "excludes everything that [we shall be] interested in".

The failure of these models might be largely attributed to several simplifying assumptions which they are built upon. To the most widely criticized belong the Rational Expectations Hypothesis (REH) and representative agent structure (Frydman and Goldberg, 2007), linear dependencies (Hommes, 2013) and the absence of the well-characterized financial sector (Bernanke et al., 1999; Tovar, 2008). Those shortcomings used to be neglected for many years as the global economy was growing steadily with little fluctuations, making the DSGE models powerful tools which provide a coherent framework for policy discussion and analysis. The beauty

of their simplicity turned, however, into their biggest nightmare as the recent financial crisis erupted. Their forecasting accuracy, highlighted on pre-crisis samples (see e.g. Christoffel et al. (2010)), in terms of Root Mean Square Error (RMSE), proved to be no better than naive forecasts (Edge and Gürkaynak, 2010).

As pointed out by Tovar (2008) "[d]espite the rapid progress made in recent years, at their current stage of development, these [DSGE] models are not fully ready to accomplish all what is being asked from them". The goal of this thesis is therefore threefold. Firstly, it contributes to the ongoing debate on economic modeling by investigating economic dynamics under heterogeneous market structures. Secondly, it proposes econometric concepts of assessing the influence of nonlinear profiles in economic relationships. Thirdly, it studies the role of the network structures in the shock propagation mechanisms of the global economy. Because of their extraordinary relevance in the real world, a lot of attention is being paid to banking and financial markets.

The role of expectations

The general equilibrium models, like the Real Business Cycle (RBC), developed by Kydland and Prescott (1982), or the new Keynesian framework, pioneered by Clarida et al. (1999) and Woodford (2003), assume at the micro level the utility-maximizing consumers, profit-maximizing companies and market clearing for all goods at all dates in all markets (Hommes, 2013). A subtle assumption of rational expectations helps to solve the models analytically and derive the macro behavior directly from the micro founded principles.

REH has a long history in economics, ranging back to the seminal papers of Muth (1961) and Lucas (1972). It states that on average economic agents act as if they could predict future outcomes perfectly. That means that the incorrect expectations cancel out with each other or are being eliminated by natural selection (Friedman, 1953) and at the aggregate level one observes perfectly accurate foresight. In mathematical terms this is parallel to equalizing a variable today

to its expected value in the market clearing equilibrium tomorrow (Garcia, 2011). Exploiting the mathematical courtesy of REH, studying the macro behavior is as easy as looking at the one representative (or average) agent and associating it with the aggregate decision making process, as in equilibrium everybody shall have the same model consistent expectations without any systematic errors.

Nevertheless, REH oversees the possibility that the incorrect expectations might be self-enforcing instead of being self-mitigating. Indeed, if bad decisions today lead to even worse decisions tomorrow this feedback mechanism might be of great importance for the aggregate economic dynamics (Frydman and Goldberg, 2007), driving the system further away from the fundamentals and creating possible bubbles. This type of feedback structure has been already recognized in the literature; for instance Soros (2003) refers to it as *vicious cycles* and Brunnermeier (2009) calls it by simply *spirals*. Frydman and Goldberg (2007) highlight that REH is very susceptible to this type of expectational dynamics.

Although, in the literature there is no consensus on how to represent economic expectations, their role and especially the influence of their interactions are an extremely important aspect of modern economic modeling (Stanislawska and Tomczyk, 2010; Evans and Honkapohja, 2001; Hommes, 2013). Recently, however, one has observed a paradigm shift from REH to the ideas of bounded rationality and heterogeneous expectations (see e.g. Conlisk (1996); Brock and Hommes (1997); Branch (2004); Branch and McGough (2009)). The reasoning behind boundedly rational agents is attributed to Simon (1955, 1957). Simon points out that because of the lack of information or limited cognitive and computing capacities, individuals might not be perfect forecasters nor optimizers but rather they tend to use simple heuristics in their decision making process when acting under uncertainty. This view has been widely confirmed in laboratory experiments (Tversky and Kahneman, 1974), proving that in reality these simple rules of thumb might lead to significant biases so that the incorrect expectations do not necessarily cancel out as suggested by REH.

This in fact puts in conflict the idea of a representative agent structure, widely present in

DSGE models. In a situation where the agents are boundedly rational they do not have to share the same information set nor use the same heuristics in forming their expectations. The *ex ante* individual prediction might thereof not coincide with the *ex post* aggregate realizations but certainly they affect them. As a consequence, the beliefs of some agents might indirectly influence the beliefs of others so that the economy becomes an expectational feedback system (Hommes, 2013). Heterogeneous expectations have been confirmed both in laboratory experiments (Hommes, 2011, 2013) and in the survey studies (Carroll, 2003; Mankiw et al., 2003) and tend to be an intriguing and thought-provoking phenomenon for economic modeling.

