Strategic Inattention, Inflation Dynamics, and the Non-Neutrality of Money

Hassan Afrouzi

Columbia University

NBER Summer Institute
Behavioral/Macro Group
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Motivation

- Understanding how inflation expectations are formed is central to monetary policy.

  "[T]he precise manner in which expectations influence inflation deserves further study . . . Most importantly, we need to know more about the manner in which inflation expectations are formed . . ."

  Janet Yellen (October 2016)

- Almost all monetary models link aggregate inflation to expectations of aggregate inflation.
  - In sticky price models: $\pi_t = \beta \mathbb{E}_t[\pi_{t+1}] + \kappa y_t$
  - In noisy/sticky information models: $\pi_t = \mathbb{E}_{t-1}[\pi_t] + \kappa y_t$
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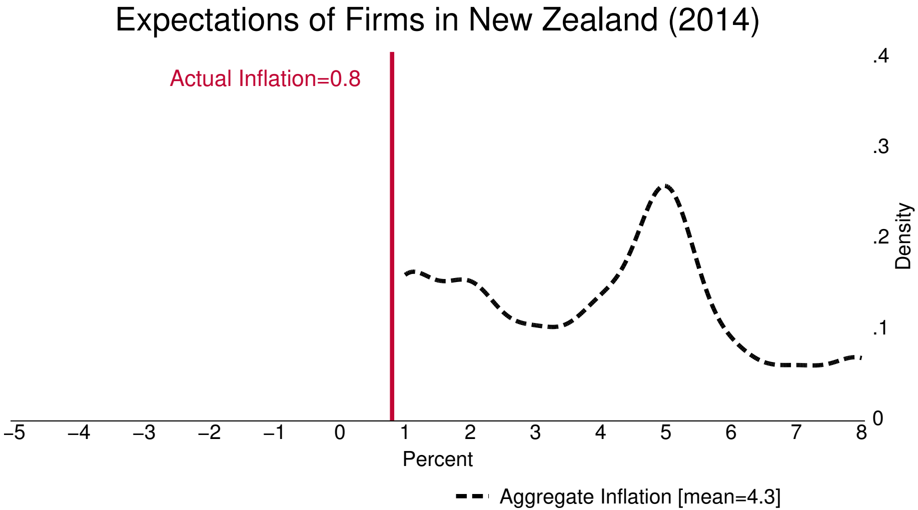
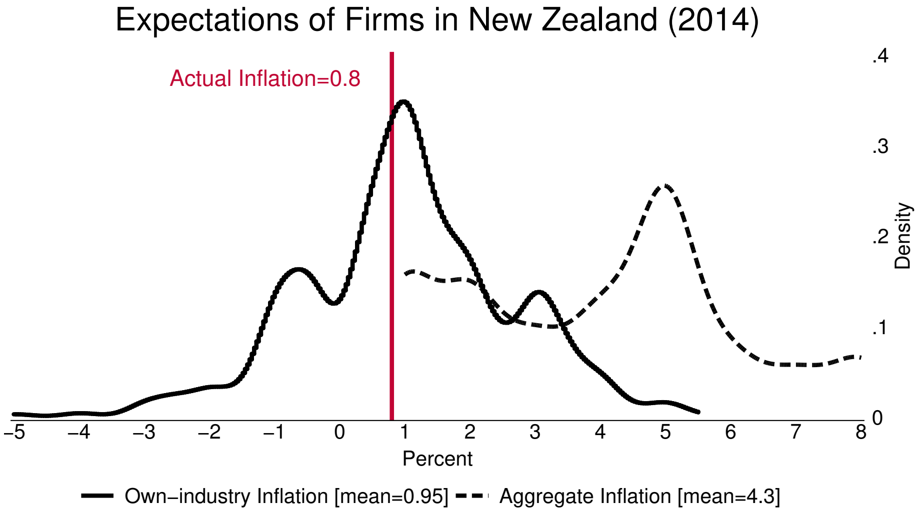


Nowcast Errors Forecasts Why New Zealand?



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Overview of Results

In a model of rational inattention and oligopolistic pricing:

- Firms endogenously ignore aggregates to form more precise expectations of their competitors' prices.
- The Phillips curve relates aggregate inflation to firms' expectations of their own competitors' prices.
- Use new firm level data to test the mechanism and calibrate the model.
- The strategic incentives of firms in information acquisition significantly increases monetary non-neutrality.

