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Collective Opinion Formation in a Business Climate Survey

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COLLECTIVE OPINION FORMATION IN A BUSINESS CLIMATE SURVEY

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abstract

A large body of literature has proposed models inspired by particle physics as formalizations of collective processes in the economic and social spheres of human societies [1, 2, 3, 4]. However, attempts at empirical validation of such models have been very sparse so far. This paper develops a broadly applicable methodology for estimating the parameters of microscopic models of social interactions. Its application to a popular business climate survey indicates that the collective behaviour of the survey respondents is well explained by a simple 'particle' model of social interactions. This result also lends support to the view that the large fluctuations of investors' and consumers' confidence are mostly due to 'animal spirits' rather than new information.

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As a simple formalization for the process of social opinion formation, we adapt an approach in the spirit of ferro-magnetism in physics [1, 2, 4]. The model assumes stochastic transitions of agents between two alternative states due to exogenous factors and group pressure. Let the two groups have occupation numbers n_+ and n_- respectively, with the overall population size being $2N$. The aggregate outcome of this collective choice process at any point in time can be described via an *opinion index*:

$$x = \frac{n}{N} = \frac{n_+ - n_-}{2N}, \qquad \text{with } x \in [-1, 1]. \tag{1}$$

A simple stochastic process of individual moves between groups can be built upon Poisson transition rates $w_\uparrow$ and $w_\downarrow$ to move from the "+" to the "−" group or *vice versa*. Following the pertinent literature we assume an exponential functional form of $w_\uparrow$ and $w_\downarrow$:

$$w_\uparrow = v \, \exp(U), \qquad w_\downarrow = v \, \exp(-U). \tag{2}$$

The function U covers those forces that make individuals change their opinion. In extant literature, it often consists of a constant factor (bias) α_0 and a second component formalizing group pressure in favor or against homogeneous decisions, $\alpha_1 x$:

$$U = \alpha_0 + \alpha_1 x. \tag{3}$$

The parameters of the model are, thus, the coefficients α_0 and α_1 as well as v which determines the frequency (time scale) of moves between groups. It is well-known that this simple group dynamics is characterized by a stationary distribution with a unique maximum for $\alpha_1 < 1$ and α_0 relatively small. For $\alpha_1 > 1$ and α_0 not too large, the stationary distribution has two maxima. If $\alpha_0 = 0$, the distribution is symmetric around 0. It becomes asymmetric if $\alpha_0 \neq 0$ with right-hand (left-hand) skewness and more concentration of probability mass in the right (left) maximum if $\alpha_0 > 0$ (< 0) holds. Finally, if $|\alpha_0|$ becomes large, the smaller mode vanishes and the stationary distribution becomes uni-modal again [2, 4].

While the stochastic properties of such population processes have been studied in great detail, this literature has not developed a systematic approach towards estimation of such models. In the following I will outline, how such models can be estimated via a fairly conventional maximum likelihood procedure. The basic ingredient in our estimation procedure is the so-called Fokker-Planck equation [5, 6] for the time development of the transitional density of macroscopic observables of the process:

$$\frac{\partial f(x)}{\partial t} = -\frac{\partial}{\partial x}\Big(A(x,\theta) f(x)\Big) + \frac{1}{2} \cdot \frac{\partial^2}{\partial x^2}\Big(D(x,\theta) f(x)\Big), \tag{4}$$

where $f(x,t)$ is the transitory density of x, and $A(x,\theta)$ and $D(x,\theta)$ are the drift and diffusion functions of the process, and θ is a set of unknown parameters that one wants to estimate ($\theta \equiv (v, \alpha_0, \alpha_1)$ in the baseline version of our model).

If no closed-form solution for $f(x,t)$ is available (which will mostly be the case), one can study the time development of the density via numerical integration of eq. (4).

If one has available discrete observations, the time-dependent solution to the transient density at the times of observations could be used to compute the likelihood of each observation conditional on the realization of the process in the previous period. The negative log-likelihood of a sample of observations $X_0, \ldots, X_T$ is

$$-\log f_0(X_0 \mid \theta) - \sum_{s=0}^{T-1} \log f(X_{s+1} \mid X_s, \theta), \tag{5}$$

where $f_0(X_0 \mid \theta)$ is the density of the initial state (which in practical applications will be skipped because of its negligible influence and the possible lack of a closed-form solution for the stationary density) and $f(X_{s+1} \mid X_s, \theta)$ is the value of the transitional density at $s+1$ conditioned on the previous observation at time s, X_s. Using the Crank-Nicolson scheme [7] for the finite difference approximation of the Fokker-Planck equation, the resulting estimates are consistent, asymptotically normal and asymptotically equivalent to full ML estimates [8]. Numerical support for the efficiency of this algorithm is provided as supplementary information.

