The Market for Inflation Risk

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Breakeven prices of inflation swaps

What we do

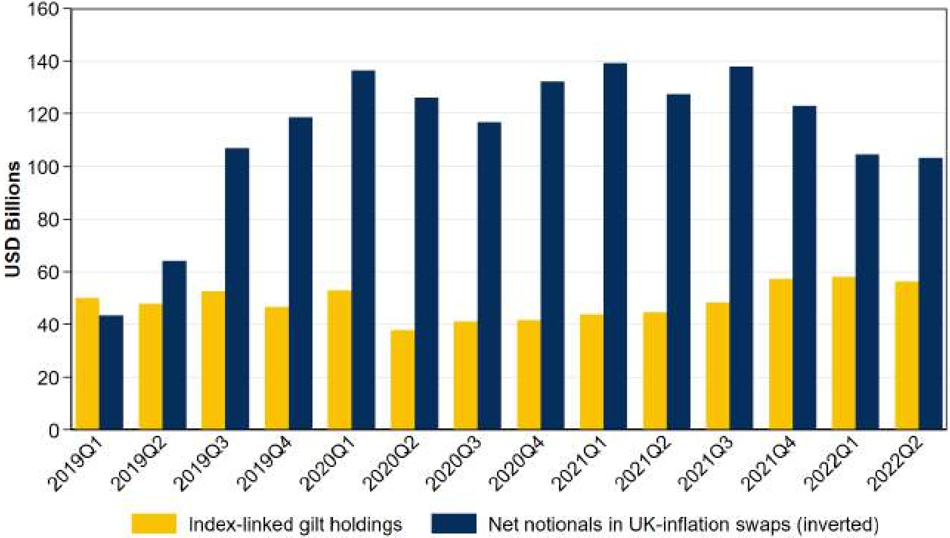
1) **Quantities behind the prices:** universal data on transactions in UK market. Data Source
   → Facts: segmentation across maturities, banks net bearers of inflation risk.

2) **Identification strategies:** for segmented markets' models
   → Decompose price changes into fundamentals and a liquidity premium (frictions).

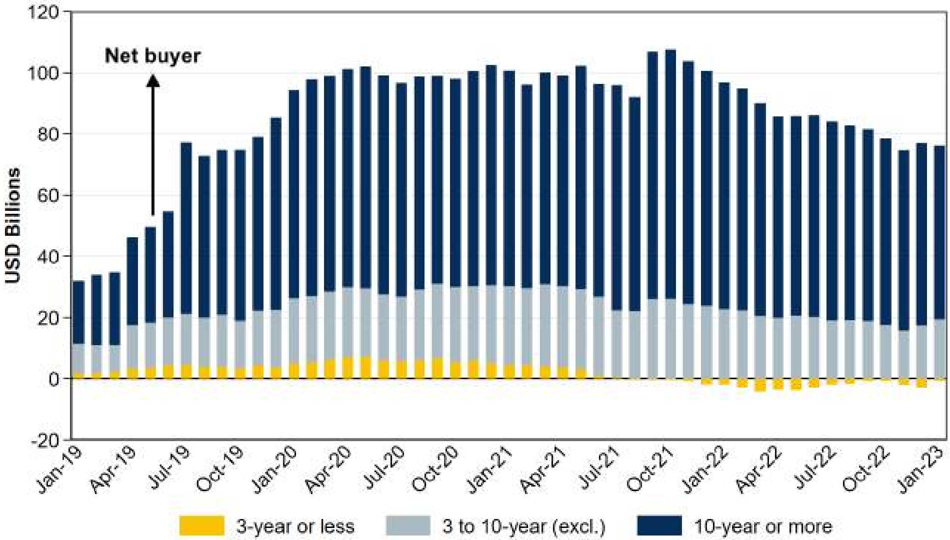
3) **Empirical estimates:** finance, macro and behavioral
   → What shocks drive the market and what are the slopes of supply and demand?
   → How reliable are these measures of expected inflation given liquidity premia?
   → How much dispersion in beliefs is there, and whose beliefs matter?

1. The facts about this market

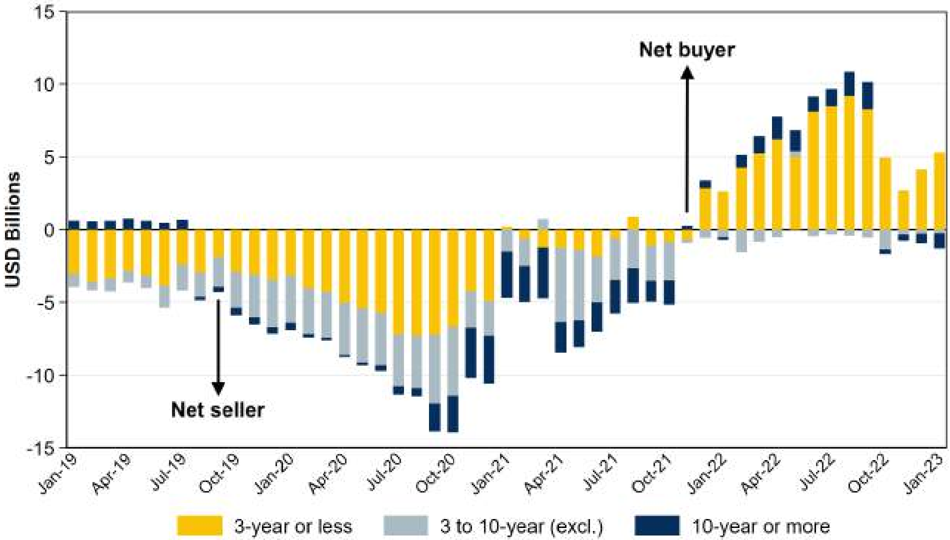
Fact 1: dealer-banks are not neutral market makers



Fact 2: pension funds buy protection at long horizon

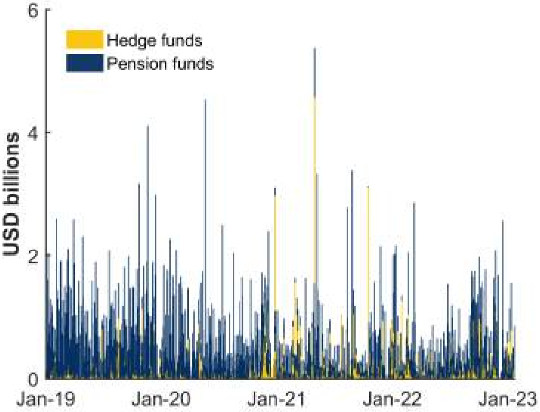


FACT 3: HEDGE FUNDS TRADE INFLATION RISK AT SHORT HORIZON

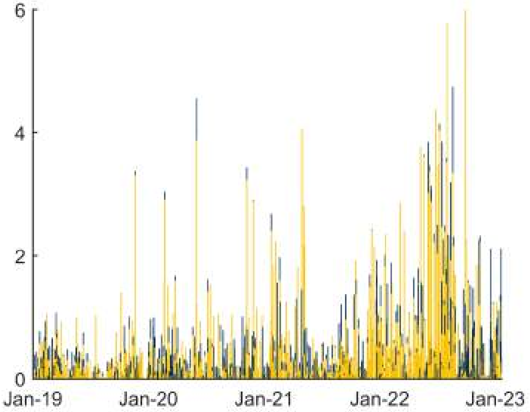


Segmentation even clearer in trading activity

Long Horizon (≥10 Years)



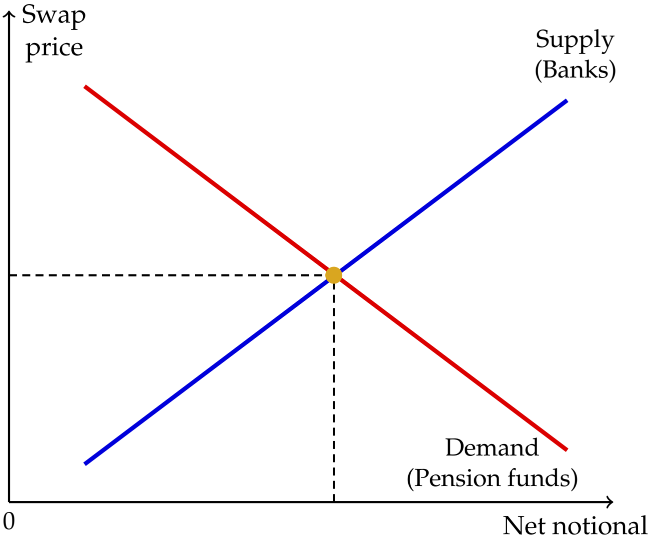
Short Horizon (≤3 Years)



Full Picture

2. Shocks in markets and identification

The long market



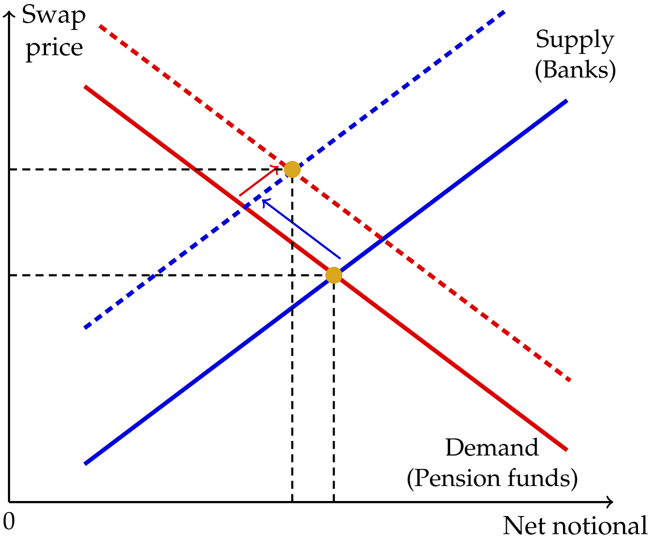
Why do banks supply insurance?

