Personal Research Statement - 2016*

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I am a macroeconomist with both theoretical and empirical interests. My research concentrates on two main areas: macroeconomics as relevant for monetary policy and applied macroeconomics or macroeconometrics. I also have additional papers outside of these two core areas. Note that this research statement mostly excludes the papers written before 2010 and a description of my research agenda as of 2010 can be found in my research statement from 2010, which is on my webpage.

1 Macroeconomics as Relevant for Monetary Policy

The last two decades saw increasing use of models in the conduct of monetary policy, with macroeconomists developing theoretical and empirical frameworks. Two key developments in this field, both of which have their roots in groundbreaking work in earlier decades, were dynamic stochastic general equilibrium (DSGE) models and vector autoregressions (VAR). The broad results that emerged from this literature as of around 2007 – just before the financial crisis – was that surprise changes in monetary policy can have large and long-lasting real effects, and a DSGE model, which has a number of optimizing agents that interact in markets, is able to capture this. A large body of research was conducted in the 2000s both on the positive and normative fronts using the so-called New Keynesian model as the workhorse model, enhancing our understanding of the interaction between monetary policy and the economy as a whole.[1]

*Refer to my CV at http://www.boraganaruoba.com for references to my papers.

[1]I want to make it clear that the question of whether or not we have a good model of the economy where all aspects of the model are immune to the Lucas (1976) critique, i.e. can be considered invariant to the policy regime, is far from settled. Various aspects of the New Keynesian model are at odds with micro evidence or otherwise found to be susceptible to changes as monetary policy regimes change. This leads some economists to dismiss the model and its implications for monetary policy altogether. I have a more agnostic, perhaps more scientific view where I would like to write down models, test them and ultimately, possibly, refute them using data. I believe that this line of research will still be useful for policy makers as long as the caveats or assumptions associated with it are well understood.

The financial crisis of 2007-2008, the Great Recession of 2007-2009 and the ensuing period of near-zero interest rates changed many things. Three aspects of this change are noteworthy, at least as they relate to my research: (1) the need to understand the interaction between the financial side and the rest of the economy, as well as shocks to the financial side, (2) the end of the Great Moderation, or at least a pause, with large shocks affecting the economy and (3) a prolonged period where monetary policy as we know it was constrained. Much of my research in recent years was related to points 2 and 3 above and I have started new projects where point 1 is key.

1.1 Completed Work

I completed three papers in this area since 2010. Two related papers, Aruoba and Schorfheide (2010, 2011) were completed prior to 2010. See my 2010 research statement for details about these papers. This research agenda has been supported by the National Science Foundation with two grants (both with Frank Schorfheide as a co-principal-investigator): "Monetary DSGE Models: Advances in Theoretical Modelling and Econometric Analysis" (2011-2013) and "Monetary DSGE Models at the Zero Lower Bound: Policy Analysis and Economic Inference" (2014-2017).

1.1.1 "Macroeconomic Dynamics Near the ZLB: A Tale of Two Countries"

(with Pablo Cuba-Borda and Frank Schorfheide, revision submitted)

This paper starts from the simple, yet powerful observation by Benhabib et al. (2001a,b): when a Taylor rule (for monetary policy) is combined with the zero lower bound (ZLB) of nominal interest rates, there are multiple equilibria. In the absence of any shocks (i.e. steady state), the economy can settle near the central bank's target inflation and a positive interest rate, or near zero interest rates and a negative inflation level. What we do in this paper is to extend this analysis to an environment with two regimes – each regime resembles the two equilibria I mentioned above – where a sunspot variable coordinates people's expectations about which regime will prevail every period. We complement this sunspot variable with a set of structural shocks. At the end, we have a model where the economy spends some time around the central bank's inflation target, fluctuating due to the structural shocks and sometimes switches regimes and spends time near the ZLB with mostly negative inflation rates. On the technical side solving such a model is very challenging and we combine state-of-the-art methods with some twists to do so.[2] On the substantive side, we address an

[2] We use a piecewise smooth approximation (as opposed to a more standard smooth approximation) where all decision rules allowed to inherit the kink from the ZLB and we identify parts of the state space in which that our solution needs to be accurate via both simulation (to get a sense of the ergodic distribution)

important question that many economists and policy makers have been worried about after the financial crisis: why does Japan seem to be stuck at the ZLB with an average inflation of -1% for the last 20 years and can that happen / is it happening in the United States? Economists had argued that the experience of Japan had a close link to what Benhabib et al. (2001a,b) had discussed, but this had not been shown in a rigorous way. We do so in this paper. After solving the model for each country, we use a nonlinear (particle) filter to extract the underlying shocks, including the sunspot variable, that best explain the data. There are some nuances, but in a nutshell our results show that both economies were in the targeted-inflation regime prior to their ZLB episodes, and while the United States remained there with a high probability, Japan did not and switched to the deflation regime.

