Herding Cycles

Edouard Schaal

CREI, UPF and BGSE

Mathieu Taschereau-Dumouchel

Cornell University

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- Many recessions are preceded by booming periods of frenzied investment after introduction of new technology ("boom-bust cycle")
  - IT-led boom in late 1990s
  - to some extent, financial innovation-led housing boom in 2000s
- While standard practice in business cycle analysis is to treat them separately, another view is that booms and busts are two sides of the same coin
  - "booms sow the seeds of the subsequent busts" (Schumpeter)
  - extent and magnitude of expansion cause and determine depth of downturn
- Our objective is to develop a theory of (quasi-)endogenous boom-and-bust cycles

This Paper

- We embed herding features into a business cycle framework
  - Social learning: people collectively fool themselves into thinking they're into a boom
  - We explore the ability of such models to generate economic booms followed by sudden crashes
  - Under multidimensional uncertainty, agents may attribute observations to wrong causes, with possibility of quick reversals in beliefs
- Preview of results:
  - Model has predictions on when booms-and-busts arise and when they collapse
  - Since cycle is endogenous, policy can be powerful in eliminating such cycles
  - Quantitatively, even with rational agents, booms-and-bust may arise with reasonably high probability ($\simeq$15%)

The Story

- 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 average beliefs to be away from true fundamentals
  - High investment indicates either:
    - state with good technology, or
    - state with bad technology but where agents hold optimistic beliefs.

- Development of a boom-bust cycle:
  - Unusually large realizations of noise may send the economy on self-confirming boom where:
    - 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 end

Related Literature

- News/noise-driven cycle literature
  - Beaudry and Portier (2004, 2006, 2014), Jaimovich and Rebelo (2009), Schmitt-Grohé and Uribe (2012), Blanchard, Lorenzoni and L'Huillier (2013), etc.
  - Shares the view of boom-bust cycles as false-positives
  - Can view our contribution as endogenizing the information process for news cycles
- Herding literature
  - Banerjee (1992), Bikhchandani et al. (1992), Chamley (2004)
  - But early herding models have been criticized:
    - Rely crucially on agents moving sequentially and making binary decisions
    - Boom-busts only arrive for specific sequence of events and particular ordering of people
  - In our model, agents move simultaneously and learn from aggregates
    - Do not rely on a specific ordering of agents to generate cycle, but instead on the endogenous evolution of beliefs in the presence common noise
    - Closest to Avery and Zemsky (1998) for herding with multidimensional uncertainty
- This paper:
  - "Smooth information cascades" with endogenous bursting
  - First application to business cycles and policy analysis

Plan

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

Plan

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

- 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-for-all
  - Transitory component $u_t \sim$ iid F^u

- Agents receive a private signal s_j
  - Example:
  $$s_j = \theta + \xi + v_j \text{ where } v_j \sim \mathcal{N}\left(0, \sigma_v^2\right)$$
  - ξ is some common noise drawn from cdf F^{ξ}
    - captures the fact that agents learn from common sources (media, govt)

- More generally, s_j is drawn from distributions with pdf $f^s_{\theta+\xi}\left(s_j\right)$
  - denote CDFs by $F^s_{\theta+\xi}\left(s_j\right)$ and complementary CDFs by $\overline{F}^s_{\theta+\xi}\left(s_j\right)$
  - assume that F^s_x satisfies *monotone likelihood ratio property* (MLRP), i.e.,
  $$\text{for } x_2 > x_1, s_2 > s_1, \quad \frac{f^s_{x_2}\left(s_2\right)}{f^s_{x_1}\left(s_2\right)} \geqslant \frac{f^s_{x_2}\left(s_1\right)}{f^s_{x_1}\left(s_1\right)} \quad \text{(MLRP)}$$
  - *Intuition:* a higher s signals a higher $\theta + \xi$

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 given by

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

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

$\Rightarrow$ learning from endogenous non-linear aggregator of private information

