Herding Cycles

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Motivation

- Many historical recessions can be described as bubble-like "boom-bust" cycles:
  - Expansion accompanied by massive investments into one sector (new technologies, finance, etc.)
  - Followed by a sharp contraction in macro aggregates
    - E.g.: IT-led boom in late 1990s

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- A prominent view is that these cycles are expectation driven (Pigou, 1927)
  - "News"-driven business cycles (Beaudry and Portier, 2004, 2006, 2014; etc.)
  - Limitation: many aspects of the cycle is exogenous (timing, sequence of shocks)
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  - Limitation: many aspects of the cycle is exogenous (timing, sequence of shocks)
  - What drives the belief dynamics remains unknown
- We provide an endogenous theory of the phenomenon based on **herding:**
  - Generate a full boom-and-bust cycle out of a single impulse shock
  - Important quantitative and policy implications

The Story

- We embed a model of rational herding into a business cycle framework:
  - Agents learn from observing the investment behavior of others (social learning)
  - People can sometimes collectively fool themselves into thinking they're in a boom until they realize their mistake (bust)

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- Boom-bust cycles as false-positives:
  - Technological innovations arrive exogenously with uncertain qualities
  - Agents have private information and observe aggregate investment rates
  - Importantly, we assume that there is common noise in private signals
    - correlation of beliefs due to agents having similar sources of information
    - allows for variation in average beliefs independent from fundamentals
  - High investment indicates either:
    - state with good technology, or
    - state with bad technology but where agents hold optimistic beliefs.

The Story

- Development of a boom-bust cycle:
  - Unusually large realizations of common noise may send the economy on self-confirming boom:
    - agents mistakenly attribute high investment to technology being good
    - leads agents to take actions that seemingly confirm their assessment
    - investment rises...
  - However, agents are rational and information keeps arriving, so probability of false-positive state rises
    - at some point, most pessimistic agents stop investing
    - suddenly, high beliefs are no longer confirmed by experience
    - sharp reversal in beliefs and collapse of investment $\Rightarrow$ bust
    - truth is learned in the long run

Preview of Results

- **Results**
  - Unique-equilibrium model that can produce an endogenous boom-bust
    - Above and below trend
  - Theory has a range of predictions on bubble-like phenomena over the business cycle:
    - When/why they arise, under what conditions, at what frequency
    - When/why they burst without exogenous shock
  - Since cycle is endogenous, policies are particularly powerful
    - Policies can affect the boom duration/amplitude and timing of the burst
    - Optimal policies (tax) leans against the wind, monetary policy ill-suited
  - Quantification:
    - Theory can generate realistic, sizable boom-bust cycles

Related Literature

- **Bubbles**
  - Macro: rational bubbles (Tirole, 1985; Martin and Ventura, 2012; Galí, 2014...), financial frictions (Kocherlakota, 1992; Miao and Wang, 2013, 2015...)
    - $\Rightarrow$ specific sequence of exogenous sunspots
  - Finance: agency problem (Allen and Gale, 2000;...), heterogeneous beliefs (Harrison and Kreps, 1978; Allen et al., 1993), asymmetric information (Abreu and Brunnermeier, 2003;...)
    - $\Rightarrow$ price $\neq$ fundamental, dynamics not the focus
- **News/noise-driven cycle**
  - Beaudry and Portier (2004, 2006, 2014), Jaimovich and Rebelo (2009), Lorenzoni (2009), Schmitt-Grohé and Uribe (2012), Blanchard, Lorenzoni and L'Huillier (2013), etc.
  - $\Rightarrow$ Our theory can endogenize the information process that leads to news-driven cycles
- **Herding**
  - Banerjee (1992), Bikhchandani et al. (1992), Avery and Zemsky (1998), Chamley (2004)
  - Drawbacks of early herding models:
    - Rely crucially on agents moving sequentially and making binary decisions
    - Boom-busts only arise for specific sequence of events and particular ordering of people
  - This paper:
    - Relax sequentiality of moves and binarity of decisions ($\Rightarrow$easier intro to standard models)
    - Boom-bust cycles arise endogenously after a single impulse shock ($\Rightarrow$natural evolution of beliefs in the presence of common noise)

Plan

1. Simplified learning model
2. Business-cycle model with herding

Learning Model

- Simple, abstract model
- Time is discrete $t = 0, 1, ..., \infty$
- Unit continuum of risk neutral agents indexed by $j \in [0, 1]$

Learning Model: Technology

- Agents choose whether to invest or not, $i_{jt} = 1$ or 0
  - Investing requires paying the cost c
- Investment technology has common return

$$R_t = \theta + u_t$$

with:

  - Permanent component $\theta \in \{\theta_H, \theta_L\}$ with $\theta_H > \theta_L$, drawn once-and-for-all
  - Transitory component $u_t \sim$ iid F^u

Learning Model: Private Information

- Agents receive a private signal s_j drawn from distributions with pdf $f^{s}_{\theta+\xi}\left(s_j\right)$
  - ξ is some common noise drawn from CDF F^{ξ}
    - captures the fact that agents learn from common sources (media, govt)

- Example: $f^{s}_{\theta+\xi} \sim \mathcal{N}\left(\theta+\xi, \sigma_s^2\right)$

$$s_j = \theta + \xi + v_j \text{ where } v_j \sim \text{iid } \mathcal{N}\left(0, \sigma_s^2\right)$$

Learning Model: Public Information

- In addition, all agents observe public signals
  - return on investment R_t
  - measure of investors m_t (social learning)

- Measure of investors is

$$m_t = \int_0^1 i_{jt} dj + \varepsilon_t$$

  where $\varepsilon_t \sim$ iid F^m captures informational noise or noise traders

- Measure m_t is an endogenous nonlinear aggregator of private information
  - how much information is released varies over time

Learning Model: Timing

Simple timing:

- At date $t = 0$: θ, ξ and the s_j's are drawn once and for all
- At date $t \geqslant 0$,
  1. Agent j chooses whether to invest or not
  2. Production takes place
  3. Agents observe $\{R_t, m_t\}$ and update their beliefs

