Adaptive Learning and Survey Expectations

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Expectations and Survey Information in DSGE models

- Expectations play a key role in the transmission of shocks in New Keynesian monetary macromodels.
- Standard models assume Rational Expectations (RE).
- RE is an extremely useful benchmark for modelling expectations.
- But RE is also a restrictive assumption for understanding actual expectations and survey data.
- There is a need for alternative hypothesis on expectations and information: Adaptive Learning (AL) is one alternative.
- The integration of survey data in macromodels allows to evaluate the empirical validity of these alternatives and to endogenize the expectation process in the model.

Expectations and Survey Information in DSGE models

- Paper (Slobodyan-Wouters) concentrates on inflation expectations: integration of SPF-inflation surveys (nowcast) in Smets-Wouters DSGE model.
- Ongoing work (Rychalovska-Slobodyan-Wouters) shows that the insights from the inflation surveys also apply to survey expectations for consumption, investment and output.

Motivation

We model realized and expected inflation jointly in a DSGE framework by using Survey (SPF) data on expected inflation as observable. There are many strong arguments for such an exercise:

- Inflation expectations became most important indicator in policy deliberations and communication.
- Inflation expectations are central in the transmission mechanism of monetary policy in New-Keynesian and Neo-Fisherian models in particular at zero lower bound.
- Survey evidence on inflation expectations are very informative and competitive predictors of future inflation realizations.
- Official forecasts include judgment that combines model and survey information in a non-systematic way.

$=>$ Using alternative hypothesis on how inflation expectations are formed - model consistent (RE) versus adaptive learning (AL) - and test consistency between model and survey forecast.

Main conclusions from this exercise

- Inflation expectations in our standard DSGE models are not consistent with Survey expectations: RE-Smets-Wouters (2007) and AL-Slobodyan-Wouters (2012).
- A simple model re-specification can solve this problem: the survey information helps to identify separately the innovations in the i.i.d. and the persistent markup shocks.
- Under AL, observing SPF data in the model improves the forecast for inflation **and** for real variables.
- The time-variation that is produced by the updating of the beliefs, captures the dynamics in the mean and the volatility of the inflation process.
- This model explains jointly the dynamics in the realized and perceived inflation: target, persistence, shock sensitivity.

Literature

- Examples of DSGE models that include survey data in the list of observables are scarce:
- RE-models:
  - early example: Monti (2010);
  - in forecast context: Warne-Smets-Wouters (2014);
  - typically introduce exogenous inflation target shock to match expectations: Eusepi-DelNegro (2011), De Graeve et al (2009), Del Negro-Schorfheide (2013);
  - use news shocks: Milani and Rajbhandari (2012).
- AL-models:
  - learning about long run inflation target: Carvalho et al (2015);
  - similar to our exercise: Ormeno-Molnar (2014).

$=>$ We review and compare alternative approaches (RE-AL) and search over model specifications.

Literature (cont'd)

- Estimation of single equation NK-PC using survey expectations as instrument: Roberts (1995);
- Replace expectations by survey counterpart and endogenize these expectations with minimal assumptions: Furher (2015), Adam and Padula (2011), Branch and McGrough (2009);
- Survey expectations deviate from Full Information Rational Expectations hypothesis: Roberts (1997), Mankiw et al (2004), Coibion and Gorodnichenko (2015), Nason and Smith (2016), Mertens and Nasson (2017), Doh and Smith (2019).

=> We use short run survey forecasts (nowcast) that is less sensitive to inefficiencies related to survey dispersion and model uncertainty.
=> We focus on the timely information content of survey forecasts and how we can exploit that information in an efficient and consistent macro setup.

Outline of the presentation

- compare survey forecast and model forecasts
- model re-specification with i.i.d. and persistent markup shock
- results with RE-model
- results with AL-model
- similar results from the application with survey forecasts for consumption, investment and output

Basic observations on Survey and Model forecasts for inflation

- Revisions in subsequent releases require a real-time data setup of the model for comparison with and integration of SPF data: re-estimate SW with 1^{st} and 2^{th} release of GDP growth and inflation data over 1971q1-2015q3 (US-data).
- Agents observe the first release of inflation and GDP-growth when forming expectations: this first release contains measurement error and is revised in the next quarter:

$$\begin{aligned} \pi\_r1_t &= \overline{\pi} + \widetilde{\pi}_t + \zeta_t^{\pi r} \\ \pi\_r2_t &= \overline{\pi} + \widetilde{\pi}_{t-1} \end{aligned}$$

- Compare model forecasts of the re-estimated RE-SW2007 and AL-SW2012 with SPF expectations (nowcast h=1 and longer horizon forecasts h=2,3,4):

$$\pi\_SPF_{t+h|t} \Leftrightarrow \overline{\pi} + E_t\widetilde{\pi}_{t+h}$$

Model inflation forecasts deviate significantly from survey expectations: RE-SW2007 - AL-SW2012

	1996q1-2015q3	
DM-test	RE versus SPF	AL versus SPF
horizon=1	4.46	3.94
horizon=2	3.07	2.82
horizon=3	3.28	2.70
horizon=4	2.29	2.03

- Diebold-Mariano test indicates significant difference between the model and survey forecasts and confirms the excellent forecasting performance of SPF in line with Ang, Bekaert and Wei (2007) and Faust and Wright (2013).

Excellent forecast performance of Survey SPF

	1996q1-2015q3		
SPF statistics: 1Q	bias	mad	rmse
$\pi\_SPF_{t+1\|t} - \pi\_r1_{t+1}$	0.03	0.17	**0.21**
$\pi\_SPF_{t+1\|t} - \pi\_r2_{t+1}$	0.01	0.16	**0.19**
$\pi\_SPF_{t+1\|t} - \pi\_rf_{t+1}$	-0.01	0.15	**0.20**
SPF for longer horizons			
$\pi\_SPF_{t+2\|t} - \pi\_r1_{t+2}$	0.04	0.19	**0.23**
$\pi\_SPF_{t+3\|t} - \pi\_r1_{t+3}$	0.07	0.19	**0.23**
$\pi\_SPF_{t+4\|t} - \pi\_r1_{t+4}$	0.07	0.21	**0.25**

Important revisions in first release: process Survey in real-time data context

	1996q1-2015q3		
Revisions	bias	mad	rmse
π_r2_t to π_r1_t	-0.02	0.05	**0.07**
π_rf_t to π_r1_t	-0.04	0.12	**0.16**
π_rf_t to π_r2_t	-0.02	0.10	**0.13**

Re-estimation using SPF forecast of inflation as observable

- Add Survey forecast as observable with measurement error :

$$\pi\_SPF_{t+1|t} = \overline{\pi} + E_t\widetilde{\pi}_{t+1} + \xi_t^{\pi f1}$$

- SPF forecast for inflation one-quarter-ahead satisfies FIRE test: no significant persistence in forecast error and no predictability of forecast error by available information or by forecast revisions.