The above model could serve as a theory for opinion formation among agents in simple, binary voting or decision problems. The simple structure of our 'canonical' model is very close to the data provided by various surveys of *business climate* or *sentiment* in that they very literally ask for whether respondents are optimistic ("+") or pessimistic ("-") concerning the prospects of their economy. The only difference to our above model is that these indices mostly also allow for a neutral assessment. We might assume that neutral subjects can be assigned half and half to the optimistic and pessimistic camp which, then, would allow us to apply our model directly to these data. Here we focus on the German ZEW index [9] as one particularly interesting example. What makes it particularly suitable for our purpose is that in contrast to many other sentiment indices it represents the average of binary resp. ternary responses in a very direct way, i.e. without any further aggregation involved, and that it has a rather constant number of participants (about 350 respondents) while other indices exhibit more fluctuations in their number of respondents over time. The group of respondents is furthermore more homogeneous than in most other surveys as it consists mainly of leading professionals from the finance industry. The index is reported as the percentage of optimists minus pessimists so that it can be directly used as the opinion index x in eq. (1). The brocken lines in Fig. 1 display the available monthly ZEW series (starting in December 1991 and running through July, 2006). What is striking is the very pronounced cyclical behavior of the ZEW index with very sudden movements upward and downward and a certain stagnation at times at a high or low plateau, both features reminiscent of a bi-modal stochastic dynamics.

Table 1 shows the estimated parameters for the baseline version and various extensions of the ferro-magnetic model of opinion formation: model 1 only estimates the parameters v, α_0 and α_1 taking the number of respondents as given. However, as it turns out, this baseline version would likely get stuck within one mode over a time horizon of the length of our sample (176 observations), cf. Fig. 1. In order to reconcile our observation of a relatively large number of apparent switches of the mood of the respondents with the 'official' system size of 350 respondents, we could argue that the 'effective' system size is smaller than the official number. This would happen if some respondents would actually move broadly synchronously and would, therefore, not act like independent agents. We could let the index itself speak on the underlying effective system size by adding N to the list of parameters estimated via approximate ML. Table 2 shows that this added flexibility leads to a large increase in the log likelihood and is preferred over the baseline model. The 'effective' number of agents in our estimation is only about 40 ($2N$) compared to the much higher official sample size of about 350. As concerns the other parameters, α_0 still is insignificant, while the interaction coefficient falls marginally below 1. Since our framework allows to incorporate exogenous effects on the opinion formation process, we can also expand the influence function U by introducing additional factors that could be of importance to the assessment of the business cycle by the respondents of the survey, e.g., macroeconomic data of the same frequency. Various such macro feedbacks have been investigated. As it turned out, industrial production (parameter: α_2) had a higher influence than other statistics, but only added a small improvement to model 2. Models 4 and 5 depict another extension: here we include a kind of 'momentum' effect (parameter: α_3) as an explanatory variable, i.e., the change of the climate index from the month $t-1$ to the last observation. As it turns out (cf. Table 2), the momentum effect is significantly positive. It again leads to a remarkable improvement of the model, but does not affect previously estimated parameters by too much. Adding industrial production as an explanatory variable (model 5) again only leads to a very modest increase of the likelihood. In summary it, therefore, appears that macroeconomic variables add only a very slight fraction of the explanatory power, while the major improvements are obtained via refinements of our social opinion formation process.

Can the estimated models explain the empirical behavior of the ZEW index? Fig. 1 exhibits three simulations of model 5 together with the empirical data over the same time horizon. In these simulations, we have injected the knowledge of the current exogenous factor (industrial production) as well as the 'momentum' of the index itself at integer time steps. As it can be seen, the visual appearance of the three Monte Carlo runs is pretty similar to that of the index itself and the feedback from industrial production seems to direct the simulations towards a pattern that is broadly synchronous with the ups and downs of the empirical record. Simulations from models 2 to 4 are, in fact, not too different in their overall appearance. In order to perform a test of the goodness-of-fit of our model, we compute conditional transient densities on the base of the Fokker-Planck equation. Fig. 2 shows the mean and 95 percent confidence bounds from the transient density computed for model 3 over the whole observation period given the first observation of the index as the initial condition and incorporating the feedback from industrial production. Since the empirical record stays within the 95 % bounds for practically the entire time horizon, we may conclude that we have no reason to reject the hypothesis that the empirical data could have emerged as one particular sample path from our stochastic model. For model 5, we could not perform the same exercise because the endogeneous momentum effect is hard to capture in the Fokker-Planck equation. Numerical simulations, however, provide an almost identical picture. As another test we try to assess whether the abruptness of the up and down movements of the index is captured by our model. For this purpose we compute a series of one-period iterations of the transient density and extract the 95 percent confidence intervals conditional on the realization in the previous period. Fig. 2 shows the 95 % confidence bounds for the subsequent period's realization from model 5 which apparently is never left by the empirical record.

