RESEARCH STATEMENT

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The main goal of econometrics is to provide a link between economic theory and data. This link is necessary because, unlike in physical sciences, economic data are plagued with unobserved heterogeneities and mismeasurements. Using such data to improve our understanding of economics requires adapted tools. Econometric theory develops statistical tools for estimation, specification analysis, and testing of various economic theories. Applied econometrics on the other hand uses data to provide forecasts, ex post policy evaluations, and other useful decision making tools that emerge from economic models. In the words of Frisch (1933), "this mutual penetration of quantitative economic theory and statistical observation is the essence of econometrics."

My contributions to econometrics are both theoretical and applied. They are motivated by particular economic theories and practices which I describe in more detail below. In econometric theory my research methodology has been mostly theoretical—using tools from mathematics, statistics, and probability theory—and often followed by numerical simulations. In applied econometrics I have used a variety of approaches ranging from observational, computational, and simulations driven; to theoretical—this time using tools from other or my own contributions in econometric theory. To describe the problems that I have worked on as well as my progress up to date, it is best to offer a rough partition of my past and current research into three main groups: (1) conditional quantiles, (2) rationality testing, and (3) structural econometrics.

My research on conditional quantiles began in the area of risk measurement. In the mid 1990s, banking industry regulators adopted the Value at Risk (VaR) as a risk measure to set capital adequacy standards of all US commercial banks. The VaR measures the worst loss that a bank can suffer due to adverse market movements. Formally, the VaR is defined as a conditional quantile of the distribution of bank's portfolio returns over a given investment horizon. Despite a large body of work on the theory of quantiles in a cross sectional context, little was known about extensions to time series models. My main contributions are threefold. Firstly, I have characterized consistent estimators for the parameters of dynamic conditional quantile models. Secondly, I have analyzed semiparametric efficiency and proposed a new efficient estimator. Lastly, I have also devised an evaluation test for forecasts produced from alternative conditional quantile models.

My research on rationality testing emerged from the theory of rational expectations. That agents are rational when they construct forecasts of economic variables is an important assumption maintained throughout much of economics and finance. This assumption became testable when a large number of macroeconomic forecasts became publicly available. For example, such data included forecasts of GDP, inflation, unemployment, or interest rates made by professional forecasters. These were collected through surveys by the Federal Reserve Bank. With the survey data available, there was a need to devise econometric tools for flexible forecast evaluation, and in particular for testing their rationality. My main contribution has been to provide tools to empirically test the validity of the rationality hypothesis using survey data on univariate as well as multivariate forecasts.

My research in structural econometrics is a result of interdisciplinary collaborations with co-authors from microeconomic theory and international trade. The first line of this research is organized around economic models with multiple equilibria. Though well studied and understood in the micro and macroeconomic literature, multiple equilibrium models have long remained unexplored in econometrics. Here, my contributions have been several. I have studied identification in such models, derived testable implications of complementarities between variables, and constructed an econometric test for monotone comparative statics. The second line of my research in structural econometrics concerns Ricardian models of comparative advantage. Here, I have derived testable implications of the Ricardian model with random productivities on the pattern of international trade. This has provided solid grounds for econometric analysis in such models.

In the remainder of this research statement, I elaborate on each of the research topics to which I have contributed, summarize my progress up to date, and describe my future research initiatives and goals.

1. Conditional Quantiles

Since the mid 1990s, the literature on VaR modeling and inference has undergone tremendous growth. At the same time, this has brought the attention of both researchers and practitioners to the theory of quantiles. In order to derive statistical methods applicable in the context of financial markets, I have focused my research on conditional quantile models that allow for time (as well as cross sectional) dependence in the data. The first statistical problem at which I have looked is the problem of estimation.

1.1. Estimation

In my paper titled "Quasi-Maximum Likelihood Estimation for Conditional Quantiles," which appeared in the *Journal of Econometrics* [1], I characterize the class of consistent quasi-maximum likelihood estimators (QMLEs). Gourieroux et al. (1984) and White (1994) have solved this problem in the context of conditional means. Prior to my work, however, no results were available for conditional quantiles.

The main finding of this paper is a new family of distributions, which I call "tick-exponential." The "tick-exponential" family provides an entire class of conditional quantile estimators not previously seen in the literature. The role of this family is analogous to that of the "linear-exponential" family proposed by Gourieroux et al. (1984) and White (1994). Together with the asymptotic results for the "tick-exponential" QMLE, I also provide a simple algorithm for its computation. The key difficulty in working with "tick-exponential" distribution functions is that they need not be everywhere differentiable. This prevents one from using traditional gradient-based methods for optimization. The main idea of my algorithm is to transform the initial "tick-exponential" likelihood maximization problem into a minimax problem involving a function that has all the desired differentiability properties.