Test statistics for SPF forecast errors: predictability

	average annual inflation forecast				one quarter ahead forecast			
	1969q1-2015q3		1996q1-2015q3		1969q1-2015q3		1996q1-2015q3	
predictability: $\left(\pi^{r1}_{t+h} - \pi^{r1}_{t+h\|t}\right) = \alpha + \beta\left(\pi^{r1}_{t+h\|t}\right)$								
α	-0.08	(-1.42)	-0.05	(-0.46)	-0.06	(-1.49)	-0.05	(-0.38)
β	0.06	(0.75)	0.03	(0.03)	-0.04	(0.71)	0.06	(0.22)
predictability: $\left(\pi^{r1}_{t+h} - \pi^{r1}_{t+h\|t}\right) = \alpha + \beta\left(\pi^{r1}_{t+h\|t}\right) + \gamma\left(\pi^{r1}_{t-1}\right) + \delta\left(r_{t-1}\right)$								
α	-0.01	(-0.26)	-0.03	(-0.34)	-0.06	(-1.55)	-0.09	(-0.71)
β	0.18	(1.07)	0.02	(0.07)	0.06	(0.46)	0.43	(1.51)
γ	0.06	(0.39)	0.04	(0.20)	0.00	(0.03)	-0.30	(-2.09)
δ	-0.15	(-3.70)	-0.03	(-0.52)	-0.02	(-0.50)	0.02	(0.35)

Test statistics for SPF forecast errors: persistence/revisions

	average annual inflation forecast				one quarter ahead forecast			
	1969q1-2015q3		1996q1-2015q3		1969q1-2015q3		1996q1-2015q3	
persistence: $\left(\pi^{r1}_{t+h} - \pi^{r1}_{t+h\|t}\right) = \alpha + \beta\left(\pi^{r1}_{t} - \pi^{r1}_{t\|t-h}\right)$								
α	-0.03	(-0.75)	-0.02	(-0.76)	-0.03	(-1.22)	-0.03	(-0.91)
β	0.39	(2.28)	0.23	(0.23)	0.04	(0.34)	-0.24	(-1.31)
predictability: $\left(\pi^{r1}_{t+h} - \pi^{r1}_{t+h\|t}\right) = \alpha + \beta\left(\pi^{r1}_{t+h\|t} - \pi^{r1}_{t\|t-h}\right)$								
α	-0.03	(-0.75)	-0.02	(-0.76)	-0.03	(-1.22)	-0.02	(-0.91)
β	0.39	(2.28)	0.23	(1.50)	0.04	0.34)	-0.25	(-1.31)

Re-estimation using SPF forecast of inflation as observable

- Compare model forecasts of these augmented models with SPF expectations:

	1996q1-2015q3	
DM-test	RE versus SPF	AL versus SPF
horizon=1	3.35	3.03
horizon=2	2.56	2.51
horizon=3	2.82	2.12
horizon=4	1.18	1.16

- Diebold-Mariano test still indicates significant difference between the model and survey forecasts.
- Including survey data as observable with m.e. but without further changes in the model specification is not effective.

Simple model re-specification

- ARMA price and wage markup shock in RE-SW2007

$$\mu_t^p = \rho_\mu^p \cdot \mu_{t-1}^p - \theta_\mu^p \cdot \varepsilon_{t-1}^p + \varepsilon_t^p$$

- i.i.d. price and wage markup shocks in AL-SW2012

$$\mu_t^p = \varepsilon_t^p$$

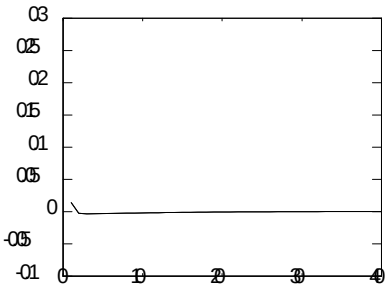
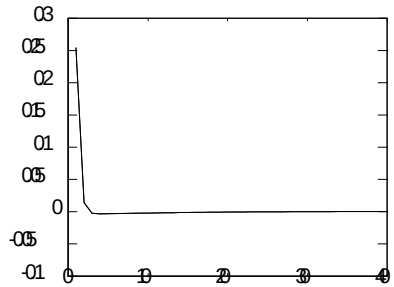
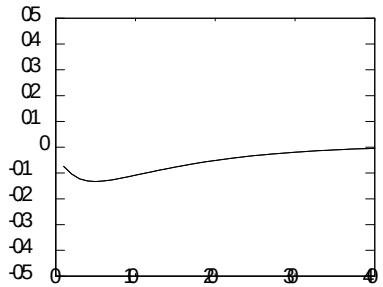
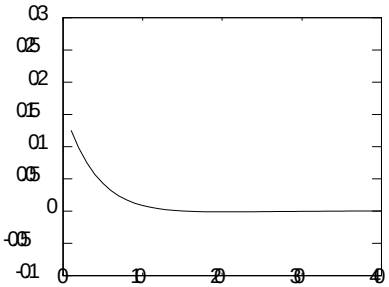
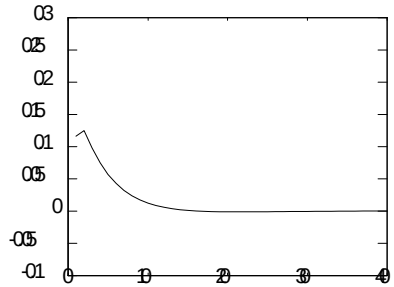
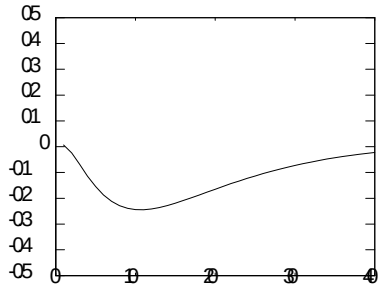
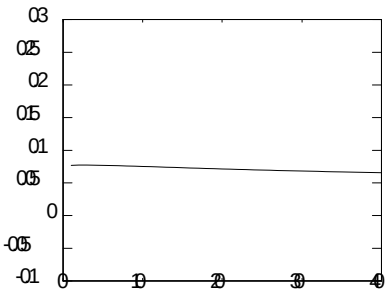
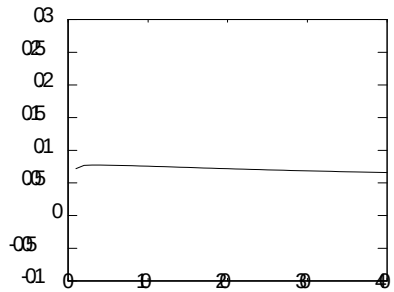
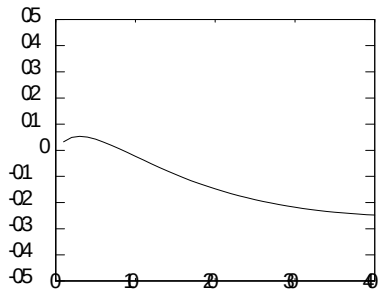
- Observing survey data allows to identify separately persistent and i.i.d. component in the markup:

$$\begin{aligned} \mu_t^p &= \mu_t^{ar} + \mu_t^{iid} \\ \mu_t^{ar} &= \rho_\mu^p \cdot \mu_{t-1}^{ar} + \varepsilon_{t-1}^{ar} \\ \mu_t^{iid} &= \varepsilon_t^{iid} \end{aligned}$$

Outcomes under RE: forecast comparison with SPF

	1996q1-2015q3
DM-test	RE versus SPF
horizon=1	1.36
horizon=2	0.45
horizon=3	1.16
horizon=4	0.06

Outcomes under RE: irfs of identified markup shocks

	inflation expectations	inflation	output
ε^{piid}			
ε^{par}			
ε^{war}			

Outcomes under RE: marginal likelihood

	RE			
	71q1-15q3		96q1-15q3	
	9obs	10obs	9obs	10obs
9obs	**-965**		**-361**	
10obs ME	-999	*-911*	-375	*-303*
10obs 2MU	**-945**	*-840*	**-345**	*-267*

Outcomes under RE: remaining issues

- The improvement in forecast performance of the model is concentrated in a few variables: inflation, inflation expectations and nominal interest rate.
- The long run inflation trend is driven by exogenous shocks. There is no unique identification of the shock that is responsible for this trend process: persistent wage markup shocks or exogenous inflation target shocks are close substitutes.
- The inflation forecast density has a constant volatility in the RE-models.

AL based on KF updating of forecast/belief models

- Start from linear model representation:

$$A_0 y_{t-1} + A_1 y_t + A_2 E_t y_{t+1} + B\epsilon_t = 0,$$

  where y_t is vector of state variables, ϵ_t vector of innovations.
- Forecasts are based on simple forecasting models (PLM):

$$E_t y_{t+1}^f = \beta_{t|t-1}^0 + \beta_{t|t-1}^1 y_t.$$

- The AL solution becomes:

$$y_t = \mu_t + T_t y_{t-1} + R_t \epsilon_t.$$

KF Updating: Set–up

- Forecasting model requires SURE estimator:

$$y^f = X\beta + U, \text{with } \Sigma = E\left[UU^T\right].$$

- Belief coefficients are assumed to follow:

$$vec\left(\beta_t - \overline{\beta}\right) = F \cdot vec\left(\beta_{t-1} - \overline{\beta}\right) + v_t,$$

  F is a diagonal matrix with diagonal $\rho \leq 1$, $V = E\left[vv^T\right]$

- KF estimator requires initialisation of β_0, P_0, Σ, and V :

  β_0, Σ are derived from moments of RE-solution:

$$\beta_0 = E[XX^T]^{-1}E[y^f X^T] \text{ and } \Sigma = E\left[\left(y^f - X\beta\right)\left(y^f - X\beta\right)^T\right]$$

$$P_0 = \gamma \cdot \left(X^T\Sigma^{-1}X\right)^{-1} \text{ and } V = \sigma \cdot \left(X^T\Sigma^{-1}X\right)^{-1},$$

$=>$ fix γ and σ, estimate ρ as crucial learning parameter

Beliefs for inflation

- AL-SW2012: AR2 specifications

$$\pi_t = \begin{bmatrix} 1 & \pi_{t-1} & \pi_{t-2} \end{bmatrix} \beta_{\pi,t-1} + u_{\pi,t},$$

- Here we augment the beliefs with the marginal cost and the innovations in the markup shocks that are signalled by the survey data:

$$\pi_t = \begin{bmatrix} 1 & \pi_{t-1} & \pi_{t-2} & mc_{t-1} & \varepsilon^{ar}_{t-1} & \varepsilon^{iid}_{t-2} \end{bmatrix} \beta_{\pi,t-1} + u_{\pi,t},$$

Outcomes under AL: forecast comparison with SPF

	1996q1-2015q3
DM-test	AL versus SPF
horizon=1	-0.12
horizon=2	1.57
horizon=3	1.26
horizon=4	0.77

Outcomes under AL: marginal likelihood

	71q1-15q3		96q1-15q3	
	9obs	10obs	9obs	10obs
9obs-RE	-965		-361	
10obs-RE-ME	-999	-911	-375	-303
10obs-RE-2MU	-945	-840	-345	-267
10obs-AL-2MU (AR2+MC+UC)	**-915**	*-787*	**-313**	*-229*

