

# Rigidity of Expectations: Additional Evidence from Density Forecasts of Professionals and Households

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# Outline

## 1 Motivation

## 2 Theory

## 3 Estimation

- AR(1)
  - SE
  - DE
  - NI
  - Hybrid of NI and SE
- Stochastic volatility
  - SE
  - DE
  - NI

## 4 Conclusion

# Motivation

- there are various theories on “irrational expectation”
- different theories can be tested using survey data in a comparable manner (Coibion and Gorodnichenko (2012))
- a good theory needs to be (relatively) consistent in predictions across different moments
- higher moments, i.e. uncertainty, brings about one more restriction
- survey also contains information about data generating process itself

# What this paper does

- ① time series and cross-sectional pattern of **uncertainty** from **density** forecasts of the inflation
- ② additional reduced-form tests of the full-information rationality null using the uncertainty
- ③ extend Coibion and Gorodnichenko (2012) in two ways
  - ▶ cross-moment estimation for each one of the particular theories on expectation
  - ▶ allowing for stochastic volatility of inflation process

- empirical tests on expectation formation
  - ▶ Mankiw et al. (2003), Carroll (2003), Branch (2004), Malmendier and Nagel (2015), Das et al. (2017), Coibion and Gorodnichenko (2012), Fuhrer (2018)
- density and probabilistic questions in expectation surveys
  - ▶ Manski (2004), Delavande et al. (2011), Manski (2018)
  - ▶ Bertrand and Mullainathan (2001), Van der Klaauw et al. (2008), Delavande (2014)
- different measures of uncertainty
  - ▶ Bachmann et al. (2013), Jurado et al. (2015), Binder (2017), Bloom (2009)

# A generic framework

$h$ -period ahead density forecast by agent  $i$  at time  $t$  based on information set  $I_{i,t}$

$$f_{i,t+h|t} \equiv f_{i,t}(y_{t+h}|I_{i,t})$$

- theories of expectation differ in  $I_{i,t}$ 
  - rational expectation (FIRE):  $I_{i,t} = y_{i,t}$
  - sticky expectation (SE):  $I_{i,t} = y_{t-\tau}$ ,  $\tau$  being the most recent update date
  - noisy information (NI):  $I_{i,t} = s_{i,t}(y_t)$ , where  $s_{i,t}$  is a vector of noisy signal(s)
- the process of variable determines the mapping from  $I_{i,t}$  to  $f_{i,t+h|t}$

# Definition and notation

Individual moments	Population moments
Mean forecast: $y_{i,t+h t}$	Average forecast: $\bar{y}_{t+h t}$
Forecast error: $FE_{i,t+h t}$	Average forecast error: $\overline{FE}_{t+h t}$
Uncertainty: $Var_{i,t+h t}$	<b>Average uncertainty:</b> $\overline{Var}_{t+h t}$
	Disagreement: $\overline{Disg}_{t+h t}$

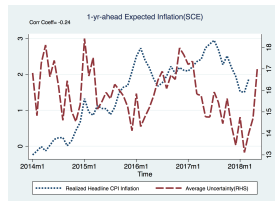
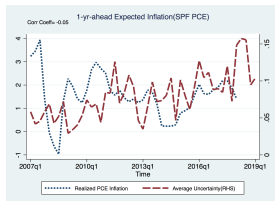
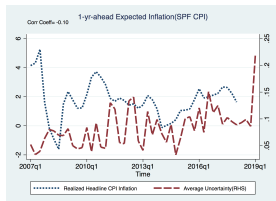
# Data

	SCE	SPF
Time period	2013M6-2018M6	2007Q1-2018Q4
Frequency	Monthly	Quarterly
Sample Size	1,300	30-50
Aggregate Var in Density	1-yr-ahead inflation	1-yr and 3-yr core CPI and core PCE
Pannel Structure	stay up to 12 months	average stay for 5 years
Demographic Info	Education, Income, Age	Industry

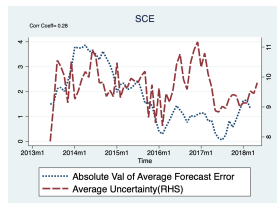
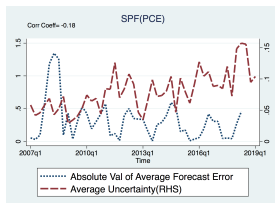
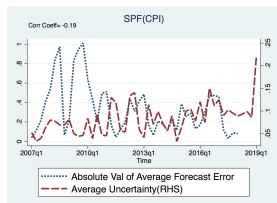
- density estimation following (Engelberg et al. (2009))
- exclude top and bottom 5% values for forecast errors and uncertainty



# Basic patterns: uncertainty and realized inflation

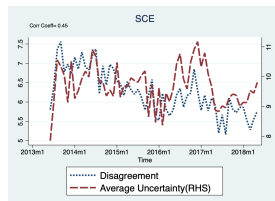
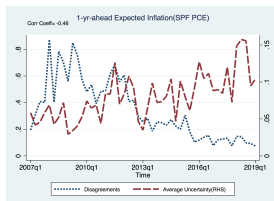
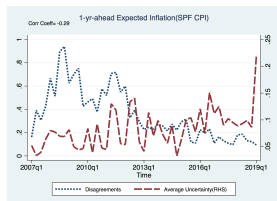


# Basic patterns: uncertainty and the size of forecast errors



- no evidence for positive correlation between high ex ante uncertainty and ex post forecast errors.