When several conditional quantile estimators are available, the question of existence of an optimal estimator comes naturally into mind. In my joint work with Q. Vuong, I explore the problem of semiparametric efficiency in dynamic models for conditional quantiles. Newey and Powell (1990) have solved this problem in the context of independent and identically distributed data. Extensions of their work to weakly dependent data have not been studied prior to our work.

In the first of our joint two papers, titled "Semiparametric Efficiency Bound in Time-Series Models for Conditional Quantiles," [6] we consider a class of M-estimators that are consistent and asymptotically normal. We proceed to show that this class contains an "optimal" estimator whose asymptotic variance is the smallest among all the M-estimators considered. In order to show that this asymptotic variance is also the semiparametric efficiency bound, we use Stein's (1956) ingenious approach, which is to construct a parametric submodel that satisfies the conditional quantile restriction, contains the data generating process, and whose maximum likelihood estimator has the same asymptotic variance as that of the "optimal" M-estimator. Stein's (1956) argument then implies that the latter asymptotic variance is the semiparametric efficiency bound, while the constructed fully parametric submodel is a "least favorable" one.

In our second joint paper, titled "Efficient Estimation in Dynamic Conditional Quantile Models," [7] we construct a feasible approximation to the "optimal" M-estimator proposed in [6]. Our efficient estimator is a MINPIN-type estimator not yet seen in the literature. In a Monte Carlo study, we show that our estimator improves upon the small sample properties of existing efficient estimators. It is important to stress, however, that the asymptotic properties of these other estimators have not yet been established in time series models.

The results of both papers [6] and [7] are new contributions to the literature on semiparametric efficiency. Despite a large number of results available for independent data (see, e.g., Chamberlain, 1987) little is known about semiparametric efficient estimation when the data are weakly dependent. Our key insight is to apply Stein's (1956) seminal result, thus offering an approach to semiparametric efficiency which is not limited to independent data. My near term goal is to propose a simple constructive method for obtaining least favorable submodels under general moment conditions, and to extend this work beyond conditional quantiles.

1.2. Forecast Evaluation and Combination

When forecasting conditional quantiles, issues related to the choice of forecasting methods naturally arise. Typically, different specification testing procedures are used to choose the best forecasting method available. This approach was taken by Christoffersen et al. (2001), for example. My approach in the paper (joint with R. Giacomini) titled "Evaluation and Combination of Conditional Quantile Forecasts," which appeared in the *Journal of Business & Economic Statistics* [2], is to instead *combine* several models.

The idea behind model aggregation is simple. There might be useful information in alternative model specifications. In this case, aggregating output from different models ("thick modeling") could lead to better results than simply choosing one best model and discarding all others ("thin modeling"). The focus of our analysis is the prediction of a given quantile of the aggregate variable—obtained by linearly combining the individual models—conditional on all available information. This prediction is optimal with respect to some loss function, which in the case of the conditional quantiles corresponds to the 'check' (or 'tick') function. Our empirical analysis of alternative VaR forecasts demonstrates that combined forecasts perform better than any of the individual models considered.

1.3. Related Risk Measures

How to quantify the tail behavior of financial time series is a question of fundamental importance in risk management. Ultimately, this question cannot be answered without having an appropriate measure of risk. Unlike my previous papers (see [1], [2], [6] and [7]), my paper titled "Asymmetric Power Distribution: Theory and Applications to Risk Measurement" published in the *Journal of Applied Econometrics* [4] focuses on a risk measure called the Expected Shortfall (or tail VaR). The Expected Shortfall (ES) is closely related to the VaR, yet differs from it. In financial terms, the ES represents the tail-loss in the market value of a given portfolio over a given time horizon. In mathematical terms, the ES is the expected value of (minus) the difference between the portfolio's return and its α-quantile, conditional on this difference being negative. Because of its subadditivity property, which is linked to diversification, the ES has gained considerable interest in the financial community.

My main contributions are to propose a new class of flexible parametric distribution functions—which I call "Asymmetric Power Distribution" or APD—and to derive closed form expressions for its moments, quantiles, and expected shortfalls. In addition, I provide algorithms for simulation of an APD random variable and for the maximum likelihood estimation of its parameters. My main empirical findings are twofold. Firstly, I find that daily financial return series have innovations that tend to be asymmetric with asymmetry parameters significantly different from one half. Secondly, I find that their exponent parameters are significantly different from one and two. In particular, this invalidates both Laplacian and Gaussian assumptions often encountered in the financial econometrics literature.