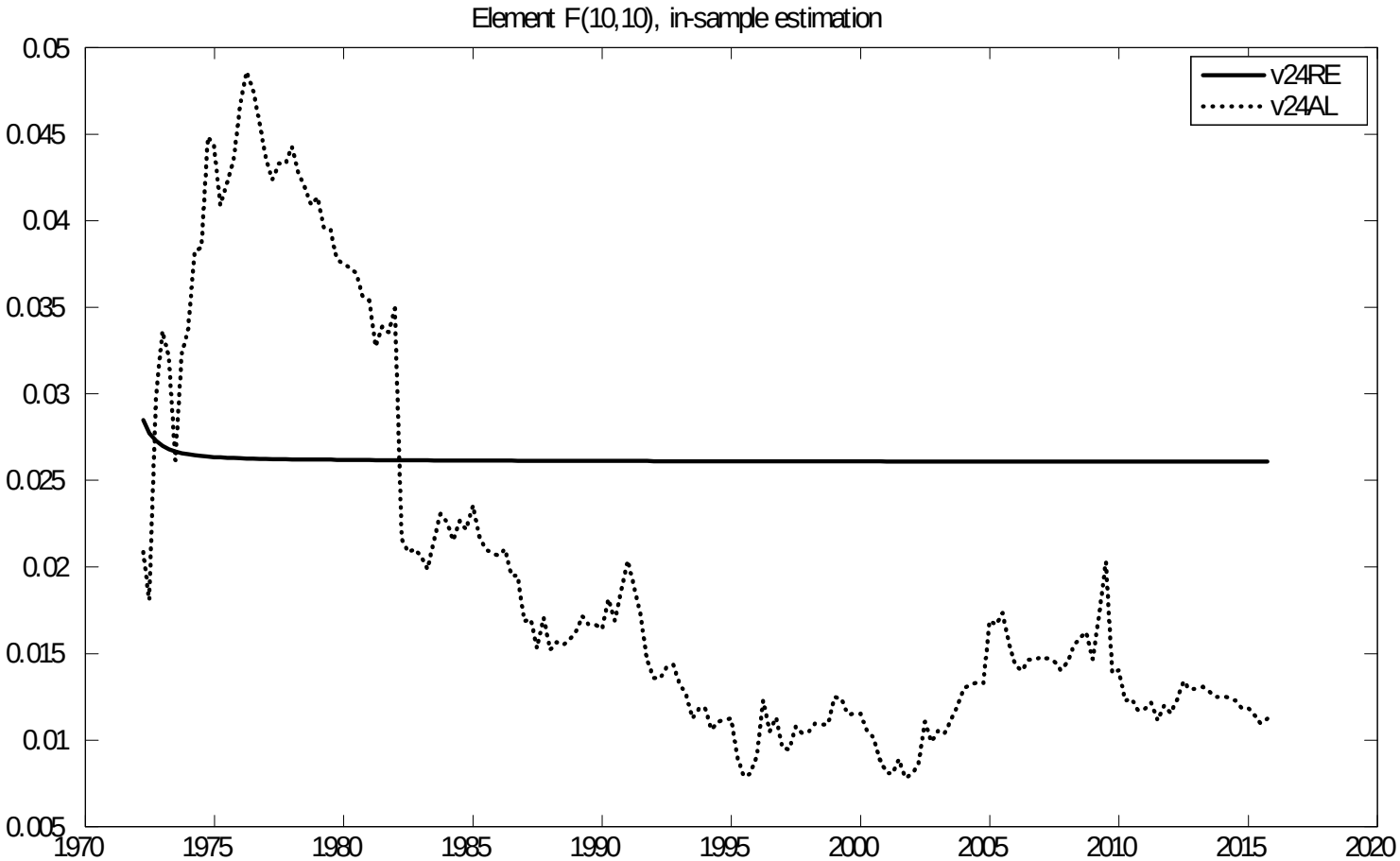
Outcomes under AL-2MU: out-of-sample rmse and score performance relative to 10obs-AL-ME

	π_r1	π_SPF	dy_r1	dc	dinve	hours	dw	r
1996q1-2015q3:								
rmse	0.82	0.80	0.92	0.99	1.03	0.90	0.97	0.93
log lik score	0.18	0.57	0.01	-0.03	-0.04	0.06	0.03	0.07

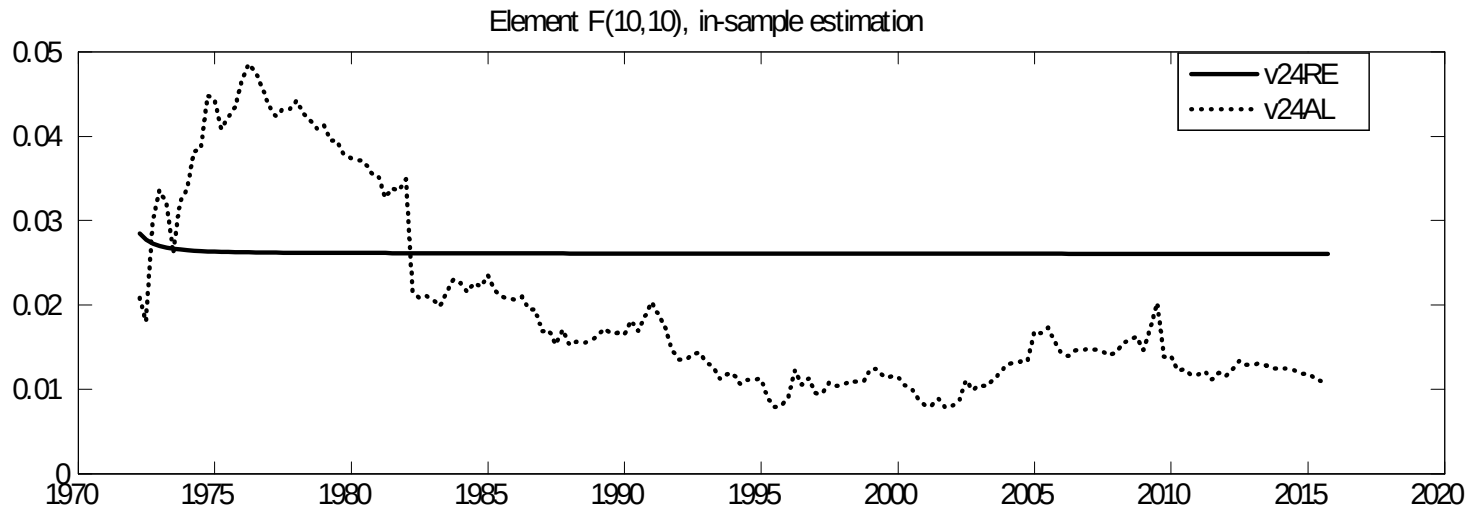
relative rmse < 1 and score > 0 $\tilde{=}$ improved forecast for AL-2MU