Could be for fundamental reasons:

(i) Disagreement about expected inflation.

(ii) different risk aversion or hedging of other assets.

THE LONG MARKET



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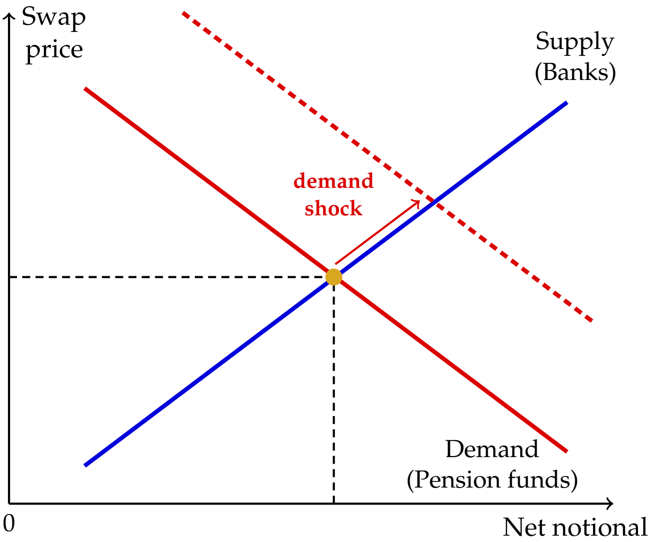
Both reasons imply both supply and demand respond to expected inflation.

The long market (II)

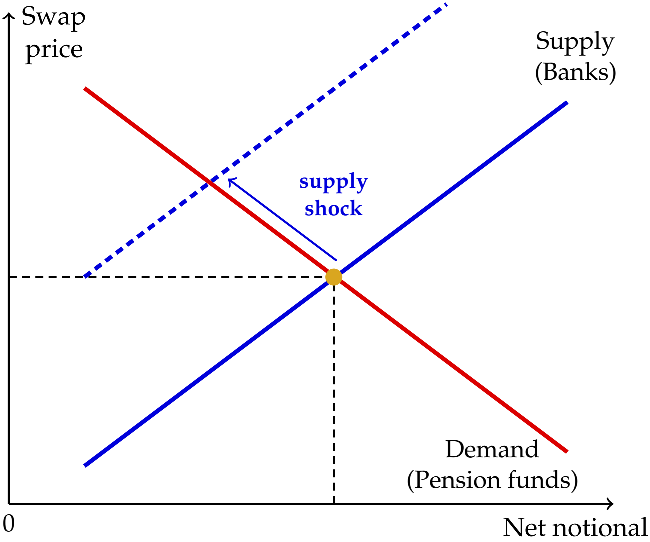


Why do banks supply insurance?

Also for non-fundamental reasons:

(i) Pension fund mandates generate background risk and trading constraints...

The long market (II)



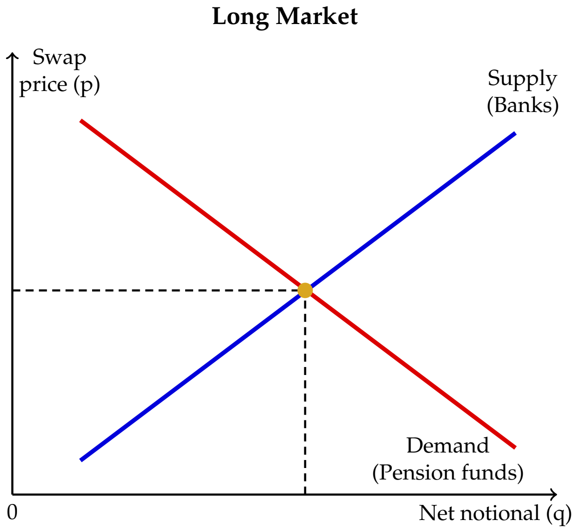
Why do banks supply insurance?

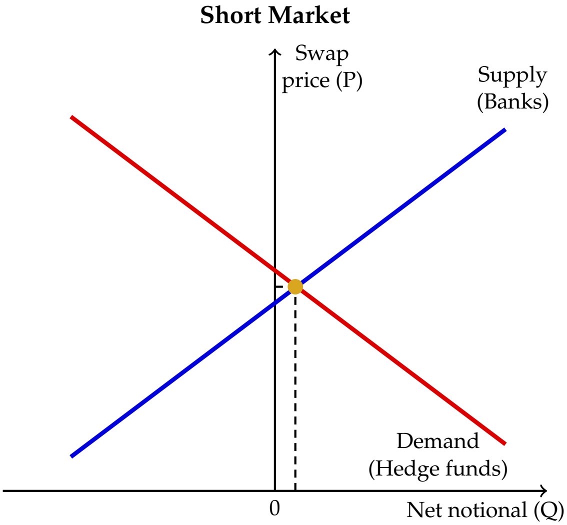
Also for non-fundamental reasons:

(i) Pension fund mandates generate background risk and trading constraints...

(ii) Banks also have trading constraints (e.g. regulatory) and have operational reasons to be long/short inflation.

SEGMENTED MARKETS





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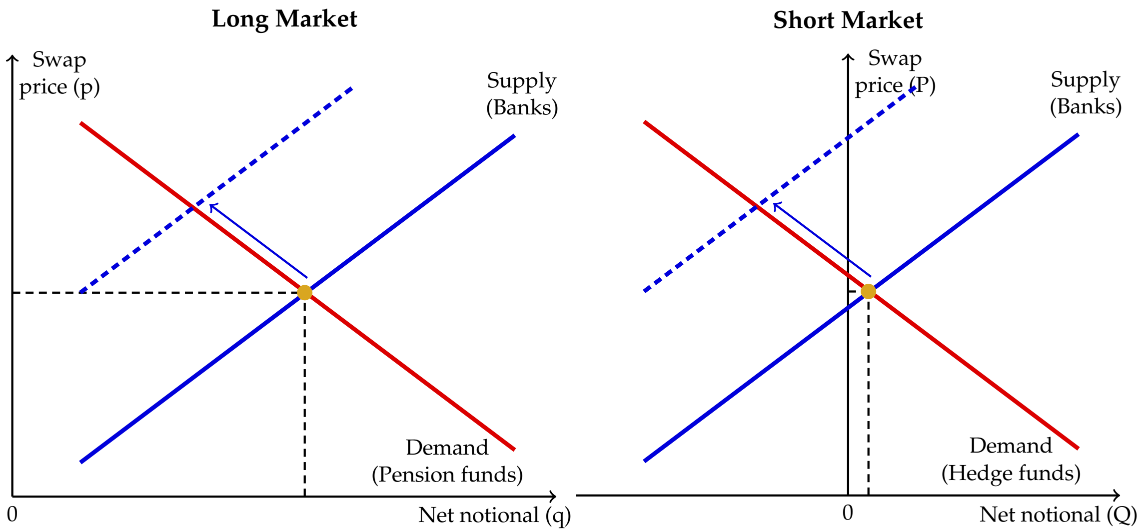

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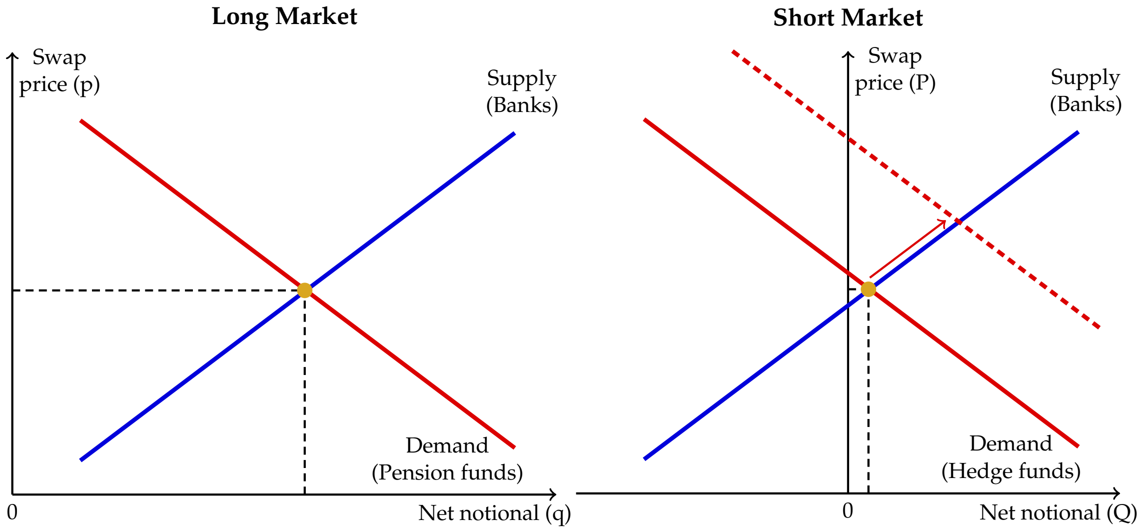

More formally (I)

Static portfolio choice problem of pension fund (f, i):

- CARA-normal (wealth, $a_{f,i}$, risk aversion, $\gamma_{f,i}$), LT inflation swap, other asset.