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Literature

- Rational Inattention on Inflation and Prices:
  - Sims (2003, 2006, 2011); Woodford (2008); Mackowiak and Wiederholt (2009, 2014); Mackowiak, Matejka, Wiederholt (2016); Matejka (2012, 2015); Stevens (2015).
- Imperfect Common Knowledge and Inflation Dynamics:
  - Woodford (2003); Nimark (2008); Angeletos and La'O (2009).
- Empirical Evidence on Information Rigidities:
  - Coibion and Gorodnichenko (2012, 2015); Coibion, Gorodnichenko and Kumar (2015); Kumar, Afrouzi, Coibion and Gorodnichenko (2015).
- Beauty Contests and Coordination:
  - Morris and Shin (2002); Hellwig and Veldkamp (2011); Angeletos and Pavan (2014); Denti (2015).

A Static Model

A Static Model

The Big Picture

Three main ingredients:

- Rational inattention.
  Inflation in Iran Inflation Expectations in Iran

- Finite number of competitors at the micro level.

- Strategic complementarity in pricing within industries.

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A Static Model
Environment

- Suppose there are J industries with K firms in each, indexed by $(j, k) \in J \times K$.

- There is a fundamental in the economy $q \sim \mathcal{N}(0, 1)$.

- Given a realization for q and a set of prices, j, k's payoff is

$$u_{j,k}((q, p_{l,m})_{(l,m)\in J\times K}) = -((1-\alpha)(p_{j,k} - q) + \alpha(p_{j,k} - p_{j,-k}))^2$$

  - $p_{j,k} - q$: difference of own price from fundamental.
  - $p_{j,k} - p_{j,-k}$: difference of own price from others.
  - $\alpha \in (0, 1)$: degree of strategic complementarity.

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Timing and Strategies

1. Firms do not observe the fundamental or prices of others directly, but choose a set of signals to see from a set of available signals $\mathcal{S}$. Structure of $\mathcal{S}$
2. After firms decide which signals to see in $\mathcal{S}$, nature draws them along with the fundamental.
3. Firms observe their signals and decide what price they want to charge.

- Given a strategy profile for others, firm j, k's problem is

$$\min_{S_{j,k}\in\mathcal{S}, p_{j,k}:S_{j,k}\to\mathbb{R}} \mathbb{E}[(p_{j,k}(S_{j,k}) - (1-\alpha)q - \alpha p_{j,-k}(S_{j,-k}))^2 | S_{j,k}]$$

$$\text{s.t.} \quad \mathcal{I}(S_{j,k}; (q, p_{l,m}(S_{l,m}))_{(l,m)\neq(j,k)}) \leq \kappa \tag{1}$$

- Firm minimizes expected loss over signals and pricing strategies.

Feasible Information

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Definition

A pure strategy equilibrium is a pure strategy profile $(S_{j,k} \in \mathcal{S}, p_{j,k} : S_{j,k} \to \mathbb{R})_{(j,k)\in J\times K}$ from which no one wants to deviate.

- The equilibrium is unique in the joint distribution of prices.
- Decompose the implied average price of others in equilibrium as:

$$p_{j,-k} = \underbrace{\delta q}_{\text{projection on } q} + \underbrace{v_{j,-k}}_{\text{orthogonal to } q}.$$

- Firm k faces an endogenous trade-off to divide its attention between
  - q: the fundamental exogenous shock in the economy.
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A Static Model

- In the static model, paying attention to q / $v_{j,-k}$ is equivalent to choosing the correlation between firm's price and q / $v_{j,-k}$. Interpretation

Proposition

In equilibrium,

1. firms pay positive attention to both the fundamental and others' mistakes.
2. a firm's attention to its competitors' mistakes
   1. increases with the degree of strategic complementarity, and
   2. decreases with the number of competitors.
3. firms do not pay attention to mistakes of firms in other industries.

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- So far:

$$p_{j,k} = \delta q + v_{j,k}$$

- In equilibrium:
  - mistakes are independent across industries:

$$p = \delta q$$

  - but they are not independent within industries:

$$p_{j,k} = \underbrace{p}_{=\delta q} + \underbrace{u_j + e_{j,k}}_{=v_{j,k}}$$

- Firms' signals are more informative of their own industry price changes than the aggregate economy:

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Corollary

If $\alpha > 0$ and $\mathsf{K} < \infty$, realized prices are closer in absolute value to average expectations from own-industry prices than the average expectations from the aggregate price:

$$|\mathsf{p} - \overline{\mathbb{E}^{j,k}[\mathsf{p}_{j,-k}]}| < |\mathsf{p} - \overline{\mathbb{E}^{j,k}[\mathsf{p}]}|$$

Moreover, the two converge to one another as $\mathsf{K} \to \infty$.