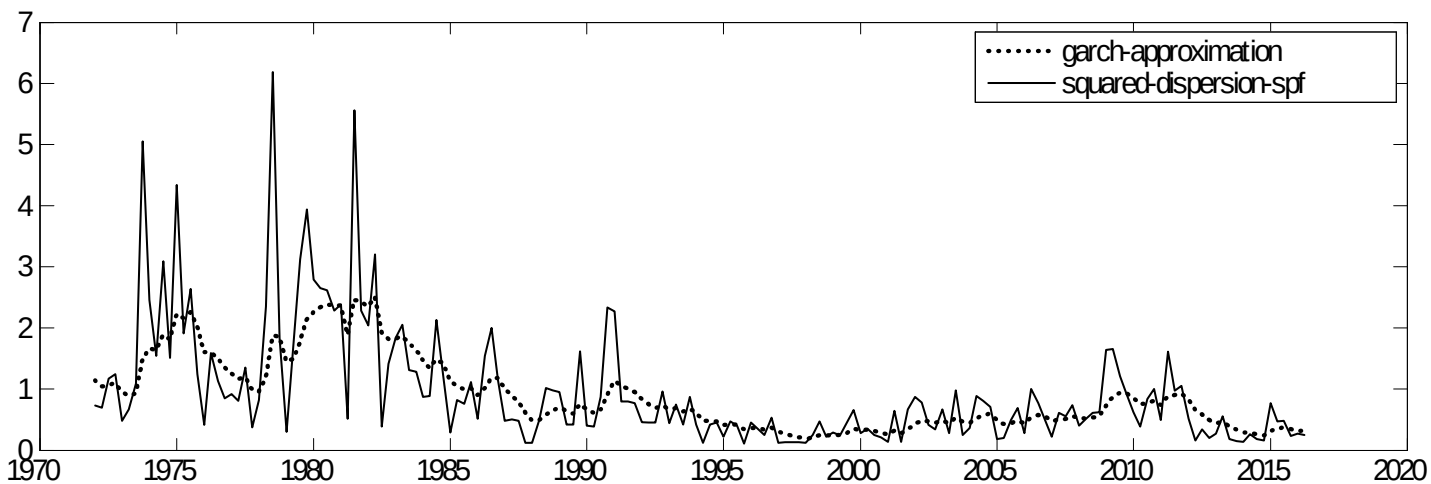
- Out-of-sample point forecasts improve not only for inflation variables but also for the real observables.

Outcomes under AL: Cond. Variance inflation forecast

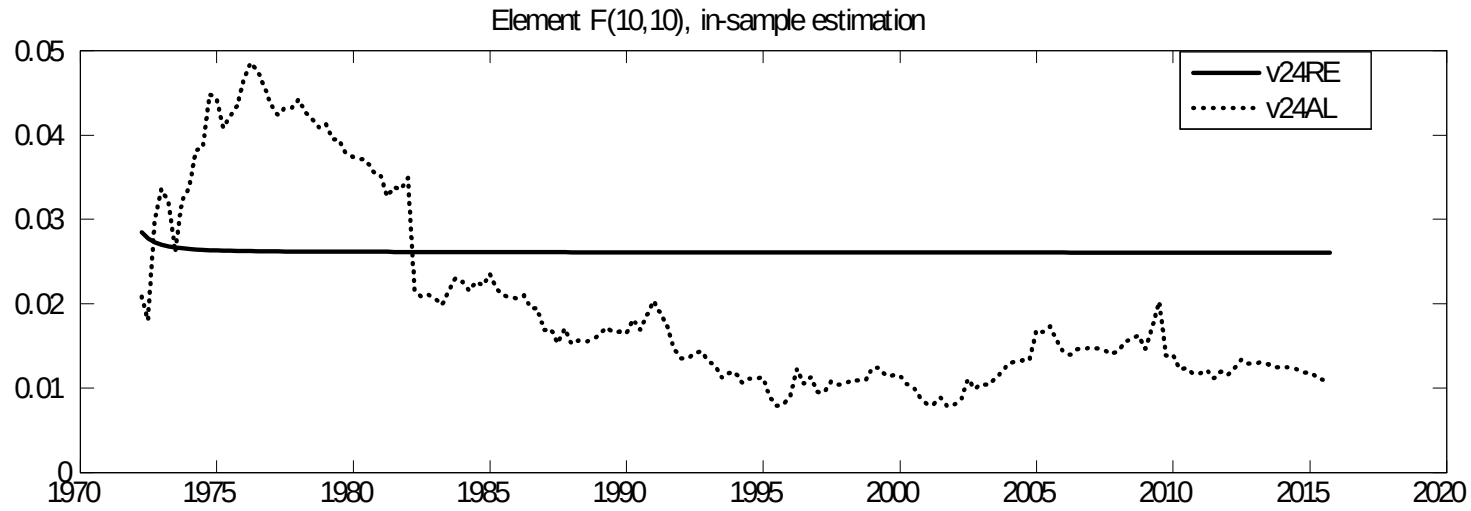


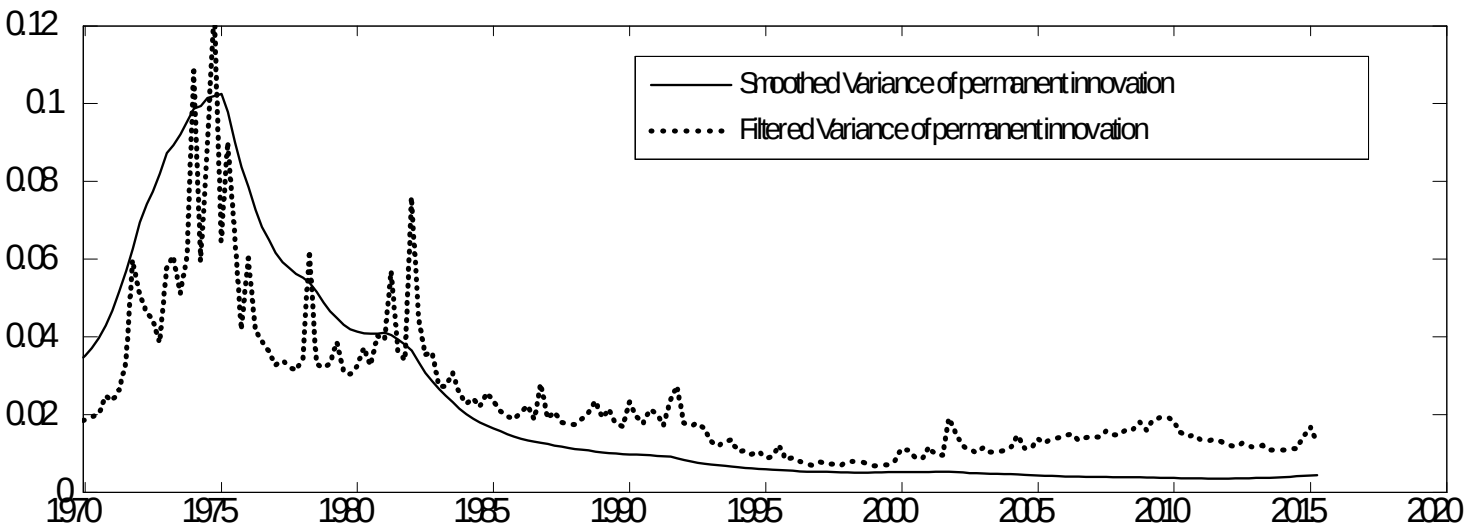
Outcomes under AL: Cond. Var. inflation forecast vs. squared SPF-dispersion





