Adaptive learning and Survey Expectations of Inflation

Y. Rychalovska (UNamur) S. Slobodyan (CERGE-EI) R. Wouters (NBB)

First Annual Czech National Bank Workshop, Prague
13-14 June, 2024

Motivation and objectives I

- We model realized and expected inflation jointly in a DSGE model, using Survey (SPF) data on expected inflation as observable. There are many strong arguments for such an exercise:
- 1. Use survey data to discipline unobserved model-based measure of inflation expectations, which play a central role in the transmission of shocks in New Keynesian macromodels
- 2. Professional surveys on inflation expectations are very informative and competitive predictors of future inflation realizations
  - Timely, rich content of inflation survey data could contribute to explaining persistent inflation developments
  - Official forecasts include judgement that combines model and survey information in a non-systematic way
- 3. Evidence on expectations helps to develop a credible theory of expectation formation:
  - How agents form their expectations is one of the most fundamental questions in macroeconomics, finance, and central banking

Motivation and objectives II

- Our objectives:
  - Propose a strategy to integrate and exploit valuable information from surveys most effectively
  - Assess consequences for the transmission mechanism and estimation outcomes
  - Evaluate alternative expectation hypothesis: RE versus imperfectly-rational belief models based on Adaptive Learning (AL)
  - Interpret the post-Covid inflation experience:
    - Why inflation was such a surprise for SPF forecasters?
    - Can we improve upon SPF forecasts?

Main insights

- Survey information helps to refine identification of shocks that drive inflation;
  - We can separately identify the innovations in the i.i.d and the persistent markup processes
- With this model re-specification, we can efficiently exploit the information from the survey:
  - Significant improvement in the model fit and forecasting performance
- AL model demonstrates superior performance compared to both the RE model and the survey
  - Model generates time variation in the perceived inflation target, persistence and in sensitivity of inflation to shocks
  - AL model detects time-varying nature of inflation process and better identifies the persistent nature of the post-Covid inflation surge

Literature

- Surveys in structural macromodels: understand information content revealed by surveys; strategies to integrate survey data; modeling expectation formation mechanism
- RE-models:
  - Introduce exogenous inflation target shock to match expectations: Eusepi-DelNegro (2011), De Graeve et al (2009), Del Negro-Giannoni-Schorfheide (2015);
  - Use news shocks: Milani and Rajbhandari (2012).
- AL-models: use survey data to illustrate deviations from RE assumption and discipline belief dynamics
  - Ormeno-Molnar (2015): use measurement equation to reconsile model-based and observed expectations.
  - Carvalho et al (2015, 2023), Gati (2023): use survey data and learning to endogenize long-term trends in expectations
- Use of survey data to test deviations from the FIRE (Coibion and Gorodnichenko, 2015) and explore various theories of expectation formation: Diagnostic Expectations, Dispersed Information, Inattention, etc.: Angeletos et al (2020), Bordalo et al (2020).

Comparing 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:
  - Estimate Smets and Wouters (AER, 2007) RE model and Slobodyan and Wouters (AEJ:Macro, 2012) AL model with 1st and 2d release of GDP growth and inflation data over 1971q1-2019q4 (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
- Compare model forecasts of the re-estimated RE-SW2007 and AL-SW2012 models with SPF expectations (nowcast h=1 and longer horizon forecasts h=2,3,4):

$$\overline{\pi} + \pi_{t+h} \iff \pi_{t+h}^{SPF}$$

- Model inflation forecasts deviate significantly from SPF, which typically outperform: model forecast errors are large, deviations from SPF are very persistent

Model inflation forecasts deviate significantly from SPF

- 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)
- SPF forecasts for $t+1$ reflect information available after the end of quarter t $=>$ superior SPF predictions relative to models

	1996q1-2019q4	
$DM-test$	RE-SW2007 versus SPF	AL-SW12 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

SPF inflation as observable and model respecification

- Integrate Survey forecast as observable with i.i.d. measurement error :

$$\pi^{SPF}_{t+1/t} = \overline{\pi} + E_t \widetilde{\pi}_{t+1} + \xi^{\pi f}_t ,$$

- Simple model re-specification: To capture useful survey information, need more flexibility in the specification of inflation dynamics
  - Observing survey data allows to identify separately persistent and i.i.d. component in the markup:

$$\begin{aligned} \mu^p_t &= \mu^{p.ar}_t + \mu^{iid}_t , \\ \mu^{p.ar}_t &= \rho^p_\mu \cdot \mu^{p.ar}_{t-1} + \varepsilon^p_{t-1} \\ \mu^{iid}_t &= \varepsilon^{iid}_t \end{aligned}$$