Model Predictions and Relation to Data

Data

- Survey of Firms' Expectations from New Zealand:
  - broad sectoral coverage.
  - exclude very small firms (less than 6 employees).
  - conducted through phone interviews.
  - response rate: 20~30 percent.
- Multiple waves:
  - Wave #1: Sept 2013 to Dec 2013 (~3,150 firms)
  - Wave #4: Dec 2014 to Jan 2015 (~1,200 firms)
  - Wave #6: Mar 2016 to Jul 2016 (~2,000 firms)

Data

Relation to the data

- In the survey:
  - report the number of competitors that they face in their product market.
  - firms assign probabilities to different outcomes for aggregate inflation and own-industry inflation.

- The "subjective uncertainty" of a firm is the standard deviation of its reported distribution.

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Testing the mechanism of the model

- Aggregate price in the model: $p = \delta q$

Prediction 1

as $K \uparrow$, firm pays more attention to q, so its subjective uncertainty about p should decrease.

- Own-industry price: $p_{j,-k} = \delta q + v_{j,-k}$

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Uncertainty about the economy

	Subjective uncertainty about			
	aggregate inflation[a]		industry inflation[b]	
firm characteristics	(1)	(2)	(3)	(4)
Number of competitors	-0.021***	-0.024***	-0.010***	-0.007***
	(0.003)	(0.003)	(0.002)	(0.002)
Firm controls and industry fixed effects	No	Yes	No	Yes
Observations	2,040	1,910	2,040	1,910
R-squared	0.036	0.050	0.009	0.020

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

A Dynamic General Equilibrium Model

Micro-founded Model

Objectives:

- Micro-found the loss function and α.
- Introduce a dynamic general equilibrium model with monetary policy shocks.
- Look at the counterfactual:
  - what happens to propagation of shocks if we increase competition.

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Environment

Households

- Take prices as given and
  - consume goods from all firms in the economy:

$$C_t \equiv \prod_{j \in J} C_{j,t}^{\frac{1}{J}}$$

$$C_{j,t} \equiv \Phi(C_{j,1,t}, \ldots, C_{j,K,t})$$

- For example, with CES form:

$$\Phi(C_{j,1,t}, \ldots, C_{j,K,t}) = K \left[\frac{1}{K} \sum_{k \in K} C_{j,k,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$$

Environment

- Households:

$$\max \mathbb{E}_0^f \sum_{t=0}^{\infty} \beta^t [\log(C_t) - L_t]$$

$$\text{s.t.} \sum_{j,k \in J \times K} P_{j,k,t} C_{j,k,t} + B_t \leq W_t L_t + (1 + i_t) B_{t-1} + \text{Profits}_t - \text{Tax}_t$$

  - demand for firm j, k: ($Q_t = P_t C_t$ is the aggregate demand)

$$C_{j,k,t} = Q_t \mathcal{D}(P_{j,k,t}, P_{j,-k,t})$$

- Firms:
  - firms are price setters, and are rationally inattentive.
  - take industry demand and wages as given:

$$\Pi(P_{j,k,t}, P_{j,-k,t}, Q_t, W_t) = (P_{j,k,t} - W_t) Q_t \mathcal{D}(P_{j,k,t}, P_{j,-k,t})$$

- Monetary Policy: $\log(\frac{Q_t}{Q_{t-1}}) = \rho \log(\frac{Q_{t-1}}{Q_{t-2}}) + u_t$.

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$$\text{s.t.} \sum_{j,k \in J \times K} P_{j,k,t} C_{j,k,t} + B_t \leq W_t L_t + (1 + i_t) B_{t-1} + \text{Profits}_t - \text{Tax}_t$$

  - demand for firm j, k: ($Q_t = P_t C_t$ is the aggregate demand)

$$C_{j,k,t} = Q_t \mathcal{D}(P_{j,k,t}, P_{j,-k,t})$$

- Firms:
  - firms are price setters, and are rationally inattentive.
  - take industry demand and wages as given:

$$\Pi(P_{j,k,t}, P_{j,-k,t}, Q_t, W_t) = (P_{j,k,t} - W_t) Q_t \mathcal{D}(P_{j,k,t}, P_{j,-k,t})$$

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Environment

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\end{aligned}
$$

Timing and Firms' Problem

- At any time t, firms
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& \underbrace{S^t_{j,k} = S^{t-1}_{j,k} \cup \{S_{j,k,t}\}}_{\text{evolution of the information set}} \quad .
\end{aligned}
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Micro-founded Model

Sources of Strategic Complementarity

- The best responses of a firm with full information:

$$P^*_{j,k,t} = \underbrace{\frac{\epsilon_D(P^*_{j,k,t}, P_{j,-k,t})}{\epsilon_D(P^*_{j,k,t}, P_{j,-k,t}) - 1}}_{\text{optimal markup}} \underbrace{W_t}_{\text{wage}}$$

- Strategic complementarity exists because elasticity of demand for the firm depends on others' prices.

