

Herding Cycles

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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
- 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 can produce an expansion-contraction cycle (**above** and **below** trend)
 - ▶ Theory that can shed light 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 (e.g., monetary policy) can support **birth/trigger** the burst of such cycles
 - Good policies can also substantially stabilize or **eliminate** 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.

The Story _____

- 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), Lorenzoni (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)
 - ▶ Relax certain assumption of early herding models:
 - 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:
 - ▶ Boom-busts cycles arise endogenously after a single impulse shock
 - ▶ Application to business cycles and policy analysis

Plan _____

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

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Learning Model ---

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

- 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 $u_t \sim \text{iid } F^u$

- Agents receive a private signal s_j

- ▶ Example:

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

- ▶ 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 $f_{\theta+\xi}^s(s_j)$

- ▶ denote CDFs by $F_{\theta+\xi}^s(s_j)$ and complementary CDFs by $\bar{F}_{\theta+\xi}^s(s_j)$

- ▶ assume that F_x^s satisfies *monotone likelihood ratio property* (MLRP), i.e.,

$$\text{for } x_2 > x_1, s_2 > s_1, \quad \frac{f_{x_2}^s(s_2)}{f_{x_1}^s(s_2)} \geq \frac{f_{x_2}^s(s_1)}{f_{x_1}^s(s_1)} \quad (\text{MLRP})$$

- ▶ *Intuition*: a higher s signals a higher $\theta + \xi$

- 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 $\varepsilon_t \sim \text{iid } F^m$ captures informational noise or noise traders

⇒ 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 $t \geq 0$,
 - 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

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

- The information set of agent j is

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

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

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

- Heterogeneous beliefs so keep track of **distribution of individual beliefs** $\{\pi_{jt}\}_j$
- Fortunately, heterogeneity is one-dimensional and constant:
 - ▶ **Distribution of private beliefs can be reconstructed anytime from public 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 (p_{jt}, q_{jt}) are given by Bayes' law:

$$p_{jt} \equiv p_j(p_t, q_t, s_j) = \frac{p_t f_{\theta_H}^s(s_j)}{p_t f_{\theta_H}^s(s_j) + q_t f_{\theta_L + \Delta}^s(s_j) + (1 - p_t - q_t) f_{\theta_L}^s(s_j)}$$

$$q_{jt} \equiv q_j(p_t, q_t, s_j) = \dots$$

- Under MLRP, individual beliefs p_j are monotonic in s_j

$$\frac{\partial p_j}{\partial s_j}(p_t, q_t, s_j) \geq 0$$

- Agents invests iff

$$E_{j_t} [R_t | \mathcal{I}_{j_t}] \geq c$$

that is, whenever $p_{j_t} \geq \hat{p}$ where

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

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

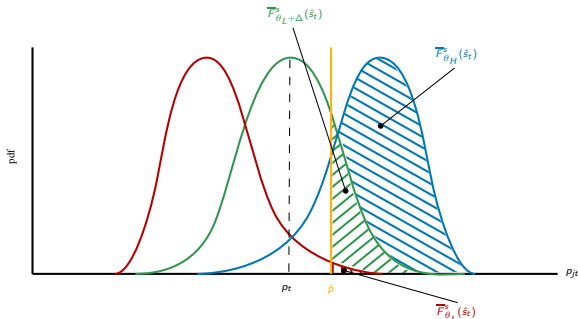
$$i_{j_t} = 1 \Leftrightarrow s_j \geq \hat{s}(p_t, q_t) \text{ with } p_j(p_t, q_t, \hat{s}_t) = \hat{p}$$

Learning Model: Endogenous Learning

- The measure of investing agents is

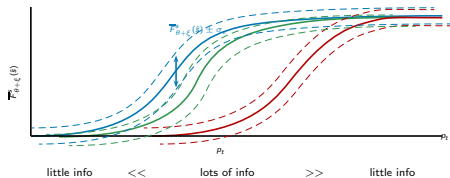
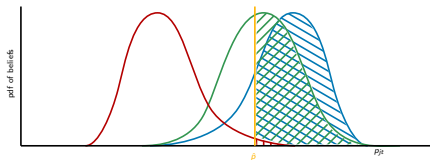
$$m_t = \overline{F}_{\theta+\xi}^s(\hat{s}(p_t, q_t)) + \varepsilon_t$$

- Since $\hat{s}(p_t, q_t)$ is known by all agents, m_t is a noisy signal about $\theta + \xi$
- \overline{F}_x^s 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 persistent "bubble" situation