Outcomes under AL: Cond. Var. inflation forecast vs. Var. of trend component in UC-SV model (F/S)



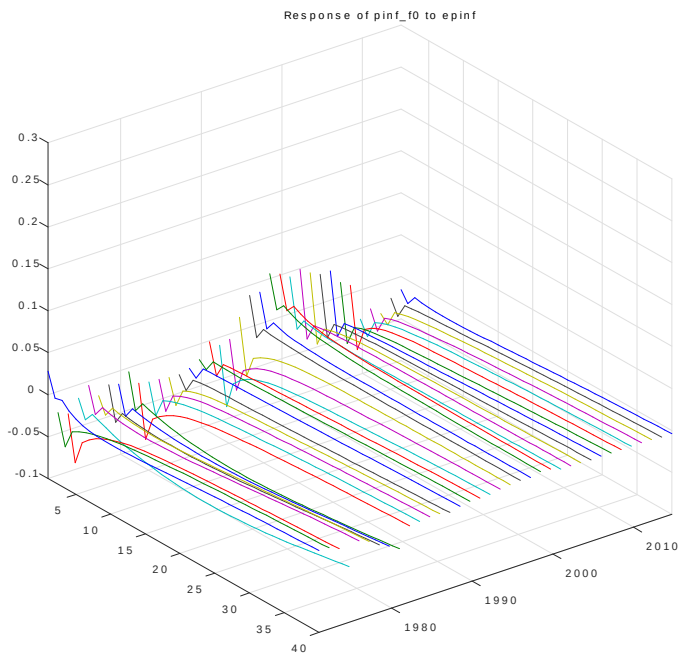


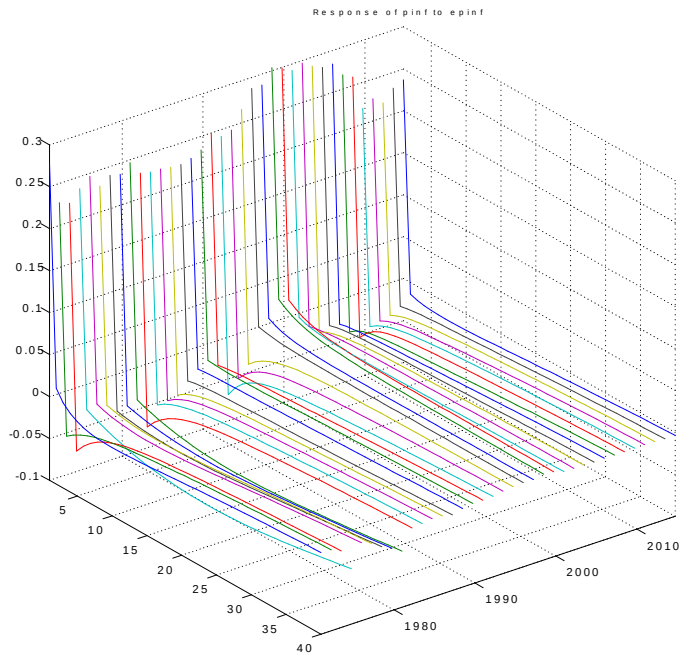
Outcomes under AL: updating in inflation beliefs

constant	marginal cost
persistence	markup shocks

Outcomes under AL: irfs

inflation expectations	inflation

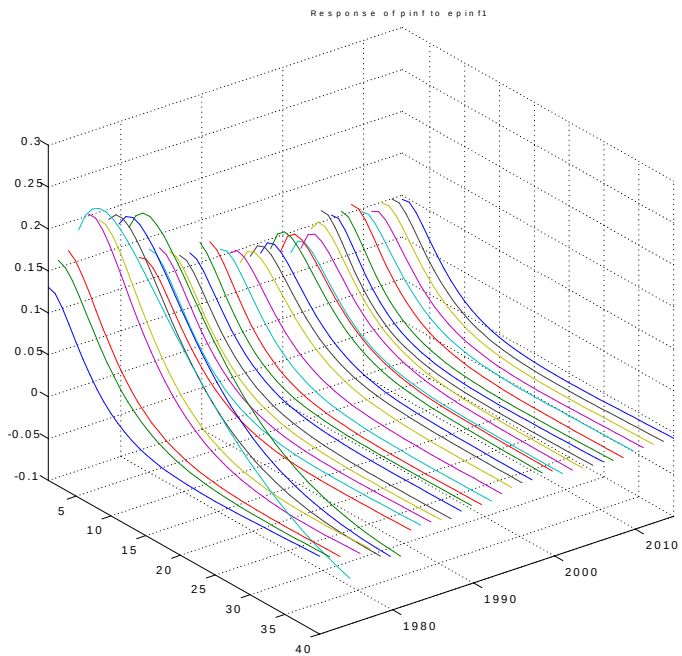


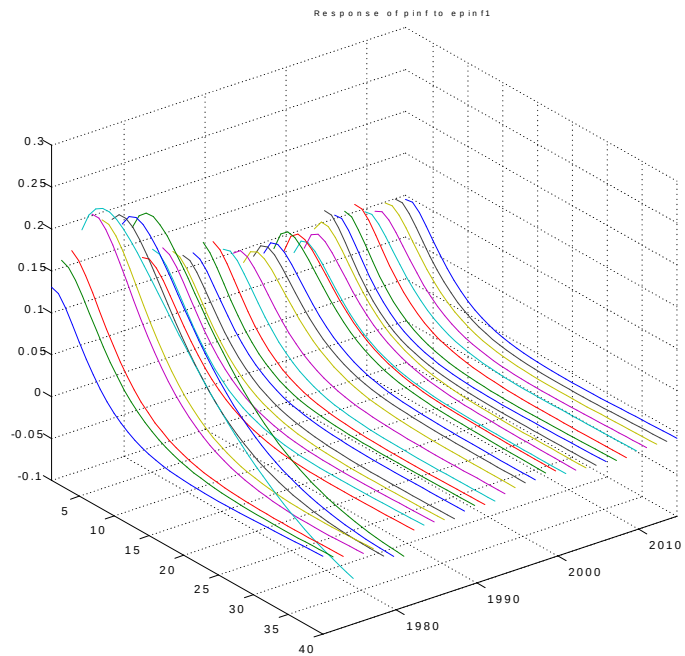


i.i.d. markup shock (ε^{piid})