# Basic patterns: uncertainty and disagreement



- uncertainty are not the same as disagreement for professionals

# Basic patterns: summary

- uncertainty varies across time
- uncertainty contains different information from widely proxies such as disagreement and forecast error

# AR(1) model of inflation

- **Inflation process**

$$y_t = \rho y_{t-1} + \omega_t$$

$$\omega_t \sim N(0, \sigma_\omega^2)$$

- **Uncertainty**

- ▶ FIRE: time-invariant

$$\overline{Var}_{t+h|t}^* = \sum_{s=1}^h \rho^{2s} \sigma_\omega^2$$

- ▶ SE: time-invariant

$$\overline{Var}_{t+h|t}^{se} = \sum_{\tau=0}^{+\infty} \lambda(1-\lambda)^\tau \overline{Var}_{t+h|t-\tau}^*$$

- ▶ NI: time-variant but quantitatively tiny due to highly efficient Kalman gain

$$\overline{Var}_{t+h|t}^{ni} = \rho^{2h} \overline{Var}_{t|t}^{ni} + \overline{Var}_{t+h|t}^*$$

# Stochastic volatility (UCSV) inflation process (Stock and Watson (2007))

- **Inflation process**

$$y_t = \theta_t + \eta_t, \quad \text{where } \eta_t = \sigma_{\eta,t} \xi_{\eta,t}$$

$$\theta_t = \theta_{t-1} + \epsilon_t, \quad \text{where } \epsilon_t = \sigma_{\epsilon,t} \xi_{\epsilon,t}$$

$$\log \sigma_{\eta,t}^2 = \log \sigma_{\eta,t-1}^2 + \mu_{\eta,t}$$

$$\log \sigma_{\epsilon,t}^2 = \log \sigma_{\epsilon,t-1}^2 + \mu_{\epsilon,t}$$

$$\xi_t = [\xi_{\eta,t}, \xi_{\epsilon,t}] \sim N(0, I_2)$$

$$\mu_t = [\mu_{\eta,t}, \mu_{\epsilon,t}]' \sim N(0, \gamma I_2)$$

# UCSV inflation process

- **Uncertainty**

- ▶ FIRE: time-varying

$$\overline{Var}_{t+h|t}^* = \sum_{k=1}^h \exp^{-0.5k\gamma_{\eta}} \sigma_{\eta,t}^2 + \exp^{-0.5h\gamma_{\epsilon}} \sigma_{\epsilon,t}^2$$

- ▶ SE: time-varying

$$\overline{Var}_{t+h|t}^{se} = \sum_{\tau=0}^{\infty} (1 - \lambda)^{\tau} \lambda \overline{Var}_{t+h|t-\tau}^*$$

- ▶ NI (1-step-ahead): time-varying

$$\overline{Var}_{t|t-1}^{\theta} = \overline{Var}_{t-1|t-1}^{\theta} + \overline{Var}_{t|t-1}^*(y_t)$$

# Simulated method of moment estimation

$$\hat{\Omega} = \underset{\{\Omega \in \Gamma\}}{\operatorname{argmin}} (M_{\text{data}} - F^o(\Omega, Y))' W (M_{\text{data}} - F^o(\Omega, Y))'$$

- $\Omega$ : parameters of the particular  $o \in \{fire, se, ni, de, seni\} \times \{ar, sv\}$
- $\Gamma$ : constraints for the parameter.
- $M_{data}$ : data moments
- $F$ : simulated model moments according to a particular theory  $o$ , a function of parameters  $\Omega$  as well as the  $Y$ , the real-time data (including history) up till each point of the time  $t$ .
  - ▶ unconditional moments, not specific to time
  - ▶ moments selected from average forecast, variance and autocovariance of forecasts, average disagreement, variance and autocovariance of disagreement, average uncertainty, etc.
- $W$ : weight matrix, identity matrix for now



# Estimation procedure and algorithm

- 1 for each theory of expectation formation and the inflation process, start with an initial value for the parameter(s) of interest
- 2 simulate individual forecasts for a large enough ( $N = 200$ ) number of forecasters
- 3 compute the average forecast errors, disagreement and average uncertainty across all agents
- 4 compute the time-series moments of the average forecast, disagreement, and uncertainty
- 5 compute the difference between the simulated moments and the data moments
- 6 keep searching the parameter value until reaching below a threshold of the loss

# Two-step and joint estimation

- ① two-step estimation: separately estimate inflation process parameters and then parameters of the inflation process
  - ▶ pros: computationally lighter
  - ▶ cons: potential misspecification. does not utilize the expectation data to understand inflation process per se.
- ② joint estimation: targeting both moments of realized inflation series and moments of forecasts to simultaneously estimate both the inflation process and the parameter of expectation formation
  - ▶ pros: additional information gain from expectations data about inflation process itself
  - ▶ cons: more computation burden

# Scoring card for a theory of expectation formation

To look if the parameter and fitness is relatively robust to

- ① use of different moments in estimation
- ② alternative assumption about underlying process
- ③ two-step estimation or joint-estimation
- ④ relatively fit with professionals and households

