OPAQUENESS AND LIQUIDITY IN OVER-THE-COUNTER MARKETS

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MOTIVATION

- OTC asset markets can be very *opaque*
  - Mortgage backed securities; key for 2008 Crisis (Gorton and Ordonez (2014))
- Parts might trade under *double-sided uncertainty*
- Acquiring the asset <u>does not translate</u> to knowing its quality

THIS PAPER

- OTC model à la Duffie, Gârleanu, and Pedersen (2005), with quality heterogeneity over the assets;
- *Ex-post* uninformed asset holders
- Uncertain sellers; affect the price of current trade
- Endogenous belief deterioration; affect prices of future trades

THIS PAPER

How are the dynamics of an OTC market when trade occurs under double-sided uncertainty?

- What kind of equilibria exist here?
- How do belief dynamics shape and are shaped by trade?
- This presentation:
    1. Present general setting and mechanics
    2. Specialize to specific support, show SS results
    3. Compare with ex-post informed asset holders

MAIN CONTRIBUTIONS

- Gorton and Ordonez (2014): No problem when information is not being produced.
  - Our model: Markets can get *stuck*. Key is *re-trade*
- Chiu and Koeppl (2016): Multiple equilibria because of *lemons*;
  - Our model: Strategic complementarities generate multiplicity
- Hellwig and Zhang (2012): Informed sellers, no role for beliefs
  - Our model: Beliefs dynamics shape equilibrium distribution of agents
- Choi (2018): Learning rates. Learning-by-holding attains max welfare
  - Our model: Explicit role of belief deterioration and re-trade

SETUP

- $t \in \mathbb{R}_+$ discounted at $r > 0$
- S assets mature with rate δ and leave the model
  - Good assets pay u_g upon maturity
  - Bad assets pay $0 < u_b < u_g$
  - Fraction $\bar{q} \in (0, 1)$ of good assets
- $1 + S$ agents can be *holders*, *sellers*, or *buyers*
- *Holders* are unshocked investors with the asset
- *Sellers* when liquidity shock arrives at κ
  - Flow of $-x$ and $\delta u_b - x > 0$
- Both indexed by $q \in [0, 1]$ private belief of holding a good asset

SETUP

- Buyers don't own the asset, meetings arrive at λ
- Make TIOLI offers
  - Uninformed holder with updated belief
- Matured agents leave the model and are replaced by *holders* with replenished beliefs according to $\alpha(q)$
  - Specialize two-belief replenish, rates (α_0, α_1) at (q_0, q_1)

SETUP

- Distribution of agents $\mu_t = \{(\mu_{ht}(q), \mu_{st}(q))_{q\in[0,1]}, \mu_{bt}\}$
- Resources constraints:

$$\int_0^1 \mu_{st}(q)dq + \int_0^1 \mu_{ht}(q)dq = S \tag{1}$$

- and the good assets feasibility

$$\int_0^1 q\mu_{st}(q)dq + \int_0^1 q\mu_{ht}(q)dq = \bar{q}S \tag{2}$$

BUYERS' PROBLEM

- Reservation prices for each seller q: $P_t(q) = V_{st}(q) - V_{bt}$
- Guess $V_{st}(q)$ is increasing, so are $P_t(q)$
- Gains from trade under $P_t(q)$

$$\underbrace{\frac{\int_0^q \mu_{st}(\tilde{q})d\tilde{q}}{\int_0^1 \mu_{st}(\tilde{q})d\tilde{q}}}_{\mathcal{M}(q)} \times \left[V_{ht}\big(\pi_t(q)\big) - V_{st}(q) \right]$$

- With $\pi_t(q) = \frac{\int_0^q \tilde{q}\mu_{st}(\tilde{q})d\tilde{q}}{\int_0^q \mu_{st}(\tilde{q})d\tilde{q}} \leq q$, *posterior belief* after trade under $P_t(q)$
- Probability of offering each $P_t(q)$: $\{\hat{\psi}_t(q)\}_{q\in[0,1]}$