- A second order approximation to loss of firm from mispricing:

$$\begin{aligned}\mathcal{L}_{j,k,t} &\equiv \Pi(P^*_{j,k,t}, P_{j,-k,t}, Q_t, W_t) - \Pi(P_{j,k,t}, P_{j,-k,t}, Q_t, W_t) \\ &= ((1-\alpha)(p_{j,k,t} - q_t) + \alpha(p_{j,k,t} - p_{j,-k,t}))^2, \quad \alpha = \frac{\varepsilon^\epsilon_D(\mu - 1)}{\varepsilon^\epsilon_D(\mu - 1) + 1}\end{aligned}$$

More

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More

The Phillips Curve

Proposition

The Phillips curve of this economy is

$$\pi_t = (1-\alpha)\overline{\mathbb{E}^{j,k}_{t-1}[\pi_t + \Delta y_t]} + \alpha\overline{\mathbb{E}^{j,k}_{t-1}[\pi_{j,-k,t}]} + (1-\alpha)(2^{2\kappa}-1)y_t$$

- If α is large, inflation is mainly driven by average expectations of industry price changes.
- In addition, firms endogenously choose to have better information about their industries.
- The slope of Phillips curve depends on α and κ.

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Calibration

- Three new parameters:
  - K, number of competitors:
    "How many competitors does this firm face in its product market?" 5-10.
  - α, the degree of within industry strategic complementarity:
    directly inferred from the survey: 0.9 Question
  - κ, capacity of processing information:
    match the correlation of forecast errors and forecast revisions about aggregate inflation: 0.86 More
    (implied Kalman gain: 0.7)
- Other parameters:
  - η, elasticity of substitution within industry goods:
    match average markups in the survey: 6
  - ρ, persistence of the growth rate of the nominal aggregate demand:
    persistence of New Zealand NGDP growth: 0.5

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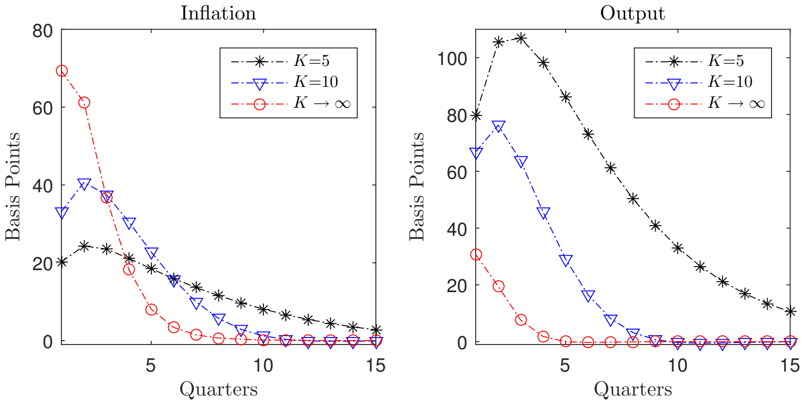
Simulations: 1% Shock to Nominal Demand

What happens if we increase competition in the economy?



- Finite competition at the micro level increases monetary non-neutrality.

Decomposition

Conclusion

- Built a dynamic model to capture strategic incentives of firms in acquiring information.
- Showed that
  - inflation is mainly driven by average expectations of firms from industry price changes, rather than aggregate inflation.
  - firms choose to be more informed about their own-industry prices than aggregate prices.
- This reconciles the puzzling expectations of firms in economies with stable inflation.
- Showed that strategic inattention:
  - amplifies monetary non-neutrality.
  - increases the persistence of output and inflation response.