Extant empirical studies of business climate and confidence indices are exclusively confined to analyses of their use in forecasting future economic activity [10, 11]. While fluctuating consumer and investor confidence play a prominent role in macroeconomic discussions, no positive models of opinion formation as a social process have been developed from this side. Our implementation of a model of interactive social opinion formation could, therefore, be seen as an empirical foundation for the alleged importance of what has been labelled animal spirits [12] in economics. Ongoing work [13] shows that the simple particle model performs equally well (with similar parameter estimates) for a broad variety of sentiment indices. The present approach to statistical inference is also applicable to a wide range of alternative microscopic models and could as well be adopted for estimation of the parameters of similar models in their original domain (i.e., in the natural sciences).

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Table 1: Parameter Estimates for Stochastic Models of Interacting Agents.

	ν	α_0	α_1	α_2	α_3	N	logL	AIC	BIC
Model 1	0.78	0.01	1.19				-726.9	1459.8	1464.1
(baseline)	(0.06)	(0.01)	(0.01)						
Model 2	0.15	0.09	0.99			21.21	-655.9	1319.7	1322.0
(end. N)	(0.07)	(0.06)	(0.14)			(9.87)			
Model 3	0.13	0.09	0.93	-4.55		19.23	-650.4	1310.9	1311.1
(feedback from IP)	(0.06)	(0.07)	(0.16)	(2.53)		(8.78)			
Model 4	0.14	0.10	0.91		2.11	27.24	-627.5	1265.1	1265.4
(momentum effect)	(0.05)	(0.06)	(0.14)		(0.76)	(9.63)			
Model 5	0.12	0.11	0.86	-2.82	2.23	25.12	-624.9	1261.9	1260.1
(momentum + IP)	(0.05)	(0.06)	(0.16)	(1.65)	(0.81)	(8.95)			

Note: Details on the underlying models appear in the main text. The numbers in brackets are standard errors of parameter estimates. logL is the log-likelihood of the pertinent model and AIC and BIC are the Akaike and Bayesian information criteria (with decreasing values from model 1 through 5 indicating that the added parameters lead to an increase in explanatory power).