- Expected inflation $\pi^e_{f,i} = \mu_{f,i}\pi^e$

- Background risk + generic trading constraints.

Demand for LT inflation swap $(q_{f,i})$:

$$\frac{q_{f,i}}{a_{f,i}} = -\gamma_{f,i} p + \underbrace{\mu_{f,i}(\pi^e - \rho_{\pi,d})}_{\text{exp. inf \& risk}} - \lambda_{f,i}.$$

Hedge Funds: same problem but ST swap market (segmentation)

OTC market: banks (b) on other side, present in both markets, supply curve.

CARA-Normal microfoundation

More formally (II)

- Demands of institution i of type pension fund (f), hedge fund (h), and dealer (b):

$$\frac{q_{f,i}}{a_{f,i}} = -\gamma_{f,i}p + \mu_{f,i}(\pi^e - \rho_{\pi,d}) - \lambda_{f,i} \qquad \frac{Q_{h,i}}{a_{h,i}} = -\gamma_{h,i}P + \mu_{h,i}(\Pi^e - \rho_{\Pi,d}) - \lambda_{h,i}$$

$$\frac{q_{b,i}}{a_{b,i}} = -\gamma^l_{b,i}p + \mu_{b,i}(\pi^e - \rho_{\pi,d}) - \lambda^l_{b,i} \qquad \frac{Q_{b,i}}{a_{b,i}} = -\gamma^s_{b,i}P + \mu_{b,i}(\Pi^e - \rho_{\Pi,d}) - \lambda^s_{b,i}$$

- The shocks: $(\pi^e - \rho_{\pi,d}, \Pi^e - \rho_{\Pi,d}) \perp (\lambda^l_{b,i}, \lambda^s_{b,i}) \perp \lambda_{f,i} \perp \lambda_{h,i}$

- Equilibrium price:

$$p^* = \underbrace{\left[\frac{\sum_{i\in\Theta_f} a_{f,i}\mu_{f,i} + \sum_{i\in\Theta_b} a_{b,i}\mu_{b,i}}{\sum_{i\in\Theta_f} a_{f,i}\gamma_{f,i} + \sum_{i\in\Theta_b} a_{b,i}\gamma_{b,i}}\right](\pi^e - \rho_{\pi,d})}_{\text{frictionless price } \widetilde{p}^*} + \underbrace{\left[\frac{\sum_{i\in\Theta_f} a_{f,i}\lambda_{f,i} + \sum_{i\in\Theta_b} a_{b,i}\lambda_{b,i}}{\sum_{i\in\Theta_f} a_{f,i}\gamma_{f,i} + \sum_{i\in\Theta_b} a_{b,i}\gamma_{b,i}}\right]}_{\text{liquidity premium } lp}$$

- Fundamental innovations, ε_π and innovations to liquidity $\varepsilon_f, \varepsilon_h, \varepsilon_b$

CARA-Normal microfoundation

Identification problem

Observe (p, P) that are driven by $\boldsymbol{\varepsilon} = (\varepsilon_h, \varepsilon_f, \varepsilon_b, \varepsilon_\pi)$

We have data $\mathbf{Y} = (Q, P, q, p)'$ on prices and quantities 2 Jan 19 to 10 Feb 23:

- q: net purchases of swaps by PFLDI with $\geq$ 10 year maturity.
- p: daily price zero-coupon RPI inflation swap in long horizon market ($>=$ 10 year).
- Q: net purchases of swaps by hedge funds $\leq$ 3year maturity.
- P: daily price of zero-coupon RPI inflation swap in short horizon market ($<=$ 3 year).

Identification problem

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- Q: net purchases of swaps by hedge funds $\leq$ 3year maturity.
- P: daily price of zero-coupon RPI inflation swap in short horizon market ($<=$ 3 year).

Identification problem: Need to learn about 4x4 matrix $\boldsymbol{\Psi}$.

$$\mathbf{Y} = \boldsymbol{\Psi}\boldsymbol{\varepsilon}$$

Estimation: add dynamics, VAR with 3 lags. Implementation

Three identification strategies

1) Heteroskedasticity: *Fundamental had a higher relative variance on announcement days.*

Formal assumption & Test

- Data shows clear shift in relative variances on those dates (reject null at 0.1% significance level).

Three identification strategies

1) Heteroskedasticity: *Fundamental had a higher relative variance on announcement days.*

2) Granularity. *Size weighted sum of idiosyncratic shocks non-zero in expectation.*

Formal assumption & Test

- Recover residuals from panel factor model

$$\frac{q_{f,i,t}}{a_{f,i,t}} = \omega'_{f,i}\mathbf{F}_{f,t} + \widetilde{\varepsilon}_{f,i,t}, \quad \text{where} \quad \mathbf{F}_{f,t} = (\pi^e - \rho_{\pi,d}, lp_t)' \quad \text{so} \quad \widetilde{\varepsilon}_{f,i,t} = \lambda_{f,i} - \gamma_{f,i} lp_t$$

- Build granular IV, $GIV_{f,t} = \sum_{i \in \Theta_f} a_{f,i,t}\tilde{\varepsilon}_{f,i,t}$. Valid instrument for ε_f as orthogonal by construction and relevant if LLN fails. Equivalent for $GIV_{h,t}$ and $GIV_{b,t}$.

- Pension funds: Pareto parameter 0.13, power law coefficient -0.9. Similar for others.

Three identification strategies

1) Heteroskedasticity: *Fundamental had a higher relative variance on announcement days.*

2) Granularity. *Size weighted sum of idiosyncratic shocks non-zero in expectation.*

3) Timing / sign restrictions. Formal assumption

- *At high frequency, hedge funds respond more to fundamental than banks than pension funds*
- *No spillovers across market desks at high frequency within banks*

$$\begin{pmatrix} \text{short qty} \\ \text{short price} \\ \text{long qty} \\ \text{long price} \end{pmatrix} = \underbrace{\begin{pmatrix} + & 0 & - & + \\ + & 0 & + & + \\ 0 & + & - & - \\ 0 & + & + & + \end{pmatrix}}_{\boldsymbol{\Psi}} \begin{pmatrix} \text{hedge fund demand} \\ \text{pension fund demand} \\ \text{dealer-bank supply} \\ \text{fundamental} \end{pmatrix}$$

Overidentification tests

Correlations of fundamental shock from the three strategies (SR, GIV, Hetero):

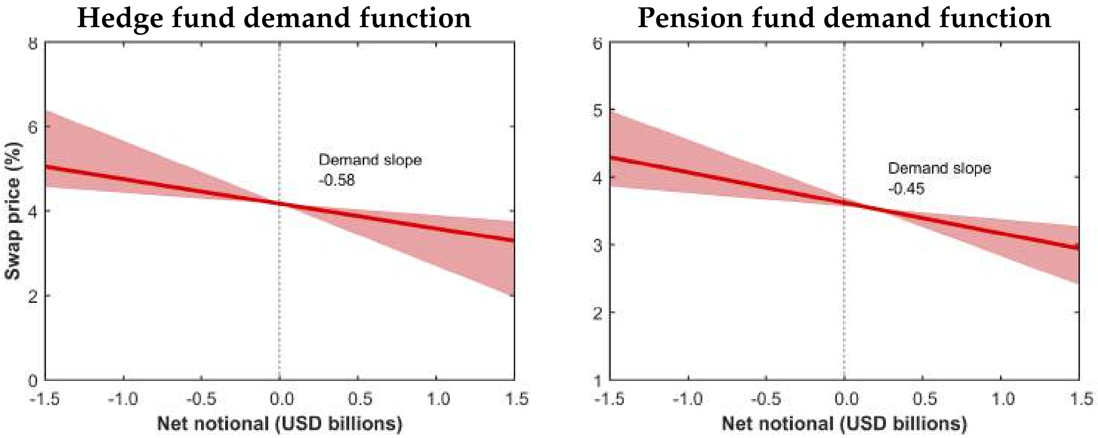
$$\begin{bmatrix} 1 & 0.9865 & 0.8038 \\ \cdot & 1 & 0.7320 \\ \cdot & \cdot & 1 \end{bmatrix}$$

- IRFs from strategies 1 & 2 confirm the sign restrictions in strategy 3. Differential reactiveness & desk separation hold in the microdata.
- ε_π from strategies 1 & 3 confirms the exclusion restriction required for the GIV.
- ε_π from strategies 2 & 3 have higher relative variance on the dates used in strategy 3.

For brevity, results now from strategy 1 (sign restrictions).

