Epidemiological Expectations

Social interactions, expectation formation and macroeconomic implications

Tao Wang
Bank of Canada

March 7, 2024

Behavioral macro class at University of Ottawa

Table of contents

Motivations

The long history of the disease metaphor

While mass media play a major role in alerting individuals to the possibility of an innovation, it seems to be personal contact that is most relevant in leading to its adoption. Thus, the diffusion of an innovation becomes a process formally akin to the spread of an infectious disease. – Arrow (1969)

The long history of the disease metaphor

While mass media play a major role in alerting individuals to the possibility of an innovation, it seems to be personal contact that is most relevant in leading to its adoption. Thus, the diffusion of an innovation becomes a process formally akin to the spread of an infectious disease. – Arrow (1969)

If we want to know why an unusually large economic event happened, we need to list the seemingly unrelated narratives that all happened to be going viral at around the same time and affecting the economy in the same direction. – Shiller (2017)

Epidemiological Expectations (EE)

- People are fundamentally social animals

Epidemiological Expectations (EE)

- People are fundamentally social animals
- Heterogeneity in income, wealth, preference, etc, prove to be important for macroeconomic outcomes – HA-macro, e.g. HANK

Epidemiological Expectations (EE)

- People are fundamentally social animals
- Heterogeneity in income, wealth, preference, etc, prove to be important for macroeconomic outcomes – HA-macro, e.g. HANK
- One important dimension of heterogeneity remains underexplored in HA-macro: $\mathbb{E}$s

Epidemiological Expectations (EE)

- People are fundamentally social animals
- Heterogeneity in income, wealth, preference, etc, prove to be important for macroeconomic outcomes – HA-macro, e.g. HANK
- One important dimension of heterogeneity remains underexplored in HA-macro: $\mathbb{E}$s
- EE models the heterogeneous $\mathbb{E}$s as a consequence of social interactions

Compared to existing models of expectation formation

- Full-information Rational Expectations (FIRE)
- Adaptive Learning (Evans and Honkapohja, 2001)
- Noisy Information (Lucas Jr, 1972; Woodford, 2001)
- Diagnostic Expectations (Bordalo et al., 2018)
- Sparsity (Gabaix, 2020)
- Rational Inattention (Sims, 2003)
- Fading Memory (Nagel and Xu, 2022)
- . . .

most of these theories are "individualistic" instead of "social", e.g. no mechanisms such that others' beliefs affect one's own beliefs...

Compared to existing models of expectation formation

- Full-information Rational Expectations (FIRE)
- Adaptive Learning (Evans and Honkapohja, 2001)
- Noisy Information (Lucas Jr, 1972; Woodford, 2001)
- Diagnostic Expectations (Bordalo et al., 2018)
- Sparsity (Gabaix, 2020)
- Rational Inattention (Sims, 2003)
- Fading Memory (Nagel and Xu, 2022)
- ...

most of these theories are "individualistic" instead of "social", e.g. no mechanisms such that others' beliefs affect one's own beliefs...

- Some **exceptions**: learning from the experience? (Malmendier and Nagel, 2015); heterogeneous expectations (Hommes, 2021); social learning (Bikhchandani et al., 1992)...

Why Epidemiological Expectations?

- Rich micro evidence of social transmission of expectations, including those with large-scale social networks like Facebook
- HA-macro+ EE: $\mathbb{E}$ is just another idiosyncratic state variable
  - whose distribution evolves either exogenously or endogenously
- EE can nest FIRE as a special case
  - "source" of beliefs *could* be Rational
  - if infection rate 100 percent $\rightarrow$ RE model

Empirical Evidence

Evidence for Social Transmissions of Expectations

Stock investment

- Hong et al. (2004), Hong et al. (2005), Brown et al. (2008), Hirshleifer and Teoh (2008), Han and Hirshleifer (2016), Hvide and Östberg (2015), Cookson and Niessner (2020), Cookson et al. (2022), Pedersen (2022), Chen and Hwang (2021)

Evidence for Social Transmissions of Expectations

Stock investment

- Hong et al. (2004), Hong et al. (2005), Brown et al. (2008), Hirshleifer and Teoh (2008), Han and Hirshleifer (2016), Hvide and Östberg (2015), Cookson and Niessner (2020), Cookson et al. (2022), Pedersen (2022), Chen and Hwang (2021)