Heterogeneous expectations, together with boundedly rational agents, proved to generate complex structures and interesting nonlinear economic dynamics in the DSGE framework (see e.g. Branch and McGough (2010) or Massaro (2013)). Therefore, they might be an alternative to the standard model assumptions, pointing out a direction for future developments. In this thesis, Chapter 2 is fully devoted to these intriguing phenomena in the DSGE new Keynesian framework with an active banking sector.

Nonlinear dynamics

The standard linear framework fits nicely in globally stable systems which are close to equilibrium. It performed tremendously well from the mid-1980s till 2006, a period often referred to as the Great Moderation, when the global economy was at a stable growth path. In the absence of large shocks, the system was settling down to its local equilibrium and the concerns arising from possible threats and risks were underestimated by both financial markets and macroprudential authorities (Blinder, 2013).

As it is known in the mathematical sciences, the dynamics around a steady state might be approximated by log-linearization. However, moving further away from that point, log-linearization produces less accurate approximations. Consequently, the linear economic models could misperceive the risks which are further away from a given equilibrium point. In fact this

was clearly visible when the US housing bubble collapsed in years 2006/2007 materializing all the risk which the world economy had been accumulating during the Great Moderation (Blinder, 2013). Nobody had expected such a big shock nor the continuing recession in the majority of advanced economies.

Linear models offer attractive mathematical properties, making them relatively easy to solve analytically. These simplifications, however, might have not kept up with the changes in the globalized and heavily digitalized economy. As pointed out by Alan Blinder, the former Vice Chairman of the Board of Governors of the Federal Reserve System, in the years before the crisis "the complexity went amok" (Blinder, 2013). Because of their design, purely linear models cannot capture the sophisticated and complex nature of the modern financial system. The need for new (nonlinear) analytical methods has been therefore widely signalized by professionals (Buiter, 2009).

The role of the financial sector and monetary policy

The importance of the financial sector (often referred to as simply banking) in economic modeling has already been recognized and included in more sophisticated models. Nevertheless, the standard RBC and the new Keynesian models are built around the Efficient Market Hypothesis (EMH), in which no financial disequilibrium is possible (Krugman, 2009). The commonly used view among practitioners highlights the inevitable link between the real economy and its financial side, especially when the presence of the latter provokes frictions and market imperfections (Bernanke et al., 1999), or may even cause significant real disturbances (Blinder, 2013).

The topic of financial frictions has attracted a lot of attention recently (Brunnermeier, 2009). Nevertheless, the recent developments in financial engineering and accounting, like emergence of Structured Investment Vehicles (Tabe, 2010), heavy leverage (Blinder, 2013), novel financial products (Datz, 2013) and global exposures and imbalances (International Monetary Fund, 2013), made it more complex in nature not only for regulators and financial authorities but also

for financial markets themselves (Datz, 2013).

As a consequence, in order to stabilize the markets and to bridle the financial complexity in the aftermath of the crisis 2007-2009, a huge mandate was given to central banks in advanced economies, like Federal Reserve, European Central Bank or Bank of Japan (International Monetary Fund, 2013). The role of standard monetary policy, i.e. stabilization of inflation dynamics (or in the US also the production level) by controlling the nominal short-term interest rates (Woodford, 2003), has evolved into something often referred to as *modern monetary policy*. Under the latter, central banks are allowed to manipulate long-term interest rates and bail-out troubled markets, or more generally as Mario Draghi, the President of the ECB, famously pledged "[to do] whatever it takes". The implications put central bankers and the modern monetary policy into an urgent need for better tools, designed to capture the complex dynamics of the global economy. This is why the ideas presented in this thesis are assessed through a prism of monetary policy and banking.