Learning Model: Information Sets

- Beliefs are heterogeneous
- Denote public information to an outside observer at beginning of period t

$$\begin{aligned}\mathcal{I}_t &= \{R_{t-1}, m_{t-1}, \ldots, R_0, m_0\} \\ &= \{R_{t-1}, m_{t-1}\} \cup \mathcal{I}_{t-1}\end{aligned}$$

- Multiple sources of uncertainty so must keep track of joint distribution of public beliefs:

$$\Lambda_t\left(\tilde{\theta}, \tilde{\xi}\right) = Pr\left(\theta = \tilde{\theta}, \xi = \tilde{\xi}\,|\,\mathcal{I}_t\right)$$

- The information set of agent j is

$$\mathcal{I}_{jt} = \mathcal{I}_t \cup \left\{s_j\right\}$$

- Recover individual beliefs Λ_{jt} using Bayes' law over Λ_t and s_j

Learning Model: Characterizing Beliefs

- For ease of exposition, simplify aggregate uncertainty to three states

$$\omega = (\theta, \xi) \in \left\{ \underbrace{(\theta_L, 0)}_{\text{bad}}, \underbrace{(\theta_H, 0)}_{\text{good}}, \underbrace{\left(\theta_L, \overline{\xi}\right)}_{\text{false-positive}} \right\} \text{ with } \theta_L < \theta_L + \overline{\xi} < \theta_H$$

  - $\omega = \left(\theta_L, \overline{\xi}\right)$ is the false-positive state: technology is low, but agents receive unusually positive news

- Just need to keep track of two state variables (p_t, q_t):

$$p_t \equiv \Lambda_t (\theta_H, 0) \text{ and } q_t \equiv \Lambda_t \left(\theta_L, \overline{\xi}\right)$$

- Can recover private beliefs $p_{jt} \equiv p_j \left(p_t, q_t, s_j\right)$ and $q_{jt} \equiv q_j \left(p_t, q_t, s_j\right)$ from Bayes' law

Details

Learning Model: Investment Decision

- Agents invests iff

$$E_{jt}\left[R_t|\mathcal{I}_{jt}\right] \geqslant c$$

- Under ▸ MLRP for f^s, optimal investment decision is a cutoff rule $s^*\left(p_t, q_t\right)$:

$$i_{jt} = 1 \Leftrightarrow s_j \geqslant s^*\left(p_t, q_t\right)$$

Learning Model: Endogenous Learning

- The measure of investing agents is

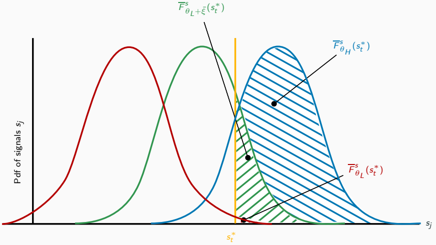
$$m_t = \overline{F}^s_{\theta+\xi}\left(s^*\left(p_t, q_t\right)\right) + \varepsilon_t$$

  - $\overline{F}^s_{\theta+\xi}\left(s_j\right)$ is complementary CDF of private signal s_j
  - Since $s^*\left(p_t, q_t\right)$ and $\left\{\overline{F}^s_{\omega}\right\}_{\omega\in\Omega}$ known to all agents, m_t is a noisy signal about $\theta + \xi$

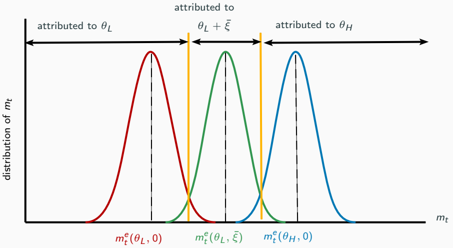
Bayesian updating

Endogenous Learning: 3-state example

- In the 3-state example, only three measures m_t are possible (up to ε_t):

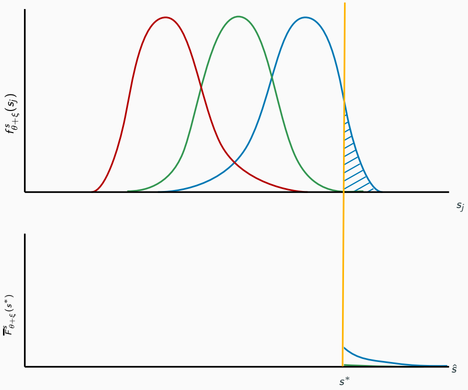


- Distributions of $m_t = \overline{F}^s(\hat{s}_t) + \varepsilon_t$ in the 3 states of the world:



State-dependent Informativeness

- Informativeness of m_t varies over time:



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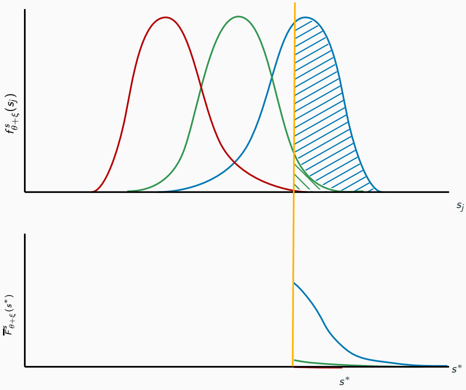

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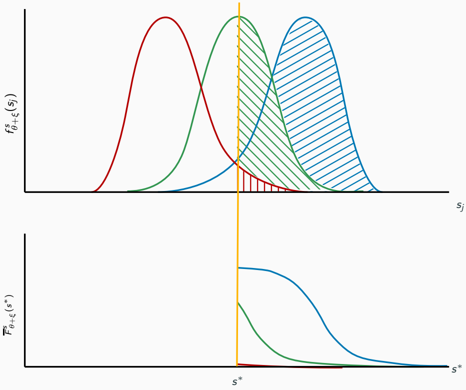

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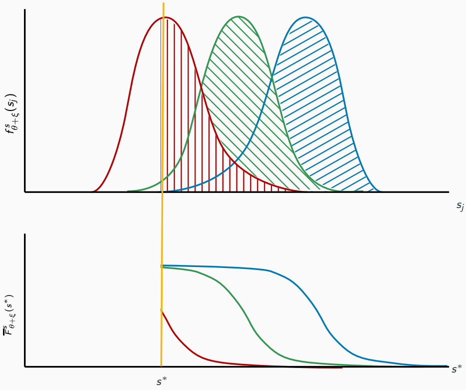