Housing investment/mortgage choices

- Burnside et al. (2016), Bailey et al. (2018), Bailey et al. (2019), Bayer et al. (2021)

Evidence for Social Transmissions of Expectations

Stock investment

- Hong et al. (2004), Hong et al. (2005), Brown et al. (2008), Hirshleifer and Teoh (2008), Han and Hirshleifer (2016), Hvide and Östberg (2015), Cookson and Niessner (2020), Cookson et al. (2022), Pedersen (2022), Chen and Hwang (2021)

Housing investment/mortgage choices

- Burnside et al. (2016), Bailey et al. (2018), Bailey et al. (2019), Bayer et al. (2021)

Macroeconomic expectations/sentiment

- Makridis (2019), Makridis and Wang (2020), Han et al. (2019), Garcia Lembergman et al. (2023), Macaulay and Song (2023), Flynn and Sastry (2022)

- More papers on topics such as bank run, insider trading, news and social media...

Epidemiological Frameworks

Common Source S-I Model

Table 1: Common Source SI Model

Date t	Susceptible_t	Infected_t
0	1	0
1	$(1-p)$	$1-(1-p)$
2	$(1-p)^2$	$1-(1-p)^2$
$\vdots$	$\vdots$	$\vdots$
n	$(1-p)^n$	$1-(1-p)^n$

- one of the micro foundation of sticky expectations (Carroll, 2001, 2003; Mankiw and Reis, 2002): information slowly diffuses through the entire population.

Personal Contact S-I Model

Table 2: Transmissible SI Model

Date t	Susceptible_t	Infected_t
0	S_0	I_0
1	$S_0 - \beta S_0 I_0$	$I_0 + \beta S_0 I_0$
2	$S_1 - \beta S_1 I_1$	$I_1 + \beta S_1 I_1$
$\vdots$	$\vdots$	$\vdots$
n	$S_{n-1} - \beta S_{n-1} I_{n-1}$	$I_{n-1} + \beta S_{n-1} I_{n-1}$

- the law of motion of individual $\mathbb{E}_{i,t}$ are state-dependent
- reminiscent of labor search and matching models a la Mortensen and Pissarides (1994)

Other Extensions

- Other states/compartments
  - Recovered/Removed (Dead)
  - Exposed (which might affect future infection risk)
  - Immune
- In addition, agents can make choices to change their "infection" rate: information choices, learning, etc... (Lucas and Moll, 2014)

Testable predictions

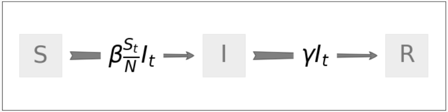
$$\Delta I_t = \alpha + \beta S_{t-1} + \beta^T S_{t-1} I_{t-1} + \epsilon_t$$

- I_t: the fraction of people in the economy who hold certain expectations, e.g. optimistic beliefs
- S_t: the fraction who don't yet
- $1 \geq \beta > 0$: diffusion from common sources, e.g. the mass media
- $\beta^T > 0$: diffusion through social communications

Can be estimated with qualitative/categorical answers in surveys...

A SIR Model of Stock Investors (Shiller and Pound, 1989)

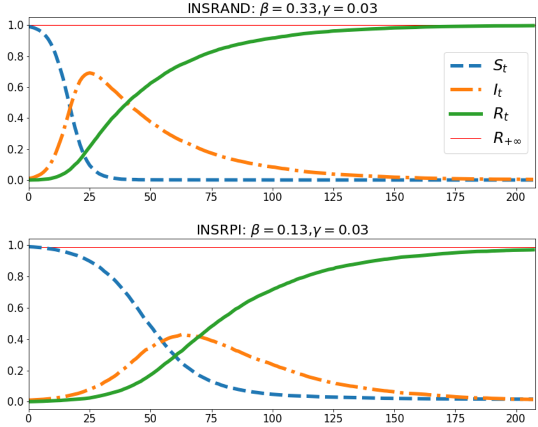
Figure 1: A SIR model of stock investors



- More recent evidence: Shive (2010), Huang et al. (2021), Bayer et al. (2021)

An SIR model of stock investors

Figure 2: Simulated trends from an SIR model of stock investors



Housing boom and busts (Burnside et al., 2016)

- Heterogeneous beliefs about housing markets resulting from social dynamics.
- Three ex-ante heterogeneous types: optimistic, skeptical, or vulnerable, who agree to disagree.
- Randomly meet up to exchange expectations and those with tighter beliefs convert the others.
- Booms: optimists turn out to be correct about fundamentals.
- Busts: skeptics turn out correct...