  - ARMA price and wage markup shock in RE-SW2007 and AL-SW2012

$$\mu^p_t = \rho^p_\mu \cdot \mu^p_{t-1} - \theta^p_\mu \cdot \varepsilon^p_{t-1} + \varepsilon^p_t$$

  - Same innovation ε^p_t drives volatile MA-component and persistent AR-component

Outcomes under RE: forecast comparison with SPF

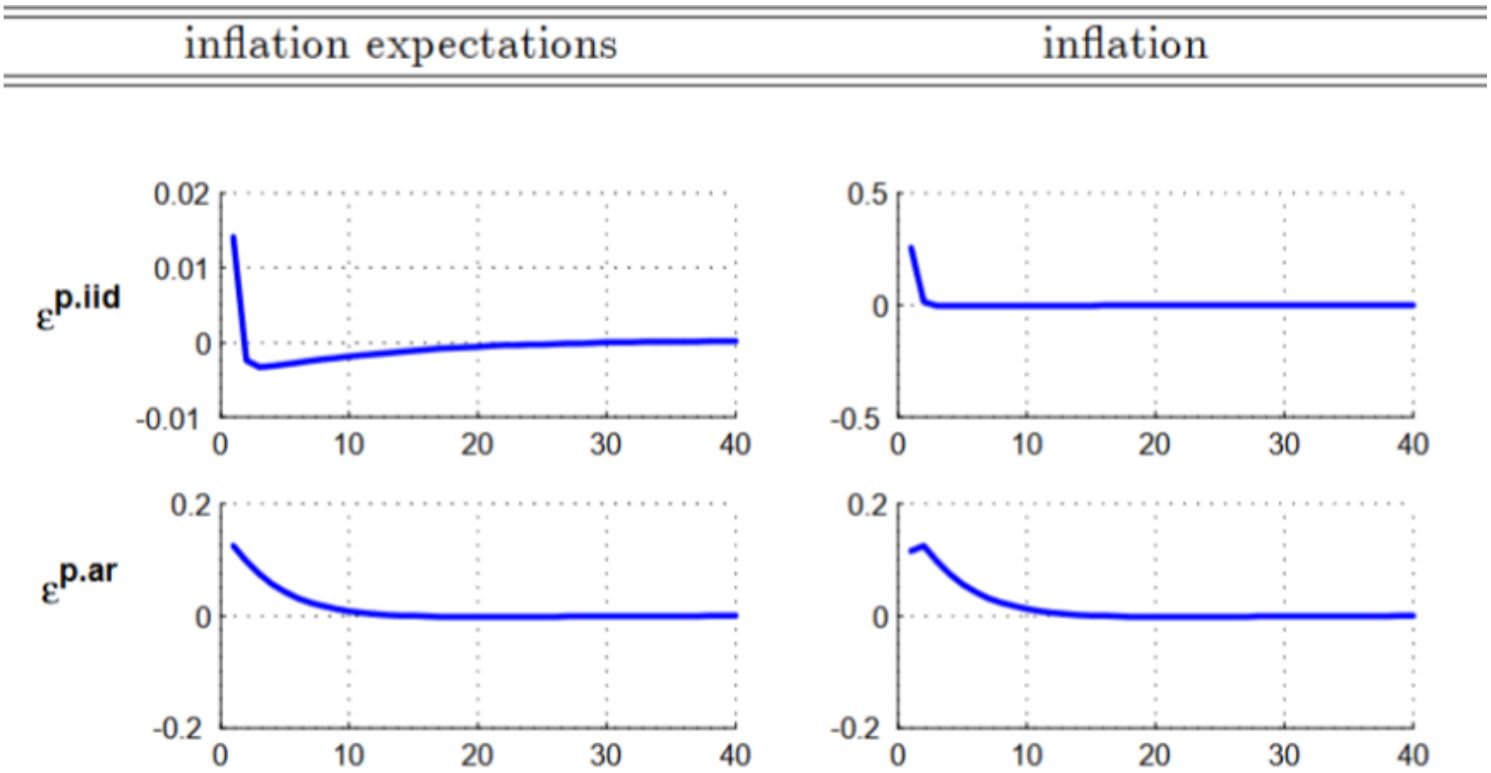
- Simple model re-specification helps to discipline model-based inflation expectations in line with observed survey data:

	1996q1-2019q4
$DM - test$	RE versus SPF
horizon=1	1.44
horizon=2	0.86
horizon=3	1.19
horizon=4	-0.37

- Measurement error in SPF nowcast equation is small
- Information from the survey is exploited effectively improving forecast of inflation and other nominal variables

Outcomes under RE: IRFs of identified markup shocks

- IRF functions for i.i.d and persistent price markup shocks:
  - iid shock: explains high-frequency variation of actual inflation but almost irrelevant for inflation expectations
  - persistent component: captures innovations in survey nowcasts



Outcomes under RE: remaining issues

- The improvement in forecast performance of the model is concentrated in a few variables: inflation, inflation expectations, wages and nominal interest rate.
- Predictability test for the survey nowcast error shows an underestimation problem in inflation data: forecast error is significantly positively related to the revision in the forecasts (see also Bordalo et al 2018, CG 2015, Angeletos 2020)
  - This test is mainly considered as showing evidence of an inefficient information processing
  - Predictability test for RE model forecasts: while observing and utilizing timely information, model inherits inefficiencies present in SPF
- Constant variance-covariance structure on the data imposed by RE, while we know from reduced form exercises that the nature of the inflation process has changed over time.

