Personal Research Statement*

S. Borağan Aruoba
University of Maryland

August 17, 2010

I am a macroeconomist with both theoretical and empirical interests. My research concentrates on two main areas: monetary economics and applied macroeconomics or macroeconometrics. I also have a few less closely related papers resulting from ideas generated while working on my core research areas. Section 1 of this research statement focuses on my work in monetary economics. I start by providing some background to put my work in perspective, followed by a summary of my completed work and ongoing projects. In Section 2, I summarize my work in macroeconometrics. In Section 3, I briefly discuss my papers that do not naturally fit in to either of the two categories. For references to my papers please refer to the enclosed vita.

1 Monetary Economics

Macroeconomics has experienced a decisive move towards microfoundations over the last 30 years, following the influential work of Nobel laureates Robert Lucas and Edward Prescott and many others. This has meant that macroeconomic models are built by carefully specifying the environment in which the decision-makers in the economy operate, being explicit about their preferences and endowments, as well as the technological constraints of the economy. A key feature of this approach, perhaps best exemplified by Lucas's (1976) critique, is distinguishing between structural and reduced-form relationships.

While this trend is clear in many parts of macroeconomics, monetary economics seems to be lagging behind, especially in terms of policy-relevant research. Many current models that contain money typically motivate a demand for money through "reduced-form" constructs, for example, by assuming that money is just like another good that gives utility to households (presumably because it provides some benefits such as making transactions easier), or by

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

assuming a fraction of goods have to be purchased using money. I, and many others, label these models reduced-form, since while they certainly have empirically reasonable outcomes, these models leave much to be desired. For example, they are silent about when a monetary equilibrium exists, that is when money is valued and when it is not valued. Or when there are multiple objects that can in principle serve the role of money, the models do not provide insights into which objects are used as media of exchange? In Kareken and Wallace's (1980) terminology, these models have too few implications. Moreover, many macroeconomic models that are used for policy-relevant research, e.g. those discussed in Woodford (2003), are "cashless" in that they do not explicitly model why the households in the economy may want to hold money. This feature is driven by both an effort to avoid making ad-hoc assumptions about money demand that may influence the answers the papers seek, and the belief that frictions related to money demand are negligible relative to others that these models feature.

A series of seminal papers by Kiyotaki and Wright (1989, 1993) took significant steps in thinking about microfoundations for money demand by providing a careful description of the frictions that result in the use of an intrinsically worthless object, commodity or fiat (government-issued) money, as a medium of exchange. These frictions, which may be relaxed and restated in various ways, are lack of perfect record-keeping (so that credit is not always available) and a lack of double coincidence of wants (so that two agents would want to trade in the first place). Various papers provided extensions, relaxing some of their restrictive features. Lagos and Wright (2005) is perhaps the state-of-the-art model in this literature.[1] It features a decentralized market where money is valued in bilateral trade when the two frictions I mentioned above are present, and a centralized market which is a standard frictionless market.

My broad research agenda in this area can be summarized by the following three objectives:

- Building models that contain many of the features commonly used in macroeconomic models and that also contain a microfounded demand for money.
- Making progress in quantifying these models and taking them to the data (either via calibration or formal estimation).
- Using these models to answer policy-relevant questions.

In sum, the main goal I seek to achieve is to continue to build a microfoundations of monetary economics within macroeconomics, demonstrating along the way that the modeling

[1] Shi (1997) takes a related but different route than Lagos and Wright (2005). While there may be valid criticisms for both approaches, choosing one or the other is essentially a matter of taste.

of money demand matters for policy.

1.1 Completed Work

Below I discuss three of my papers in this area that I find most important and representative. I also mention my other papers briefly.

Shortly after the Lagos-Wright (LW) model made its debut, I started thinking about extending this model. Whereas in LW the frictionless centralized market (CM) was introduced as a "trick" to overcome some technical problems, **Aruoba and Wright (2003)** take the CM more seriously and introduce capital and labor markets and firms in to the CM. This is the first attempt at integrating mainstream macroeconomic models and microfounded models of money, but with modest success: the two models end up living side by side rather than interacting in an interesting way.

We follow up this paper in **Aruoba, Waller and Wright (2008)** [AWW] where we change a key assumption in order to remedy the problem in the previous paper: we allow the sellers in the decentralized market (DM) to have access to capital for production purposes. This means that investment decisions now take into account the benefit of being able to use capital in the DM, as well as in the CM. This changes the implications of the model drastically since the frictions in the DM, as well as inflation, have profound effects on capital accumulation.