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## 4 Conclusion

# SE parameter estimate

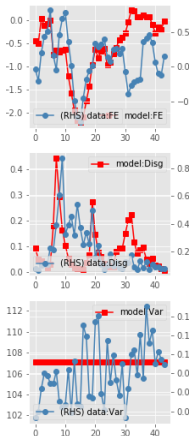
Table: SMM Estimates of SE

0	1	2	3		SE: $\hat{\lambda}_{SPF}(Q)$	SE: $\hat{\lambda}_{SPF}(Q)$	SE: $\rho$	SE: $\sigma$	SE: $\hat{\lambda}_{SCE}(M)$	SE: $\hat{\lambda}_{SCE}(M)$	SE: $\rho$	SE: $\sigma$
FEVar	FEATV				0.47	0.36	1	0.08	0.2	0.5	0.84	0.25
FEVar	DisgATV	DisgVar			0.47	0.38	1	0.1	0.21	0.54	0.92	0.18
FEVar	FEATV	DisgVar	DisgATV	Var	0.47	0.36	1	0.08	0.21	0.5	0.84	0.25

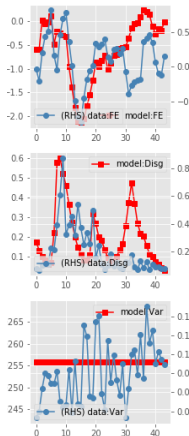
- $\lambda$ : update rate in SE

# Professionals and SEAR

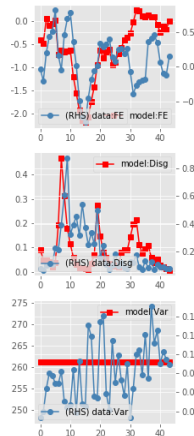
(a) FE



(b) Disg

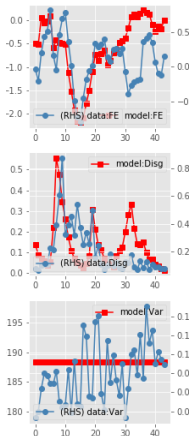


(c) FE/Disg

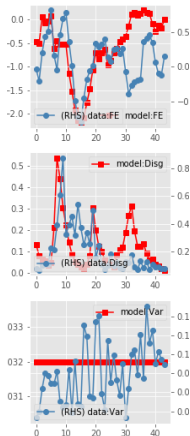


# Professionals and SEAR: joint estimation

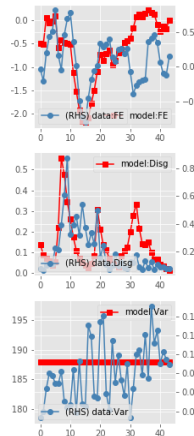
(a) FE



(b) Disg

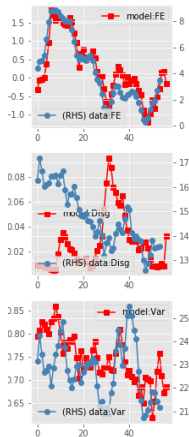


(c) FE/Disg

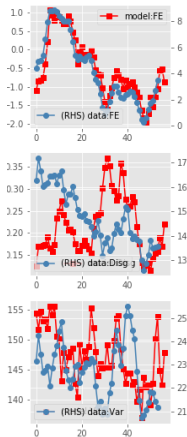


# Households and SEAR

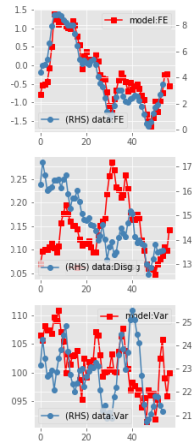
(a) FE



(b) Disg



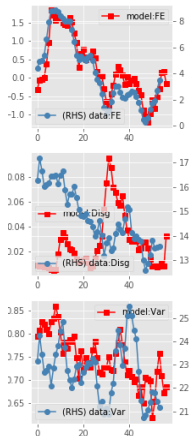
(c) FE/Disg



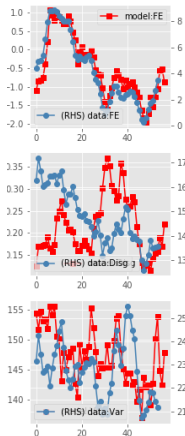


# Households and SEAR: joint estimates

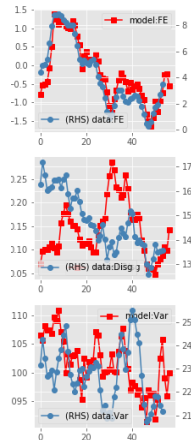
(a) FE



(b) Disg



(c) FE/Disg



# DE parameter estimate

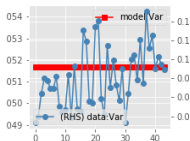
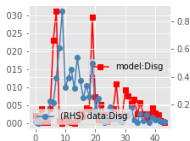
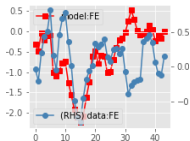
Table: SMM Estimates of DE