VALUE FUNCTIONS

- Let $u(q) = qu_g + (1 - q)u_b$
- Holders

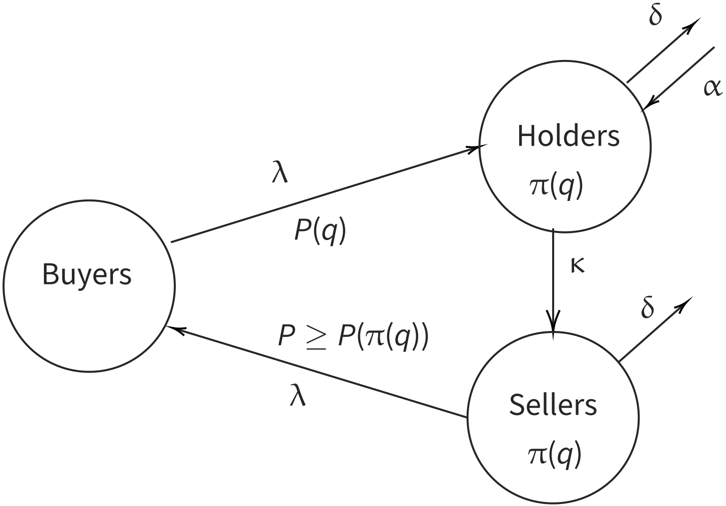
$$rV_{ht}(q) = \kappa \left(V_{st}(q) - V_{ht}(q)\right) + \delta \left(u(q) - V_{ht}(q)\right) + \dot{V}_{ht}(q)$$

- Sellers

$$rV_{st}(q) = \delta\,(u(q) - V_{st}(q)) - x + \lambda \left\{ \int_q^1 \psi_t(\tilde{q}) \Big(\underbrace{V_{st}(\tilde{q})}_{V_b + P_t(\tilde{q})} - V_{st}(q) \Big) d\tilde{q} \right\} + \dot{V}_{st}(q)$$

- Today: look for SS pure strategy equilibria

DYNAMICS



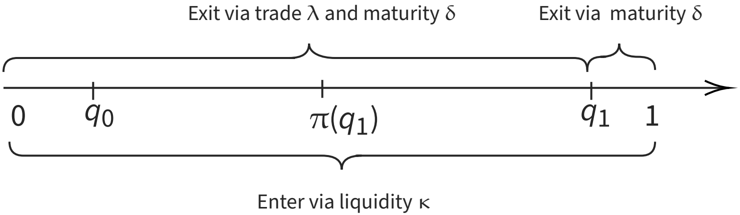
▸ LOM ▸ Equilibrium

TWO-BELIEF REPLENISH

- Now agents enter at a pair $q_0, q_1 \in [0,1]$ at rates α_0, α_1
- Need $\alpha_0 + \alpha_1 = \delta$ and $\frac{\alpha_0 q_0 + \alpha_1 q_1}{\delta} = \bar{q}$
- We construct SS equilibrium with high price ($P(q_1)$) and low price ($P(q_0)$)
  - Is there any other? No!

HIGH PRICE EQUILIBRIUM

Sellers



HIGH-PRICE EQUILIBRIUM

- $\mu_h(q) = \mu_s(q) = 0$ for all $q \neq q_0, q_1, \pi(q_1)$ ▸ LOM

$$\mu_s(q_0) = \frac{\alpha_0 \kappa}{\delta(\kappa + \delta + \lambda) + \lambda\kappa} S$$

$$\mu_s(q_1) = \frac{\alpha_1 \kappa}{\delta(\kappa + \delta + \lambda) + \lambda\kappa} S$$

$$\mu_s(\pi(q_1)) = \frac{\lambda\kappa^2}{(\delta(\kappa + \delta + \lambda) + \lambda\kappa)(\delta + \kappa + \lambda)} S$$

- We must have $\pi(q_1) = \frac{\alpha_0 q_0 + \alpha_1 q_1}{\delta} = \bar{q}$

HIGH PRICE SS EQUILIBRIUM

For individual rationality of $P(q_1)$ we must check: ▸ Gains from Trade

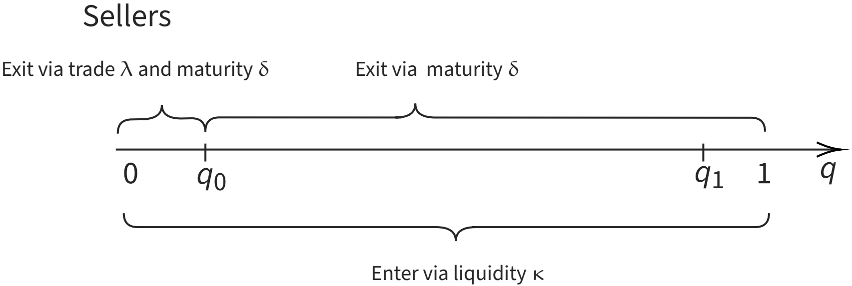
- Gains from trade
- No deviation to $P(q_0)$
- No deviation to $P(\pi(q_1))$