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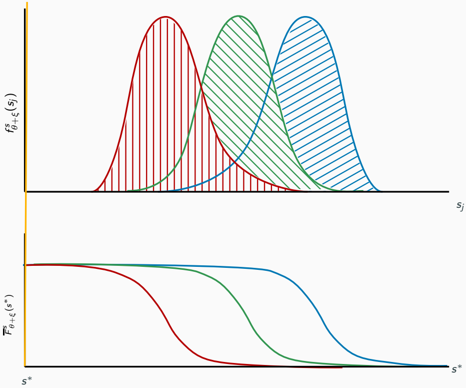

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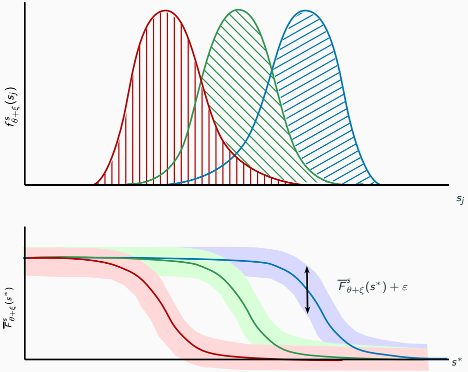

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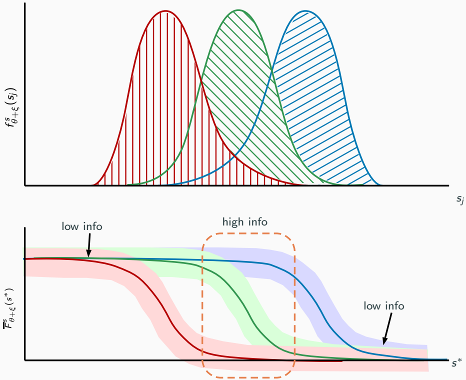


Information Cascades

- Informativeness of m_t varies over time:
  - When $F^{s}_{\theta+\xi}(s^*)$ are close, the states are hard to distinguish
    - $\Rightarrow$ the signal-to-noise ratio is low
- Markets reveal little information when people herd on same action (s^* high/low)
  - Most people invest (or not) in all states
  - Few people use their private information to go against the crowd
  - Hard to detect them so learning is slow
  - $\Rightarrow$ smooth form of information cascades
- **Implications:**
  - Slow boom when few people invest
  - Persistent "bubble" situations when many invest

Simulations

- **Parametrization**
  - Fundamentals: $\theta_h = 1.0$, $\theta_l = 0.5$, $\overline{\xi} = 0.4$, $c = 0.80$
  - Priors: $\mathrm{P}(\theta_h, 0) = 0.25$, $\mathrm{P}\left(\theta_l, \overline{\xi}\right) = 0.05$, $\mathrm{P}(\theta_l, 0) = 0.7$
  - Signals: Gaussian, e.g.:

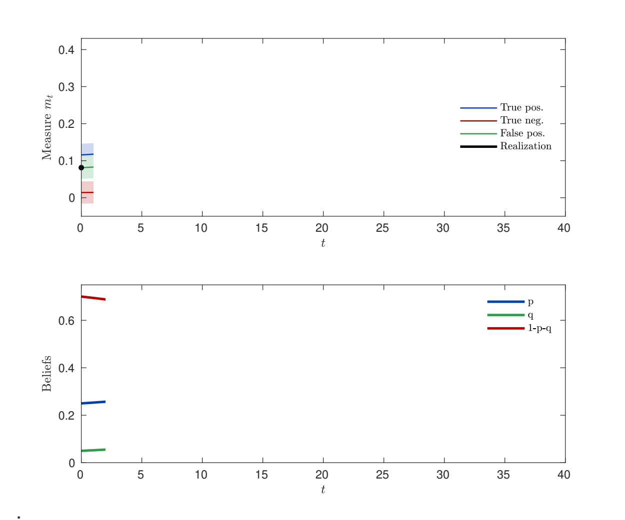
$$s_j = \theta + \xi + v_j \text{ with } v_j \sim \mathcal{N}\left(0, \sigma_v^2\right)$$

with $\sigma_s = 0.5$ (private), $\sigma_\varepsilon = 0.2$ (m_t), $\sigma_u = 2.5$ (R_t)

True negative True positive

Simulations: False Positive $(\theta_I, \overline{\xi})$

- **Boom phase:**



- Mechanism:
  - high investment rates consistent with true and false positive $\Rightarrow$ p and q rise progressively
  - for initial q_0 sufficiently low, most of it is attributed to high state (p dominates)

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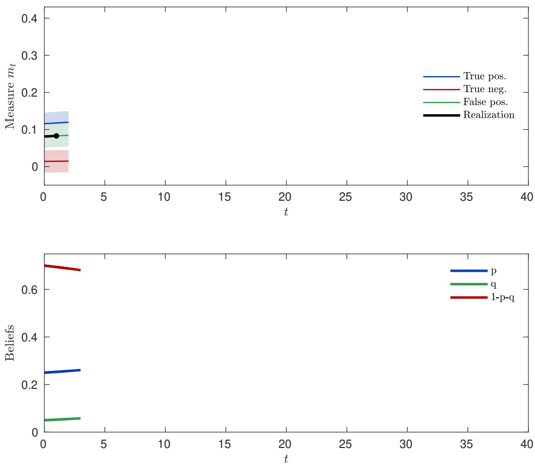

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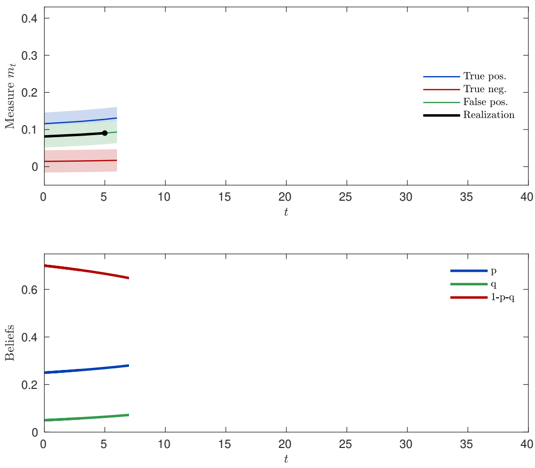