Outcomes under AL: irfs

inflation expectations	inflation

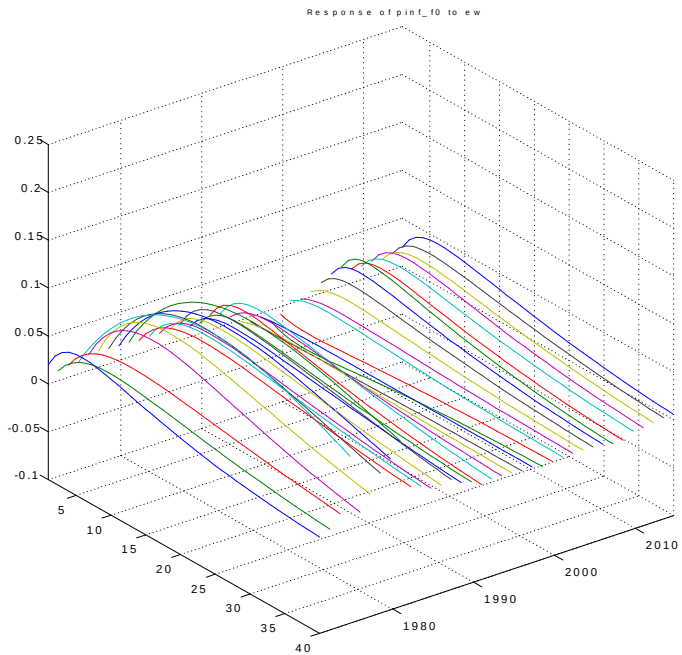


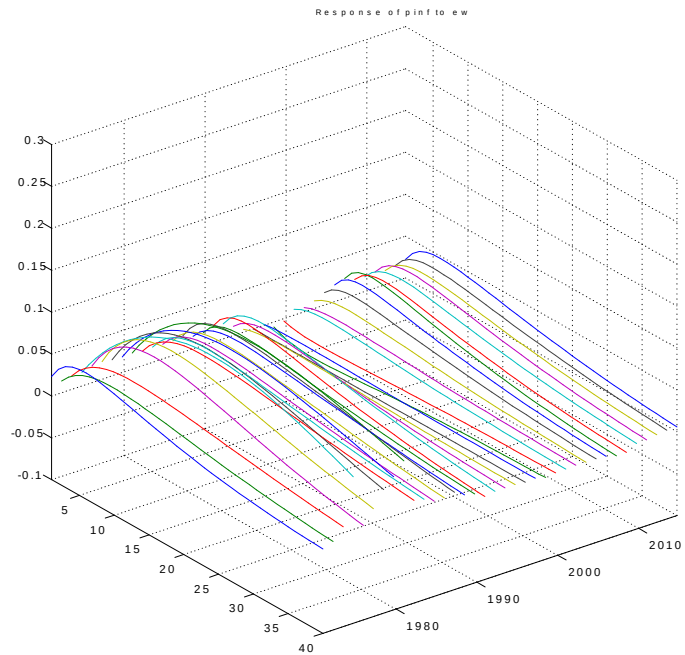


persistent markup shock (ε^{par})

Outcomes under AL: irfs

inflation expectations	inflation





persistent wage markup shock (ε^{war})

Outcomes under AL: cond. variance decomposition

	ε^{a}	$\varepsilon^{b+g+qs+m}$	ε^{piid}	ε^{wiid}	ε^{par}	ε^{war}	$\zeta^{\pi f1}$
1 quarter horizon							
π_f1	0.65	0.10	3.72	1.93	**92.94**	0.03	0.60
π_r1	0.19	0.02	**81.18**	0.57	18.03	0.01	0.00
w	0.02	0.43	15.33	**82.67**	0.06	1.48	0.00
y	15.77	80.07	0.21	0.35	3.59	0.01	0.00
10 year horizon							
π_f1	17.29	28.21	3.27	17.55	31.89	1.75	0.08
π_r1	11.66	19.00	29.03	11.84	27.29	1.18	0.00
w	0.55	57.89	6.17	29.00	3.64	2.75	0.00
y	11.19	83.14	0.95	1.13	2.61	0.11	0.00

Robustness exercises: alternative timing SPFobservable

- Use $\pi_{t+1|t-1}$ forecast that is formed a quarter before the publication of the first release data as observable instead of $\pi_{t+1|t}$.
- The model specification with the flexible two markup shock specification (i.i.d. and ar component) is still the best setup to match simultaneously the realized and the expected inflation data (outperforming the measurement error specification).
- The big gain in forecasting power under AL when agents are allowed to use the timely shock information in their belief models is no longer observed: in line with results of Giannone-Reichlin-Small (2008), Krane (2011), Leduc and Sill (2013).

Main insights from inflation expectations and surveys

- A proper integration of survey expectations - as measured by the SPF - in a DSGE model makes it possible to identify separately the transitory and the persistent shocks in inflation.
- By improving the efficiency of the model filter, the forecasts improve both for inflation and for other macrovariables.
- Under AL, the updating of the belief models that are augmented with the information signals from the survey data, generate time-varying estimates of the perceived inflation target, the perceived inflation persistence and sensitivity of inflation to shocks.
- In this way, the model provides a consistent story for the joint dynamics in the first and second moments of realized and expected inflation.