- Parametrization

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

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

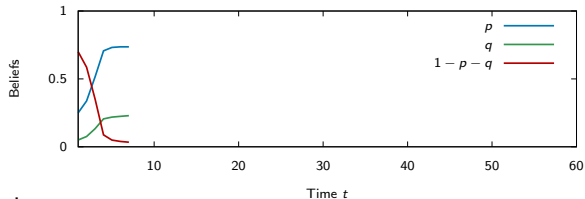
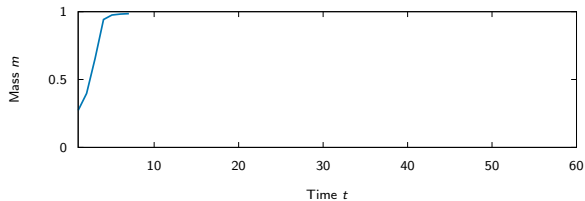
with $\sigma_v = 0.4$ (private), $\sigma_\varepsilon = 0.2$ (m_t), $\sigma_u = 2.5$ (R_t)

▶ True negative

▶ True positive

Simulations: False Positive (θ_I, Δ)

- **Boom phase:**

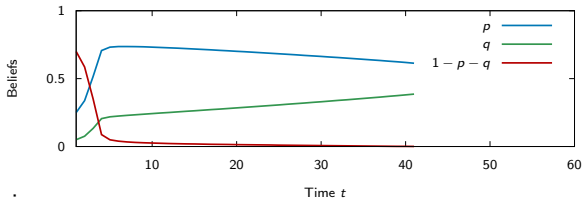
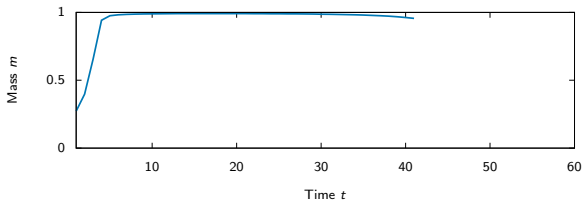


- **Mechanism:**

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

Simulations: False Positive (θ_I, Δ)

- **Information Cascade**

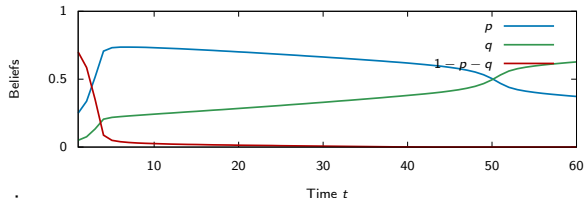
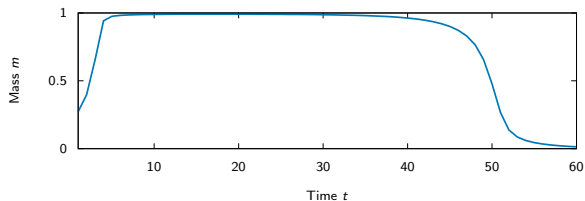


- **Mechanism:**

- ▶ 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_I, Δ)

- **Bursting**



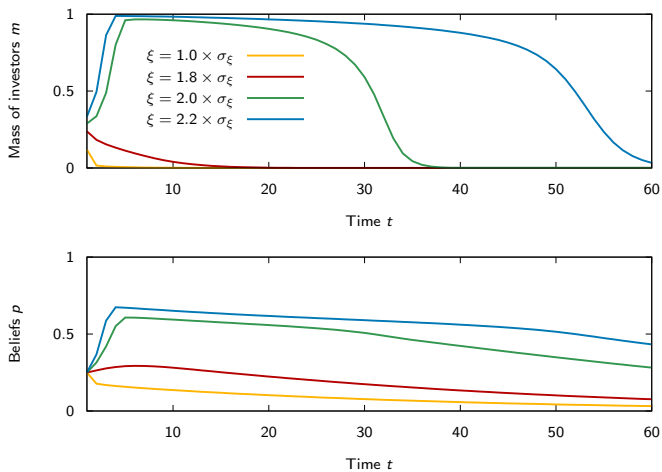
- **Mechanism:**

- ▶ 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

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

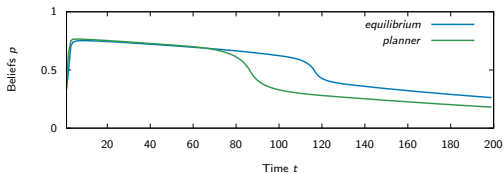
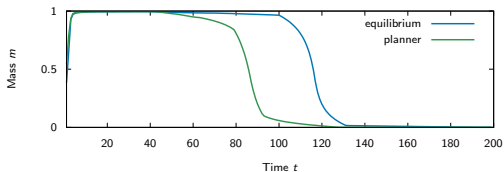


Proposition

For $F_{\theta+\xi}$ unbounded or $\sigma_u < \infty$ (public info), there always exists a large enough $\underline{\xi}$ such that $\xi \geq \underline{\xi}$ 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.: binding budget or borrowing constraints...