More specifically, when the terms of trade in the DM are determined via bilateral bargaining, agents internalize the fact that their actions directly influence the terms of trade. This leads to an investment holdup problem, where the households under-invest in capital because they understand that the benefits of this investment will be shared with their trading partner.[2] The fact that the microfundations of money intrinsically lead to a holdup problem involving capital is a novel finding that has significant policy implications, as this paper and a number of my subsequent papers demonstrate.

From a theoretical perspective, the major contribution of this paper, in addition to the investment holdup problem, is the development of a general equilibrium model that has most of the key features of modern macroeconomic models and has a microfounded motive for money demand. This model can be and is used as a benchmark that can be used to build more complicated models to analyze monetary issues, just as the neoclassical growth model serves this role for building real models. From a quantitative perspective, this paper is the first to take a variant of the model developed in Lagos and Wright (2005) to the data by calibrating

[2] A holdup problem occurs when an agent makes an ex-ante, costly and irreversible investment decision whose ex-post return can be appropriated by another agent.

it using some real and nominal calibration targets. From a normative perspective, this paper shows that the additional frictions generated by the monetary environment significantly alter the welfare cost of inflation.[3]

Having investigated the long-run aspects of the model, in **Aruoba (2011)** I turn to the short-run. I demonstrate that a number of different versions of the model developed in AWW perform no worse than a typical flexible-price reduced-form model, with a particular version showing some modest improvements. The model is also able to generate a counter-cyclical markup, in line with many empirical studies. While more work is certainly necessary, this paper establishes that in terms of their positive implications, the search-based models are promising.

I continue investigating both the positive and normative implications of the model in AWW in a series of papers, . which bring together my two major interests (search-based models and macro-econometrics). In **Aruoba and Schorfheide (2010a)** we have three goals. First, we extend the model in AWW to feature some nominal rigidities, frictions that lead to firms not changing their prices every period. Doing so enables us to relate our results to the so-called New Keynesian literature. This is especially useful because a typical paper in the New Keynesian literature abstracts from any explicit money demand motive: one can view our model as introducing such a motive into a cashless New Keynesian model by introducing the DM where the frictions create a role for money.

Second, we estimate this model using post-war U.S. aggregate data, utilizing Bayesian methods. This paper is the first to formally estimate a model based on the Lagos-Wright framework.[4] We compare the performance of our estimated model to two models: an unrestricted vector autoregression (VAR) and a version of an estimated New Keynesian model where money demand is introduced via a separable utility function for money (MIU model). We find that both the search-based model and the MIU model perform significantly worse relative to the VAR in terms of their marginal likelihoods. Comparing the two among themselves, we find that the MIU model fits the data better than the search-based model. I will touch upon this result in Section 1.2.

Third, we use the estimated model to measure the relative strengths of two channels through which central bank policy influences welfare in the longrun. First, holding money is costly due to the foregone interest from not holding a nominal bond. This channel is shut

[3] In addition to the investment holdup problem I explained above, there is also a similar holdup problem on money demand whereby households do not hold the socially efficient amount of money.

[4] We also have two contributions to the growing DSGE-estimation strand of the literature: since we take money demand seriously in our model, we also use a monetary measure (inverse velocity) as an observable, which is not very common and we use a time-varying inflation target to capture the different monetary policy regimes in our estimation sample.

down when the long-run inflation rate equals minus the real interest rate, yielding a zero nominal interest rate. Second, due to the nominal rigidities present in the model, deviation of the long-run inflation rate from 0% (in either direction) creates a welfare loss. Since we estimate our model, we are able to take parameter uncertainty into account when we calculate these welfare losses. Our results show that the two channels are similar in strength. Thus, based only on these two channels, the optimal longrun policy is away from 0% inflation, since the first channel, which can only be measured by having an explicit money demand motive, has a significant influence on welfare.

In **Aruoba and Schorfheide (2010b)** we extend our previous paper to allow for the possibility that some of the households' capital may be used as a medium of exchange, along the lines of Lagos and Rocheteau (2008).

In order to contribute to an understanding of normative issues, **Aruoba and Chugh (2010a)** conduct an optimal-policy analysis using the benchmark model in AWW, as well as the model without capital in Lagos and Wright (2005). For certain versions of the model where the money-demand holdup problem is not present, we prove that the Friedman rule of zero nominal interest rate is not optimal. This is because the Ramsey planner finds it optimal to distort the activity in the DM and a deviation from the Friedman rule turns out to be the only way to do this with a just-complete system of tax instruments.[5]

The fact that DM activity is distorted under the optimal policy bears upon investment. Since capital is also used in the DM, the households underinvest in capital. The Ramsey planner chooses to subsidize capital income to offset this inefficiency. Moreover, the investment-holdup problem that AWW emphasized increases the underinvestment, and thus the subsidy.