Trade off quality and liquidity

HIGH PRICE SS EQUILIBRIUM

- Let $d = u(q_1) - u(q_0)$
- Can define thresholds on $\frac{x}{d}$ for each of the cases
- $\left(\frac{\bar{x}}{d}\right)_h$ the maximum of the three cases
- $P(q_1)$ is equilibrium price iff $\frac{x}{d} \geq \left(\frac{\bar{x}}{d}\right)_h$

LOW PRICE SS EQUILIBRIUM



- Positive mass only at q_0 and q_1
- Posterior is $\pi(q_0) = q_0$. ▸ SS Distribution

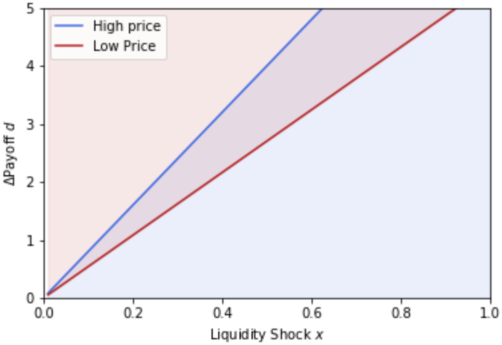
LOW PRICE SS EQUILIBRIUM

- Strict positive gains from trade $V_h(q_0) - V_s(q_0) = \frac{x}{r+\delta+\kappa}$
- No deviation to $P(q_1)$:

$$\mathcal{M}(q_0)\big(V_h(q_0) - V_s(q_0)\big) \geq V_h(\pi(q_1)) - V_s(q_1)$$

- Find a threshold $\left(\frac{\bar{x}}{d}\right)_\ell$ such that we need $\frac{x}{d} \leq \left(\frac{\bar{x}}{d}\right)_\ell$

EQUILIBRIUM REGIONS



$\kappa = 0.1, \lambda = 0.2, r = 0.2, \alpha_0 = 0.5, \alpha_1 = 0.9$

- Multiple equilibria region $\longrightarrow$ **Strategic Complementarities**

SUMMARY OF RESULTS

High Price Equilibrium

- High volume of trade and liquidity
- Buyers pay info. rent today, collect some of it in the future
- Pooling price, deteriorates beliefs and affects future market conditions

Low Price Equilibrium

- Low volume of trade; only pessimistic type trade
- No informational rent to any agent. Asset is "correctly priced"

SUMMARY OF RESULTS

Other Results

- Regions of Mixed strategy Eq. Appendix
- (Lemma) No other (pure strategy) SS equilibrium price can be sustained Proof
- Comparative Statics Appendix
  - High frequency of re-trade ($\lambda\kappa$) shock harm high price equilibrium
  - Low search frictions, pure strategy eq. always exists

BELIEF DETERIORATION MECHANISM

- Assume $\alpha(q) = \delta\mu(q)$ for all q

Lemma

For any steady state in pure and symmetric strategies with μ_s as SS distribution of sellers and q_{min} := $\min_q \text{supp}\, \mu_s$, we cannot have any $P(q)$ for $q > q_{min}$ as an equilibrium price.

- Only possible equilibrium candidate is one where only the most pessimistic trade
- Idea: after infinite cycles of re-trade, beliefs fully deteriorate
- Only bad news percolate in equilibrium
- Flipside of Camargo, Gerardi and Maestri (2019) in a sense

CONTRASTING WITH LEARNING-BY-HOLDING

- Learning-by-holding assumption (Hellwig and Zhang (2012), Guerrieri and Shimer (2014))
- Specialize $q_0 = 0$, $q_1 = 1$ and $\alpha_0 = \alpha_1 = \delta/2$
- Under high price eq, direct gains are the same as in the baseline.
- Different composition, different prob. of trade
- High price eq. cutoff

$$\left(\frac{\bar{x}}{d}\right)^{lbh} := \frac{\delta(r+\delta+\kappa)}{r+\delta+\lambda}$$