Expectations and Social Network

EE with social network: Makridis and Wang (2020)

- People don't **randomly** meet and "infect" each other
- Locations and the structure of communications may mater

Belief updating via social network: "naive learning"

- ψ_t: an aggregate state of the economy not perfectly observable and to be learned via local signals $\xi_{i,t}$

$$\tilde{\psi}_{i,t} = \underbrace{(1-\lambda)\hat{\psi}_{i,t}}_{\text{private updating}} + \underbrace{\lambda \sum_{j=1}^{N} w_{i,j}\tilde{\psi}_{j,t-1}}_{\text{social communication}}$$

$$\hat{\psi}_{i,t} = (1-k) \underbrace{\tilde{\psi}_{i,t-1}}_{\text{prior belief}} + k \underbrace{s_{i,t}}_{\text{local news}}$$

- λ: the degree of social communication
- k: individual responsiveness to local news
- $w_{i,j}$: the "listening weight" that i gives to j's belief

More | Why 'Naive'? | Social Network

Why “naive”?

- Ideally: weights = true precision
- Realistically: bounded rationality
  - not knowing perfectly friend ties: who are friends’ friends
  - not knowing perfectly the precision of friend’s signals
  - i.e. treating them as independent signals
- Experimental evidence: (Enke and Zimmermann, 2019; Chandrasekhar et al., 2020)
- Consequence: “persuasion bias” (DeMarzo et al., 2003):
  - **inefficiency** due to the dominant weights of the influencers
  - **no “wisdom of crowds”**: the converged belief (if any) of the society is not the “truth” starting from different priors
  - persistent **disagreements** in beliefs

Back

Social network

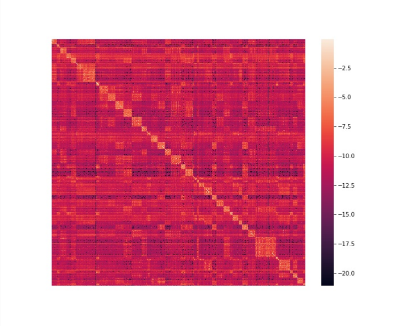
- "Listening matrix" W (sized $N \times N$):

$$w_{i,j} = \frac{l_{i,j}}{\sum_{k=1}^{N} l_{i,k}}$$

  - Degree $d_j = \sum_{i=1}^{N} w_{i,j}$: how influential j is in the network
  - Row sum: $\sum_{i=1}^{N} w_{i,j} = 1 \quad \forall i$
  - $w_{i,i} = 1$ if "you only have yourself as a friend"

Back

The Listening Matrix



- The diagonal: “self-influence”
- Blocks along the diagonal: within-state influence

Relation to the literature

- private updating
  - Kalman filtering/efficient learning:
    - $\kappa_{i,t}$ dynamically adjusted based on the signals' precision (Woodford, 2001)
    - stead-state gain: k^*
  - Constant-gain learning: $\kappa_{i,t} = k > 0$
    - $k < k^*$: underreaction/inattention (Mankiw and Reis, 2002; Sims, 2003; Coibion and Gorodnichenko, 2015)
    - $k > k^*$: overreaction, a la diagnostic expectation (Bordalo et al., 2020)
- social communication (SC) via naive learning (DeGroot, 1974; DeMarzo et al., 2003)
  - $\lambda = 0$: no SC
  - $\lambda = 1$: full SC
- rational benchmark (under imperfect information)
  - $\kappa_{i,t} = k^*$ and $\lambda = 0$: no SC and efficient private updating