0	1	2	3	4	5	6	DE: $\theta_{SPF}$	DE: $\sigma_{\theta, SPF}$	DE: $\theta_{SPE}$	DE: $\sigma_{\theta, SPE}$	DE: $\rho$	DE: $\sigma$	DE: $\theta_{SCE}$	DE: $\sigma_{\theta, SCE}$	DE: $\theta_{SCE}$	DE: $\sigma_{\theta, SCE}$	DE: $\rho$	DE: $\sigma$
FE	FEVar	FEATV					-0.23	0.22	NA	NA	NA	NA	9.35	10.65	0.82	0.85	1	0
FE	FEVar	FEATV	Disg	DisgVar	DisgATV		-0.26	1.41	-0.14	1.44	0.99	0.16	8.2	9.52	4.79	4.59	0.58	0.55
FE	FEVar	FEATV	Disg	DisgVar	DisgATV	Var	-0.24	1.43	-0.17	1.44	0.99	0.16	4.78	3.01	NA	NA	NA	NA

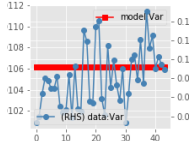
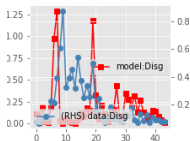
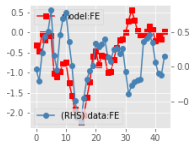
- $\theta$ : representativeness parameter,  $\theta > 0$  according to DE.
- $\sigma_{\theta}$ : dispersion of representativeness across population

# Professionals and DEAR

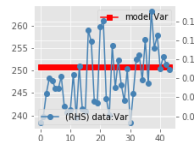
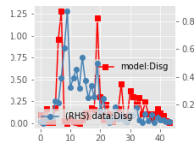
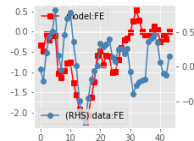
(a) FE



(b) Disg



(c) FE/Disg



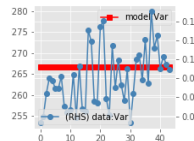
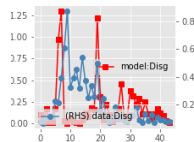
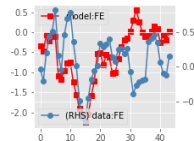
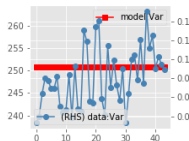
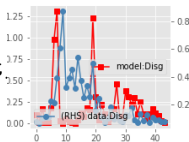
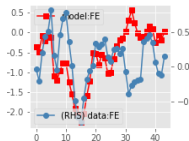
# Professionals and DEAR: joint estimate

(a) FE

(b) Disg

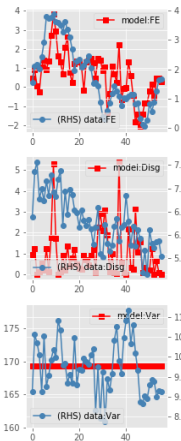
(c) FE/Disg

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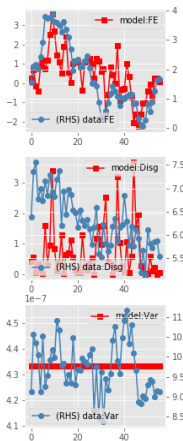


# Households and DEAR

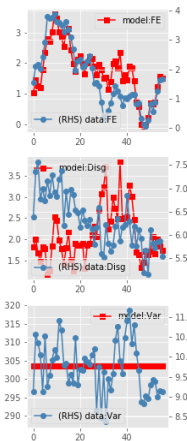
(a) FE



(b) FE/Disg

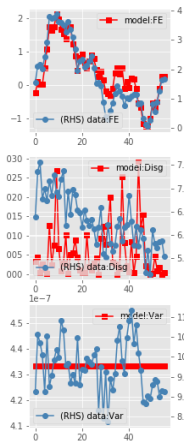


(c) FE/Disg/Var

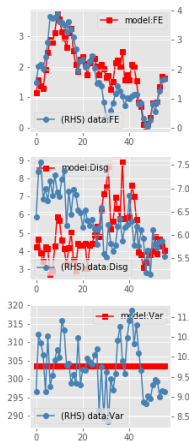


# Households and DEAR: joint estimates

(a) FE



(b) FE/Disg



(c) FE/Disg/Var

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# NIAR parameters

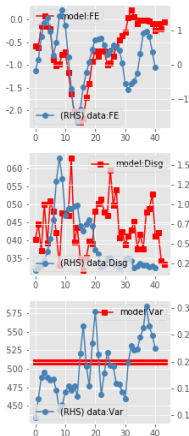
Table: SMM Estimates of NI

0	1	2	3	4	NI: $\hat{\sigma}_{pb,SPF}$	$\hat{\sigma}_{pr,SPF}$	NI: $\hat{\sigma}_{pb,SPF}$	$\hat{\sigma}_{pr,SPF}$	NI: $\rho$	NI: $\sigma$	NI: $\hat{\sigma}_{pb,SCE}$	$\hat{\sigma}_{pr,SCE}$	NI: $\hat{\sigma}_{pb,SCE}$	$\hat{\sigma}_{pr,SCE}$	NI: $\rho$	NI: $\sigma$
FEVar	FEATV				0.09	2.77	0.093	1.408	0.911	0.422	3.4	15.4	3.397	15.395	0.997	0.027
FEVar	FEATV	DisgVar	DisgATV		0.09	2.77	0.093	1.408	0.911	0.422	3.4	15.4	3.397	15.395	0.997	0.027
FEVar	FEATV	DisgVar	DisgATV	Var	0.14	3.85	0.133	1.359	0.911	0.422	4.9	22.4	4.860	22.367	0.997	0.027