CONTRASTING WITH LEARNING-BY-HOLDING

- Our high price equilibrium is more *fragile* when:

$$\left(\frac{\bar{x}}{d}\right)_h > \left(\frac{\bar{x}}{d}\right)^{lbh}$$

- True if $\kappa\lambda$ is large relative to δ
- $\delta \to 0 \Rightarrow$ high price is always equilibrium with learning-by-holding
- May not be sustainable with *ex-post* uninformed agents
- Intuition: information gets *coarser*
  - Mass of uninformed investors as a threat

EXTENSION: COSTLY LEARNING

- Buyers acquire learning rate θ at a cost $c(\theta)$
- Additional term in value functions (similar for sellers)

$$+\theta\left(qV_h(1,\theta) + (1-q)V_h(0,\theta) - V_h(q,\theta)\right)$$

- Choi (2018): Exog learning. Welfare is max with $\theta \to \infty$
- Endogenous θ: interaction Mkt Liquidity and Learning
- Our model delivers extreme result: No incentives to costly learn!
- Inefficiency: High price region larger for $\theta^* > 0$

FINAL REMARKS

- We drop the usual learning-by-holding assumption to model assets that are hard to verify
- Belief deterioration arises endogenously and is the central force determining price and liquidity
  - It hinders liquidity by making off-equilibrium threats more attractive for buyers
- Future work: asset design

Thank You!

Appendix

BASELINE MODEL

LAWS OF MOTION

Holders

$$\dot{\mu}_{ht}(q) = -\kappa\mu_{ht}(q) + \delta\mu_{st}(q) + \alpha(q)S + \lambda\left[\psi_t(\pi^{-1}(q))\int_0^q d\mu_{st}(\tilde{q})\right] \tag{3}$$

Sellers

$$\dot{\mu}_{st}(q) = \kappa\mu_{ht}(q) - \delta\mu_{st}(q) - \lambda\mu_{st}(q)\left[\int_q^1 d\psi(\tilde{q})\right] \tag{4}$$

Buyers

$$\dot{\mu}_{bt} = 0$$

EQUILIBRIUM

Definition

An **equilibrium** is a path of $\{(\psi_t(q))_{q\in[0,1]}\}$, $\mu_t(q), V_t(q) = (V_{st}(q), V_{ht}(q), V_{bt})$, and an initial condition $\mu_0(q)$, such that, given the initial condition:

i. Given $V_t(q)$ and $\mu_t(q)$, $\{\psi_t(q)\}_{q\in[0,1]}$ characterizes buyers' strategy in the stage game played at time $t, \forall t, q \in [0,1]$;

ii. Given $\{\psi_t(q)\}_{q\in[0,1]}, \forall t, q \in [0,1]$, $\mu(q)$ follows the LOM's;

iii. Given $\{\psi_t(q)\}_{q\in[0,1]}, \forall t$, V_t follows the value functions $\forall t, q \in [0,1]$.

iv. $(\mu_{st}(q), \mu_{ht}(q))_{q\in[0,1]}$ satisfies the resource constraints for all t

- **SS equilibrium**, setting LOM's to zero.

▸ Back

HIGH PRICE SS EQUILIBRIUM

- LOM for beliefs q_i, $i = 1, 2$

$$\dot{\mu}_h(q_i) = -\kappa\mu_h(q_i) - \delta\mu_h(q_i) + \alpha_i S \xrightarrow{\text{S.S.}} \mu_h(q_i) = \frac{1}{\delta + \kappa}\alpha_i S$$

$$\dot{\mu}_s(q_i) = \kappa\mu_h(q_i) - \delta\mu_s(q_i) - \lambda\mu_s(q_i) \xrightarrow{\text{S.S.}} \mu_h(q_i) = \frac{\delta + \lambda}{\kappa}\mu_s(q_i)$$

HIGH PRICE SS EQUILIBRIUM

- For q_1' there is inflow via trade!