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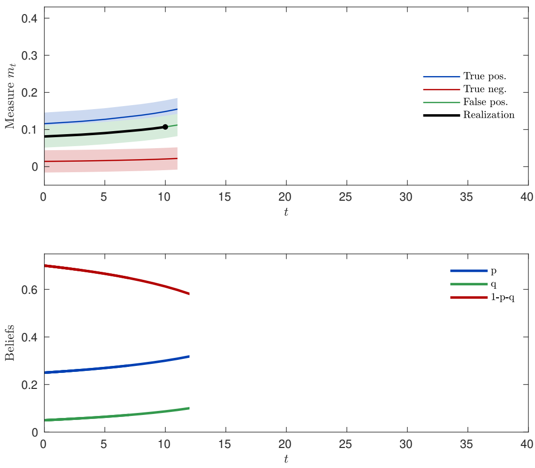

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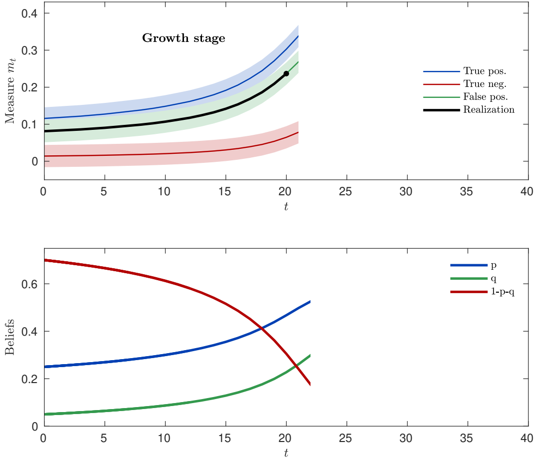

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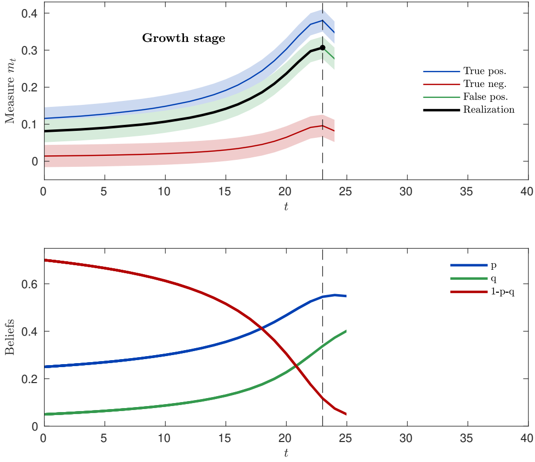

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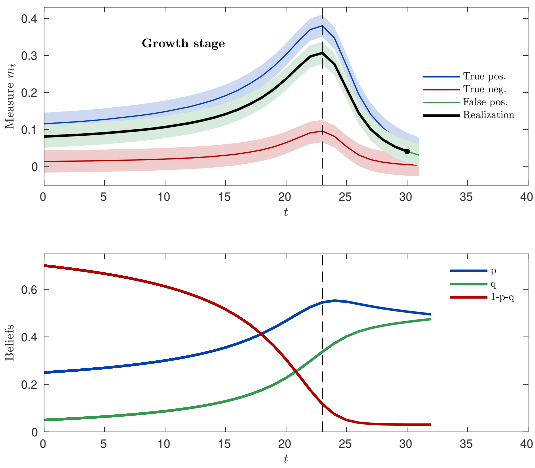

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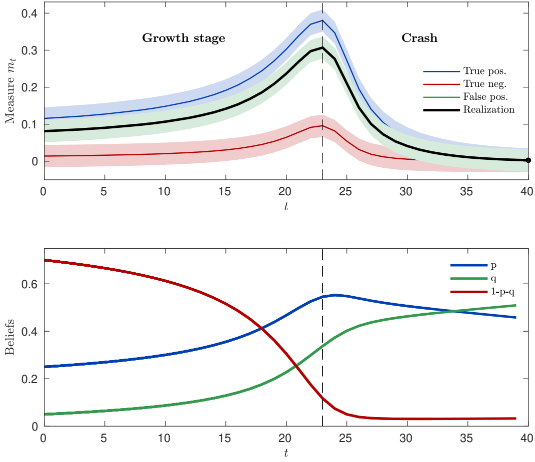

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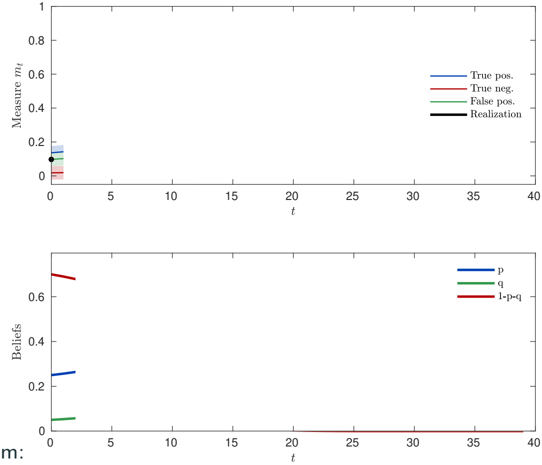

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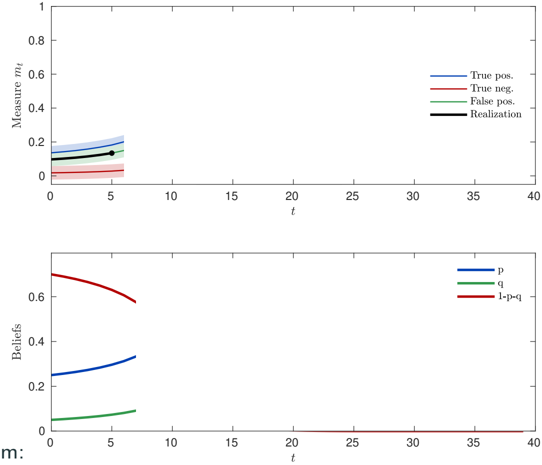