Available Information

- The set of available information ($\mathcal{S}$) is rich:
  - in addition to q, there are countably many independent sources of randomness in the universe;

$$\mathcal{B} = \{\mathsf{q}, \mathsf{e}_1, \mathsf{e}_2, \dots\}.$$

  - the set of available information, $\mathcal{S}$, contains all finite linear combinations of $\mathcal{B}$:

$$\mathcal{S} \equiv \{\mathsf{a}_0\mathsf{q} + \sum_{\mathsf{n}=1}^{\mathsf{N}} \mathsf{a_n e}_{\sigma(\mathsf{n})} | \mathsf{N} \in \mathbb{N},\ (\mathsf{a_n})_{\mathsf{n}=0}^{\mathsf{N}} \in \mathbb{R}^{\mathsf{N}+1}, \sigma(.) \text{ is a permutation}\}.$$

  - perfect information about fundamental is available.

Return

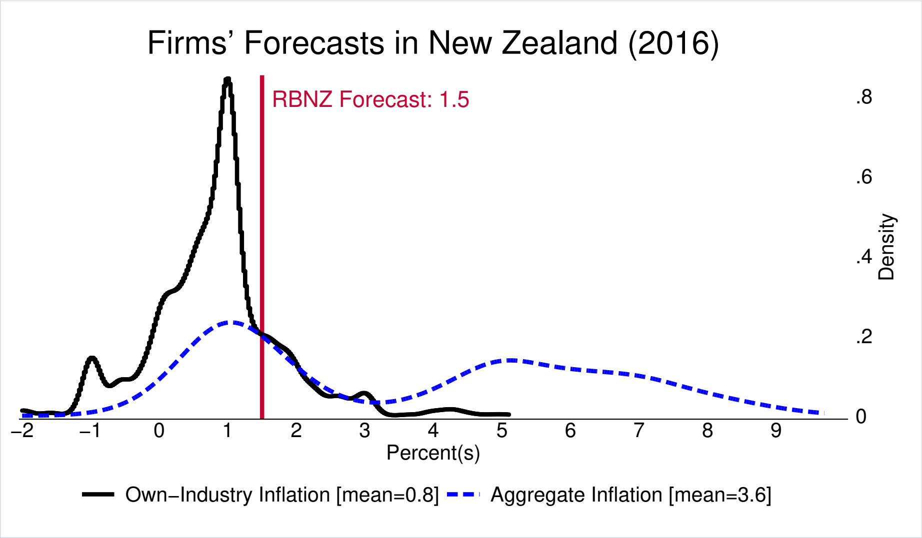
Feasible Information

- Firms have finite attention:
  - given a strategy for others, $(\mathsf{S}_{l,m} \in \mathcal{S}, \mathsf{p}_{l,m} : \mathsf{S}_{l,m} \to \mathbb{R})_{(l,m)\neq(j,k)}$, firm j, k cannot know more than κ about the fundamental and others' prices:

$$\mathcal{I}(\mathsf{S}_{j,k}; (q, \mathsf{p}_{l,m}(\mathsf{S}_{l,m}))_{(l,m)\neq(j,k)})$$
$$\equiv \frac{1}{2}\log_2\Bigg(\frac{\overbrace{|\mathrm{var}[(q, \mathsf{p}_{l,m}(\mathsf{S}_{l,m}))_{(l,m)\neq(j,k)}]|}^{\text{Ex-ante Uncertainty}}}{\underbrace{|\mathrm{var}[(q, \mathsf{p}_{l,m}(\mathsf{S}_{l,m}))_{(l,m)\neq(j,k)}|\mathsf{S}_{j,k}]|}_{\text{Ex-post Uncertainty}}}\Bigg) \leq \kappa$$

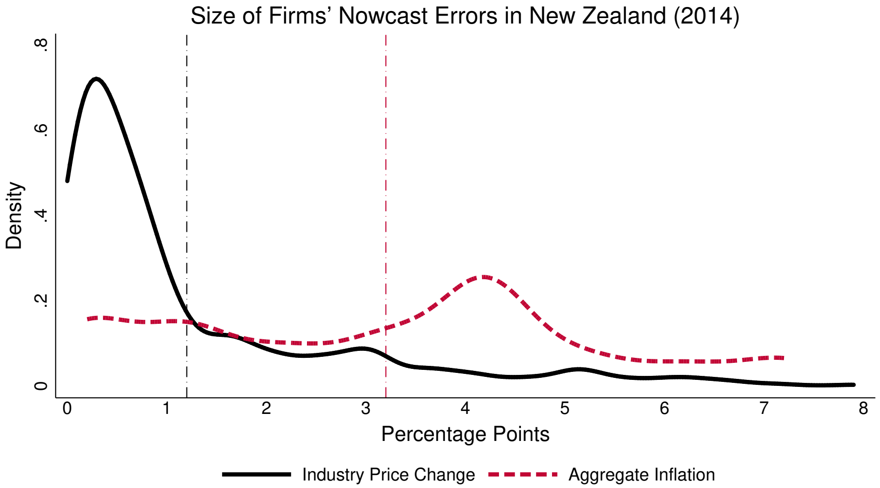
  - perfect information is not feasible neither about the fundamental nor others' signals.