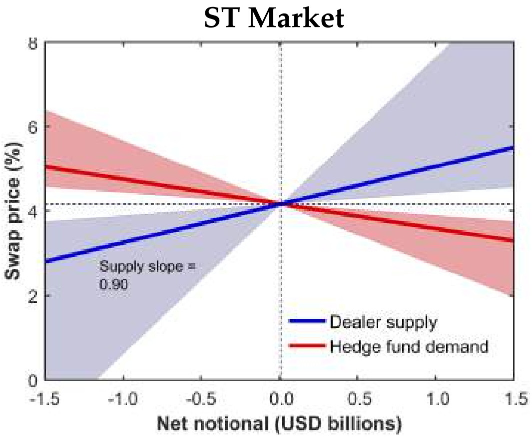
4. The financial market

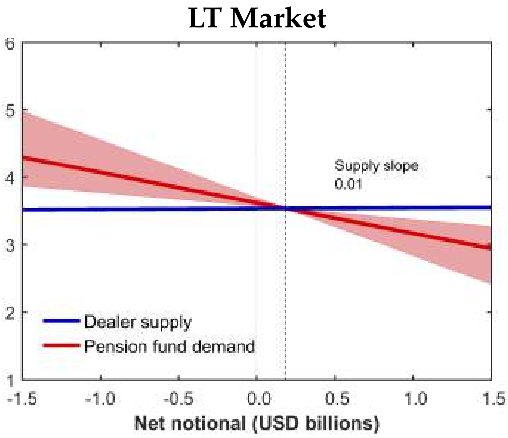
Slope of demand functions: similar



IRFs

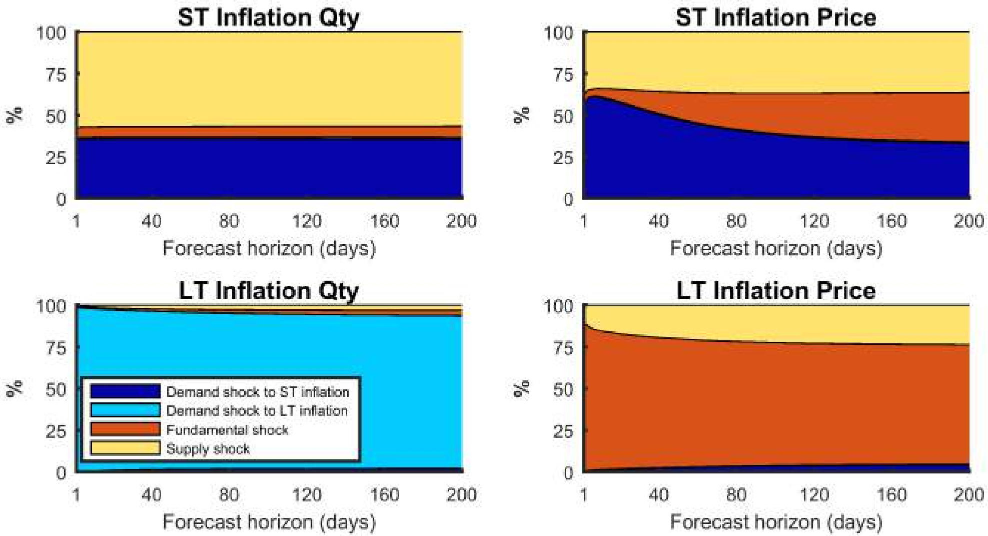
Slope of supply function: horizontal in long market





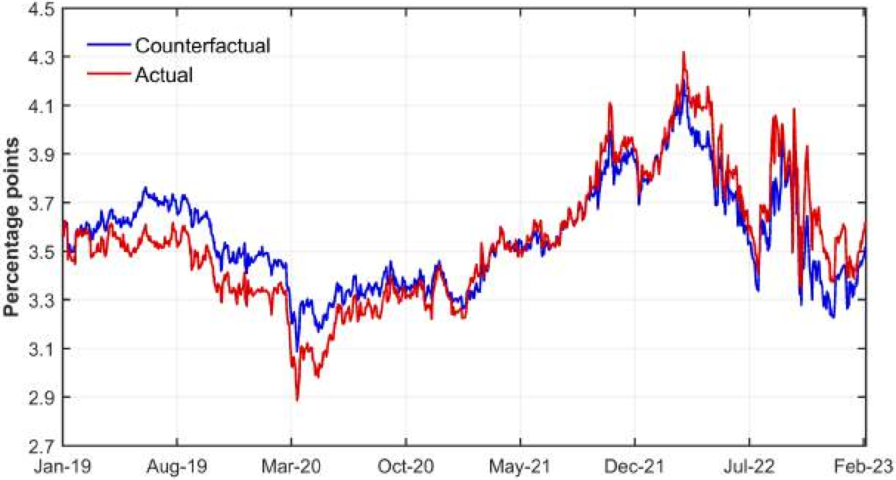
IRFs

Forecast error variance decomposition



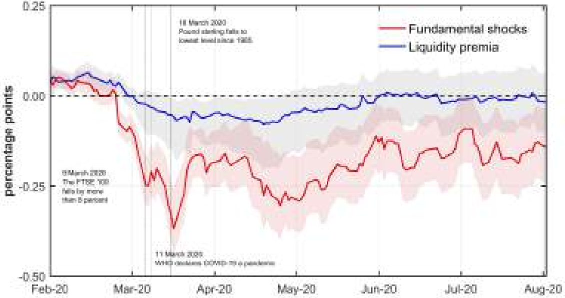
5. The macro inferences for inflation

Historical decomposition of LT prices

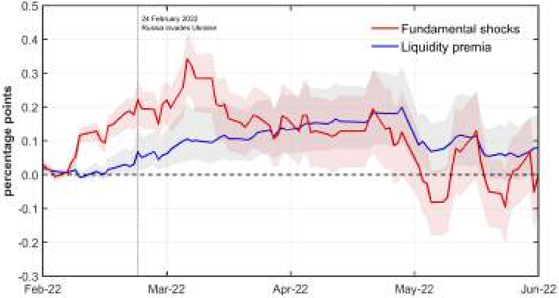


ZOOMING IN: COVID AND UKRAINE

Covid period



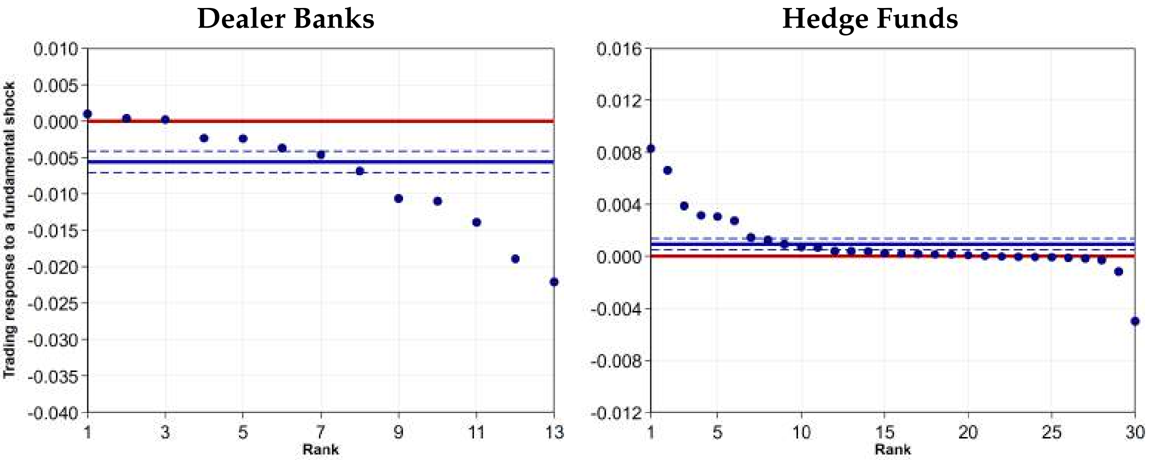
Ukraine invasion



Comparison with bid-ask spreads

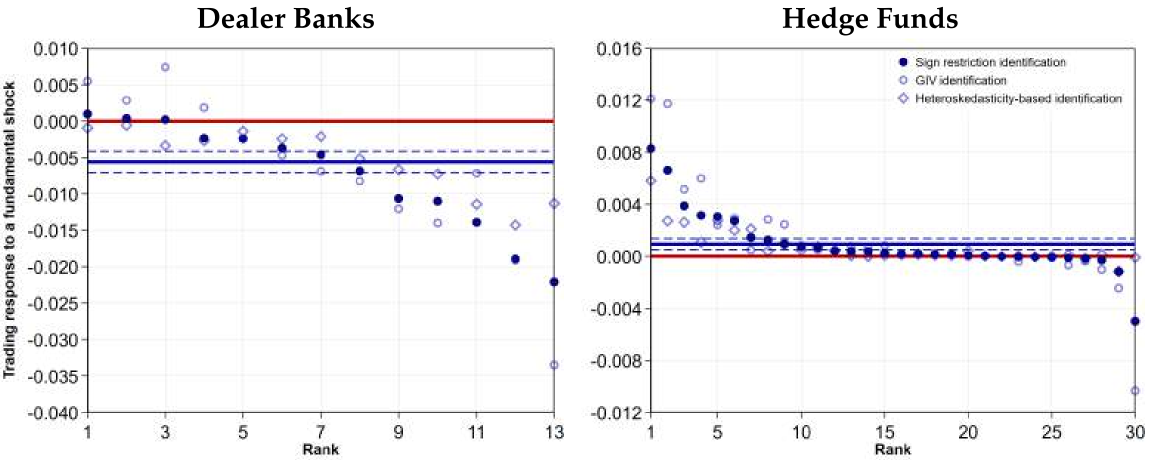
6. Disagreement and expectations

Relative price impact of individual institutions



LT market

Relative price impact of individual institutions



LT market Markets versus surveys

7. Conclusions

Conclusions

1) Facts: At short horizons, hedge funds and dealers alternate between negative and positive net positions. At long horizons, dealers provide inflation protection to pension funds.

2) Propose three separate identification strategies that exploit information/variability in daily frequency, concentration across institutions, and time series.