Learning Model: Timing

Simple timing:

- At date 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

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

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

- The information set of agent j is

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

Learning Model: Characterizing Beliefs

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

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

- Heterogeneous beliefs so keep track of distribution of individual beliefs $\left\{\pi_{jt}\right\}_j$
- Fortunately, heterogeneity is one-dimensional and constant:
  - Distribution of private beliefs can be reconstructed anytime from public beliefs

Learning Model: Characterizing Beliefs

- For ease of exposition, simplify aggregate uncertainty to three states (slides only)

$$\omega = (\theta, \xi) \in \left\{ (\theta_L, 0), (\theta_H, 0), (\theta_L, \Delta) \right\} \text{ with } \theta_L < \theta_L + \Delta < \theta_H$$

  - $\omega = (\theta_L, \Delta)$ 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):

$$p_t \equiv \pi_t (\theta_H, 0) \text{ and } q_t \equiv \pi_t (\theta_L, \Delta)$$

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

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

$$q_{jt} \equiv q_j\left(p_t, q_t, s_j\right) = \ldots$$

- Under MLRP, individual beliefs p_j are monotonic in s_j

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

- Agents invests iff

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

that is, whenever $p_{jt} \geqslant \hat{p}$ where

$$\hat{p}\theta_H + (1-\hat{p})\,\theta_L = c$$

- The optimal investment decision takes the form of a cutoff rule $\hat{s}\,(p_t, q_t)$

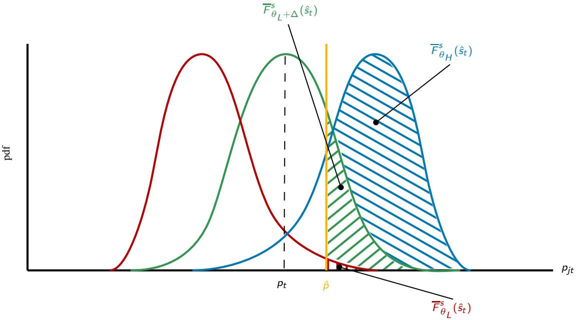
$$i_{jt} = 1 \Leftrightarrow s_j \geqslant \hat{s}\,(p_t, q_t) \text{ with } p_j\,(p_t, q_t, \hat{s}_t) = \hat{p}$$

- The measure of investing agents is

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

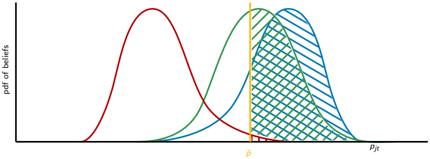
  - Since $\hat{s}\left(p_t, q_t\right)$ is known by all agents, m_t is a noisy signal about $\theta + \xi$
  - $\overline{F}^s_x$ is known, so inference problem is tractable ▸ Bayesian updating

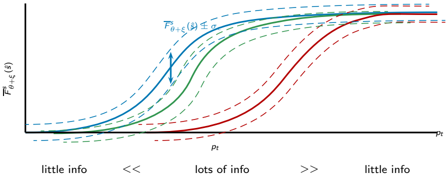
- In the 3-state example, only three measures m_t are possible (up to ε_t):



Nonmonotonicity of Information

- As in early herding model, markets stop revealing info for extreme public beliefs
  - For high/low p_t, only agents with extreme private signals go against the crowd
  - There are few of them, so hard to detect if m_t is noisy
  - "Smooth" information cascade $\Rightarrow$ persitent "bubble" situation





Simulations

- Parametrization
  - Fundamentals: $\theta_h = 1.0$, $\theta_l = 0.5$, $\Delta = 0.4$, $c = 0.75$
  - Priors: $\mathrm{P}(\theta_h, 0) = 0.25$, $\mathrm{P}(\theta_l, \Delta) = 0.05$, $\mathrm{P}(\theta_l, 0) = 0.7$
  - Signals: Gaussian, e.g.:

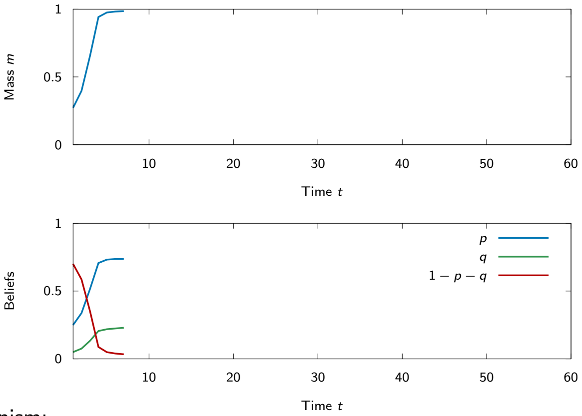
$$s_j = \theta + \xi + v_j \text{ with } v_j \sim \mathcal{N}\left(0, \sigma_v^2\right)$$

with $\sigma_v = 0.4$ (private), $\sigma_\varepsilon = 0.2$ (m_t), $\sigma_u = 2.5$ (R_t)

▸ True negative ▸ True positive

Simulations: False Positive (θ_l, Δ)

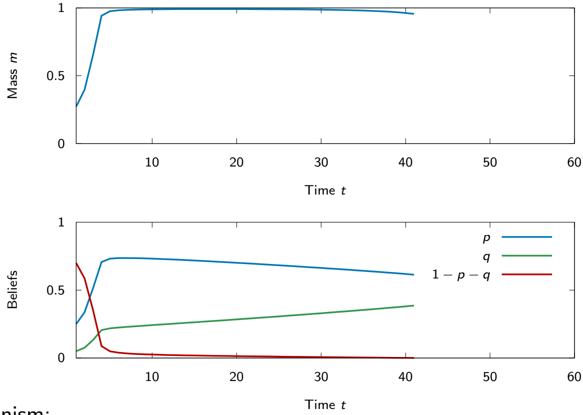
- **Boom phase:**



- Mechanism:
  - High investment rates quickly exclude low state $(\theta_l, 0)$ $\Rightarrow p$ and q rise progressively
  - For initial q_0 sufficiently low, p picks up more strongly

Simulations: False Positive (θ_I, Δ)

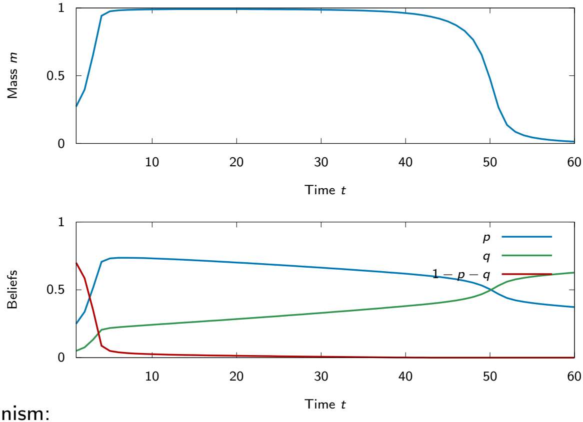
- **Information Cascade**



- Mechanism:
  - p is so high that almost everyone invests, releasing close to no information
  - because information not exactly 0, q slowly rises in the background

Simulations: False Positive (θ_l, Δ)