Thesis outline

The methods developed and applied in this thesis aim to contribute to the ongoing discussion on the fascinating, rapidly changing and *primo loco* highly nonlinear profile of the financial world, being a potentially attractive standpoint for policy makers and practitioners. Chapter 2 studies the implications of a presence of boundedly rational agents in a monetary policy framework with an active banking sector. Chapters 3 and 4 develop econometric tests of studying nonlinear Granger (1969) causal relations in two different settings. Chapter 5 is a result of my stay at the International Monetary Fund (IMF) in the Summer of 2013 and presents an application of the network modeling to the global banking sector and sovereign bond market and explores the role of safe havens in shock propagation mechanism. Chapters 2-4 are published as working papers at the National Bank of Poland and Center for Nonlinear Dynamics in Economics and Econometrics (CeNDEF) at the University of Amsterdam; Wolski (2013b) is based on Chapter 2, Diks

and Wolski (2013) is based on Chapter 3 and Wolski (2013a) is based on Chapter 4. Chapter 5, co-authored by Franziska Ohnsorge and Y. Sophia Zhang, is forthcoming as an IMF working paper. The ideas contained in this thesis aim at encouraging a thought-provoking discussion on the nature of nonlinear structures in economic dynamics and econometrics and shall not be associated with views of any of the aforementioned institutions nor their policies.

Chapter 2 investigates the phenomenon of heterogeneous expectations, analyzing their role in monetary policy conduct with an active banking sector. In addition to fundamentalists, we assume a constant fraction of boundedly rational agents who use simple heuristics to form their expectations. We focus on two types of heuristics which are most commonly referred to throughout the literature (Hommes, 2013), i.e. adaptive and extrapolative expectations. Both assume that future realizations depend on the past performance of particular variables, however, the former assumes that the influence of past realizations decreases over time whereas the latter manifests the opposite. The impact of those biased beliefs is studied in the aggregate economy framework with an active banking sector, originally developed by Goodfriend and McCallum (2007). We first show that the presence of the banking sector changes the determinacy structure of the system and, depending on the heuristics used, the presence of boundedly rational agents might have either stabilizing or destabilizing effect. In particular, when boundedly rational agents have extrapolative expectations, the range of the stable (determinate) monetary policy instruments is narrowed.

In Chapter 3 we propose an extension of the nonlinear Granger causality test, originally introduced by Diks and Panchenko (2006). We show that the basic test statistic lacks consistency in the multivariate setting. The problem is the result of the kernel density estimator bias, which does not converge to zero at a sufficiently fast rate when the number of conditioning variables is larger than one. In order to overcome this difficulty we apply the data-sharpening method for bias reduction (Hall and Minnotte, 2002). We then derive the asymptotic properties of the sharpened test statistic and we investigate its performance numerically. We conclude with an empirical application to the US grain market, as it creates an ideal environment to test our

methodology. Chapter 3 does not exploit the financial markets explicitly and might be treated as a general introduction to the topics covered in the Chapter 4. Nevertheless, nonparametric Granger causality tests have been widely applied to financial time series (for instance to exchange rates in Bekiros and Diks (2008a) and to crude oil prices in Bekiros and Diks (2008b)) so that one may easily extend our reasoning to a different financial setting. In fact, Chapter 4 is closely related to Chapter 3 and raises the discussion on nonparametric Granger causality testing to the financial environment.

More specifically, Chapter 4 proposes a new methodology of assessing the effects of individual institution's risk on the others and on the system as a whole. We build upon the Conditional Value-at-Risk approach. However, we introduce explicit Granger causal linkages and we account for possible nonlinearities in financial time series. Conditional Value-at-Risk-Nonlinear Granger Causality, or NCoVaR as we call it for simplicity, has regular asymptotic properties which makes it particularly appealing for practical applications. We test our approach empirically and assess the contribution of the euro area financial companies to the overall systemic risk. We find that only a few financial institutions pose a serious *ex ante* threat to systemic stability risk, whereas, given that the system is already in trouble, there are more institutions which hamper its recovery. Moreover, we discover non-negligible nonlinear structures in the systemic risk profile of the euro zone.

In Chapter 5 we create a network of bilateral correlations of changes in sovereign bond yields and individual bank equity price changes. We study the nature and the evolution of this network in the years 2000-2013. We show that, in this context, safe havens have an intuitive representation as countries in which changes in sovereign bond yields and bank equity prices are positively correlated. Safe havens, however, have one additional feature, i.e. their asset prices are highly correlated with those of other countries making them hubs for capital flows. We investigate how these two properties of safe havens have affected the propagation of bank and sovereign shocks in our asset price network since 2000, in a simple shock propagation framework. On balance, we find that the presence of safe havens has amplified shock propagation.

Chapter 6 concludes and offers some ideas for future research on nonlinear dynamics in economics and econometrics.

Each chapter is a self-contained manuscript, with separate introduction, summary and appendices, and might be read independently from other chapters. For the reader's convenience, the common bibliography is collected at the end of the thesis. A digital copy of these pages can be found in the online libraries of the Universiteit van Amsterdam (www.uba.uva.nl) and Universität Bielefeld (www.ub.uni-bielefeld.de).