Return



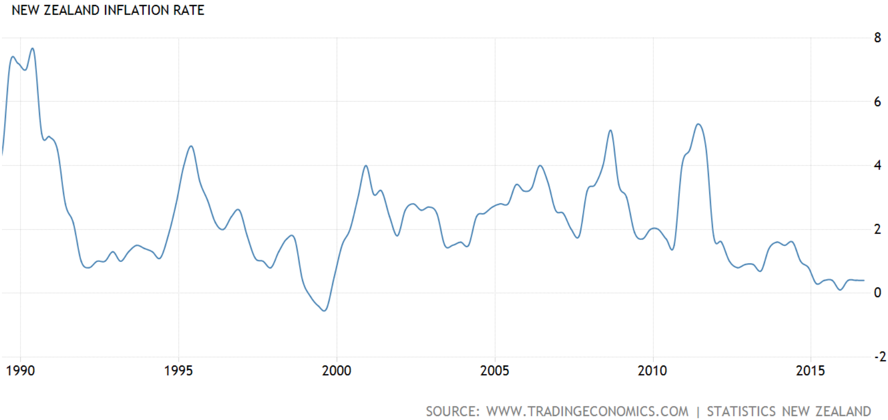
Firms' Forecasts in New Zealand (2016)
RBNZ Forecast: 1.5
.8
.6
.4
.2
0
Density
–2
–1
0
1
2
3
4
5
6
7
8
9
Percent(s)
Own–Industry Inflation [mean=0.8]
Aggregate Inflation [mean=3.6]

◂ Return

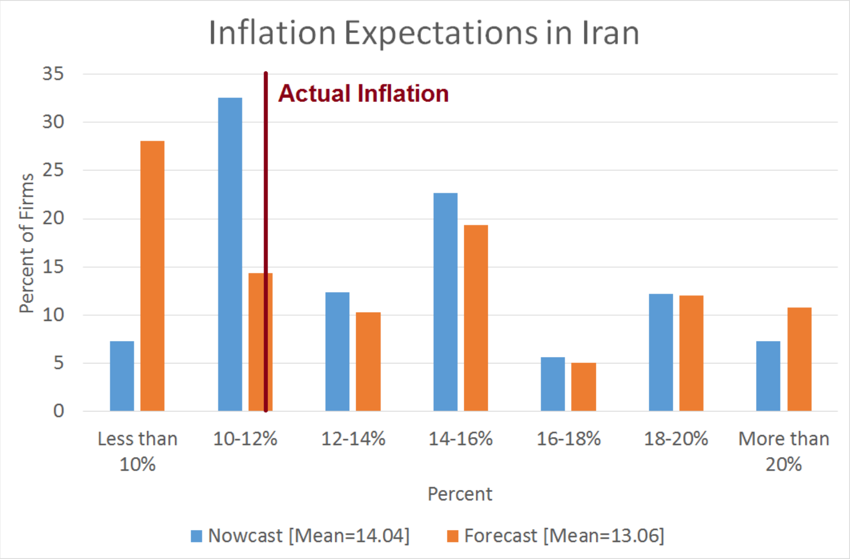

Size of Firms' Nowcast Errors in New Zealand (2014)
Density
0
.2
.4
.6
.8
0
1
2
3
4
5
6
7
8
Percentage Points
Industry Price Change
Aggregate Inflation