- **Bursting**



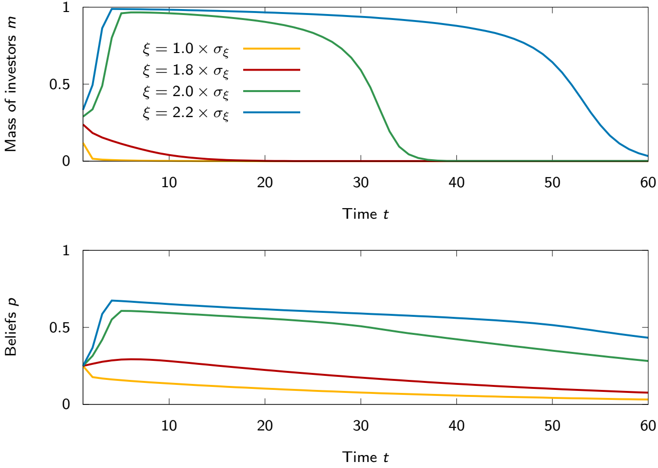
- Mechanism:
  - when q high enough, some investors leave the market, releasing more information
  - early exit of investors incompatible with high state $\Rightarrow$ quick collapse of investment

Simulations: Continuous ξ

- Previous simulations may look knife-edge
  - require state (θ_l, Δ) 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 $\left(\theta_I = 0, \xi = \text{multiple of } \sigma_\xi\right)$



Additional Results

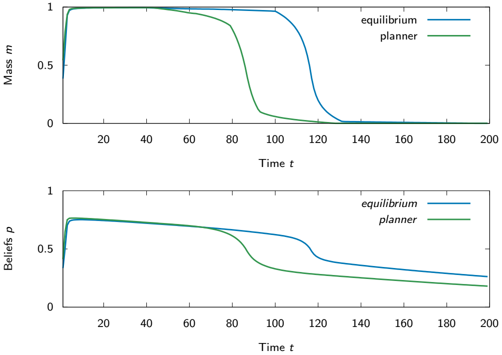
Proposition

For $F_{\theta+\xi}$ unbounded or $\sigma_u < \infty$ (public info), there always exists a large enough $\underline{\xi}$ such that $\xi \geqslant \underline{\xi}$ triggers a boom and bust episode.

- Asymmetry: slow boom and sudden crash?
  - We extend to continuous arrival of private information Go
  - Initially, with little public information, distribution of private beliefs fans out, slowing the boom
  - Crash remains sudden because it arises later when public signals have accumulated and beliefs are less dispersed
- Intensive margin: robustness?
  - mechanism survives as long as individual investment displays concavity in beliefs (Straub and Ulbricht, 2018)
  - Ex.: budget or borrowing constraints...

Welfare

- Information externality: agents do not internalize how investment affects the release of information
- We study the social planning problem ▸ Go
  - Optimal policy leans against the wind to maximize collect of information
  - Implementation with investment tax/subsidy



Plan

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

A News-driven Business Cycle Model?

- We want a model in which rising beliefs cause a boom, then a recession when beliefs collapse
  - Key difficulty is to generate comovement in absence of technology shock
    - Wealth effect reduces labor and output
    - For risk aversion greater than 1 (IES<1), want to move resources from rich to poor states: investment declines before realization of productivity
- Build on the news-driven business cycle literature
  - Beaudry and Portier (2004, 2014); Jaimovich and Rebelo (2009); Lorenzoni (2009)

Business Cycle Model: Ingredients

- Parsimonious NK DSGE model with:
  1. Dynamic arrival of new technologies and technology choice
  2. Two types of capital: Traditional (T) and IT
     - Investment is required to enjoy the new technology
  3. Nominal rigidities (Lorenzoni, 2009)
     - Without, large spike in interest rate which lowers consumption and investment
     - With nominal rigidities, interest rate response is muted, consumption rises (wealth effect)
- Key mechanism:
  - Each period, entrepreneurs choose their technology and agents learn from measure of tech adopters
  - Learning akin to previous simplified model

Business Cycle Model: Population

- Agents:
  - Households ▸ Households
  - 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

$$\omega_n > \omega_o$$

- 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

- 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

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

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

Calibration: Standard Parameters

Parameter	Value	Target
α	.36	Labor share
β	.99	4% annual interest rate
γ	1	risk averion (log)
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)
κ	9.11	Schmitt-Grohe and Uribe (2012)
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