1.1.2 "Assessing DSGE Model Nonlinearities"

(with Luigi Bocola and Frank Schorfheide)

We start this paper with a challenge. Most macroeconomic models, at least as parameterized to match the data during the Great Moderation, are roughly linear. This observation makes our life (relatively) easy: we can use well-known and computationally-efficient methods to solve (e.g. perturbation) and estimate (e.g. likelihood-based methods utilizing the Kalman filter to obtain the likelihood function) these models. However, this result mostly relies on the researcher solving and/or estimating the same model using linear and nonlinear methods and comparing results. This may give one (a perhaps false) sense of security since it does not address a deeper question: what kinds of nonlinearities are there in the data and are our models able to capture these? In this paper we take a first stab in addressing this issue for a particular kind of nonlinearity, one where there are no kinks. This could be the result of, for example, high curvature in the utility function and/or large volatility for shocks. We develop a new statistical model that we call QVAR (quadratic vector autoregression) model which generalizes a VAR by including squared terms for the dependent variables and interactions of lagged dependent variables with current innovations.[3] We propose an intuitive procedure to answer the question I posed above. First we estimate the QVAR using actual data and obtain credible sets for the parameters of the QVAR. To the extent that the credible sets for the "nonlinearity" parameters exclude zero, we conclude that there are some nonlinearities in the data that can be captured by the QVAR. Next, we take a DSGE model and we simulate many artificial data paths from the model that is of the same length as the original data. We estimate the QVAR on each of these paths and generate posterior predictive distributions for each parameter. If the parameter estimate from the actual data

and filtering (to reflect the region where the ZLB is binding).

[3] There are some technical issues which we discuss in the paper that make this a nontrivial extension. At the end, the model is specified as a state-space model.

(the median of the posterior distribution) lies within the distribution from the model, we can conclude that this particular nonlinearity can be generated by the DSGE model. The application in the current version of the paper uses a standard New Keynesian model (without the ZLB) and investigates the nonlinearities in the data for output growth, inflation and the nominal interest rates. We are currently working on a more interesting application where we focus on a measure of labor supply (say hours) and labor productivity and investigate if the nonlinearities in the data can be captured by a DSGE model with asymmetric adjustment costs.

1.1.3 "Inflation During and After the Zero Lower Bound"

(with Frank Schorfheide, *2015 Jackson Hole Symposium Volume*, 2016)

This paper is an off-shoot of the "tale of two countries" paper and was solicited by the Federal Reserve Bank of Kansas City for their 2015 Jackson Hole Symposium. We do three things in this paper. First, using a statistical model that is known to be a good descriptive model of inflation, we assess the probability of deflation in the short-to-medium run for the United States, Japan and the Euro Area. We find that there is a less than 20% probability for observing deflation in the United States or the Euro Area, but a substantial one for Japan. Second, we repeat our analysis in the "tale of two countries" paper to include the Euro Area. We find that with the data we had access to (through the first quarter of 2015), the evidence of a switch to a deflationary regime was small. Finally, we consider an experiment where the Federal Reserve changes its inflation target to 4%, either historically back in 1984 or in 2013. We find that, ignoring some of the unmodeled costs of such a move, if the Federal Reserve had this target starting in 1984, the recession in 2008 would have been milder and recovery would have been quicker, primarily because the Federal Reserve would have room to conduct more expansionary policy in 2008-2009. We find, however, that a surprise change in 2013 would have no significant positive effects.

This paper is very much representative of the questions I am interested in and my research approach. The idea of increasing the inflation target of the Fed has been floated by some prominent economists but a careful cost-benefit analysis has not been provided. In this paper, admittedly focusing on only a subset of possible channels that affect welfare, we do this kind of an analysis, using a DSGE model that is suited for this analysis.

