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Estimation of an agent-based model of investor sentiment formation in financial markets

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ABSTRACT

We use weekly survey data on short-term and medium-term sentiment of German investors to estimate the parameters of a stochastic model of opinion formation governed by social interactions. The bivariate nature of our data set also allows us to explore the interaction between the two hypothesized opinion formation processes, while consideration of the simultaneous weekly changes of the stock index DAX enables us to study the influence of sentiment on returns. Technically, we extend the maximum likelihood framework for parameter estimation in agent-based models introduced by Lux (2009a) by generalizing it to bivariate and tri-variate settings. As it turns out, our results are consistent with strong social interaction in short-run sentiment. While one observes abrupt changes of mood in short-run sentiment, medium-term sentiment is a more slowly moving process in which the influence of social interaction seems to be less pronounced. The tri-variate model entails a significant effect from short-run sentiment on prices in-sample, but its out-of-sample predictive performance does not beat the random walk benchmark.

1. Introduction

Opinion dynamics in financial markets have been modeled by Topol (1991), Kirman (1993), Lux (1995, 1998) and Alfarano et al. (2008) among others. These models make use of epidemic processes of information transmission between agents that allow for an endogenous formation of expectations. Markets with such interacting speculators give easily rise to speculative bubbles, crashes and excess volatility, and therefore, provide an avenue towards an explanation of these ubiquitous phenomena. Perhaps even more important, a certain number of these agent-based models has also been shown to exhibit more fundamental statistical properties of financial returns: Models like those proposed by Lux and Marchesi (1999, 2000), Iori (2002) or Pape (2007) generate time series that replicate the well-known stylized facts like fat tails and clustered volatility, even up to close numerical proximity of key empirical statistics of financial data (cf. Lux, 2009b, for an overview of this literature).

Our aim in this paper is to estimate the parameters of an agent-based model of opinion formation and its impact on prices. This goal means that we attempt to identify structural parameters of an agent-based model (ABM) from aggregate data. The literature on estimation of ABMs has got started only recently and pertinent contributions are still scarce. Early

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research in this vein has concentrated on regime-switching models with two regimes accounting for periods of dominating chartist or fundamentalist influence in financial markets. Examples include Vigfusson (1997) and Westerhoff and Reitz (2003). While the former reports weakly favorable results for a chartist and fundamentalist framework, the latter authors find that fundamentalists' reactions might not be sufficiently strong to prevent amplification of distortions in the foreign exchange market. More recent contributions have also started to estimate heterogeneous agent models with performance-based switching rules for the choice of strategies or predictor functions. Boswijk et al. (2007) estimate a dynamic asset pricing model with heterogeneous, boundedly rational agents. In this model, a discrete choice-style selection mechanism based on past profits governs agents' switching between a fundamentalist and a chartist predictor. They estimate this model via nonlinear least squares for yearly data of the U.S. stock market from 1871 until 2003 and find that they can reject a benchmark linear asset-pricing model against the nonlinear two-group framework. Belief coefficients are strongly significant and indicate the prevalence of different strategies among market participants.

Somewhat less clear-cut evidence for the explanatory power of a similar ABS model is reported for daily stock index data by Amilon (2008). This author points out that replication of stylized facts like volatility clustering hinges on the specification of the noise term while the nonlinearity introduced via the structural ABM model does not contribute much to the overall fit of the model. Franke (2009), in contrast, obtains a better fit of a simple ABM framework to selected moments that capture important stylized facts.

A similar approach has been pursued by Goldbaum and Mizrach (2008) who adopt the discrete-choice approach to mutual fund allocation decisions. On the base of 10 years of data on inflow of capital to actively and passively managed funds, they estimate a discrete-choice model on the base of utility differences of investors from the active or passive varieties. They find that about 80% of the variation of fund flows can be explained by the model. A discrete-choice framework for the choice of expectation formation rules for inflation forecasts has been studied by Branch (2004). Using micro data from the Michigan Survey of Consumer Attitudes and Behavior, he finds significant evidence of heterogeneity among respondents. Allowing for the possibilities of vector autoregressive, adaptive and naive expectations, Branch finds that the respondents' choice of predictors reacts negatively to mean squared prediction error.

ABM models with contagious interpersonal communication have been estimated by Gilli and Winker (2003), Alfarano et al. (2005), Klein et al. (2008), Franke (2008) and Lux (2009a). Gilli and Winker (2003) estimate the "ant" model of pairwise exchange of information of Kirman (1993) for foreign exchange data and find evidence for bi-modality, i.e. changes between dominance of both underlying opinions (chartist and fundamentalist predictors in the application to a foreign exchange market). Alfarano et al. (2005) estimate the parameters of a closely related model with asymmetric switching propensities and find that different markets are governed by different prevailing tendencies towards fundamentalist or chartist behavior. Klein et al. (2008) attempt to estimate the more involved model by Lux and Marchesi (1999) that combines the chartist-fundamentalist dichotomy with social interactions among agents. While they do not report parameter estimates, they provide results on the estimated fraction of chartists as it develops over time. Results appear to be in good harmony with historical perceptions of the financial history over the last 60 years.

Closest to our current paper are the recent contributions by Franke (2008) and Lux (2009a) who attempt to estimate the parameters of models of social opinion formation among agents for economic sentiment data. Our goal in this paper is to go one (or two) steps beyond a previous paper (Lux, 2009a) that introduced a method for identification of the parameters of microscopic opinion processes from aggregate data. This paper, however, was confined to estimation of the parameters of a model for a univariate time series, namely the diffusion index form (number of optimistic individuals minus number of pessimistic individuals) of a business climate survey. While the same model and estimation methodology could be applied for financial sentiment data (which often share the format of diffusion indices), a univariate model would only allow us to cover one of the building blocks of the above asset pricing models. As a minimum requirement, however, for an empirical validation of a stochastic behavioral asset pricing model one would like to study the joint dynamics of asset prices and sentiment. We will, therefore, extend our previous model into this direction and provide parameter estimates for a simple version of a simultaneous system. Since our underlying time series cover two sentiment variables, one for the short horizon and one for the medium-term horizon, we can even go one step further and study two interacting opinion processes together with the time development of the asset price. Since this amounts to studying the dynamics of a tri-variate series, we proceed in this paper from the 1D case of Lux (2009a) to the 2D and 3D cases. As in the previous paper, the methodology presented below could be applied to a wide variety of hypothesized opinion dynamics interacting with objective economic variables. In order to demonstrate the practical use of estimated agent-based models, we also perform an out-of-sample forecasting experiment based on our estimated models.

Apart from the still relatively sparse literature on estimation of agent-based models our approach could also be linked to a much more voluminous strand of empirical research: Empirical models of survey measures of sentiment or investment (business, consumer) climate. Since we will use a diffusion approximation to our underlying opinion process, we could also interpret our exercise as estimation of a time series model motivated by an agent-based model. Sentiment indices could be considered as risk factors in the asset pricing equation in such a setting. Our research would, then, explore the added explanatory power of nonlinearities introduced through the interaction of agents while previous research has mainly used linear models for modeling sentiment and its explanatory power as a risk factor for stock price movements (cf. Brown and Cliff, 2004; Schmeling, 2009).

The rest of the paper is structured as follows: In Section 2 we introduce our stochastic framework of sentiment dynamics and simultaneous price changes. Section 3 provides details on our estimation methodology, maximum