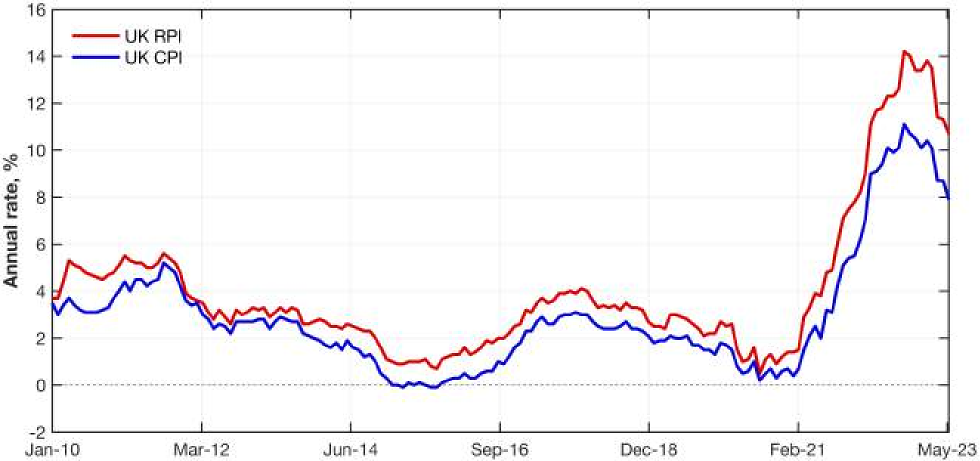
3) At short horizon, supply curve is steep, liquidity shocks drive prices; at long horizons, supply curve is flat, fundamentals account for 80% of price variation.

4) New measure of expected inflation cleaned of liquidity frictions reacts less to key shocks, is more anchored.

5) Risk-neutral expectations inferred from market positions match with subjective expectations inferred from survey answers.

Appendix

RPI versus CPI



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The EMIR Trade Repository Data

- **Data source:** European Market Infrastructure Regulation, post-2008 reporting requirements for all transactions in almost real time.
- **The market:** OTC, centrally cleared, all through dealer banks.
- **Observations:** all derivative transactions where a UK-regulated institution (including UK branches/subsidiaries of global banks) is a counterparty, includes hedge funds, pension funds and others.
- **Information:** counterparties' names and contract terms like length, price, index. Will focus on UK RPI today, but also have HICP for EA and CPI-U for US.
- **Frequency and span:** 3.5 billion observations since 31 Oct 2017, 34 million cleaned inflation swaps. Use daily observations from January 2, 2019 to February 10, 2023.

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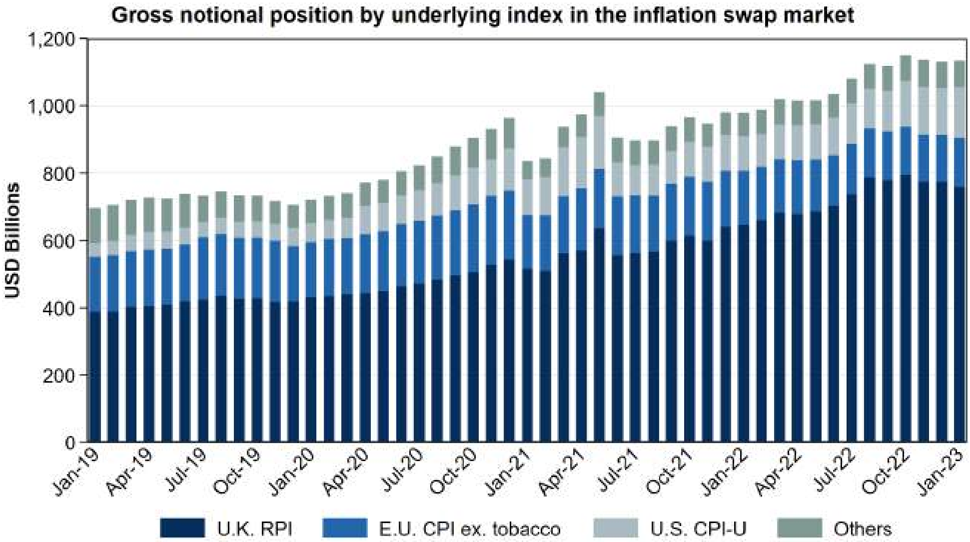
TYPE OF CONTRACT



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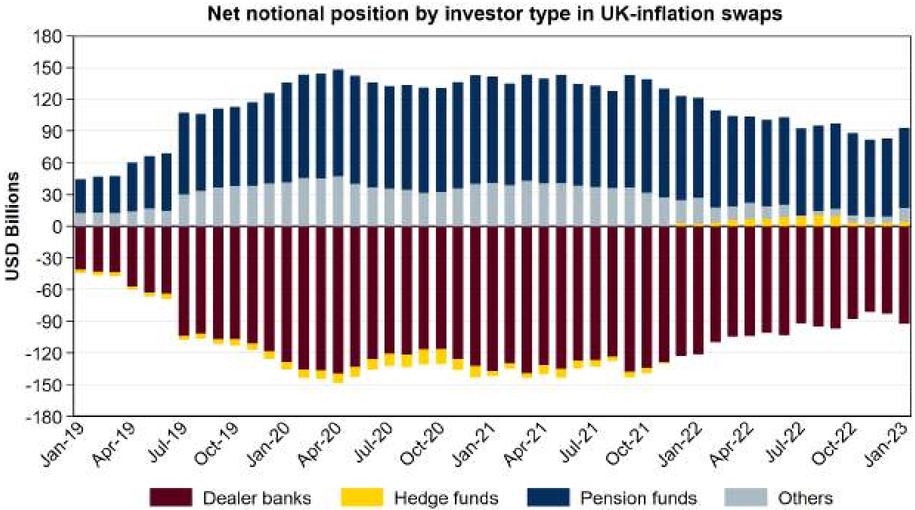
THE FULL PICTURE



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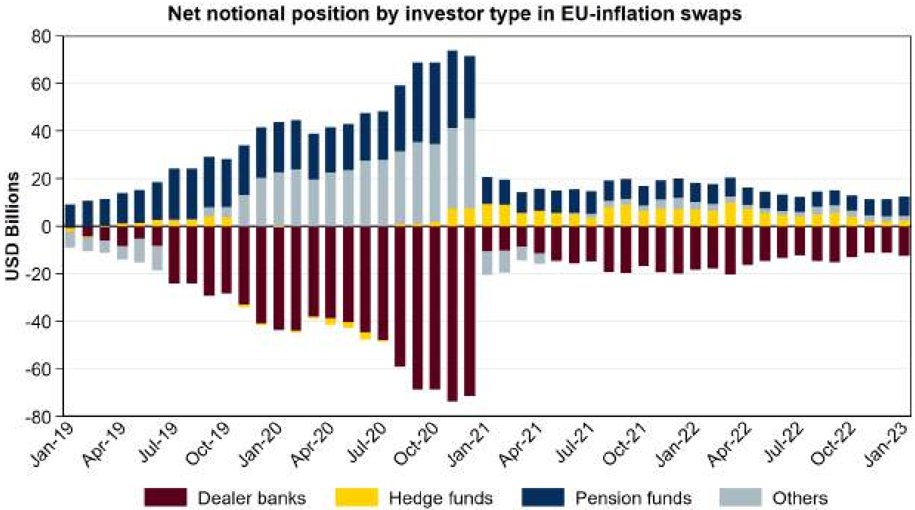
THE FULL PICTURE FOR THE EUROZONE



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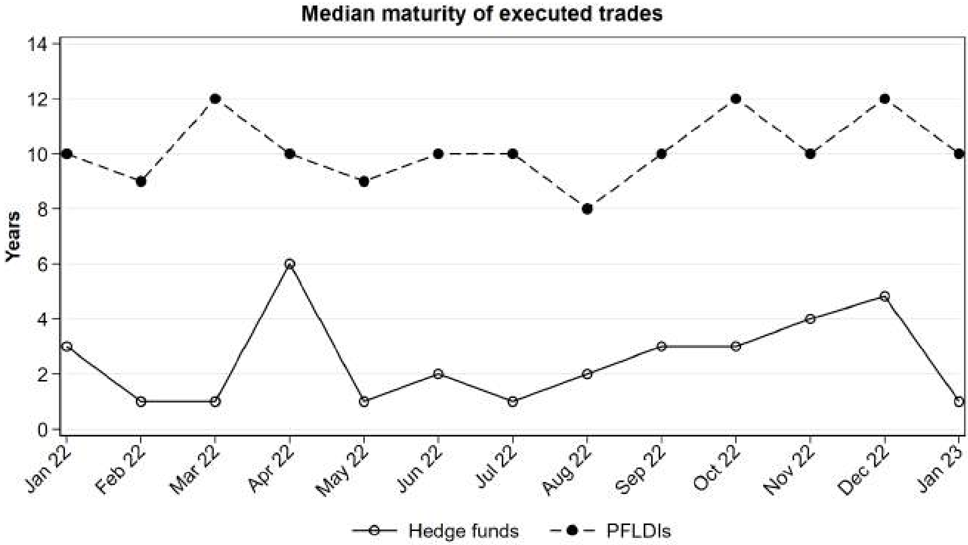
TRADES


Median maturity of executed trades
Years
14
12
10
8
6
4
2
0
Jan 22
Feb 22
Mar 22
Apr 22
May 22
Jun 22
Jul 22
Aug 22
Sep 22
Oct 22
Nov 22
Dec 22
Jan 23
Hedge funds
PFLDIs

Back

Formalising things – Pension funds' problem

Types: pension funds (index f, set Θ_f), dealers (index b, set Θ_b), hedge funds (index h, set Θ_h). Many agents indexed by i, maximization of terminal wealth, single trading day.