1.2 Ongoing and Future Work

I have two current projects, each of which may involve multiple papers in this broad area.

First, I am working with models where financial frictions and/or shocks interact with the

ZLB constraint on monetary policy. From a technical point of view, these models involve two occasionally-binding constraints (the ZLB constraint and a financial constraint), which make them extremely hard to solve. From a substantive point of view, there are at least two insights these models can give us that their counterparts in the literature may not. First, in 2008-2009, two things happened simultaneously in the United States. A large financial crisis was triggered and monetary policy pushed the interest rate to the ZLB. However arguably from 2010 or so onwards, the financial crisis subsided, yet the ZLB remained in place. So a realistic model that aims to capture this episode should allow for each constraint to bind independently from the other. Second, a large debate in the literature is the "missing deflation puzzle" (given the large decline in real activity during and after the Great Recession, a simple Phillips curve relationship would predict a large decline in inflation, likely to deflationary levels, something that did not happen), which prompted some economists to dismiss the DSGE models that were used extensively pre-crisis. It is reasonable to think that the link between the real side of the economy and inflation (essentially the Phillips curve) may change drastically as different constraints become binding. If this is true then we should not be judging the performance of a pre-crisis DSGE model that ignores either of the constraints we are considering.

Second, we are working on developing methods that can efficiently estimate nonlinear models. Our vision is that for any reasonable analysis with DSGE models to be conducted post-crisis, the estimation method should be able to handle changes in regimes with large nonlinearities (like the kink created by the ZLB). Current methods (such as the particle filter) require an immense amount of computational power, which makes "everyday" analysis impossible. We are hoping to develop methods that do just that.[4]

2 Applied Macroeconomics

I also have a broad interest in applied work in a variety of topics in macroeconomics. The common theme across much of this work, as was the case above, is policy relevance. In the three papers written since 2010 that I summarize below and in my earlier work summarized in my research statement from 2010, I either assess the effect of policy or develop methods or measures that would help policy makers better monitor the economy. The Federal Reserve Bank of Philadelphia produces three products based on my research – two of the three papers below and the earlier paper "Real-Time Measurement of Business Conditions". These

[4]For example, in Aruoba Cuba-Borda and Schorfheide (2016) simply using the particle filter for a given set of parameters turns out to be time consuming. The focus of our agenda is to use a fairly simple solution such as a piecewise smooth one (solved globally) and adapt the particle filter to efficiently handle the filtering.

are "GDPplus," "Aruoba Term Structure of Inflation Expectations," and "Aruoba-Diebold-Scotti Business Conditions Index."

2.1 "Term Structures of Inflation Expectations and Real Interest Rates"

(submitted)

In this paper I start from a simple observation. The Nelson-Siegel model has been a very good description of the yield curve, both dynamically and in the cross-section. One can think of another curve – the term structure of inflation expectations – where we plot the expected inflation over various horizons. These two curves should be quite similar in how they look: smooth with no drastic changes in curvature and perhaps one peak. Thus, I set out to model the inflation expectations curve using the Nelson-Siegel model. The raw data comes from two key surveys, the Survey of Professional Forecasters and the Blue Chip Survey. These surveys contain many questions that fill in points in the inflation expectations curve and with the structure of the Nelson-Siegel model, I am able to combine the information in all these questions to extract an estimate of the curve. In the paper I show that the forecasts obtained from the curve I compute are at least as good as some competitors, especially those that use information that comes from financial markets, if not better. I also compute a real yield curve combining the nominal yield curve and the inflation expectations I generate. Using these two curves, I analyze the impact of the unconventional policies of the Federal Reserve between 2008 and 2015. My results show that the Federal Reserve was able to keep long-run inflation expectations anchored while providing a massive amount of stimulus via low (and mostly negative) real interest rates.