Back

Aggregate belief dynamics

$$\underbrace{\tilde{\psi}_t}_{\text{N x 1}} = \underbrace{M}_{\text{N x N}} \tilde{\psi}_{t-1} + (1-\lambda)k \underbrace{s_t}_{\text{N x 1}}$$

$$\underbrace{M}_{\text{“transition” matrix}} = (1-\lambda)(1-k) \underbrace{I}_{\text{Identify matrix sized N}} + \lambda W$$

Belief dynamics depend on

- λ: the degree of social communication
- k: individual responsiveness to the news
- W: symmetry of social network   More

Belief propagation

Figure 3: IR of the Average Belief $\tilde{\psi}^{av}_{t+v}$ to Local News Shocks

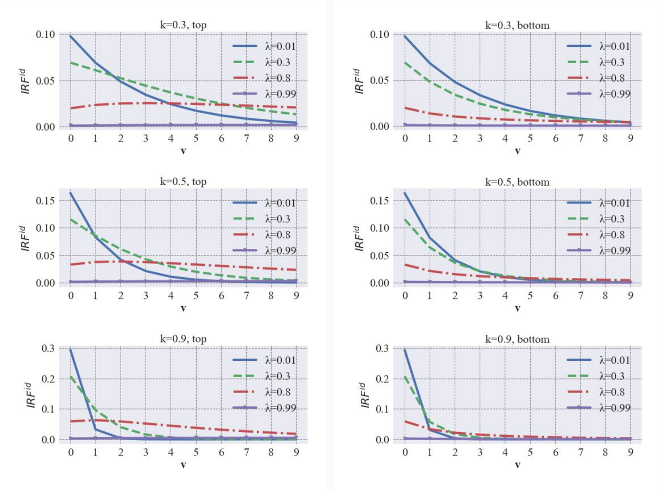
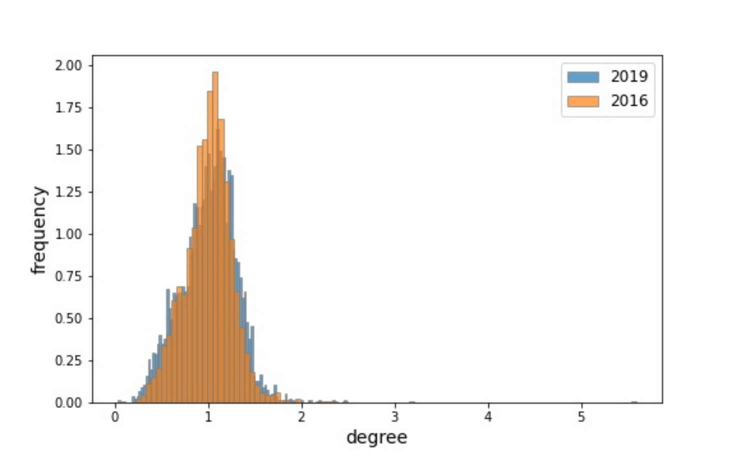


Figure 4: Degree Distributions in the Facebook Network



Does it matter for macroeconomic fluctuations?

- *Idiosyncratic* noises do not cancel out in aggregation
- *Aggregate* shocks propagate sluggishly
- *Granularity*: shocks to "influencers" matter in the aggregate (in Gabaix (2011)'s word)
- Lower within-group and higher inter-group inequality
- Social complementarity drives aggregate fluctuations

Conclusion

Conclusion

An idea is like a virus. Resilient. Highly contagious. And even the smallest seed of an idea can grow.

– The movie Inception [2010]

Some resource

Literature

- Litmaps on Epidemiological Expectations

Modeling tools

- Epidemiological Expectations (Carroll and Wang, 2022)
- Econ-ark: Python-based HA-macro modeling tool
- Sequence-space Jacobians: solving methods of HA-macro models with aggregate risks
- NetworkX: a Python library for Network analysis
- NDlib: a Python library for simulating diffusion models

Data

- Meta/Facebook Social Connectedness Index
- Social Capital Atlas

Questions?

Social network and beliefs

- Key statistic: the dispersion of the degrees (always mean 1)
    - Zero dispersion (social autarky, egalitarian, or symmetric influence)

$$d_i = 1 \forall i$$

    - Non-zero dispersion (W being asymmetric)
        - Belief multiplier effect: following an exogenous shock to belief of each node, average belief response is greater than the shock
          Details
- Similar mechanism in the production networks (**?**) or social multiplier via peer effects (Manski, 1993)

Back

References

Arrow, Kenneth J., "Classificatory Notes on the Production and Transmission of Technological Knowledge," *The American Economic Review*, 1969, *59* (2), 29–35.