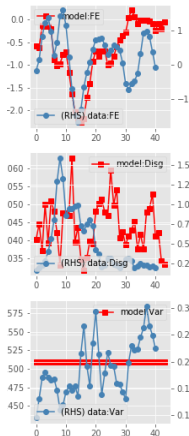
- $\sigma_{pb}$ : noisiness of public signals in NI
- $\sigma_{pr}$ : noisiness of private signals in NI

# Professionals and NIAR

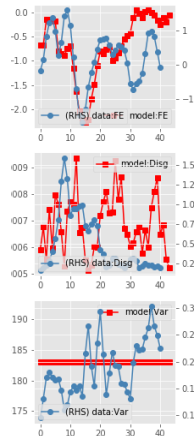
(a) FE



(b) Disg



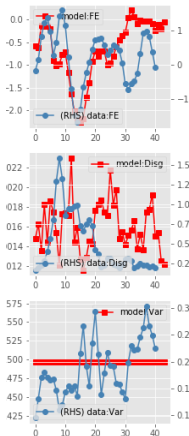
(c) FE/Disg/Var



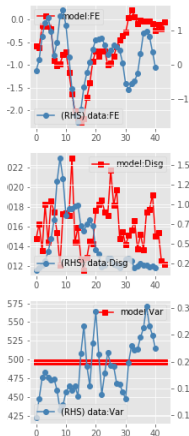


# Professionals and NIAR: joint estimates

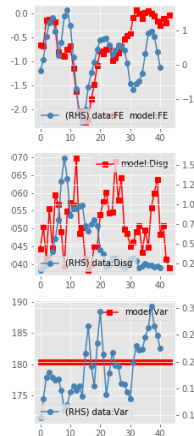
(a) FE



(b) Disg

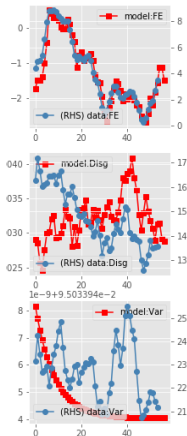


(c) FE/Disg

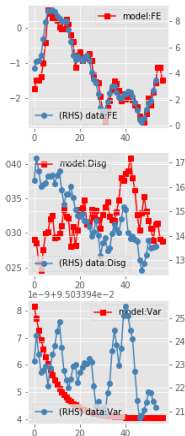


# Households and NIAR

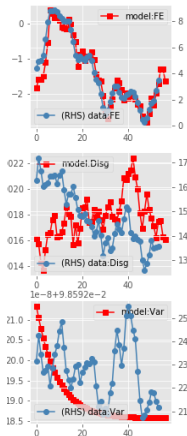
(a) FE



(b) FE/Disg

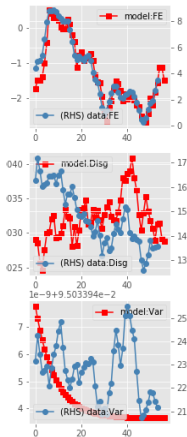


(c) FE/Disg/Var

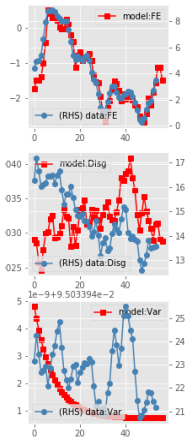


# Households and NIAR: joint estimates

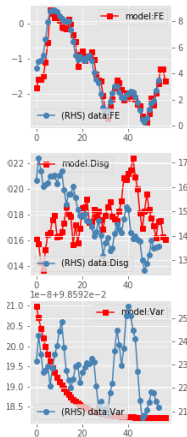
(a) FE



(b) FE/Disg



(c) FE/Disg/Var



# SENIAR parameters

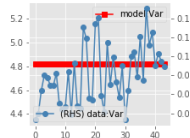
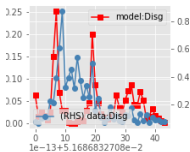
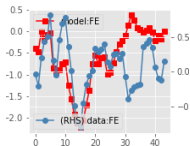
Table: SMM Estimates of SENI

0	1	2	3	4	5	6	SENI: $\lambda$	SENI: $\sigma_{pb,SPF}$	SENI: $\sigma_{pr,SPF}$	SENI: $\lambda$	SENI: $\sigma_{pb,SCE}$	SENI: $\sigma_{pr,SCE}$
FE	FEVar	FEATV					0.64	0.16	0	0.19	0.2	0.21
FE	FEVar	FEATV	Disg	DisgVar	DisgATV		0.62	4.77	0.17	0.25	0.1	0.35
FE	FEVar	FEATV	Disg	DisgVar	DisgATV	Var	0.62	13.7	0.17	NA	NA	NA