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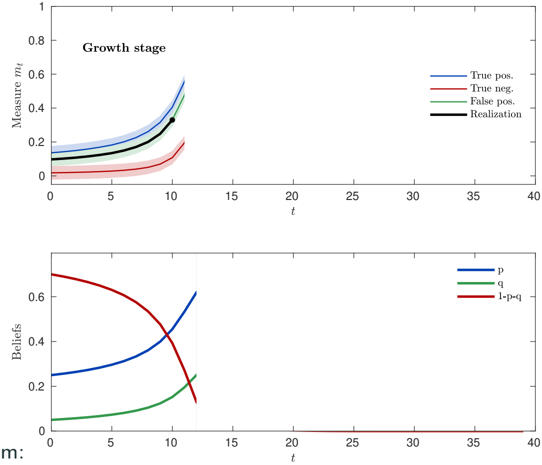

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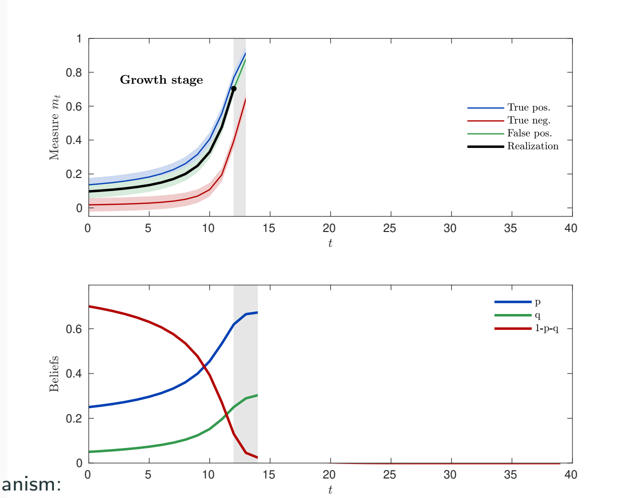

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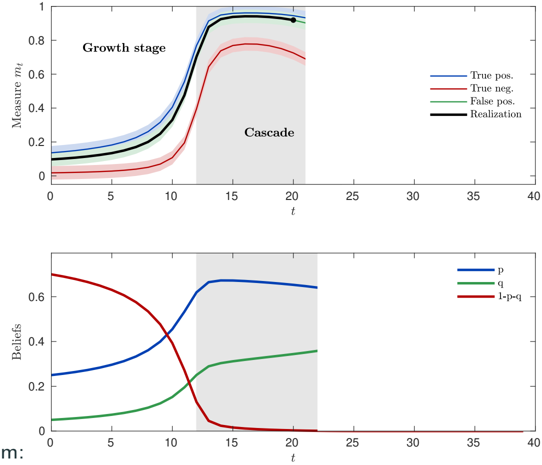

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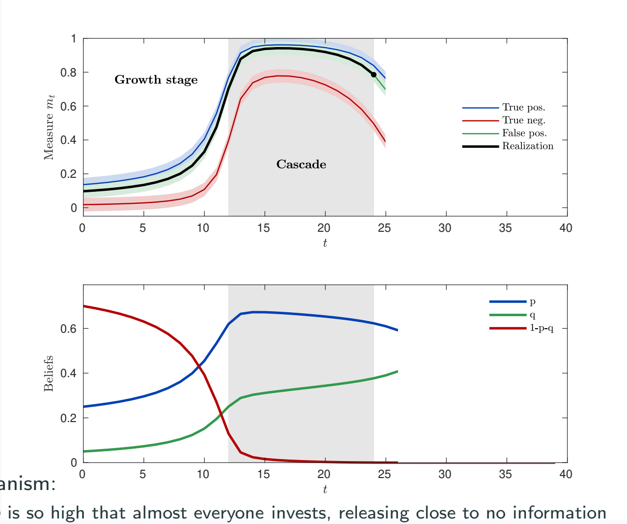

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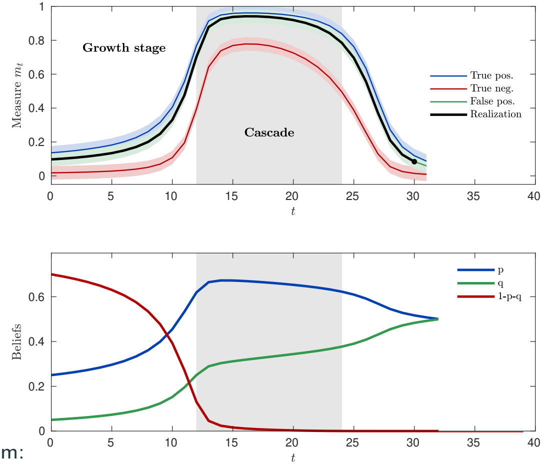

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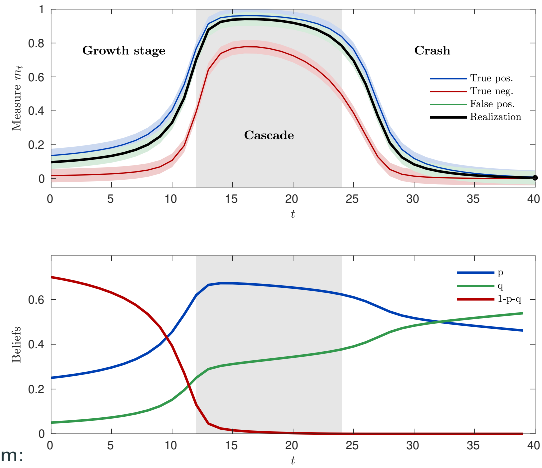

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Additional results in the paper

- Allow ξ to take a continuum of values ▸ Go
  - Results survive
  - **Proposition**: there always exists a threshold $\underline{\xi}$ such that $\xi \geqslant \underline{\xi}$ triggers a boom and bust episode.
- Planner's problem ▸ Go
  - The equilibrium is inefficient
  - Planner adopts lean-against-the-wind policies

Plan

1. Learning model
2. Business-cycle model with herding

Herd-driven Business Cycle Model

- **Objective:**
  - How do boom-and-bust in beliefs lead to general macroeconomic expansion, followed by a below-trend contraction?
  - Full-fledge macro model amenable for quantification and policy analysis