Return

Inflation in New Zealand

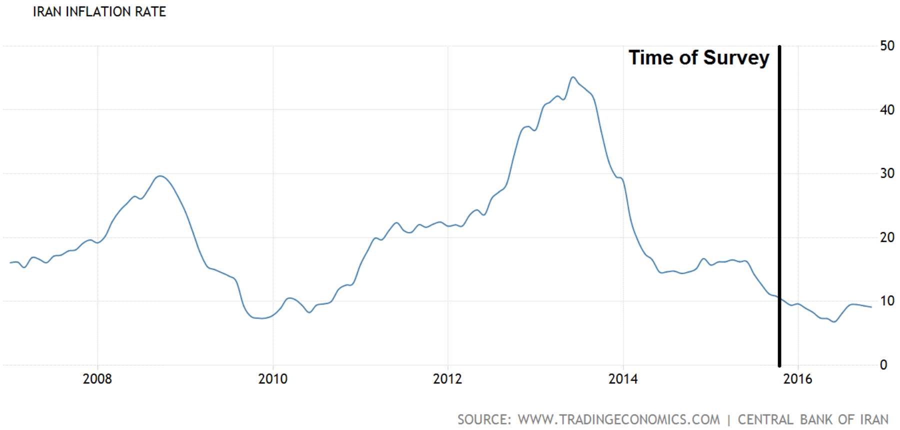


Return



Return Inflation in Iran

Inflation in Iran

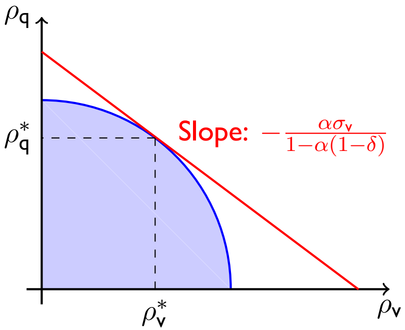


Return
Inflation Expectations in Iran

A Static Model: Reinterpretation of Attention Problem

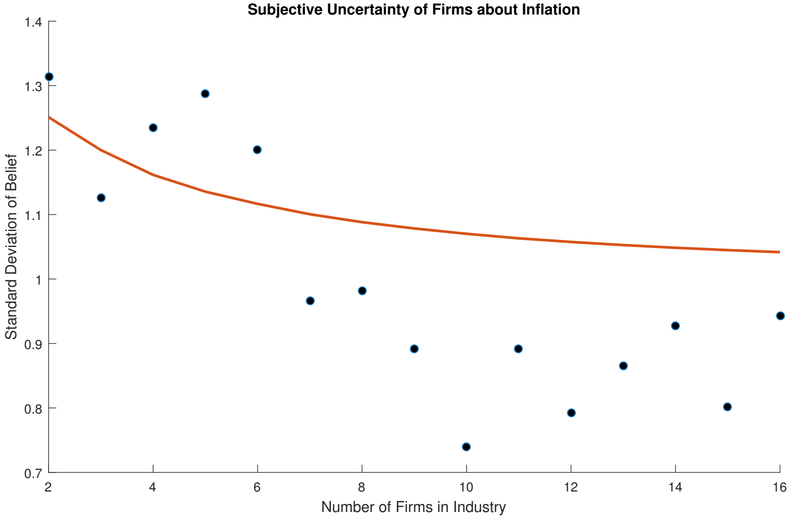
- In the static model, paying attention to q and $v_{j,-k}$ is equivalent for the firm to choosing correlations between its signal and q/$v_{j,-k}$:

$$\max_{\rho_q \geq 0, \rho_v \geq 0} \rho_q + \frac{\alpha \sigma_v}{1-\alpha(1-\delta)} \rho_v$$
$$\text{s.t. } \rho_q^2 + \rho_v^2 \leq \lambda$$



Return

Extension: Subjective Uncertainty in Model



General Equilibrium

Definitions

A GE is an allocation for the household,

$$\Omega^H \equiv \{(C_{j,k,t})_{j,k \in J \times K}, L_t^s, B_t\}_{t=0}^{\infty},$$

a strategy profile for all firms

$$\Omega^F \equiv \{(S_{j,k,t} \subset \mathcal{S}^t, P_{j,k,t} : S_{j,k}^t \to \mathbb{R}, Y_{j,k,t}, L_{j,k,t}^d)_{t=0}^{\infty}\}_{j,k \in J \times K} \cup \{S_{j,k}^{-1}\}_{j,k \in J \times K},$$

and a set of prices $\{i_t, P_t, W_t\}_{t=0}^{\infty}$ such that

1. given prices, Ω^H solves household's problem.
2. given demand and Ω^F, no firm wants to deviate from it.
3. monetary policy: $\log(\frac{Q_t}{Q_{t-1}}) = \rho \log(\frac{Q_{t-1}}{Q_{t-2}}) + u_t$.
4. goods and labor markets clear.