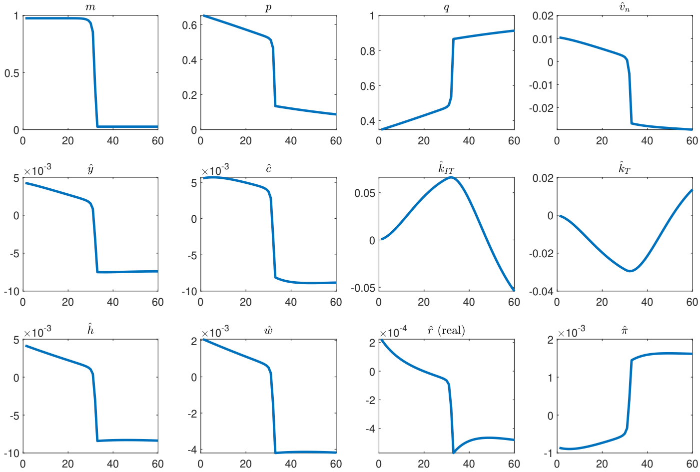
Parameter	Value	Target
ω_o	.34	IT invest in GDP pre-1995 (2.86%)
ω_n	.36	IT investment post-2005 (3.56%)
λ	1/10	Duration of NASDAQ boom-bust 1998Q4-2001Q1
θ_h	1.045	SPF's highest growth forecast over 1998-2001
θ_l	.95	SPF's lowest growth forecast over 1998-2001
s_j	$N(0, .137)$	SPF's avg. dispersion in forecasts over 1998-2001
μ	5%	Fraction of noise traders
ε	Beta(2, 2)	Normalization
ξ	$N\left(0, \sigma_\xi^2\right)$	See below

Tricky parameters:

- Noise traders μ and ε: little guidance in the literature (David, et al. 2016)
  - Sensitivity $\mu \in [0.02, 0.15]$: agents learn too fast if $\mu < 0.02$, too slowly if $\mu > 0.15$ (no quick collapse)
- Common noise ξ: little information without a large sample of such crises
  - We trace out the probability of boom-bust cycles as we vary σ_ξ
    - Trade-off: high $\sigma_\xi \Rightarrow$ large ξ quickly detected, low $\sigma_\xi \Rightarrow$ boom-bust have low proba

IRF to False-Positive

True state: $(\theta, \xi) = (\theta_l, 0.95\,(\theta_h - \theta_l))$



Summary of results

- Quantitative:
  - Endogenous boom-bust with positive comovement between c, i, h and y
  - But boom-bust cycles arise with fairly high probability $\simeq$ 16% $\gg 10^{-6}$ (Avery and Zemsky, 1998)
  - Peak-to-trough is $\sim$1.5%, less than 2-3% in the data (standard pb with news shocks)
- Policy:
  - *Leaning-against-the-wind* monetary policy dampens magnitude of cycle
  - Investment tax/subsidy can virtually eliminate false-positives at the cost of slowing "good booms"

- 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 partially eliminate boom-busts
- We show two examples of leaning-against-the-wind policies:
  - Monetary policy rule:

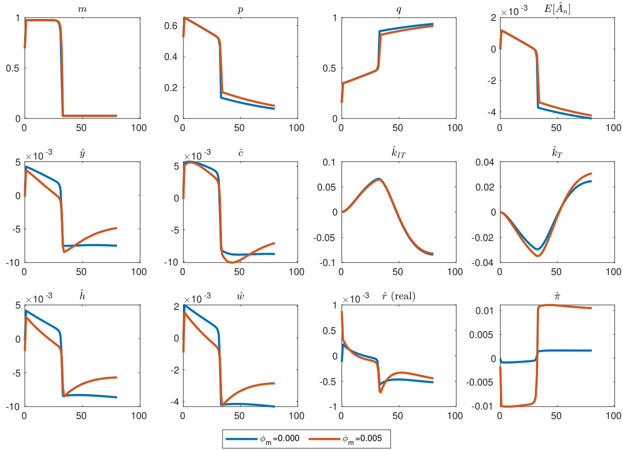
$$r_t = \phi_\pi \pi_t + \phi_y y_t + \phi_m m_t$$