- Parsimonious NK DSGE model with: Details
  1. Dynamic arrival of new technologies and technology choice
  2. Entrepreneurs choose new vs. old technology and learn from measure of tech adopters
  3. Two types of capital: Traditional (T) and Information Technology (IT)
     - IT investment is required to enjoy the new technology
  4. Nominal rigidities
     - Study impact of monetary policy

- Mechanism:
  - Entrepreneurs choose new vs. old technology and agents learn from measure of tech adopters
  - Boom fueled by build-up of IT capital and positive wealth effect on consumption
  - Belief reversal causes sudden realization of misallocation in investments

  $\Rightarrow$ negative wealth effect and collapse of IT investment causing recession

IRF to False-Positive

- **Calibration:** Details
  - Based on the dot-com boom-bust episode
  - Uses data from the Survey of Professional Forecaster to discipline beliefs

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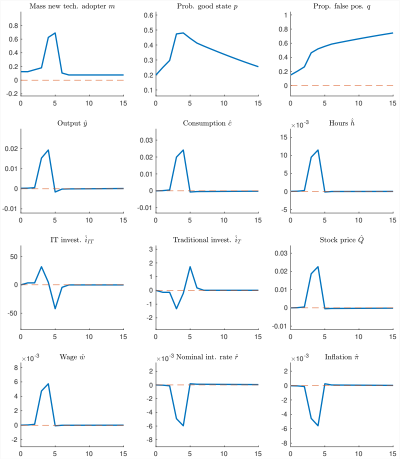
- **Impulse response:** false positive $(\theta, \xi) = (\theta_l, 0.75\,(\theta_h - \theta_l))$



Summary of results

- Mechanism:
  - Positive wealth effect $c \nearrow$,
  - Build-up of future IT capital $i^{IT} \nearrow$
  - Anticipation of future productivity growth $\Rightarrow \pi \searrow$, $r \searrow$
  - Aggregate demand$\nearrow \Rightarrow y \nearrow$,$h \nearrow$
- Quantitative:
  - Endogenous boom-bust with positive comovement between c, i, h and y
  - But boom-bust may arise at high probability (benchmark 15% $\gg 10^{-6}$ (Avery and Zemsky, 1998)

Policy Analysis: Summary

- Govt policies are powerful in this setup:
  - Learning externality: agents do not internalize that investment affects release of info
  - Since cycle is endogenous, policies can substantially dampen boom-busts
- Monetary policy that leans-against-the-wind: Details
  - May succeed in dampening fluctuations
  - But barely affects the new vs. old technology trade-off to take care of learning externality
  - Stabilizes boom-bust in the new technology at the expense of other sector

Conclusion

- Introduce herding phenomena as a potential source of business cycles
- We have proposed a business cycle model with herding
  - people can collectively fool themselves for extended period of time
  - endogenous boom-bust cycles patterns after unusually large noise shocks
  - the model has predictions on the timing and frequency of such phenomena
- Quantitatively, such crises can arise with relatively high probability despite fully rational agents
- Provides rationale for leaning-against-the-wind policies which can substantially dampen fluctuations

Learning Model: Characterizing Beliefs

- Private beliefs $\left(p_{jt}, q_{jt}\right)$ are given by Bayes' law:

$$p_{jt} \equiv p_j\left(p_t, q_t, s_j\right) = \frac{p_t f^s_{\theta_H}\left(s_j\right)}{p_t f^s_{\theta_H}\left(s_j\right) + q_t f^s_{\theta_L+\overline{\xi}}\left(s_j\right) + \left(1 - p_t - q_t\right) f^s_{\theta_L}\left(s_j\right)}$$

$$q_{jt} \equiv q_j\left(p_t, q_t, s_j\right) = \frac{q_t f^s_{\theta_L+\overline{\xi}}\left(s_j\right)}{p_t f^s_{\theta_H}\left(s_j\right) + q_t f^s_{\theta_L+\overline{\xi}}\left(s_j\right) + \left(1 - p_t - q_t\right) f^s_{\theta_L}\left(s_j\right)}$$

- Under MLRP, individual beliefs p_j are monotonic in s_j

$$\frac{\partial p_j}{\partial s_j}\left(p_t, q_t, s_j\right) \geqslant 0$$

Return

Monotone Likelihood Ratio Property

- **Assumption:** F_x^s satisfies *monotone likelihood ratio property* (MLRP)
  - *i.e.:* a higher s signals a higher $\theta + \xi$

$$x_2 > x_1 \text{ and } s_2 > s_1 \quad \Rightarrow \quad \frac{f_{x_2}^s(s_2)}{f_{x_1}^s(s_2)} \geqslant \frac{f_{x_2}^s(s_1)}{f_{x_1}^s(s_1)} \quad \text{(MLRP)}$$

- Satisfied by many standard distributions like $f_\theta^s \sim N\left(\theta, \sigma^2\right)$, etc.

Return

Learning Model: Updating public beliefs

- After observing m_t, public beliefs are updated

$$p_{t+1} = \frac{p_t f^m \left(m_t - \overline{F}^s_{\theta_H} \left(s_t^* \right) \right)}{\Omega}$$

and

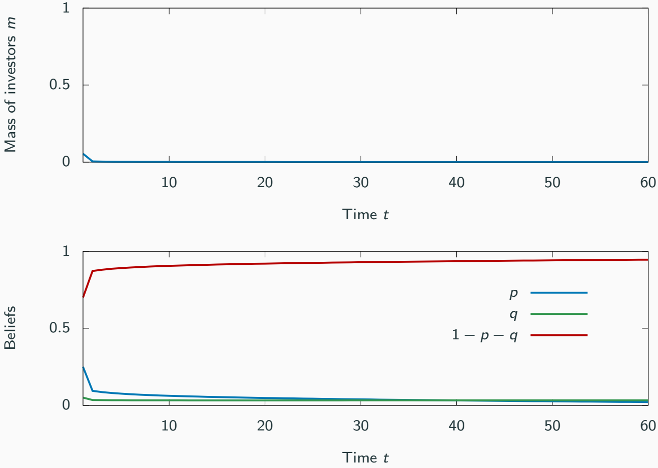
$$q_{t+1} = \frac{q_t f^m \left(m_t - \overline{F}^s_{\theta_L + \overline{\xi}} \left(s_t^* \right) \right)}{\Omega}$$

where
$\Omega = p_t f^m \left(m_t - \overline{F}^s_{\theta_H} \left(s_t^* \right) \right) + q_t f^m \left(m_t - \overline{F}^s_{\theta_L + \overline{\xi}} \left(s_t^* \right) \right) + (1 - p_t - q_t) f^m \left(m_t - \overline{F}^s_{\theta_L} \left(s_t^* \right) \right)$