Calibration

Sources of Strategic Complementarity

- Strategic complementarity is given by structure of demand:

$$\epsilon_{\mathsf{D}}(\mathsf{P}_{\mathsf{j,k,t}}, \mathsf{P}_{\mathsf{j,-k,t}}) = \eta - (\eta - 1)\left(\frac{\mathsf{P}_{\mathsf{j,k,t}}^{1-\eta}}{\sum_{\mathsf{l}\in\mathsf{K}} \mathsf{P}_{\mathsf{j,l,t}}^{1-\eta}}\right)^{1+\xi} \left(\frac{\bar{\mathsf{P}}^{1-\eta}}{\sum_{\mathsf{l}\in\mathsf{K}} \bar{\mathsf{P}}^{1-\eta}}\right)^{-\xi}$$

For these elasticities:

$$\mu = \frac{\eta}{\eta - 1} + \frac{1}{(\eta - 1)(\mathsf{K} - 1)}, \qquad \alpha = \frac{(1+\xi)(1-\eta^{-1})}{\mathsf{K} + \xi(1-\eta^{-1})}$$

◂ Return

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Return

Calibration

- "[S]uppose that you get news that the general level of prices went up by 10% in the economy:

  a. By what percentage do you think your competitors would raise their prices on average?

  b. By what percentage would your firm raise its price on average?

c. By what percentage would your firm raise its price if your competitors did not change their price at all in response to this news?"

$$p_{j,k} = \overbrace{\underbrace{(1-\alpha)\mathbb{E}^{j,k}[q]}_{\text{answer to c.}} + \alpha \underbrace{\mathbb{E}^{j,k}[p_{j,-k}]}_{\text{answer to a.}}}^{\text{answer to b.}}$$

◂ Return

Calibration

Capacity of Processing Information.

- First paper that calibrates κ based on microlevel data.
- Kalman filtering:

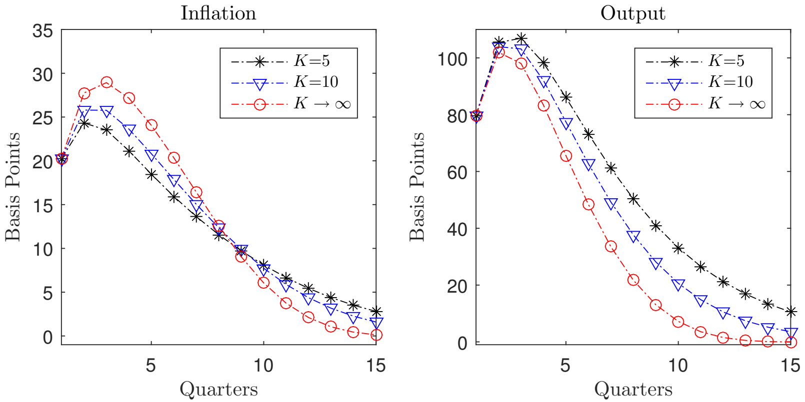
$$\underbrace{\mathbb{E}_t^{j,k}[\pi_t] - \mathbb{E}_{t-1}^{j,k}[\pi_t]}_{\text{forecast revision}} = \gamma(\underbrace{\pi_t - \mathbb{E}_{t-1}^{j,k}[\pi_t]}_{\text{forecast error}}) + e_{j,k,t}$$

- $\gamma = 1$ if there is no information rigidity.
- In NZ data, $\gamma = 0.83$ for yearly forecast revisions.
- My approach: find κ that generates this γ in the model.
- $\lambda \equiv 1 - 2^{-2\kappa} = 0.7$, ($\kappa = 0.85$).

Return

Simulations: 1% Shock to Nominal Demand

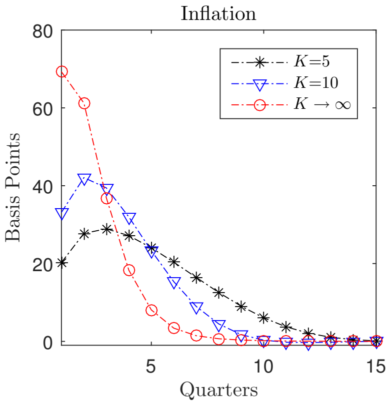
What happens if we increase competition in the economy? (attention reallocation effect)

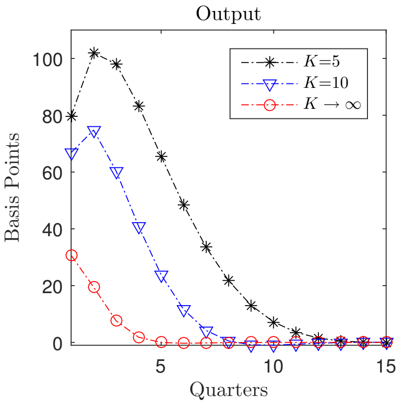


- Fix α. Let K only change attention allocation.

Simulations: 1% Shock to Nominal Demand

What happens if we increase competition in the economy? (strategic complementarity effect)





- Fix K $= \infty$ for attention reallocation. Let K only change strategic complementarity. Return