- **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)

- 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

- 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 $\theta_H > \theta_L$

- 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 $f_{\theta+\xi}^s$
 - ▶ same assumptions as before (MLRP, etc.)
- Social learning takes place through economic aggregates which reveal

$$m_t = (1 - \mu) \bar{F}_{\theta+\xi}^s(\hat{s}_t) + \mu \varepsilon$$

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

Calibration: Standard Parameters

Parameter	Value	Target
α	.36	Labor share
β	.99	4% annual interest rate
γ	1	risk aversion (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

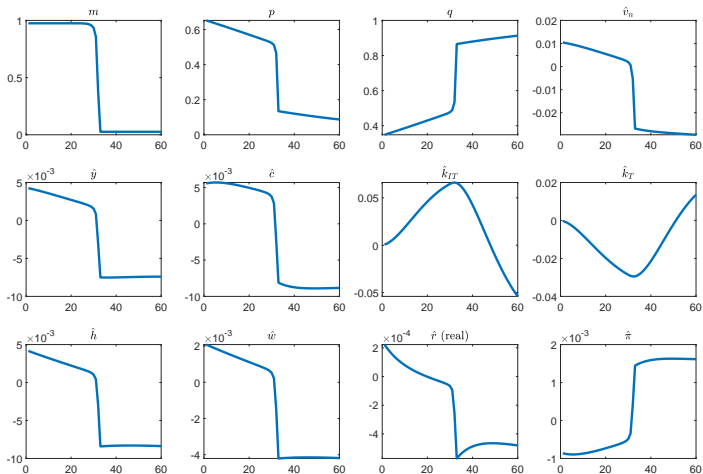
Parameter	Value	Target
ω_o	.34	IT invest in GDP pre-1995 (2.86%)
ω_n	.36	IT investment post-2005 (3.56%)
λ	1/10	Duration of NASDAQ boom-bust 1998Q4-2001Q1
θ_h	1.045	SPF's highest growth forecast over 1998-2001
θ_l	.95	SPF's lowest growth forecast over 1998-2001
s_j	$N(0, .137)$	SPF's avg. dispersion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

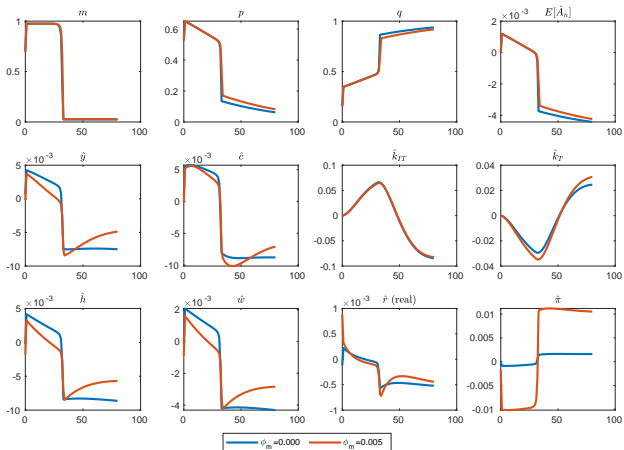
$$r_t = \phi_\pi \pi_t + \phi_y y_t + \phi_m m_t$$

- ▶ A direct tax on using the new technology

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

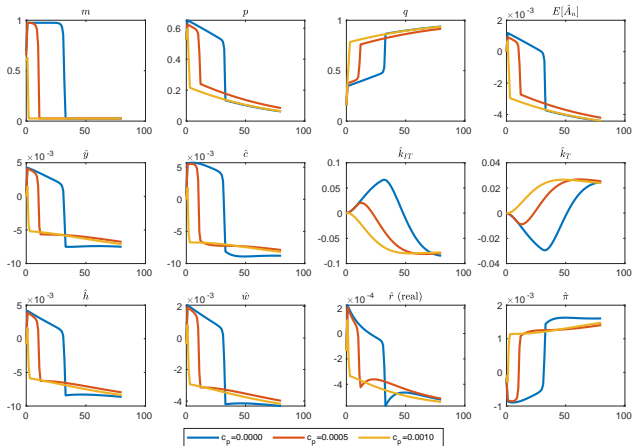
- Optimal policy: in the making...