2.2 "Improving GDP Measurement: A Forecast Combination Perspective" and "Improving GDP Measurement: A Measurement Error Perspective"

(with Frank Diebold, Jeremy Nalewaik, Frank Schorfheide and Dongho Song, *Recent Advances and Future Directions in Causality, Prediction, and Specification Analysis: Essays in Honor of Halbert L. White*, 2012 and *Journal of Econometrics*, 2016)

These two papers have a simple objective. In principle gross domestic product (GDP) computed from the expenditure side should be identical to the one computed from the income side. In practice, they are not. The Bureau of Economic Analysis (before we wrote these papers) focused almost exclusively on the expenditure-side measure and the income-side measure was buried deep inside the releases. We wondered if we could do better by

combining the two measures, putting them on equal footing. In the "forecast combination" paper we do this treating the two measures as forecasts of the underlying GDP. Once one does so the celebrated result of forecasting applies – a combination of two unbiased forecasts is more accurate than each individual forecast (unless they are perfectly correlated). Our results in that paper suggest that the best forecast can be constructed by combining the two measures with the weight of the income-side measure a little over 50%.

The "measurement error" paper sets up a simple state space model which assumes that each of the two measures is equal to true GDP plus a measurement error. We show various ways such a state-space model can be identified. We extract a measure of GDP and show the differences between this measure and the traditional expenditure-side measure.

3 Miscellaneous

I have a number of completed papers and projects in the works which cannot be easily pigeon-holed into categories with my other work since 2010. These are spurred by the broad interests that I have in macroeconomics as a whole, and in some cases the insight that I could apply some of my existing skills outside of the domains in which I had developed these skills.[5]

3.1 Completed Work

3.1.1 "Homework in Monetary Economics: Inflation, Home Production and Production of Homes"

(with Morris Davis and Randall Wright, *Review of Economic Dynamics,* 2016)

We start with an interesting observation from the data for the United States and many other countries; there seems to be a positive long-run relationship between inflation and the value of home capital (the sum of the value of the land, the structure and the durable goods in a house), appropriately deflated. We develop a model that includes monetary exchange, home production and production of homes. A calibrated version of the model is able to capture most of the quantitative relationship we find in the data.

3.1.2 "A Comparison of Programming Languages in Macroeconomics"

(with Jesus Fernandez-Villaverde, *Journal of Economic Dynamics and Control,* 2015)

We wrote this paper primarily to provide a benchmark for graduate students or macroeconomists who are interested in learning a new programming language. We pick a fairly

[5] I am currently revising "Informal Sector, Government Policy and Institutions", whose first draft was written in 2009. See my research statement from 2010 for details of that paper.

challenging but standard problem in macroeconomics and write a code in close to ten different languages, using different compilers or approaches, where available. The goal is to compare the running time and difficulty of the codes across these languages in as controlled a way as possible. We find that Fortran and C++ perform much better than the competition, while languages such as Julia which has just-in-time compiling, or MATLAB with the option to compile parts of the code using C++ or Fortran, provide excellent alternatives to Fortran or C++, which are more tedious to use.

3.1.3 "A Structural Model of Electoral Accountability"

(with Allan Drazen and Razvan Vlaicu, submitted)

This is a paper that uses structural estimation methods to answer an important question in political economy. Does the accountability provided by elections improve outcomes for the voters and if so, how? At least two important reasons are provided for this in the literature: discipline (by promising to reward good behavior in office the voters get better performance in early terms) and selection (politicians that do not perform in office are identified and replaced by new ones). While there have been attempts at measuring the importance of these two channels using reduced-form methods, a structural approach has not been used in the literature before. We fill this gap and estimate one of the workhorse models of political economy, the political agency model. Our results show that the two channels have about the same size with discipline being somewhat larger. We also find that the commonly-used two-term regime in the United States for governors improves the welfare of voters by 4.2% relative to an alternative regime with a one-term limit.

3.2 Ongoing and Future Work

Recently I became interested in using micro-level data to answer some important macro questions. These datasets include the Nielsen datasets at the Kilts Center for Marketing at Chicago Booth and CRISM dataset from the Federal Reserve Bank of Philadelphia. There are multiple teams that include my colleagues Sebnem Kalemli-Ozcan, Felipe Saffie, Luminita Stevens and Ronel Elul from the Federal Reserve Bank of Philadelphia. The questions we are interested in include the effect of the house-price decline on consumption at an individual level, and how individual-level (micro) responses to the financial crisis aggregate up to macro responses. Results are too preliminary to include here but I hope to have first drafts of multiple papers in late 2016 or early 2017.

References

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