To my knowledge, this paper is the first one that features a link between monetary policy and capital taxation; in most models the prediction of the monetary model in terms of capital taxation coincides with that of the underlying real model. Moreover, the optimality of the Friedman rule is a very common result in this type of analysis and our contradictory result and the reasons behind it are unique. **Aruoba and Chugh (2010b)** follows up to analyze the quantitative aspects of optimal policy in the model in AWW, looking at the dynamic properties of inflation and other tax instruments under the optimal policy.

Aruoba Rocheteau and Waller (2007) is a paper that I wrote a few years ago that does not fit in the main agenda that I outline above but it helps us understand an important aspect of the model in Lagos and Wright (2005). Another paper that does not fit my broader

[5] A tax system is said to be complete if there is at least one tax instrument that independently influences every margin of adjustment, so that the distortions that the Ramsey planner wants to create can be implemented by a set of taxes. I use the term "just-complete" to denote the case where there is exactly one tax instrument per margin. There can be more than one set of tax instruments that are just-complete.

agenda but uses a search-based monetary model is **Aruoba (2009)**. I will discuss this paper in Section 3.2.

1.2 Ongoing and Future Work

While I believe my research has made significant progress in showing that the modeling of money demand makes a difference for positive and normative questions, there is much to do, especially on the positive side. One significant step would be to provide some proof that the class of models I work on matters – that they tell us something other models cannot. Two immediate ways to argue this may be that these models are on firmer ground since they are micro-founded and that they have different and interesting normative implications. But one can go further. A useful step forward would be to show that these models can indeed capture phenomena that other models cannot. I am currently approaching this on three fronts.

Frank Schorfheide and I are following up on our previous two papers. A useful way of interpreting our results, especially in the first paper, is that the data strongly rejects both the MIU and the particular version of the search-based model we considered, while preferring the former over the latter. We take this as a call for action for developing the search-based models further so that they fit the data better. There are a number of variations one can consider, with the one developed in Rocheteau and Wright (2005) being quite promising. On the normative side, we extend our work in earlier papers to consider stabilization policies, taking into account the steady state trade-off I explained above, as well as the zero-lower-bound (of nominal interest rates) constraint a policy maker needs to respect.

In another ongoing project, I am comparing the macroeconomic implications of a number of reduced-form monetary models with some versions of the search-based model in AWW. Recognizing that a useful way to test macroeconomic models is by looking at their micro implications, in another project I consider a related question, but from the micro side. I am working with micro (consumer) data to investigate if the money demand that is implied by the search-based model can explain micro data better than other alternatives. These projects are at very early stages.

2 Applied Macroeconomics

I also have a broad interest in applied work in a variety of topics in macroeconomics. I believe that such non-structural applied work can be very useful in developing macroeconomic models, since it points to the aspects of the data that models will have to capture. A common thread across my papers in this area is that they highlight some facts that arise from the

analysis of the data that might guide the building of theoretical models. Below I briefly summarize my papers in this area.

2.1 Completed Work

The relationship of the yield curve and the macroeconomy is a topic that is of great interest to policy-makers and financial markets. In **Diebold, Rudebusch and Aruoba (2006)** we address this relationship using a model of the yield curve which is augmented by some macroeconomic variables.[6] We show that there is a bi-directional link between the yield curve and macroeconomic variables. There are many related papers in the literature that focus on only one direction or the other, and our paper is one of the first that emphasizes this bi-directional link. Its estimation strategy, which casts the model in a state-space environment and utilizes a one-step maximum likelihood estimation, is also innovative and extends some earlier work in this literature. To date, this paper continues to influence both theoretical and empirical research in this area and is highly cited.

Aruoba (2008) is the first comprehensive analysis of the statistical properties of data revisions. Using the real-time data set that is compiled by the Federal Reserve Bank of Philadelphia, I show that the final revisions of most macroeconomic indicators, ranging from measures of output and its components to inflation, labor productivity and industrial production, are not "well-behaved", failing to satisfy some common statistical conditions. A direct implication of this is that one cannot (or should not) take the announcements by statistical agencies at their face value. One must assess their reliability more carefully. It also calls for a more careful modeling of the information set of the decision-makers in our economic models.