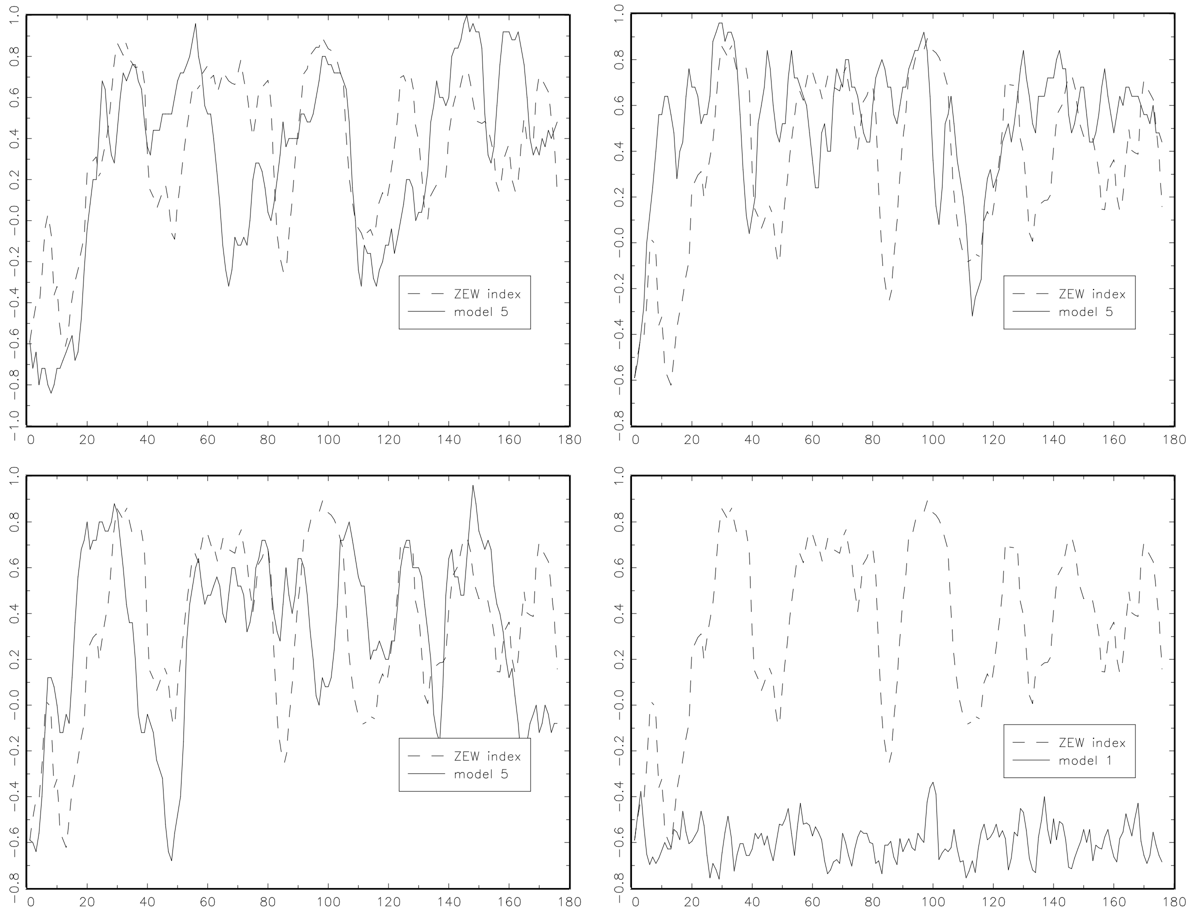

Figure 1:

Simulated trajectories from models 5 and 1: The upper panels and the lower left panel compare three simulations from model 5 (solid line) to the empirical series (broken line). While these simulations are qualitatively close to the empirical series, simulations of model 1 typically get stuck in a lasting majority of “-” opinions (lower right-hand panel) with very little variation over time.

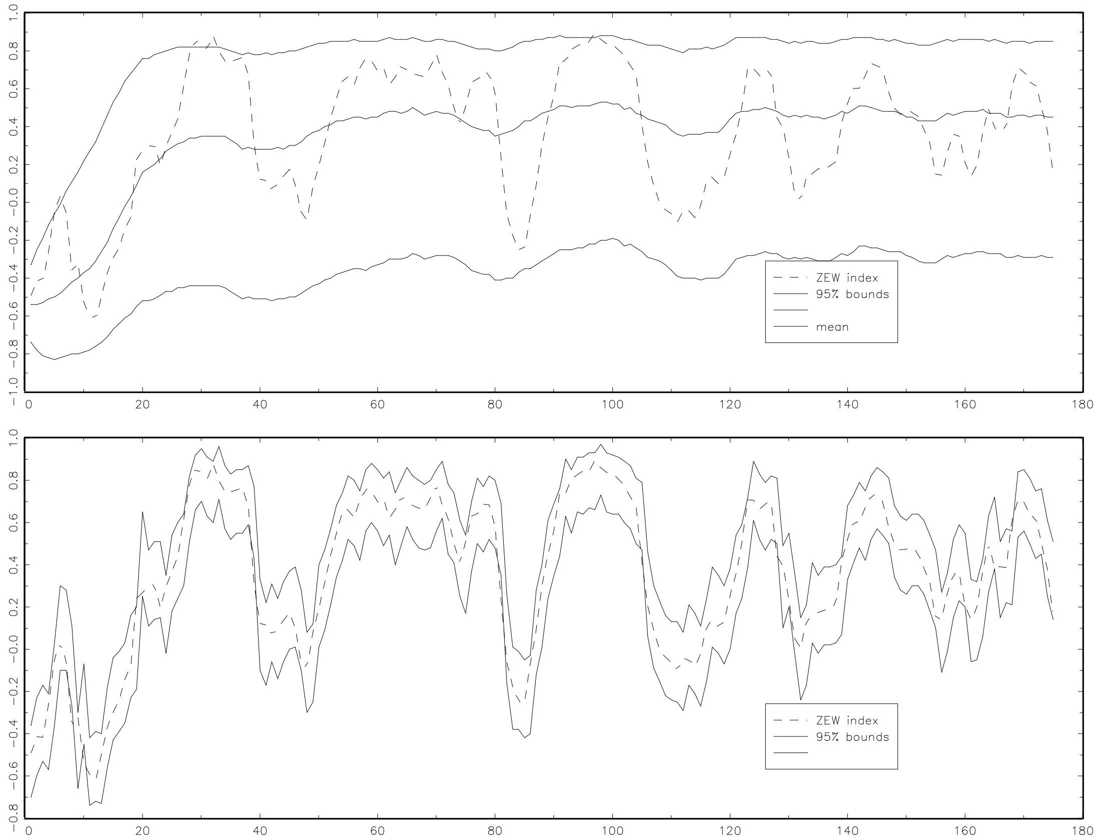

Figure 2:

Two specification tests of our estimated model of opinion dynamics: The upper panel shows the mean and 95 percent bound of the transient densities of model 3, conditional on the initial condition (the first observation recorded in 12/1991)and the available macroeconomic information (industrial production). The lower panel shows the transient density conditional on all information available in the previous period (the index value, macroeconomic information and the contemporaneous momentum of the index). In both cases the 95 percent intervals computed from the Fokker-Planck equation include most or all of the variation of the empirical series (broken line) over the 176 monthly observations within the period 1991 to 2006.

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