Objective: $$\max \mathbb{E}_{f,i}\left[-\exp\left(-\widetilde{\gamma}_{f,i} a'_{f,i}\right)\right] \quad \text{with} \quad \widetilde{\gamma}_{f,i} = \gamma_{f,i}/a_{f,i}$$

Budget Constraint: $$a'_{f,i} = a_{f,i} + (\pi - p)q_{f,i} + (d - s)e_{f,i} + y_{f,i}, \quad \pi, d, y \sim Normal$$

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Formalising things – Pension funds' problem

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Budget Constraint: $a'_{f,i} = a_{f,i} + (\pi - p)q_{f,i} + \underbrace{(d-s)e_{f,i} + y_{f,i}}_{\text{other asset \& background risk}}$, $\pi, d, y \sim Normal$

Formalising things – Pension funds' problem

Types: pension funds (index f, set Θ_f), dealers (index b, set Θ_b), hedge funds (index h, set Θ_h). Many agents indexed by i, maximization of terminal wealth, single trading day.

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Trading Constraints: $G_f(q_{f,i}, z_{f,i}) \geq 0$ with $g_{f,i} \equiv \partial G_f(q^*_{f,i}, z_{f,i})/\partial q_{f,i}$

Beliefs: $\mathbb{E}_{f,i}(\pi) = \mu_{f,i}\pi^e$

Formalising things – Pension funds' problem

Types: pension funds (index f, set Θ_f), dealers (index b, set Θ_b), hedge funds (index h, set Θ_h). Many agents indexed by i, maximization of terminal wealth, single trading day.

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Beliefs: $$\mathbb{E}_{f,i}(\pi) = \mu_{f,i}\pi^e$$

Two markets: short horizon (ST, capitalized) and long horizon (LT).

Assumption 1: Segmented markets. *Pension funds do not participate in the ST market* $Q_{f,i} = 0$ *and hedge funds do not participate in the LT market* $q_{h,i} = 0$.

Dealers' problem

- Dealers similar but in both markets:

$$a'_{b,i} = a_{b,i} + (\pi - p)q_{b,i} + (\Pi - P)Q_{b,i} + (d - s)e_{b,i} + y_{b,i}$$

- **Assumption 2: Desk separation within the day.** *Dealers face separate capacity constraints:*

$$G^S_b(Q_{b,i}) \geq 0 \quad \text{and} \quad G^L_b(q_{b,i}) \geq 0$$

so that $\partial G^S_b(\cdot,\cdot)/\partial q_{b,i} = 0$ *and* $\partial G^L_b(\cdot,\cdot)/\partial Q_{b,i} = 0.$

- Market clearing, and definition of supply and demand:

$$q^* \equiv \sum_{i \in \Theta_f} q^*_{f,i} = -\sum_{i \in \Theta_b} q^*_{b,i} > 0, \; Q^* \equiv \sum_{i \in \Theta_h} Q^*_{f,i} = -\sum_{i \in \Theta_b} Q^*_{b,i} \approx 0$$

Demand Curves

Frictionless market equilibrium

- Complete markets so no background risk:

$$\sigma_{\pi,y_{b,i}} = \sigma_{\pi,y_{f,i}} = \sigma_{\pi,y_{h,i}} = 0$$

- Non-binding capacity constraints, so Lagrange multipliers:

$$\lambda^L_{b,i} = \lambda_{f,i} = \lambda^S_{b,i} = \lambda_{h,i} = 0$$

- If $\widetilde{p}$ is the frictionless price of a long horizon inflation swap, in equilibrium, it is:

$$\widetilde{p}^* = \underbrace{\left[\frac{\sum_{i\in\Theta_f}\widetilde{\gamma}_{f,i}^{-1}\mu_{f,i}}{\sum_{i\in\Theta_f}\widetilde{\gamma}_{f,i}^{-1}+\sum_{i\in\Theta_b}\widetilde{\gamma}_{b,i}^{-1}} + \frac{\sum_{i\in\Theta_b}\widetilde{\gamma}_{b,i}^{-1}\mu_{b,i}}{\sum_{i\in\Theta_f}\widetilde{\gamma}_{f,i}^{-1}+\sum_{i\in\Theta_b}\widetilde{\gamma}_{b,i}^{-1}}\right]}_{\text{size-weighted dispersion of beliefs}} \underbrace{\pi^e}_{\text{expected inflation}} - \underbrace{\frac{\theta_d - \widetilde{s}^*}{\sigma_d^2}\sigma_{\pi,d}}_{\text{risk premium}}$$

Liquidity premium

Observed price is frictionless price plus a liquidity premium: $p^* = \widetilde{p}^* + lp^*$

$$lp^* = \underbrace{-\frac{\sum_{i\in\Theta_b}\left\{\sigma_{\pi,y_{b,i}} + \frac{\lambda^L_{b,i} g^L_{b,i}}{\widetilde{\gamma}_{b,i}}\right\}}{\sum_{i\in\Theta_f}\widetilde{\gamma}^{-1}_{f,i} + \sum_{i\in\Theta_b}\widetilde{\gamma}^{-1}_{b,i}}}_{\equiv\varepsilon_b,\ \text{the supply friction from dealer banks}} + \underbrace{-\frac{\sum_{i\in\Theta_f}\left\{\sigma_{\pi,y_{f,i}} + \frac{\lambda_{f,i} g_{f,i}}{\widetilde{\gamma}_{f,i}}\right\}}{\sum_{i\in\Theta_f}\widetilde{\gamma}^{-1}_{f,i} + \sum_{i\in\Theta_b}\widetilde{\gamma}^{-1}_{b,i}}}_{\equiv\varepsilon_f,\ \text{the demand friction from pension funds}} .$$

Optimal demand curve: pension funds

- Three components (hedge funds similar in short market, dealers in both markets)

$$\frac{q^*_{f,i}}{a_{f,i}} = \underbrace{\frac{\mu_{f,i}\pi^e - p^*}{\gamma_{f,i}\sigma^2_\pi(1-\rho^2_{\pi,d})}}_{\text{price and beliefs}} - \underbrace{\left(\frac{\sigma_d}{\sigma_\pi}\right)\left[\frac{\theta_d - s^*}{\gamma_{f,i}\sigma^2_d(1-\rho^2_{\pi,d})}\right]\rho_{\pi,d}}_{\text{hedging demand}}$$

$$- \underbrace{\left[\frac{1}{(1-\rho^2_{\pi,d})\sigma^2_\pi}\right]\left(\frac{\sigma_{\pi,y_{f,i}}}{a_{f,i}} + \frac{\lambda_{f,i}g_{f,i}}{\gamma_{f,i}}\right)}_{\text{liquidity frictions}}$$

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Dynamics and implementation for all strategies

- For dynamics: VAR, implemented as Bayesian VAR with diffuse priors and 3 lags:

$$\mathbf{Y}_t = \mathbf{c} + \sum_{\ell=1}^{L} \mathbf{\Phi}_\ell \mathbf{Y}_{t-\ell} + \mathbf{u}_t \quad \text{and} \quad \mathbf{u}_t = \mathbf{\Psi} \boldsymbol{\varepsilon}_t$$

- Sign restrictions: as in Arias, Rubio-Ramirez and Waggoner (2018), sign restrictions on $\mathbf{\Psi}$ for set identification.
- Granularity identification: as in Stock and Watson (2018), using *GIV* as proxy instrumental variables
- Heteroskedasticity identification: VAR as in Brunnermeier, Palia, Sastry, Sims (2021),

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First identification strategy: heteroskedasticity

- 48 dates (out of 1078) where monthly inflation data is released plus September 6th 2022 (Truss energy cap). In total 49 days out of 1078 where swap prices move a lot, lumpy arrival of news.

- **Assumption 3c: Heteroskedascity at known dates due to fundamentals.** *If $\mathbf{\Sigma}_h$ is the variance-covariance matrix of the shocks $\boldsymbol{\varepsilon}$ at data release dates, and $\mathbf{\Sigma}_l$ the one at other dates, then the largest diagonal element of $\mathbf{\Sigma}_h'\mathbf{\Sigma}_l$ is the one associated with the variance of the fundamentals ε_π.*

- In data, the maximum eigenvalue of $\mathbf{\Sigma}_h'\mathbf{\Sigma}_l$ is 4.651. Wald test Lutkepohl (2021): reject null of no heteroskedasticity at 0.1% significance level.

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Second identification strategy: granularity

- Write asset demand system as an interactive fixed effects factor model:

$$\frac{q_{f,i,t}}{a_{f,i,t}} = \boldsymbol{\omega}'_{f,i}\mathbf{F}_{f,t} + \widetilde{\varepsilon}_{f,i,t}, \ \mathbf{F}_{f,t} = (\pi^e_t, lp^*_t)'$$

- Construct instrument as a weighted sum of the residuals:

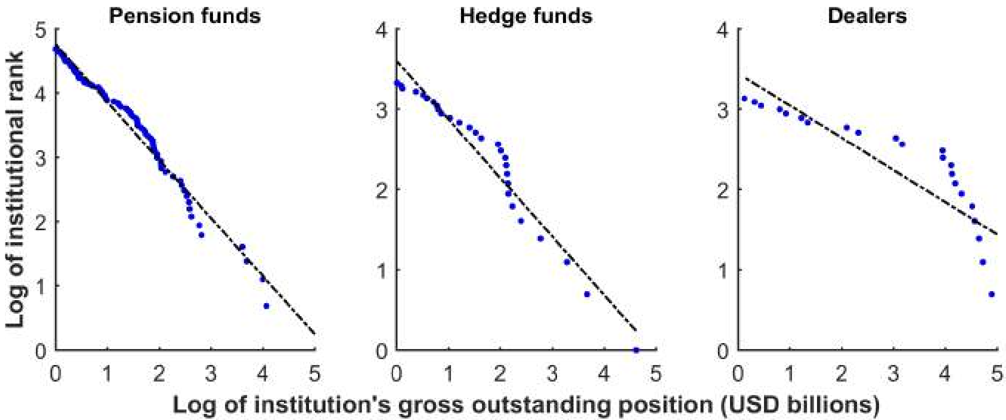
$$GIV_{f,t} = \sum_{i \in \Theta_f} a_{f,i,t}\tilde{\varepsilon}_{f,i,t}$$

$\mathbf{F}_{f,t}$ spans $(\varepsilon_{b,t}, \varepsilon_{\pi,t})$: $\mathbb{E}(GIV_{f,t}\varepsilon_{\pi,t}) = \mathbb{E}(GIV_{f,t}\varepsilon_{b,t}) = 0$. Ass. 1: $\mathbb{E}(GIV_{f,t}\varepsilon_{h,t}) = 0$.