Policy makers, Wall Street, and Main Street are all interested in finding out about aggregate business conditions. This is especially important around turning points and during recessions. Many different pieces of information about aggregate business conditions come out every day, all of which are noisy signals. A useful way to collect and distill this information is using a factor model, where it is assumed that a small number of underlying factors explain a large fraction of the common movement across observed variables. This is of course a very well-known idea in macroeconomics, applied for example by Stock and Watson (1989) to the measurement of business cycles. In **Aruoba, Diebold and Scotti (2009)** we extend this framework to combine indicators of different observation frequencies. We demonstrate how one can use the state-space framework and the Kalman filter to this end, and provide a prototypical example to extract a measure of economic activity.

[6] We use the Nelson-Siegel model, with the interpretation as a factor model by Diebold and Li (2006).

This paper has had a practical application. We developed this methodology further after the paper was published and the Federal Reserve Bank of Philadelphia expressed interest in producing a real-time measure of economic activity. The Aruoba-Diebold-Scotti Business Conditions Index made its debut in January 2009 and it has been followed widely since then, often cited when new economic data is released. While there are a number of similar (and older) measures available, this index differs from others in that it is produced in real time and combines variables of different frequencies, providing instant feedback whenever new data are released.

In **Aruoba and Diebold (2010)** we apply the same methodology in extracting a measure of inflation. We extract the common component of changes in consumer prices, producer prices, energy and non-energy commodity prices, wages and the GDP deflator. We find that there was a pronounced decline in all prices in 2008, just as the U.S. economy was experiencing one of the worst recessions in history. Moreover, comparing the inflation factor with its real counterpart, we can easily identify demand- and supply-driven recessions and expansions, exploiting the way different shocks affect prices and quantities.

The Federal Reserve Bank of Philadelphia is also interested in producing the inflation index we developed in this paper. We hope to debut this index in the months to come. Especially in a period where there is uncertainty about inflation following the massive intervention by the Federal Reserve during the financial crisis and the recession of 2007-2009, this new measure is sure to be of widespread interest.

2.2 Ongoing and Future Work

An ongoing project, **Aruoba, Diebold, Kose and Terrones (2011)**, extends the methodology of Aruoba, Diebold and Scotti (2009) to the G-7 countries. We proceed in two steps. In the first step, we extract the country-specific common components from a number of indicators for every country. The end result is seven country-specific factors that summarize the business cycles of each country, which yield many country-specific insights. We then proceed to further decompose each country factor into a G-7 factor and a idiosyncratic factor. By using the G-7 factor, we can evaluate the importance of common shocks such as the one to oil prices in 1974. Our preliminary results show that the period between 1975 and 2007 was a period of relative calm as far as common business cycles go, affected slightly by global shocks such as oil-price events. We also verify that the "great recession" of 2008 was by far the worst global event in the 40-year sample, even though it is not so for a subset of

countries, including the U.S.[7] One of the interesting questions in international economics is the effect of globalization on the synchronicity of the business cycles of countries.[8] We find that after a relatively unsynchronized period following the oil price shocks of the 1970s, the business cycles of the G-7 countries have become highly synchronized in the last decade, especially immediately before and during the great recession. Our results also highlight some interesting cross-country stylized facts that can be used to guide theoretical models. In future versions of this paper, we will incorporate more countries. We also hope to make the framework of this paper operational in real-time monitoring of global business conditions to be implemented by an international organization.

Related to my earlier work on yield curves, a natural next step for me, which is an ongoing project, is to integrate my work on yield curves with the work on business conditions described above.

3 Miscellaneous

Three miscellaneous papers cannot be easily pigeon-holed into categories with my other work. These papers were spurred by the broad interests that I have in macroeconomics as a whole and the insight that I could apply some of my existing skills outside of the domains in which I had developed these skills.

One of the insights from my and others' work at the intersection of macroeconomics and public finance is that a government would set fiscal and monetary policy optimally to finance a given amount of revenue by creating the least amount of distortions. When examining a large set of countries, one sees that there is large dispersion in tax rates and inflation rates (the latter reflecting monetary policy). In a paper I recently finished, **Aruoba (2009)**, I investigate how far one can go in explaining this dispersion by using the insight that countries with bad institutions cannot raise enough revenues through taxation, since households easily evade taxes. Governments then have to rely on inflation. In the data, this is indeed true: using a dataset of 118 countries, I demonstrate that countries with good institutions tend to have lower inflation rates, higher taxes and smaller informal sectors (which proxy for the extent of tax evasion). I develop a simple general equilibrium model with an explicit concept of institutions and a government that chooses policies optimally.