2. Rationality Testing

Typically the empirical literature has tested rationality of forecasts in conjunction with the assumption that mean squared error (MSE) loss adequately represents the forecaster's objectives. Under this loss function forecasts are easy to compute through least squares methods and have well established properties such as unbiasedness and lack of serial correlation at the single-period horizon. Mean squared error loss, albeit a widely used assumption, is often difficult to justify on economic grounds and is certainly not universally accepted. For instance, Granger and Newbold (1986, page 125) argue that an assumption of symmetry for the loss function is much less acceptable than an assumption of a symmetric forecast error density.

2.1. Forecasts of a Single Variable

In my joint work with G. Elliott and A. Timmermann, I provide test statistics that can be used to test the joint hypothesis that loss belongs to a general family of loss functions (which includes MSE as a special case) and that information is used efficiently in the computation of the forecasts. The first of our joint two papers appeared in *The Review of Economic Studies* and is titled "Estimation and Testing of Forecast Rationality under Flexible Loss" [3].

This paper provides theory for identification and estimation of the parameters of loss functions applicable to situations where time series data on point forecasts are available but the underlying model used by the forecaster is unknown. Already Hansen and Singleton (1982) have considered the idea of backing out the loss function parameter values. Our main contribution with respect to their work is to provide primitive conditions under which the parameters of the loss function are identified and can be consistently estimated even in situations in which the econometrician does not observe all the information used by the forecasters.

Our empirical analysis of the IMF and OECD forecasts indicates that both agencies systematically overpredict government budget deficits. This is consistent with a loss function that penalizes underpredictions more heavily than overpredictions. Our point estimates of the IMF and OECD asymmetry parameters suggest strong asymmetries in the forecasters' loss function both from an economic and a statistical point of view. For some countries, they indicate that the agencies view underpredictions of budget deficits as up to three times costlier than overpredictions.

Our second joint paper, titled "Biases in Macroeconomic Forecasts: Irrationality or Asymmetric Loss?" appeared in the *Journal of the European Economic Association* [5]. In this paper we examine the theoretical importance of asymmetries in tests for forecast rationality. The economic relevance and practical importance of asymmetric losses has been illustrated by Kilian and Manganelli (2007), for example.

We start by revisiting the standard forecast efficiency tests, which are typically performed in two steps (see, e.g., Mincer and Zarnowitz, 1969). First, the realized value of the target variable is regressed on an intercept and the forecast. Second, a joint test is performed that the coefficients on these terms are equal to zero and unity, respectively. We show that the standard regression coefficients are biased if the loss function is not symmetric. We evaluate this bias analytically for the loss functions introduced in our previous work [3]. Our main findings are as follows. Under asymmetric loss, standard rationality tests do not control size and may lead to false rejections of rationality. Conversely, even large inefficiencies in forecasters' use of information may not be detectable by standard tests when the true loss is asymmetric.

We apply our results to the data obtained from the Survey of Professional Forecasters (SPF). A detailed description of this data set can be found at http://www.philadelphiafed.org/econ/spf/bibliography.cfm. Focusing on real output growth and inflation in the US, we find strong evidence of bias in the forecast errors of many individual survey participants. Close to one-half of the individual predictions lead to rejections of the joint hypothesis of rationality and symmetric loss at the 5% critical level for real output growth or inflation. Allowing for asymmetric loss, we observe rejection rates that are much lower and closer in line with forecast rationality.

2.2. Multivariate Forecasts

While my previous papers [3] and [5] focus on single variable forecasts, it is not unusual for forecasters to predict two or more correlated variables at a time. For example, the SPF survey participants report joint forecasts of output and inflation. From a theoretical viewpoint, macroeconomic models typically rely on interactions between a large number of variables to generate predictions. Even the belief in the most elementary macroeconomic relationships—the Phillips curve or the Fisher hypothesis—introduces dependence in the variables being forecast. Tests of these forecasts' properties, on the other hand, are generally conducted ignoring the multivariate nature of the underlying model (see [3] and [5]).

In my joint paper with M. Owyang, titled "Multivariate Forecast Evaluation and Rationality Testing," [8] I propose a multivariate extension of the loss function considered in [3] and [5]. This flexible family of multivariate losses is novel to the literature. It extends the loss function proposed by Chaudhuri (1996), which he has used to define geometric quantiles for multivariate data. The main feature of our multivariate loss is that it allows the forecast rationality to be tested jointly in multiple variables. Our main empirical finding is that smaller degree of asymmetry is needed to rationalize survey forecasts once we allow for correlations in the variables.