Bailey, Michael, Eduardo Dávila, Theresa Kuchler, and Johannes Stroebel, "House price beliefs and mortgage leverage choice," *The Review of Economic Studies*, 2019, *86* (6), 2403–2452.

__ **, Ruiqing Cao, Theresa Kuchler, and Johannes Stroebel**, "The economic effects of social networks: Evidence from the housing market," *Journal of Political Economy*, 2018, *126* (6), 2224–2276.

Bayer, Patrick, Kyle Mangum, and James W Roberts, "Speculative fever: Investor contagion in the housing bubble," *American Economic Review*, 2021, *111* (2), 609–51.

Bikhchandani, Sushil, David Hirshleifer, and Ivo Welch, "A Theory of Fads, Fashion, Custom, and Cultural Change as Informational Cascades," *Journal of Political Economy*, 1992, *100* (5), 992–1026.

Bordalo, Pedro, Nicola Gennaioli, and Andrei Shleifer, "Diagnostic expectations and credit cycles," *The Journal of Finance*, 2018, *73* (1), 199–227.

_ , _ , Yueran Ma, and Andrei Shleifer, "Overreaction in Macroeconomic Expectations," *American Economic Review*, 2020.

Brown, Jeffrey R, Zoran Ivković, Paul A Smith, and Scott Weisbenner, "Neighbors matter: Causal community effects and stock market participation," *The Journal of Finance*, 2008, *63* (3), 1509–1531.

Burnside, Craig, Martin Eichenbaum, and Sergio Rebelo, "Understanding Booms and Busts in Housing Markets," *Journal of Political Economy*, August 2016, *124* (4), 1088–1147.

Carroll, Christopher D, "The epidemiology of macroeconomic expectations," Technical Report, National Bureau of Economic Research Cambridge, Mass., USA 2001.

__ , "Macroeconomic expectations of households and professional forecasters," *the Quarterly Journal of economics*, 2003, *118* (1), 269–298.

__ **and Tao Wang**, "Epidemiological expectations," in "Handbook of Economic Expectations" Elsevier 2022.

Chandrasekhar, Arun G, Horacio Larreguy, and Juan Pablo Xandri, "Testing models of social learning on networks: Evidence from two experiments," *Econometrica*, 2020, *88* (1), 1–32.

Chen, Hailiang and Byoung-Hyoun Hwang, "Listening in on investors' thoughts and conversations," *Journal of Financial Economics*, 2021.

Coibion, Olivier and Yuriy Gorodnichenko, "Information Rigidity and the Expectations Formation Process: A Simple Framework and New Facts," *American Economic Review*, 2015, *105* (8), 2644–2678.

Cookson, J. Anthony and Marina Niessner, "Why Don't We Agree? Evidence from a Social Network of Investors," *The Journal of Finance*, 2020, *75* (1), 173–228.

Cookson, J Anthony, Joseph Engelberg, and William Mullins, "Echo chambers," *Available at SSRN 3603107*, 2022.

DeGroot, Morris H, "Reaching a consensus," *Journal of the American Statistical association*, 1974, *69* (345), 118–121.

DeMarzo, Peter M, Dimitri Vayanos, and Jeffrey Zwiebel, "Persuasion bias, social influence, and unidimensional opinions," *The Quarterly journal of economics*, 2003, *118* (3), 909–968.

Enke, Benjamin and Florian Zimmermann, "Correlation neglect in belief formation," *The Review of Economic Studies*, 2019, *86* (1), 313–332.

Evans, George W and Seppo Honkapohja, *Learning and expectations in macroeconomics*, Princeton University Press, 2001.

Flynn, Joel P and Karthik Sastry, "The macroeconomics of narratives," *Available at SSRN 4140751*, 2022.

Gabaix, Xavier, "The granular origins of aggregate fluctuations," *Econometrica*, 2011, *79* (3), 733–772.

— , "A behavioral New Keynesian model," *American Economic Review*, 2020, *110* (8), 2271–2327.