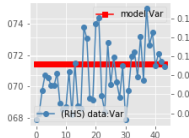
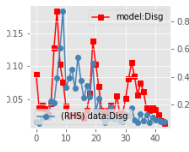
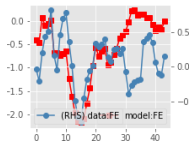
- $\sigma_{pb}$ : noisiness of public signals in NI
- $\sigma_{pr}$ : noisiness of private signals in NI

# Professionals and SENIAR

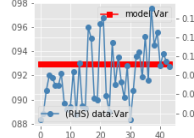
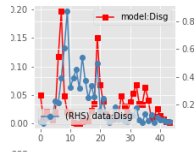
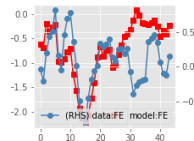
(a) FE



(b) FE/Disg

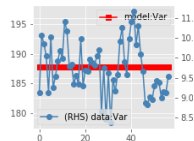
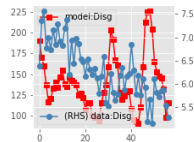
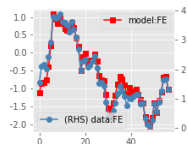


(c) FE/Disg/Var

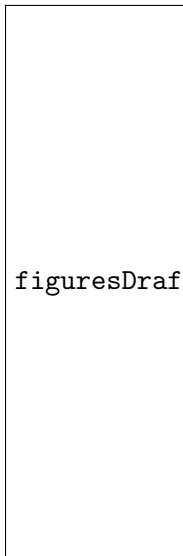


# Households and SENIAR

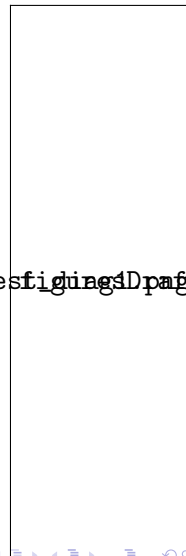
(a) FE



(b) FE/Disg



(c) FE/Disg



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# Outline

## 1 Motivation

## 2 Theory

## 3 Estimation

- AR(1)
  - SE
  - DE
  - NI
  - Hybrid of NI and SE
- Stochastic volatility
  - SE
  - DE
  - NI

## 4 Conclusion

# SESV parameters

Table: SMM Estimates of Parameters of SESV

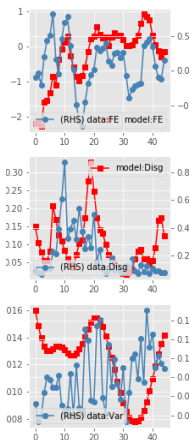
0	1	2	3	SE: $\hat{\lambda}_{SPF}(Q)$	SE: $\hat{\lambda}_{SPF}(Q)$	SE: $\gamma$	SE: $\hat{\lambda}_{SCE}(M)$	SE: $\hat{\lambda}_{SCE}(M)$	SE: $\gamma$
DisgATV	Var			0.3	0.46	2.52	0.09	0.09	0.7
FEATV	DisgVar	DisgATV		0.3	0.46	2.53	0.07	0.07	0.26
FEATV	DisgVar	DisgATV	Var	0.3	0.46	1.26	0.07	0.07	0.26

- $\lambda$ : update rate in SE
- $\gamma$ : size of the innovation to volatility