  - A direct tax on using the new technology

$$t_t = c_0 + c_p p_t + c_q q_t$$

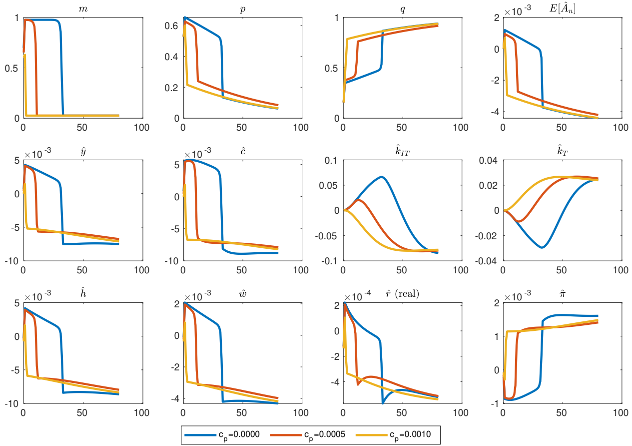
- Optimal policy: in the making...

Policy Analysis: Monetary Policy



- In this simple framework, monetary policy:
  - dampens the cycle but inefficient at fighting the information cascade
    - barely affects the technology choice, mostly the magnitude of boom and bust
  - at the additional cost of slowing down true booms

Policy Analysis: Tax Policy



- Tech-specific tax policy can effectively affect the technology choice
  - may eliminate some of the boom-bust cycles
  - trade-off in slowing down true booms and maximizing collect of information

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

- After observing m_t, public beliefs are updated

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

and

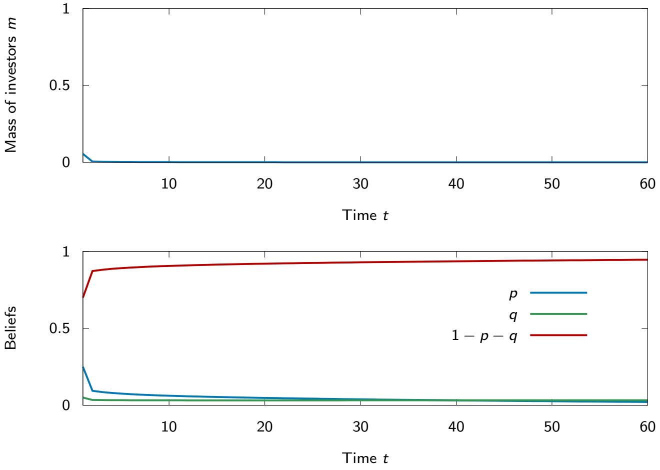
$$q_{t+1} = \frac{q_t f^m \left(m_t - \overline{F}^s_{\theta_L + \Delta} (\hat{s}_t) \right)}{\Omega}$$

where $\Omega = p_t f^m \left(m_t - \overline{F}^s_{\theta_H} (\hat{s}_t) \right) + q_t f^m \left(m_t - \overline{F}^s_{\theta_L + \Delta} (\hat{s}_t) \right) + (1 - p_t - q_t) f^m \left(m_t - \overline{F}^s_{\theta_L} (\hat{s}_t) \right)$