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, only 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 collection 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

Learning Model: Updating public beliefs

- After observing m_t , public beliefs are updated

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

and

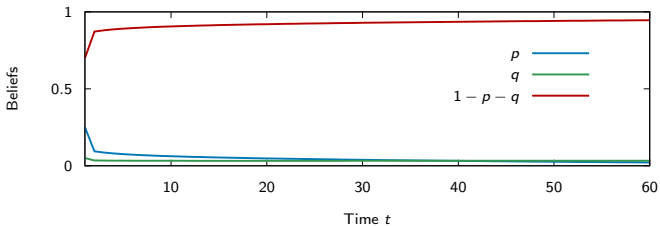
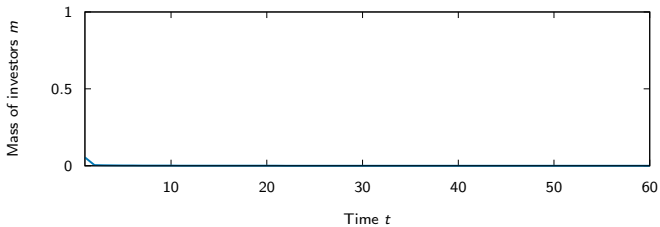
$$q_{t+1} = \frac{q_t f^m \left(m_t - \bar{F}_{\theta_L+\Delta}^s (\hat{s}_t) \right)}{\Omega}$$

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

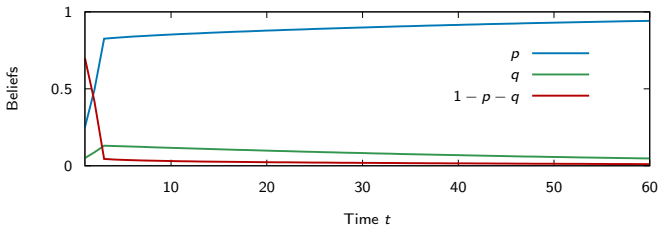
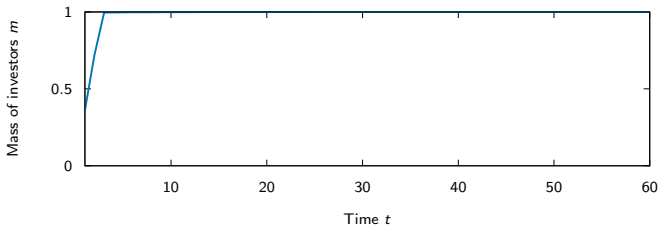
- Similar updating rule with exogenous signal $R_t = \theta + u_t$

◀ Return

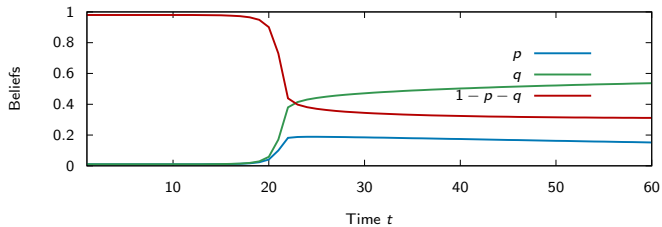
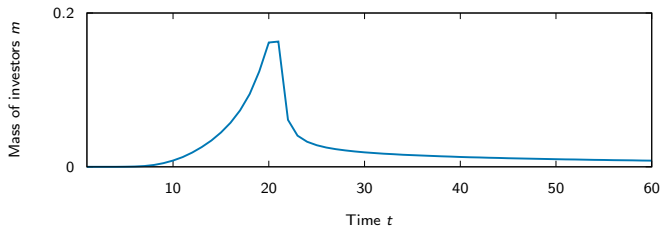
Simulations: True Negative ($\theta_I, 0$)



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



Continuous Arrival of Private Signals



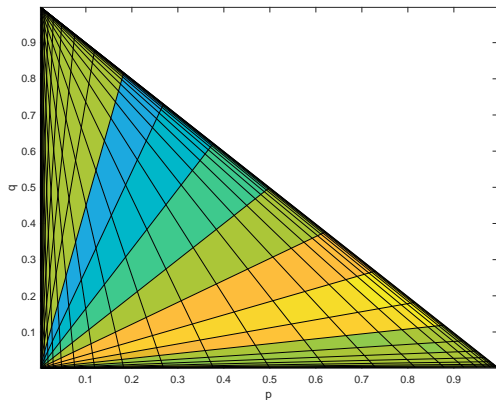
- We adopt the welfare criterion from Angeletos and Pavan (2007)

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

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

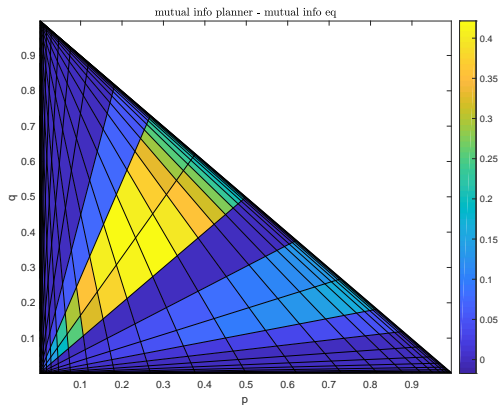
- Crucially, the planner **understands how \hat{s} affects evolution of beliefs**

- Entry threshold planner vs equilibrium



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

- More information is endogenously released in the efficient allocation



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

Business Cycle Model: Households

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

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

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

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

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

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

◀ Return