- Similar updating rule with exogenous signal $R_t = \theta + u_t$

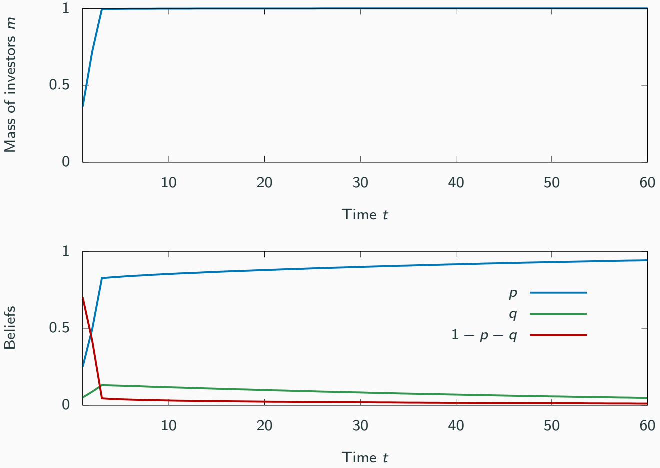
Return

Simulations: True Negative $(\theta_l, 0)$



Return

Simulations: True Positive $(\theta_h, 0)$



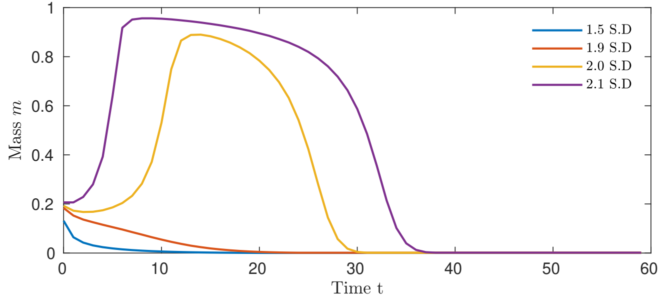
Return

Simulations: Continuous ξ

- Previous simulations may look knife-edge
  - require state $\left(\theta_l, \overline{\xi}\right)$ to be infrequent and resemble $(\theta_H, 0)$
- We now allow ξ to take a continuum of values
- Take-away:
  - small shocks (<1 SD) are quickly learned,
  - but unusually large shocks lead to boom-bust pattern

Simulations: Continuous ξ

- True fundamental $\left(\theta_I = 0, \xi = \text{multiple of } \sigma_\xi\right)$



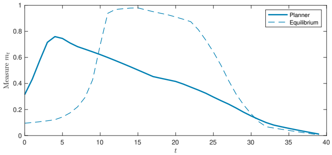
Boom-and-Busts in Continuous Case

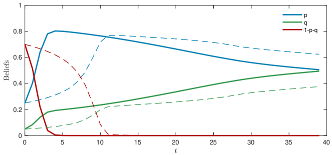
Proposition
In the Gaussian case, for θ and ξ independent and R_t sufficiently uninformative, there always exists a threshold $\underline{\xi}$ such that $\xi \geqslant \underline{\xi}$ triggers a boom and bust episode.

Return

Welfare

- Information externality: agents do not internalize how investment affects the release of information
  - They invest too much in a boom (too little in a negative boom)
- We study the constrained-efficient planning problem Go
  - Optimal policy leans against the wind to maximize collect of information
  - Implementation with investment tax/subsidy
  - Stabilizing "bubbles" comes at the cost of slowing good booms





Return

Welfare

- We adopt the welfare criterion from Angeletos and Pavan (2007)

$$V(p,q) = \max_{\hat{s}} E_{\theta,\xi}\left[\int_{\hat{s}} E\left[\theta - c|\mathcal{I}_j\right] dj + \gamma V\left(p',q'\right)|\mathcal{I}\right]$$

  where $\mathcal{I}$ is public info and $\mathcal{I}_j$ is individual info
- Crucially, the planner understands how $\hat{s}$ affects evolution of beliefs

Return

Business Cycle Model: Summary

- Four types of agents:
  - Households, Entrepreneurs, Retailers and Monetary Authority
- Three sectors: entrepreneur sector, retail sector and final good
- Two types of capital: IT vs. traditional
- Entrepreneurs choose between two technologies: new vs. old
  - new technology more intensive in IT capital

$$Y_{it} = A_{it}\left(\omega_i\left(K_i^{IT}\right)^{\frac{\zeta-1}{\zeta}} + (1-\omega_i)\left(K_i^{T}\right)^{\frac{\zeta-1}{\zeta}}\right)^{\alpha\frac{\zeta}{\zeta-1}}(L_{it})^{1-\alpha}, \; i \in \{n, o\}$$

- Herding in technology adoption:
  - $\theta \in \{\theta_H, \theta_L\}$ is drawn and entrepreneurs receive private signals (+ common noise ξ)
    - Initially $A_{nt} = A_{ot}$ until technology matures (prob. λ) then $A_{nt} = \theta$.
  - Measure of entrepreneurs using new technology

$$m_t = (1-\mu)\,\overline{F}^s_{\theta+\xi}\left(s_t^*\right) + \mu\varepsilon_t$$

where μ = measure of noise entrepreneurs

  - Entrepreneurs learn from observing m_t

Return Details

Business Cycle Model: Population

- Agents:
  - Households ▸ Details
  - Retailers and monetary authority ▸ Details
  - Entrepreneurs
- Three sectors: entrepreneur sector, retail sector and final good
  - Entrepreneur sector: technology choice, no nominal rigidities
  - Retail sector: buys the bundle of goods from entrepreneurs, subject to nominal rigidities
  - Final good: bundle of retail goods used for consumption and investment