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

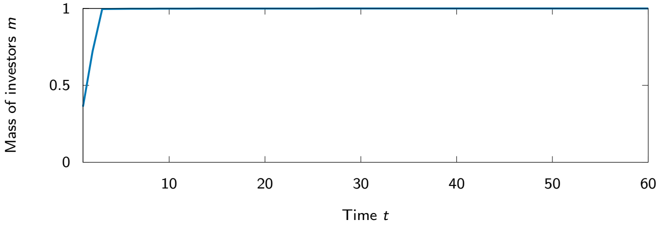
Return

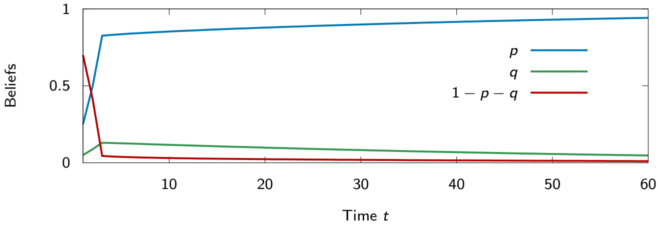
Simulations: True Negative $(\theta_l, 0)$



Return

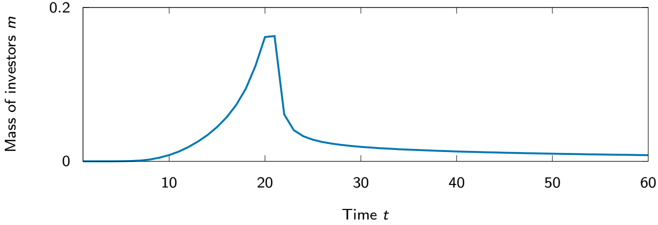
Simulations: True Positive $(\theta_h, 0)$

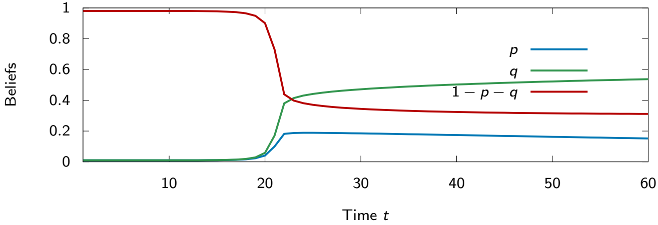




◂ Return

Continuous Arrival of Private Signals





Return

Welfare

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

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

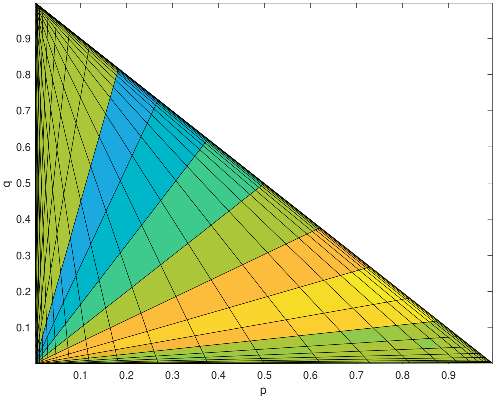
where $\mathcal{I}$ is public info and $\mathcal{I}_j$ is individual info

- Crucially, the planner understands how $\hat{s}$ affects evolution of beliefs

Return

Welfare

- Entry threshold planner vs equilibrium

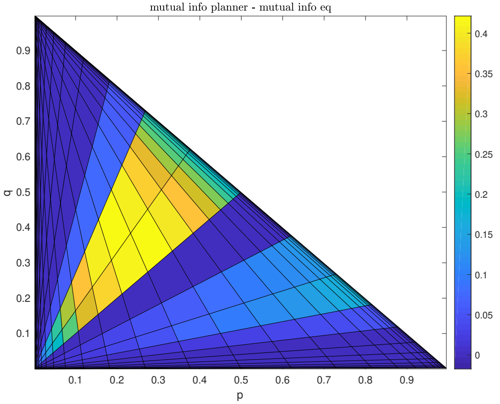


yellow = less investment in planner, green = same, blue = more

Return

Welfare

- More information is endogenously released in the efficient allocation



purple = same info in planner, light blue = more, yellow = a lot more

Return

Business Cycle Model: Households

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

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

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

- Adjustment costs in capital

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

- 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