Han, Bing and David A. Hirshleifer, "Social Transmission Bias and Active Investing," *Social Science Research Network*, 2016.

__ **, David Hirshleifer, and Johan Walden**, "Visibility bias in the transmission of consumption beliefs and undersaving," Technical Report, National Bureau of Economic Research 2019.

Hirshleifer, David and Siew Hong Teoh, "Thought and Behavior Contagion in Capital Markets," *Social Science Research Network*, 2008.

Hommes, Cars, "Behavioral and experimental macroeconomics and policy analysis: A complex systems approach," *Journal of Economic Literature*, 2021, *59* (1), 149–219.

Hong, Harrison, Jeffrey D Kubik, and Jeremy C Stein, "Social interaction and stock-market participation," *The journal of finance*, 2004, *59* (1), 137–163.

— , — , and — , “Thy neighbor’s portfolio: Word-of-mouth effects in the holdings and trades of money managers,” *The Journal of Finance*, 2005, *60* (6), 2801–2824.

Huang, Shiyang, Byoung-Hyoun Hwang, and Dong Lou, “The rate of communication,” *Journal of Financial Economics*, 2021.

Hvide, Hans K and Per Östberg, “Social interaction at work,” *Journal of Financial Economics*, 2015, *117* (3), 628–652.

Jr, Robert E Lucas, “Expectations and the Neutrality of Money,” *Journal of economic theory*, 1972, *4* (2), 103–124.

Lembergman, Ezequiel Garcia, Ina Hajdini, John Leer, Mathieu Pedemonte, and Raphael Schoenle, “The expectations of others,” 2023.

Lucas, Robert E and Benjamin Moll, “Knowledge growth and the allocation of time,” *Journal of Political Economy*, 2014, *122* (1), 1–51.

Macaulay, Alistair and Wenting Song, "News Media, Inflation, and Sentiment," in "AEA Papers and Proceedings," Vol. 113 American Economic Association 2014 Broadway, Suite 305, Nashville, TN 37203 2023, pp. 172–176.

Makridis, Christos, "The effect of economic sentiment on consumption: Evidence from social networks," *Available at SSRN 3092489*, 2019.

— **and Tao Wang**, "Learning from friends in a pandemic: Social networks and the macroeconomic response of consumption," *Available at SSRN 3601500*, 2020.

Malmendier, Ulrike and Stefan Nagel, "Learning from inflation experiences," *The Quarterly Journal of Economics*, 2015, *131* (1), 53–87.

Mankiw, N Gregory and Ricardo Reis, "Sticky information versus sticky prices: a proposal to replace the New Keynesian Phillips curve," *The Quarterly Journal of Economics*, 2002, *117* (4), 1295–1328.

Manski, Charles F, "Identification of endogenous social effects: The reflection problem," *The review of economic studies*, 1993, *60* (3), 531–542.

Mortensen, Dale T and Christopher A Pissarides, "Job creation and job destruction in the theory of unemployment," *The review of economic studies*, 1994, *61* (3), 397–415.

Nagel, Stefan and Zhengyang Xu, "Asset pricing with fading memory," *The Review of Financial Studies*, 2022, *35* (5), 2190–2245.

References x

Nolan, Christopher, "Inception [Motion Picture]: the Shooting Script," Technical Report, Producers: Christopher Nolan, Emma Thomas; Director: Christopher Nolan; Screenwriter: Christopher Nolan; Studios: Legendary Pictures, Syncopy 2010.

Pedersen, Lasse Heje, "Game on: Social networks and markets," *J. financ. econ.*, December 2022, *146* (3), 1097–1119.

Shiller, Robert J, "Narrative economics," *American Economic Review*, 2017, *107* (4), 967–1004.

_ **and John Pound**, "Survey evidence on diffusion of interest and information among investors," *Journal of Economic Behavior & Organization*, 1989, *12* (1), 47–66.

Shive, Sophie, "An epidemic model of investor behavior," *Journal of Financial and Quantitative Analysis*, 2010, pp. 169–198.

Sims, Christopher A, "Implications of rational inattention," *Journal of monetary Economics*, 2003, *50* (3), 665–690.

Woodford, Michael, "Imperfect common knowledge and the effects of monetary policy," Technical Report, National Bureau of Economic Research 2001.