[Peering into the mist: social learning over an opaque observation network]

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Communication pervades human existence. In addition to the myriad of cultural interactions, people directly share economic information like job opportunities and prices, and indirectly reveal information to each other as they trade goods and services. The study of how information is shared over a network of interactions is therefore an important field of economic research.

The topic of social learning -- examining if, how and how quickly people's beliefs might converge -- when people communicate via a network has been examined extensively in the microeconomic literature. There has been little to no application of this work to questions of macroeconomics, however, despite the famous work of Lucas (1972) and Phelps (1984) arguing that agents' imperfect access to information is critical to explaining the movement of aggregate variables.

The reason for this is that three other features commonly deemed essential to the discussion of macroeconomics -- (a) that agents' act repeatedly; (b) that agents' act strategically, with their payoffs a function of other agents' actions; and (c) that although imperfectly informed, agents' expectations are (close to) rational -- make comprehensive analysis of network learning intractable in anything other than trivially small networks (Jackson, 2008).

This paper presents a solution to this problem by proposing a simplifying assumption: that the network is *opaque*, in that agents do not know exactly who is connected to whom. Instead, I suppose that agents know the probability distribution from which everybody draws the identity of their observees.[1] I also replicate a key feature of observed networks by supposing that while most agents are unlikely to be observed, some groups of agents are disproportionately highly observed, even as the number of people in the network becomes very large.

With agents attempting to learn about a hidden state variable by observing each other's actions, I derive the law of motion for the full hierarchy of agents' aggregate expectations. With an opaque network, the hierarchy includes the usual the average expectation regarding the hidden state, the average expectation of the average expectation, etc., but also includes an infinite sequence of weighted-average expectations and higher-order combinations between them.

Following a shock to the hidden state, I show that average expectations respond more quickly than they do when agents do not observe each other in a network, but also temporarily *overshoot* the truth, in a form of herding behaviour that combines the mechanisms described by Banerjee (1992), where agents observe others' actions but have no strategic motive, and Morris and Shin (2002),

[1] That is, it is known that agent *1* is observed with probability $\varphi(1)$, agent *2* is observed with probability $\varphi(2)$, etc.

where agents have a strategic motive but do not observe each other's' actions. The degree of persistence is shown to be increasing in the number of agents observed.

Agents' idiosyncratic shocks, which in many models have no effect on aggregate variables, are shown to influence the hierarchy of aggregate beliefs. Even when idiosyncratic shocks last only one period, these effects are also shown to be persistent over several periods. The paper therefore adds to a new field of research demonstrating that aggregate volatility may emerge from idiosyncratic shocks.[2]

Because of the focus on a setting with a dynamic underlying state and the demonstrated law of motion for the hierarchy of average expectations, a researcher is able to determine the aggregate effects of network learning without a need to simulate individual agents' decisions.[3] This makes the model particularly amenable to nesting within broader general equilibrium models of the economy.

**References**

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[2] See, for example, Gabaix (2011) or Acemoglu, Carvalho, Ozdaglar and Tahbaz-Salehi (2012).

[3] The model is calibrated with two additional parameters: one specifying the number of other agents each player observes and one describing the degree of irregularity in the network.