$$\dot{\mu}_h(q_1') = -\kappa\mu_h(q_1') - \delta\mu_h(q_1') + \lambda M_s(q_1) \xrightarrow{\text{S.S.}} \mu_h(q_1') = \frac{\lambda}{\delta + \kappa} M_s(1)$$

$$\dot{\mu}_s(q_1') = \kappa\mu_h(q_1') - \delta\mu_s(q_1') - \lambda\mu_s(q_1') \xrightarrow{\text{S.S.}} \mu_h(q_1') = \frac{\delta + \lambda}{\kappa} \mu_s(q_1')$$

▸ Back

LOW PRICE EQ DISTRIBUTION

- From LOM we can get:

$$\mu_s(q_0) = \frac{\alpha_0 \kappa(\delta + \kappa + \lambda)}{\alpha_0(\delta + \kappa + \lambda)^2 + \alpha_1(\delta + \kappa)^2} S$$

$$\mu_s(q_1) = \frac{\alpha_1 \kappa(\delta + \kappa)}{\alpha_0(\delta + \kappa + \lambda)^2 + \alpha_1(\delta + \kappa)^2} S$$

Back

SUMMARY OF RESULTS

- Some comparative statics (from simulations not analytically) ▸ Graphs
- For High price equilibrium $\frac{x}{d} \geq \left(\frac{\bar{x}}{d}\right)_h$
  i. $\nearrow$ in α_0
  ii. $\searrow$ in α_1
  iii. $\searrow$ in λ
  iv. $\nearrow$ in κ
  v. $\searrow$ in r

▸ Back

SUMMARY OF RESULTS

- Some comparative statics (from simulations not analytically) ‣ Graphs
- For Low price equilibrium $\frac{x}{d} \leq \left(\frac{\bar{x}}{d}\right)_\ell$
    i. $\nearrow$ in α_0
    ii. $\nearrow$ in α_1 (via δ)
    iii. $\searrow$ in λ
    iv. $\searrow$ in κ
    v. $\searrow$ in r

‣ Back

HIGH PRICE SS EQUILIBRIUM

- Direct gain from trade from deviating to any $P(q)$, $q \leq q_1$

$$V_h(\pi(q)) - V_s(q) = \frac{1}{(r+\delta+\kappa)(r+\delta+\lambda)} \Big[(\kappa + r + \delta + \lambda)\delta u(\pi(q)) - \\ - \lambda\delta u(q_1) - (r + \delta + \kappa)\delta u(q) + x(r + \delta + \lambda) \Big]$$

- First term is negative and might be smaller for higher q
- But probability of trade increases with $q \longrightarrow$ **Trade off quality and liquidity**

Back

NO OTHER SS EQUILIBRIUM PRICE

Lemma

There does not exist any other reservation price $P(q)$ with $q \neq q_0, q_1$ that is an SS equilibrium price.

- By contradiction and follow SS mechanics
- Suppose $P(\hat{q})$ for $\hat{q} < q_0$ and $\hat{q} \neq q_1$
- But $q_0 \in \operatorname{supp} \mu_s$, so $\pi(\hat{q}) < \hat{q}$.
- So $\mu_h(\hat{q}) = 0 \implies \mu_s(\hat{q}) = 0$, Deviation

NO OTHER SS EQUILIBRIUM PRICE

- Also $P(\hat{q})$ for $\hat{q} < q_0$ cannot be equilibrium prices.
- Would need that $\hat{q} = \min \operatorname{supp} \mu_s(q)$ and hence $\pi(\hat{q}) = \hat{q}$.
- LoM for holders and sellers in SS we have:

$$\dot{\mu}_h(\hat{q}) = -(\delta + \kappa)\mu_h(\hat{q}) + \lambda\mu_s(\hat{q}) \implies \mu_h(\hat{q}) = \frac{\lambda}{\delta + \kappa}\mu_s(\hat{q})$$

$$\dot{\mu}_s(\hat{q}) = \kappa\mu_h(\hat{q}) - (\lambda + \delta +)\mu_s(\hat{q}) \implies \mu_h(\hat{q}) = \frac{\lambda + \delta}{\kappa}\mu_s(\hat{q})$$