[7] In Aruoba and Diebold (2010) we show that in terms of depth, the 1981-82 recession was worse than the 2007-2009 recession while in terms of a combination of depth and length, the 2007-2009 recession was worse.

[8] The theoretical literature has mixed results. In a nutshell, due to the specialization that results from globalization, the business cycles may be less synchronized but since countries face more correlated shocks the reverse result may obtain.

In the model, households decide whether or not they want to engage in informal activity, taking as given both the policies set by the government (larger formal sector taxes and smaller inflation encourages informal activity) and the institutions of the country, which are proxied by the expected punishment for evading taxes. Understanding how its decisions alter private incentives, the government chooses an optimal mix for formal sector taxes and inflation, with the objective of creating the smallest possible distortions. The model is successful qualitatively and also quantitatively in replicating the cross-country observations, as well as the dispersion of policies. A number of previous papers focus on the link between informal sector and (optimal) policies or between (exogenous) policies and informal activity, but to my knowledge my paper is the first to consider all three in the same model and to assess how both government policies and private actions react to institutions. I am working on extending this analysis to explain some other cross-country differences such as volatility and cyclicality of inflation.

Much of my work makes extensive use of computational methods. In **Aruoba, Fernandez-Villaverde and Rubio-Ramirez (2006)** we provide a comparison of different solution methods for solving the workhorse model of modern macroeconomics, the one-sector growth model. This paper is the first comprehensive study of its kind since an earlier volume in early 1990s. We use various local methods (those that are valid near a point) such as first-, second- and fifth-order perturbation and some global methods (those that are valid in the whole state space). We compare these methods to value function iteration, the only solution method that is guaranteed to work but is also the most costly in terms of implementation. We conclude that global methods or higher order local approximations can both deliver high degree of accuracy with very little computational cost. The codes we used in this paper are available on a companion website. They have been very widely used by students and researchers and the paper is highly cited.

In **Aruoba and Kearney (2010)**, we use a unique dataset on U.S. lotteries to investigate whether standard preference models can represent how individual decision makers behave in this context. We have weekly data covering 7 states and 13 years on state lotteries (multi-state and single-state) including sales, the announced and realized jackpots and the odds of winning. Using this dataset, we estimate a number of different utility specifications using Generalized Method of Moments. We find that the expected utility specification (with constant absolute or relative risk aversion) cannot satisfactorily explain the behavior of lottery bettors. Two other specifications fit the data better: one that assumes decision-makers overweight small probabilities (part of prospect theory) or one where playing a lottery provides some entertainment value.

References

[1] Diebold, Francis X. and Canlin Li (2006), "Forecasting the Term Structure of Government Bond Yields," *Journal of Econometrics*, 130, 337-364.

[2] Kareken, John H. and Wallace, Neil (1980), "Introduction", in M*odels of Monetary Economics*, eds. John H. Kareken and Neil Wallace, Federal Reserve Bank of Minneapolis.

[3] Kiyotaki, Nobuhiro and Randall Wright (1989), "On Money as a Medium of Exchange", *Journal of Political Economy*, 97, 927-954.

[4] Kiyotaki, Nobuhiro and Randall Wright (1993), "A Search-Theoretic Approach to Monetary Economics", *American Economic Review*, 83, 63-77.

[5] Lagos, Ricardo and Randall Wright (2005), "A Unified Framework for Monetary Theory and Policy Analysis", *Journal of Political Economy*, 113(3), 463-484.

[6] Lagos, Ricardo and Guillaume Rocheteau (2008), "Money and Capital as Competing Media of Exchange," *Journal of Economic Theory*, 142, 247-258.

[7] Lucas, Robert Jr. (1976), "Econometric policy evaluation: A critique," *Carnegie-Rochester Conference Series on Public Policy*, 1(1), 19-46.

[8] Rocheteau, Guillaume and Randall Wright (2005), "Money in Search Equilibrium, in Competitive Equilibrium and in Competitive Search Equilibrium," *Econometrica*, 73(1), 175-202.

[9] Shi, Shouyong (1997), "A Divisible Search Model of Fiat Money", *Econometrica*, 65, 75-102.

[10] Stock, James H. and Mark W. Watson, 1989. "New Indexes of Coincident and Leading Economic Indicators," NBER Chapters, in: NBER Macroeconomics Annual 1989, ..

[11] Woodford, Michael (2003), *Interest and Prices: Foundations of a Theory of Monetary Policy,* Princeton University Press.