Business Cycle Model: Entrepreneurs

- Unit measure of entrepreneurs indexed by $j \in [0, 1]$
  - monopolistic producers of a single variety
- At any date, there is a traditional technology ("old") to produce varieties

$$Y_{jt}^{o} = A^{o} \left(\omega_o \left(K_o^{IT} \right)^{\frac{\zeta-1}{\zeta}} + (1-\omega_o) \left(K_o^{T} \right)^{\frac{\zeta-1}{\zeta}} \right)^{\alpha \frac{\zeta}{\zeta-1}} \left(L_{jt}^{o} \right)^{1-\alpha}$$

- With probability η, an innovative technology arrives ("new")

$$Y_{jt}^{n} = A_t^{n} \left(\omega_n \left(K_n^{IT} \right)^{\frac{\zeta-1}{\zeta}} + (1-\omega_n) \left(K_n^{T} \right)^{\frac{\zeta-1}{\zeta}} \right)^{\alpha \frac{\zeta}{\zeta-1}} \left(L_{jt}^{n} \right)^{1-\alpha}$$

where

$$\omega_n > \omega_o$$

Business Cycle Model: Entrepreneurs

- The new technology needs to mature to become fully productive

$$A_t^n = \begin{cases} A^o & \text{before maturation} \\ \theta & \text{after} \end{cases}$$

- The new technology matures with probability λ per period
- The true productivity θ is high or low $\theta \in \{\theta_H, \theta_L\}$ with $\theta_H > \theta_L$

Business Cycle Model: Technology Choice

- Each period, entrepreneurs choose which technology to use
  - for simplicity, assume no cost of switching so problem is static
  - denote m_t the measure of entrepreneurs that adopt the new technology
- A fraction μ of entrepreneurs is clueless when it comes to technology adoption
  - "noise entrepreneurs"
  - random fraction ε_t adopts the new technology

Business Cycle Model: Information

- At $t = 0$, all entrepreneurs receive a private signal about θ from pdf $f^s_{\theta+\xi}$
  - same assumptions as before (MLRP, etc.)
- Social learning takes place through economic aggregates which reveal

$$m_t = (1-\mu)\,\overline{F}^s_{\theta+\xi}\,(s^*_t) + \mu\varepsilon$$

- Assume public signal $S_t = \theta + u_t$ which capture media, statistical agencies, etc.
- No additional uncertainty, hence information evolves identically to learning model

◂ Return to summary of the model ◂ Return

Business Cycle Model: Households

- Households live forever, work, consume and save in capital
- Preferences

$$E\left[\sum \beta^t \log\left(C_t - \frac{L_t^{1+\frac{1}{\psi}}}{1+\frac{1}{\psi}}\right)\right], \quad \sigma \geqslant 1, \psi \geqslant 0,$$

where $C_t = \left(\int_0^1 C_{jt}^{\frac{\sigma-1}{\sigma}} dj\right)^{\frac{\sigma}{\sigma-1}}$ is the final good

- Law of motion for the two capitals

$$K_{jt+1} = (1-\delta) K_{jt} + I_{jt}, j = o, n$$

- Budget constraint

$$C_t + \sum_{j=o,n} I_{jt} + \frac{B_t}{P_t} = W_t L_t + \sum_{j=o,n} R_{jt} K_{jt} + \frac{1+r_{t-1}}{1+\pi_t} \frac{B_{t-1}}{P_{t-1}} + \Pi_t$$

Return

Business Cycle Model: Others

- Retail sector:
  - buys the bundle of goods produced by entrepreneurs
  - differentiates it one-for-one without additional cost
  - subject to Calvo-style nominal rigidity $\rightarrow$ standard NK Phillips curve
- Monetary authority follows the Taylor rule

$$r_t = \phi_\pi \pi_t + \phi_y y_t$$

Return

Calibration: Standard Parameters

Parameter	Value	Target
α	.36	Labor share
β	.99	4% annual interest rate
θ_p	.75	1 year price duration
σ	10	Markups of about 11%
ϕ_y	.125	Clarida, Gali and Gertler (2000)
ϕ_π	1.5	Clarida, Gali and Gertler (2000)
ψ	2	Frisch elasticity of labor supply
ζ	1.71	Elas. between types of K (Boddy and Gort, 1971)

Calibration: Non-Standard Parameters

Objective: target moments from the late 90s Dot com bubble

Parameter	Value	Target
ω_o	.11	Share IT capital 1991
ω_n	.26	Share IT capital 2007
λ	1/22	Duration of NASDAQ boom-bust 1995Q4-2001Q1
θ_h	1.099	SPF's highest growth forecast over 1995-2001
θ_l	.912	SPF's lowest growth forecast over 1995-2001
s_j	$N(0, .156)$	SPF's avg. dispersion in forecasts over 1995-2001
μ	15%	Fraction of noise traders
ε	Beta(2, 2)	Non-uniform distribution over [0, 1]
p_0	0.20	See below
q_0	0.15	See below

Tricky parameters:

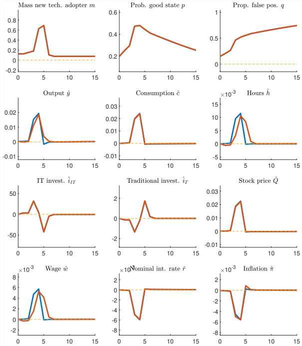
- Noise traders μ and ε: little guidance in the literature (David, et al. 2016)
  - Sensitivity $\mu \in [0.02, 0.2]$: agents learn too fast if $\mu < 0.02$, too slowly if $\mu > 0.2$ (no quick collapse)
- p_0, q_0: hard to tell with a single historical episode
  - The paper offers sensitivity over these two parameters

Return

Monetary Policy

- Taylor rule that leads against the wind:

$$r_t = \phi_\pi \pi_t + \phi_y (y_t - \overline{y}) + \phi_i \left(i_t^{IT} - \overline{i}^{IT} \right)$$



- A leaning-against-the-wind monetary policy:
  - Dampens fluctuations in output (welfare +0.002%)
  - But fails to improve tech adoption threshold and info collection
  - Other more directed tools (tech subsidies/taxes) more promising

Return