3. Structural Econometrics

My work in structural econometrics came as a response to economic problems that traditionally motivated theoretical work in microeconomics and international trade. In 2003, when I started my research on models with multiple equilibria, surprisingly few (yet remarkably important) econometrics papers have been published on this issue (see, e.g., Jovanovic, 1989; Tamer, 2003). Today, this area of research is one of the fastest growing in econometrics.

3.1. Models with Multiple Equilibria

In many conventional economic models, equilibrium uniqueness comes at a cost of strong and often untenable assumptions. Consider, for example, general equilibrium models: the uniqueness conditions with some natural economic meaning imply the strong weak axiom, which in turn cannot be expected to hold beyond single-agent economies (see, e.g., Arrow and Hahn, 1971). Therefore it is not surprising to find equilibrium multiplicity present in a variety of contexts, ranging from general equilibrium models in microeconomics, oligopoly models and network externalities in industrial organization, to non-convex growth models in macroeconomics or models of statistical discrimination in labor economics. In my joint work with F. Echenique, I focus on the problem of testing for complementarities between explanatory and dependent variables in models in which equilibrium multiplicity is allowed to exist.

Our first paper is currently at its 4th round at *Econometrica* and is titled "Testing Models with Multiple Equilibria by Quantile Methods" [9]. In this paper we show how complementarities produce testable implications on the (small and large) quantiles of the dependent variable, despite the presence of multiple equilibria. The key features of our approach are that we work with a nonparametric structural model of a continuous dependent variable (as opposed to the discrete case studied e.g. in Tamer, 2003), that we allow the unobservable to be correlated with the explanatory variable in a reasonably general way, that we do not require the structural function to be known or estimable, and that we remain fairly agnostic on how an equilibrium is selected.

Our second joint paper titled "A Test for Monotone Comparative Statics" [10] uses the insights from the first paper [9] to design an econometric test for monotone comparative statics (MCS). Here, the main contribution is to derive a likelihood ratio test, which to the best of our knowledge, is the first econometric test of the MCS property proposed in the literature. The test is an asymptotic "chi-bar squared" test for order restrictions on intermediate conditional quantiles.

A key econometric issue that arises in models with multiple equilibria is that of identification. There is an impressive body of work on identification in structural models dating back to Koopmans and Reiersøl (1950). All of this work, however, assumes that the structural model under consideration has a unique equilibrium so that a reduced form of the model exists. This prompted me to revisit the issue of identification in my recent paper titled "Global Identification in Nonlinear Semiparametric Models" [11].

In this paper I derive primitive conditions for global identification in nonlinear simultaneous equations systems that satisfy a set of unconditional moment restrictions. My work not only demonstrates a clear interaction between equilibrium multiplicity and identification, but also weakens the existing primitive conditions for global identification in nonlinear GMM models such as those given by Fisher (1966) and Rothenberg (1971).

My mid term goal is to extend the above findings to more general settings in which the structural model under consideration need not be additively separable in the unobservable term. Identification of such models has not yet been established under moment restrictions weaker than independence. Moreover, little is known about semiparametric estimation in non-additive contexts. If positive results on identification and estimation are obtained, they would represent a valuable tool to micro and macroeconomists who work with nonlinear models such as demand models, or models based on Euler equations.

3.2. Structural Trade Models

In my note related to [11], which I titled "Global Identification of the Semiparametric Box-Cox Model" [12], I focus my attention on the Box-Cox model. This model has been widely used in empirical applications, including those concerning international trade models. My note derives sufficient conditions under which the parameters of the Box-Cox transformation are globally identifiable. As discussed in Powell (1996) for example, such identifiability results are non trivial to establish due to the nature of the Box-Cox transformation.

In particular, I focus on the identification conditions that do not require the disturbance in the model to be independent of the explanatory variable. My main contribution is to show what restrictions on the support of the conditional distribution of the disturbance (given the explanatory variable) are sufficient to globally identify the parameters of the Box-Cox model.

While in [12] I take the form of the model as given, a question remains as to what microeconomic foundations give rise to particular parametric specifications? In a joint paper with A. Costinot, titled

"What Goods Do Countries Trade? A Structural Ricardian Model" [13], we offer clear theoretical foundations for cross-industry regressions that have long been performed in the empirical trade literature. The main contributions of this work are to use the structure of the Ricardian model in order to discuss the economic origins of the error term and the plausibility of orthogonality conditions that it satisfies, and to control for biases induced by selection errors in the trade data actually observed.

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