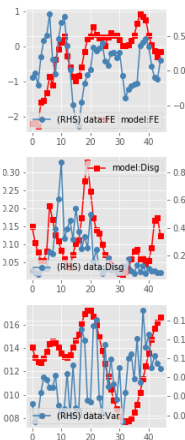


# Professionals and SESV

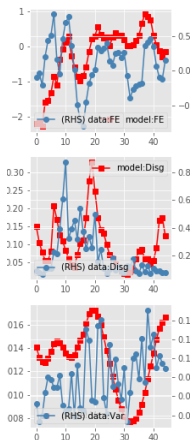
(a) FE



(b) Disg

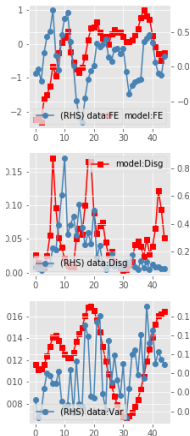


(c) FE/Disg

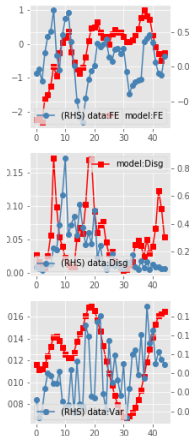


# Professionals and SESV: joint estimates

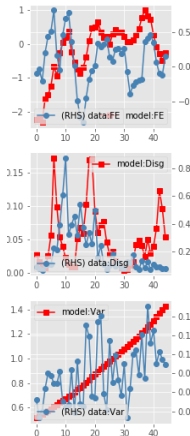
(a) FE



(b) Disg

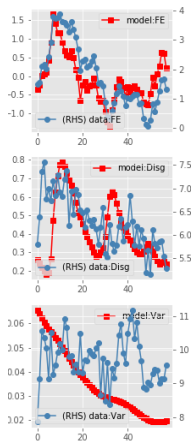


(c) Disg

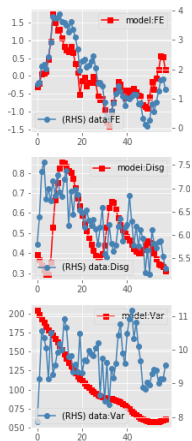


# Households and SESV

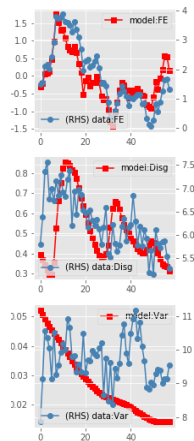
(a) Disg/Var



(b) FE/Disg

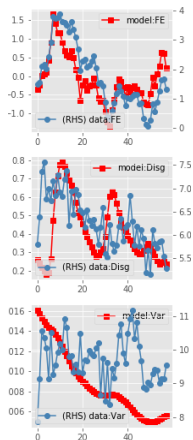


(c) FE/Disg/Var

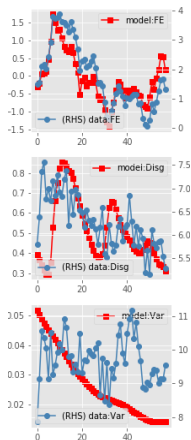


# Households and SESV: joint estimates

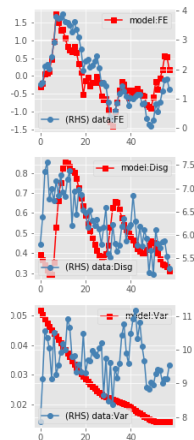
(a) Disg/Var



(b) FE/Disg



(c) FE/Disg/Var



# DESV parameters

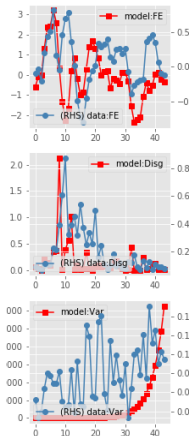
Table: SMM Estimates of Parameters of DESV

0	1	2	3	4	DE: $\theta$	$\sigma_\theta$	DE: $\theta$	$\sigma_\theta$	$\gamma$	DE: $\theta$	$\sigma_\theta$	DE: $\theta$	$\sigma_\theta$	$\gamma$
FE	FEVar	FEATV			-0.44	0.36	-0.43	1.03	0.13	7.81	4.39	7.81	2.99	0.7
FEVar	FEATV	DisgVar	DisgATV		-0.44	0.27	-0.44	0.27	0.3	7.64	6.46	7.64	6.46	0.7
FEVar	FEATV	DisgVar	DisgATV	Var	-0.43	0.26	-0.43	0.26	0.14	1.03	0	1.03	0	0.2

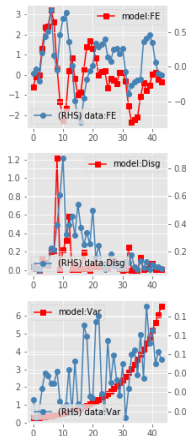
- $\theta$ : representativeness parameter
- $\sigma_\theta$ : dispersion of representativeness across population
- $\gamma$ : size of the innovation to volatility