- Both simultaneously can not hold

▸ Back

n BELIEF SUPPORT

- Case where replenish happens along $\{q_0, ..., q_N\}$ at rates $\{\alpha_0, ..., \alpha_N\}$
- $\sum_{i=1}^{N} \alpha_i = \delta$ and $\sum_{i=1}^{N} \alpha_i q_i = \delta \bar{q}_0$
- Posterior $P(q_N)$ is offered $\bar{q}'_N$
- The distribution

$$\mu_S(q_i) = \frac{\kappa \alpha_i}{(\kappa + \delta)(\delta + \lambda)} S \;\; \forall i \in \{1, 2, ..., N\}$$

$$\mu_S(\bar{q}'_N) = \frac{\lambda \kappa^2}{(\kappa + \delta + \lambda)(\kappa + \delta)(\delta + \lambda)} S \;\; \forall i \in \{1, 2, ..., N\}$$

n BELIEF SUPPORT

- As N increases with δ fixed may have $\alpha_i \to 0$. Posterior dominates!
- (Conjecture) But then equilibrium region of high price shrinks, as economy goes to $\bar{q}'_N$

Back

OLD INFO ACQUISTION

STAGE GAME

Informed Buyers

- We assume verification and its result are common knowledge, such that assets are traded by $P_t(0)$ or $P_t(1)$
- Buyers' surplus after acquiring information:

$$\pi_t(1)\Big(V_{ht}(1) - V_{st}(1)\Big) + (1 - \pi_t(1))\Big(V_{ht}(0) - V_{st}(0)\Big) - I$$

- Comparing the surplus of acquiring vs. not acquiring info we get a threshold I^* and the probability of checking asset's quality $\hat{\phi}_t$

VALUE FUNCTIONS

Buyer

$$rV_{bt} = \lambda \Bigg\{ \phi_t \Big[\pi(1) \big(V_{ht}(1) - V_{st}(1) \big) + (1 - \pi(1)) \big(V_{ht}(0) - V_{st}(0) \big) - I \Big] +$$

$$(1 - \phi_t) \Big[\int_0^1 \psi_t(\tilde{q}) \mathcal{M}(\tilde{q}) \Big(V_{ht}\big(\pi(\tilde{q})\big) - V_{st}(\tilde{q}) \Big) d\tilde{q} \Big] \Bigg\} + \dot{V}_{bt}$$

MIXED STRATEGY

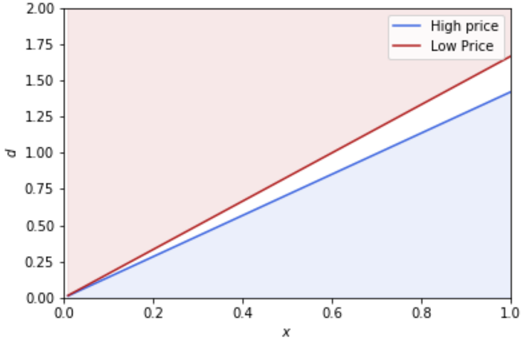
MIXED STRATEGY EQUILIBRIUM

- Lemma rules out positive prob. on any $q \in [0, q_0) \bigcup (q_1, 1]$
- SS argument as before.
- The max of support cannot be bigger than q_1
- The min of support cannot be smaller than q_0
- What happens in between? Not sure, but we rule out intervals!
- (Lemma): Any SS Mixed Strategy Eq σ is such that:

$$\text{supp } \sigma = \{q_0, \pi^k(q_1), \pi^{k-1}(q_1), ..., \pi(q_1), q_1\}$$

for some $k = 0, 1, 2, ...$

MIXED STRATEGY EQUILIBRIUM



$\kappa = 0.1, \lambda = 0.2, r = 0.9, \alpha_0 = 0.5, \alpha_1 = 0.9$

- Gap between two pure strategy equilibria $\longrightarrow$ Mixed Strategy?

MIXED STRATEGY EQUILIBRIUM

- Construct one with supp $\sigma = \{q_0, q_1\}$
- Expression look a bit like before, shrinking λ
- Analytically cumbersome to check...
- Boils down to find σ_2 that equates gain of $P(q_1)$ and $P(q_0)$
- Some graphs ‣ Link
- Still need to check deviations, and then construct the area of equilibrium...
- Mixed strategy might be weird at first, but in SS is an eq. with price dispersion

PROOF MIXED STRATEGIES

Proposition

$\sigma(q) = 0, \forall q \in (q_1, 1]$

- Assume $\sigma(1) > 0$. Since $\pi(q') < q', \forall q' \in (0, 1]$ we have that $\pi(1) < 1$
- Also note that the replenish occurs only at $q \in \{q_0, q_1\}$. Therefore, we must have $\mu_h(1) = 0$.
- By LoM:

$$\dot{\mu}_s(1) = \kappa\mu_h(1) - \delta\mu_s(1) - \sigma(1)\mu_s(1) = 0 \Rightarrow \mu_s(1) = 0$$

- Update the maximum in the support of the beliefs and repeat this argument. This rules out all prices $P(q)$ for $q \in (q_1, 1]$.