- **Assumption 3b: Granularity of the institutions.** *Asset positions are granular:*

$$\mathbb{E}(GIV_{f,t}\varepsilon_{f,t}) \neq 0 \ \text{ and } \ \mathbb{E}(GIV_{b,t}\varepsilon_{b,t}) \neq 0 \ \text{ and } \ \mathbb{E}(GIV_{h,t}\varepsilon_{h,t}) \neq 0 \qquad (1)$$

Second identification strategy: granularity



PFLDIs: 210 institutions, Pareto parameter 0.13, power law coefficient -0.9, first-stage F-stat of 72.3. For hedge funds, -.73 and 22.3, for dealer banks, -0.40 and 43.5. Back

Third identification strategy: heterogeneity in reactivity

- **Assumption 3a) Differential reactiveness to fundamental news about inflation.** *Dealer banks respond more to fundamental long-horizon expected inflation than pension funds but less to fundamental short-horizon expected inflation than hedge funds:*

$$\frac{\sum_{i\in\Theta_h}\widetilde{\gamma}_{h,i}^{-1}\mu_{h,i}}{\sum_{i\in\Theta_h}\widetilde{\gamma}_{h,i}^{-1}+\sum_{i\in\Theta_b}\widetilde{\gamma}_{b,i}^{-1}} > \frac{\sum_{i\in\Theta_b}\widetilde{\gamma}_{b,i}^{-1}\mu_{b,i}}{\sum_{i\in\Theta_f}\widetilde{\gamma}_{f,i}^{-1}+\sum_{i\in\Theta_b}\widetilde{\gamma}_{b,i}^{-1}} > \frac{\sum_{i\in\Theta_f}\widetilde{\gamma}_{f,i}^{-1}\mu_{f,i}}{\sum_{i\in\Theta_f}\widetilde{\gamma}_{f,i}^{-1}\sum_{i\in\Theta_b}\widetilde{\gamma}_{b,i}^{-1}}$$

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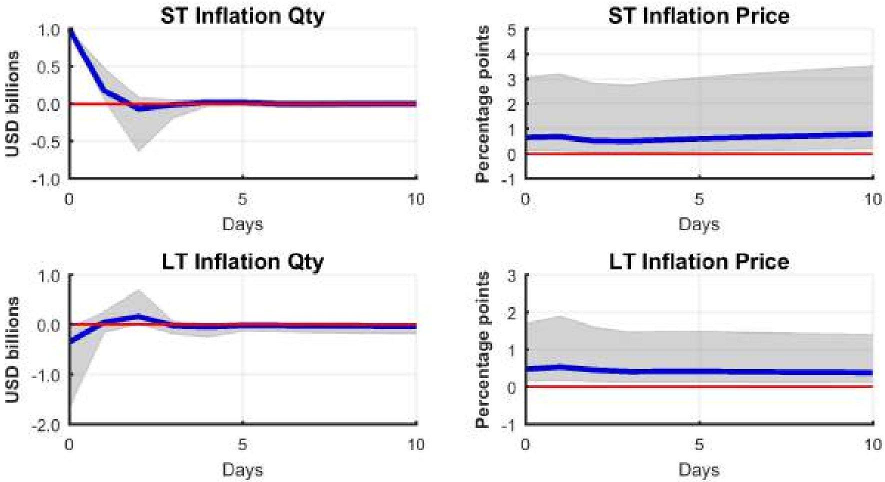
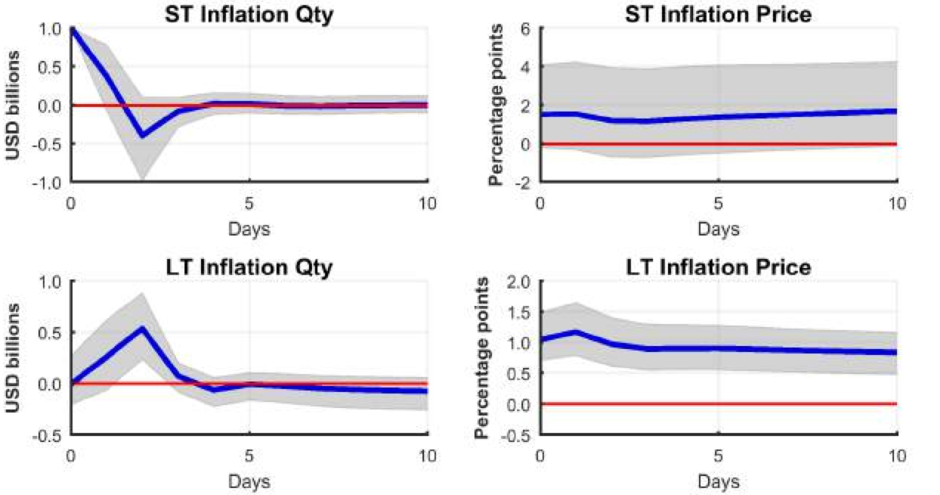
Response to a fundamental shock



IRF TO FUNDAMENTAL WITH GIV



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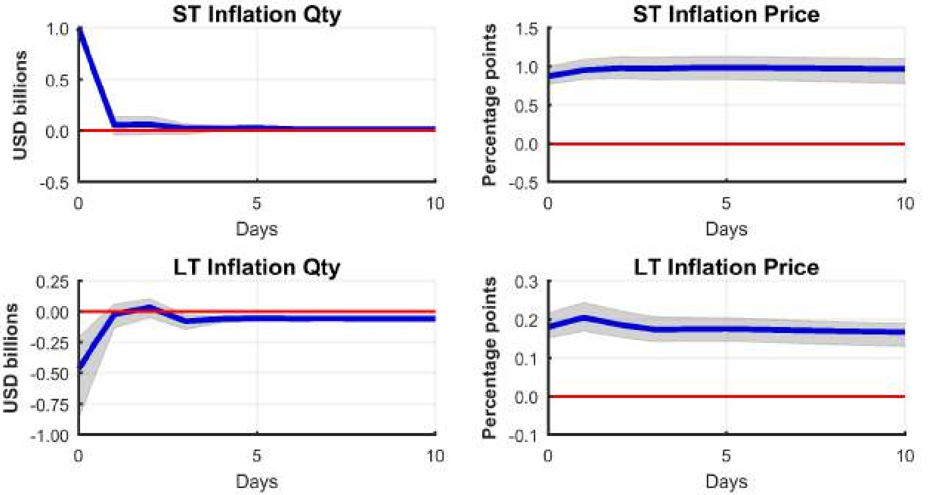
IRF to fundamental with Heteroskedasticity



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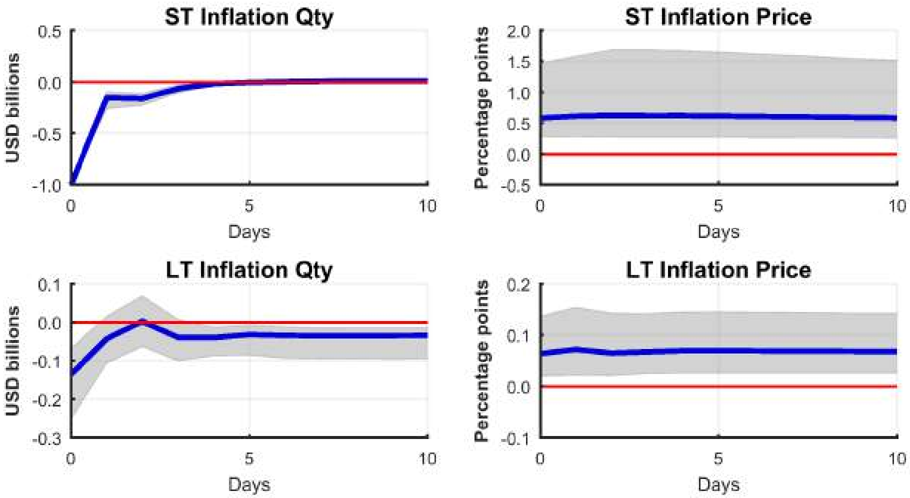
RESPONSE TO LIQUIDITY SHOCKS TO DEALERS