# Professionals and DESV

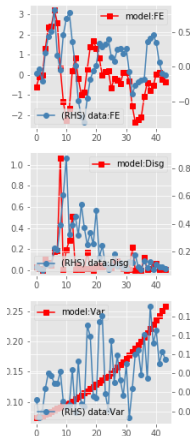
(a) FE



(b) FE/Disg

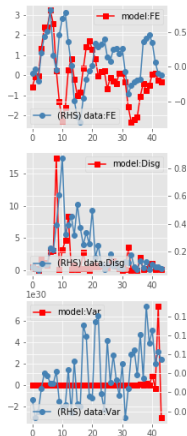


(c) FE/Disg/Var

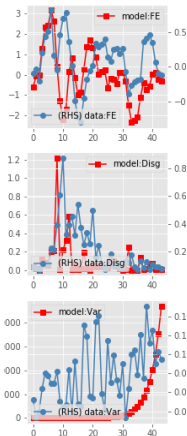


# Professionals and DESV: joint estimates

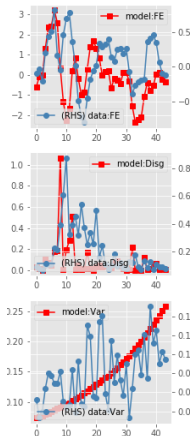
(a) FE



(b) FE/Disg

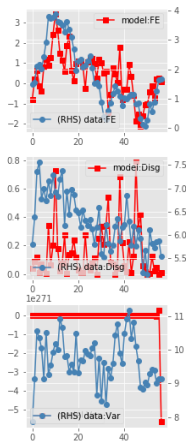


(c) FE/Disg/Var

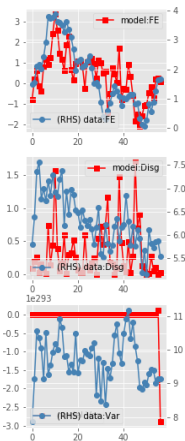


# Households and DESV

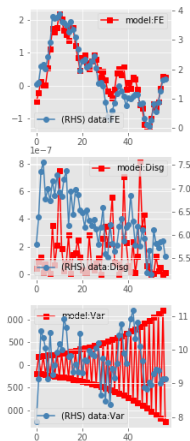
(a) FE



(b) FE/Disg



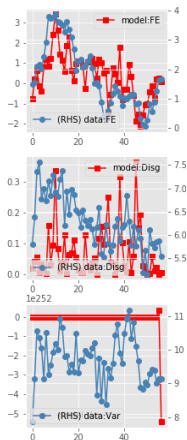
(c) FE/Disg



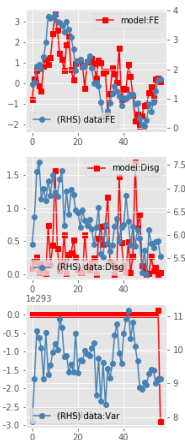


# Households and DESV: joint estimates

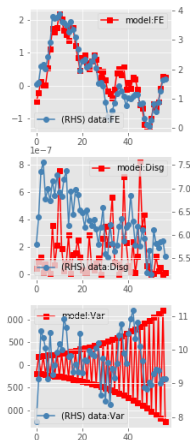
(a) FE



(b) FE/Disg



(c) FE/Disg/Var



# NISV parameters

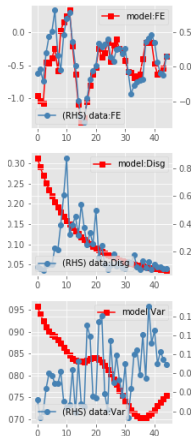
Table: SMM Estimates of Parameters of NISV

0	1	2	3	4	NI: $\hat{\sigma}_{pb,SPF}$	$\hat{\sigma}_{pr,SPF}$	NI: $\hat{\sigma}_{pb,SPF}$	$\hat{\sigma}_{pr,SPF}$	$\gamma$	NI: $\hat{\sigma}_{pb,SCE}$	$\hat{\sigma}_{pr,SCE}$
FEVar	FEATV	Var			2.35	2	2.04	23.01	2.53	2.00014E+14	3.63
FEVar	FEATV	DisgVar	DisgATV	Var	3.33	1.71	2.04	22.96	2.53	1.09884E+13	3.63

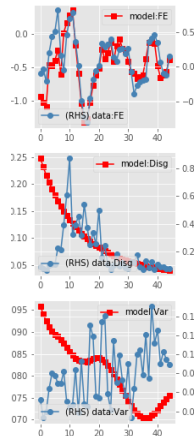
- $\sigma_{pb}$ : noisiness of public signals in NI
- $\sigma_{pr}$ : noisiness of private signals in NI
- $\gamma$ : size of the innovation to volatility

# Professionals and NISV

(a) FE/Var

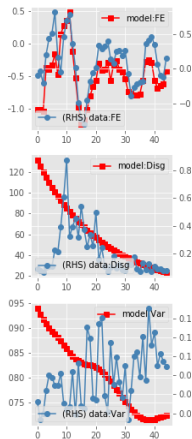


(b) FE/Disg/Var

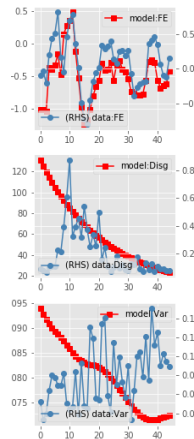


# Professionals and NISV: joint estimates

(a) FE/Var

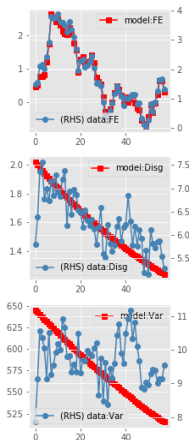


(b) FE/Disg/Var

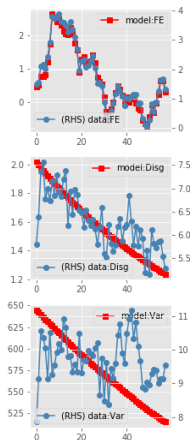


# Households and NISV

(a) FE/Var

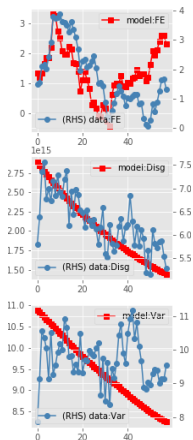


(b) FE/Disg/Var

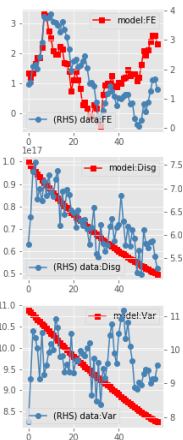


# Households and NISV: joint estimates

(a) FE/Var



(b) FE/Disg/Var



# Conclusion

- Sticky expectation (SE) matches data of inflation and expectations better compared to noisy information (NI)
- Within each model, households are more irrational compared to professionals
- Incorporating higher moments, i.e. uncertainty, helps “discipline” theories on expectation formation
- Higher moments from surveys also contain useful information about the inflation dynamics itself

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