Application on consumption, investment and output survey

- SPF-survey forecasts for real variables are also very informative and significantly different from model forecasts.
- SPF forecasts help to identify the nature of the shocks: identify i.i.d. and persistent component of risk premium, exogenous (public) spending shocks and investment shocks.
- Survey information from each of these variables (c,inv,y) helps the model to better predict the other variables as well.
- AL is more flexible than the RE setup to capture the information from the survey forecasts: cyclical beliefs for the constant ($\cong$expected growth rate) and time-varying perceived shock sensitivity for consumption and investment.

Excellent forecast performance of Survey SPF for consumption, investment and output growth

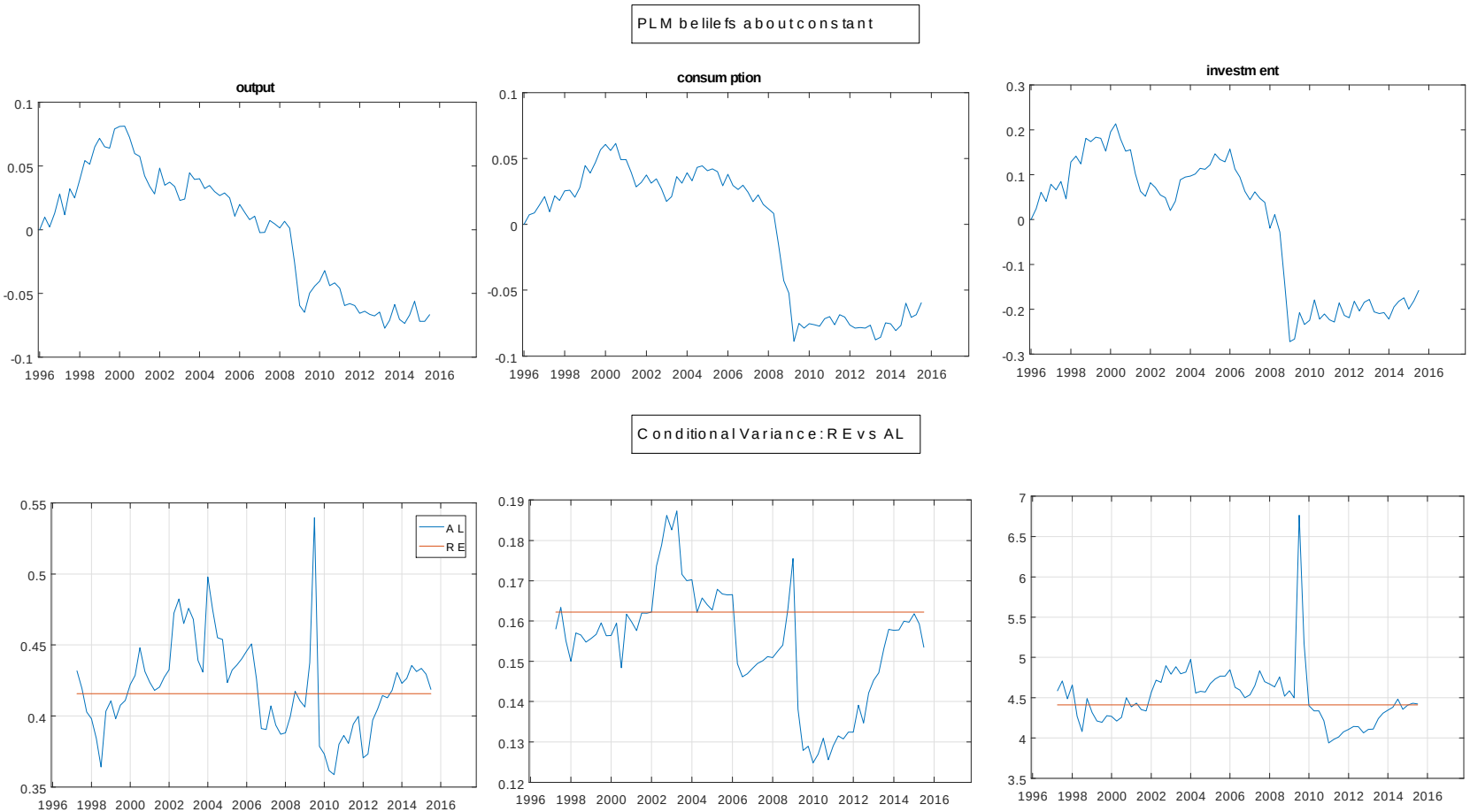
	1996q1-2015q3			
SPF statistics: 1Q	Inflation	Consumption	Investment	GDP
$\Delta\_SPF_{t+1\|t} - \Delta\_r1_{t+1}$	0.21	0.41	1.53	0.35
$\Delta\_SPF_{t+1\|t} - \Delta\_r2_{t+1}$	0.19	0.41	1.55	0.43
$\Delta\_SPF_{t+1\|t} - \Delta\_rf_{t+1}$	0.20	0.46	1.25	0.49
SPF for longer horizons				
$\Delta\_SPF_{t+2\|t} - \Delta\_r1_{t+2}$	0.23	0.46	1.88	0.46
$\Delta\_SPF_{t+3\|t} - \Delta\_r1_{t+3}$	0.23	0.45	2.16	0.51
$\Delta\_SPF_{t+4\|t} - \Delta\_r1_{t+4}$	0.25	0.48	2.26	0.54

Model forecasts (RE) for real variables deviate significantly from survey expectations:

	1996q1-2015q3			
	Inflation	Consumption	Investment	GDP
RMSE SPF-nowcast	0.21	0.41	1.53	0.35
RMSE RE-1Q ahead	0.22	0.48	1.91	0.46
DM-test	0.92	1.66	3.46	3.18

- Diebold-Mariano test indicates significant difference between the model and survey forecasts for consumption (10%), investment and output growth.

Model with AL and survey forecasts generates cyclical growth beliefs and time-varying volatility:



Concluding remarks

Which surveys matter: professional forecasters versus households and firms? (Coibion et al 2018)

- Different surveys might contain different information: signals on the nature of fundamental innovations versus indicators of sentiment;
- Different surveys might require different specification of measurement equation: disciplining the model forecast versus identifying sentiment shock orthogonal to fundamental shocks.

Median (consensus) forecast versus individual survey responses?

- Heterogeneity in survey responses can help to identify alternative belief models and how agents switch between these beliefs (Busetti et al 2018 on anchoring of inflation expectations, Arifovic et al 2018 on social learning and switches between PLMs under the ZLB).

Point forecast versus distribution forecast?

- Uncertainty can be independent state variable driving precautionary behavior.