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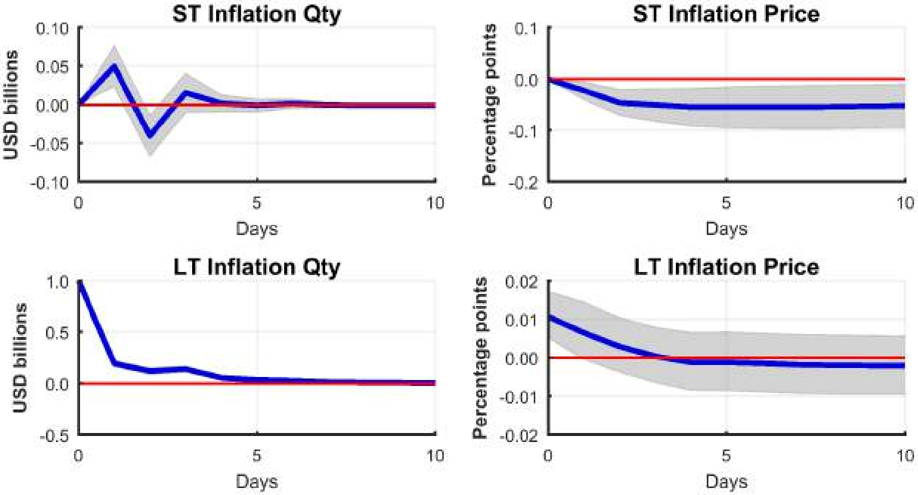
RESPONSE TO LIQUIDITY SHOCK TO PENSION FUNDS



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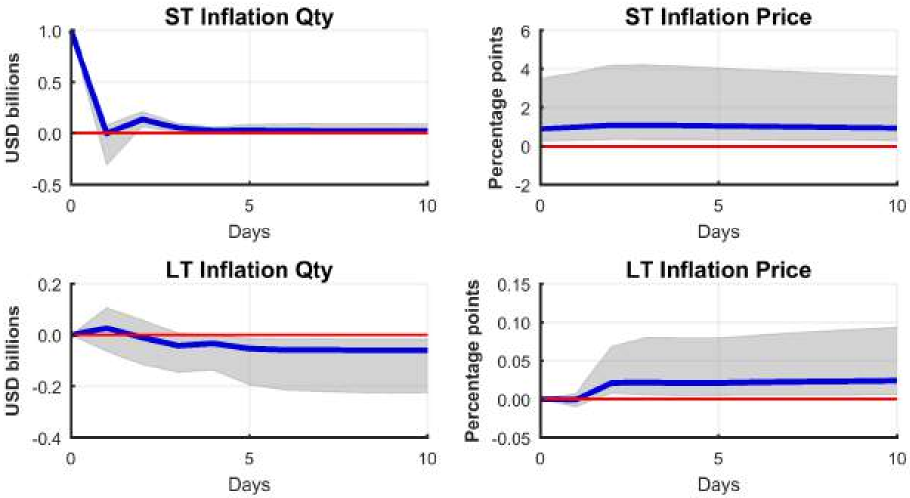
Response to liquidity shock to hedge funds



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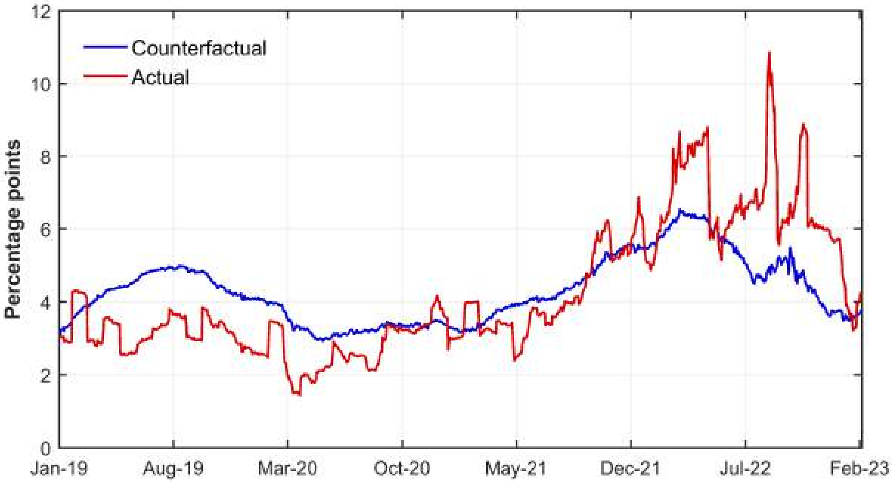
HISTORICAL DECOMPOSITION OF ST PRICES



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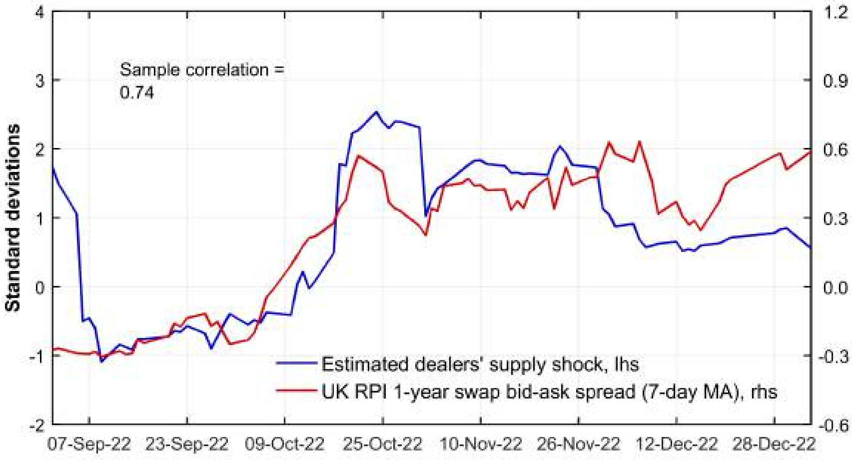
Comparisons with market bid-ask spreads

(a) LDI Crisis period



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Comparisons with market bid-ask spreads

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Comparisons with market bid-ask spreads

(c) COVID-19 period

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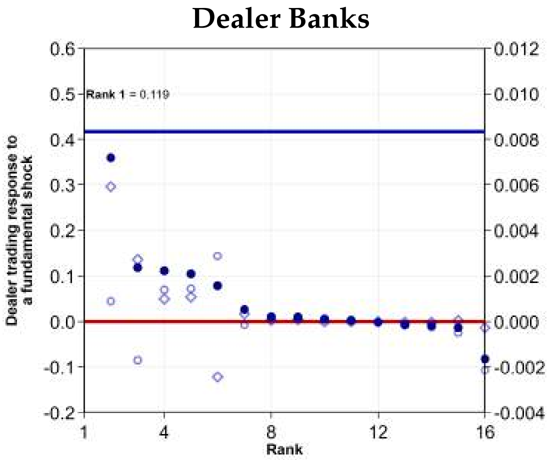
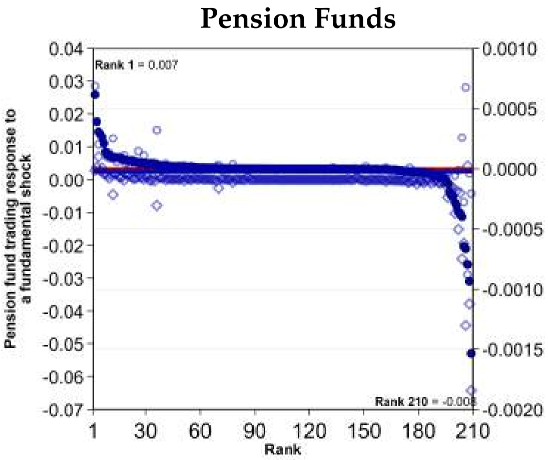
Price impact of individual institutions: LT market





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Markets versus surveys

- Focus on dealers in ST market

- **Trading behaviour**, regress quantity traded by an institution on our identified fundamental ε_t^π

$$\frac{Q_{b,i,t}}{a_{b,i,t}} = \beta_{b,i}\varepsilon_t^\pi + \text{residual}_{b,i,t}$$

  $\beta_{b,i}$ are negative, consistent with assumption 3a. Differential response, to either subjective expectations or risk premia.

- **Agent's expectations** Bloomberg monthly panel of forecasts for inflation, $\hat{\Pi}^e_{b,i}$

$$\Delta\hat{\Pi}^e_{b,i,t} = \mu_{b,i}\Delta P_t^* + \text{residual}_{b,i,t},$$

  $\mu_{b,i}$ measures disagreement about subjective expectations.

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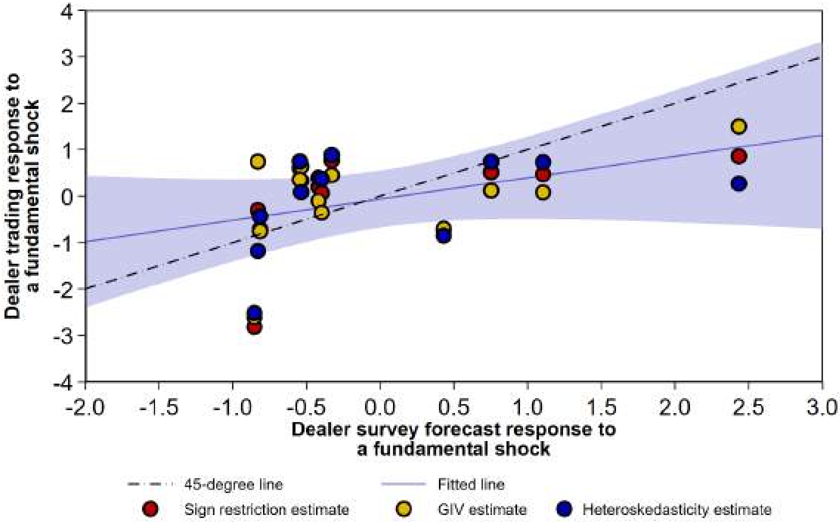
MARKETS VERSUS SURVEYS



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