Proposition

$\sigma(q) = 0, \forall q \in [0, q_0)$

- We cannot follow the same argument since $\pi(0) = 0$. By LoM

$$\dot{\mu}_h(0) = -\mu_h(0)(\kappa + \delta) + \underbrace{\lambda\sigma(0)\mu_s(0)}_{\text{enter via trade}} = 0 \implies \mu_h(0) = \frac{\lambda\sigma(0)\mu_s(0)}{\kappa + \delta}$$

$$\dot{\mu}_s(0) = \big(\underbrace{\lambda \int_0^1 \sigma(\tilde{q})d\tilde{q}}_{=1} - \delta\big)\mu_s(0) + \kappa\mu_h(0) = 0 \implies \mu_h(0) = \frac{\delta + \lambda}{\kappa}\mu_s(0)$$

Therefore

CONTINUUM REPLENISH MODEL

CONTINUUM REPLENISH OF AGENTS

- δdt leave the model due maturity
- αdt enters following cdf $F(q)$
- Steps: Suppose $P(q^*)$ is price offered.
- Given $P(q^*)$ derive $G_s(q|q^*)$ and $G_h(q|q^*)$
- $P(q^*)$ will be eq price if:

$$q^* \in \text{argmax}_{q\in[0,1]} \mathcal{M}(q|q^*) \left(V_h(\pi(q|q^*)|q^*) - V_s(q|q^*)\right)$$

CONTINUUM REPLENISH OF AGENTS

- $\delta = \alpha$
- $\int_0^1 q dF(q) = \bar{q}_0$
- Endogenous distribution of sellers

$$G_S(q|q^*) = \begin{cases} \frac{\delta\kappa}{(\delta+\kappa)(\delta+\lambda)} F(q) & \text{if } q < \pi(q^*) \\ \frac{\delta\kappa}{(\delta+\kappa)(\delta+\lambda)} F(q) + \frac{\lambda\kappa^2}{(\delta+\kappa+\lambda)(\delta+\kappa)(\delta+\lambda)} F(q^*) & \text{if } q \in [\pi(q^*), q^*) \\ \frac{\kappa}{\delta+\kappa} F(q) - \frac{\lambda\kappa}{(\delta+\kappa+\lambda)(\delta+\kappa)} F(q^*) & \text{if } q \geq q^* \end{cases}$$

CONTINUUM REPLENISH OF AGENTS

- FOC for buyer's problem:

$$\Theta f(q^*) \left(\frac{\delta \kappa d}{(r_h r_s)} (\pi(q^*) - q^*) + \frac{x}{r_s} \right) - (\Theta + \lambda\kappa) F(q^*) \frac{\delta d}{r} \left(1 - \frac{q^* f(q^*)}{\Gamma(1|q^*)} \right) = 0 \qquad (5)$$

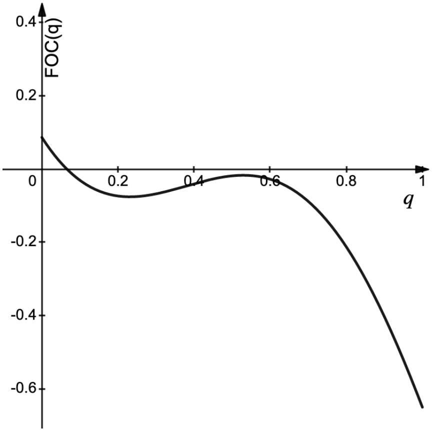
- Sufficient condition for (local) max is f(1) small enough:

$$\bar{q} > f(1) \frac{(\delta + \kappa + \lambda)}{\kappa}$$

- Single crossing? Multiplicity?

EXAMPLE

- $F(q) = q(2 - q)$



High κ = 0.3

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