Models with non-rational expectations

- Full-information rational expectations (FIRE) is an extremely useful benchmark for modelling expectations
- But FIRE is also a restrictive assumption for understanding actual expectations and survey data
- Explore Adaptive Learning (AL) approach following Evans and Honkapohja (2001)
- Replace forward variables with belief models, which are updated every period on the basis of Kalman Filter learning algorithm as in Slobodyan and Wouters, 2012
- Survey Nowcasts add discipline on the belief specification and the updating process

Models with non-rational expectations: belief updating I

- Starting from the linearized structural model representation:

$$A^{+}E_t y_{t+1}^{f} + A^{-}y_{t-1} + A^{0}y_t + B_0\epsilon_t = 0$$

- Agents use belief models (PLM) to form expectations:

$$\begin{aligned} y_t^f &= \beta_{t-1}^0 + y_{t-1}^T\beta_{t-1} \\ E_t y_{t+1}^f &= \beta_{t|t-1}^0 + y_t^T\beta_{t|t-1}. \end{aligned}$$

- Information set in y_{t-1} (constant+ lags of model endogenous states and shocks) may deviate from the information used by rational agent
- PLM beliefs for inflation:
  - Include the most important determinants of inflation dynamics (AR2 + marginal cost) and available information about the nature of markup shock components signalled by the survey data:

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

Models with non-rational expectations: belief updating II

- Time-varying belief coefficients β and corresponding covariance matrix are updated using Kalman Filter
  - Updating of the constant is important for long-run inflation trend
  - AR(2) process, which captures time-varying perceived persistence, allows for sufficient flexibility in the updating
  - Innovations of the structural shocks:
    - to capture the rich information of the SPF-nowcasts and to compete with the surveys in terms of forecasting performance
    - to allow inflation expectations to react to shocks instantaneously => enhance propagation mechanism
- Time varying beliefs allow for flexible filtering of SPF innovations into the price mark-up components
- The expectations implied by the PLM process lead to the model solution in a form (ALM):

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

Outcomes under AL: model fit

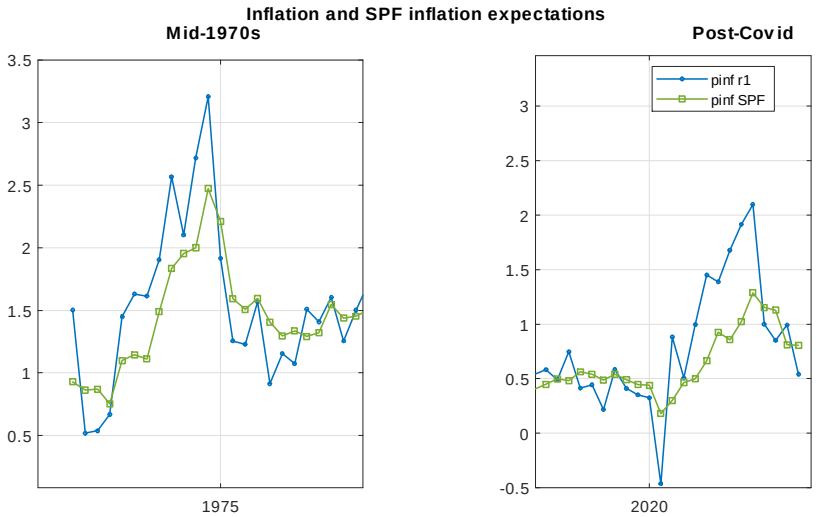
- Model effectively exploits timely information from surveys:
  - the accuracy of the AL model forecasts is not significantly different from SPF
  - improved identification of the mark-up shock components
- Impressive gain in the model fit: Marginal likelihood of alternative model specifications

	1971q1-2019q4	1996q1-2019q4
RE-ME	-911.05	-302.57
RE-2MU	-839.96	-267.14
AL-2MU	-787.18	-228.69

- The impressive gain of AL model is explained by two features of the forecasts distribution:
  - the mean forecast precision: out-of-sample point forecasts improve not only for inflation variables but also for the real observables
  - the time-varying volatility

Application: Post-Covid inflation dynamics I

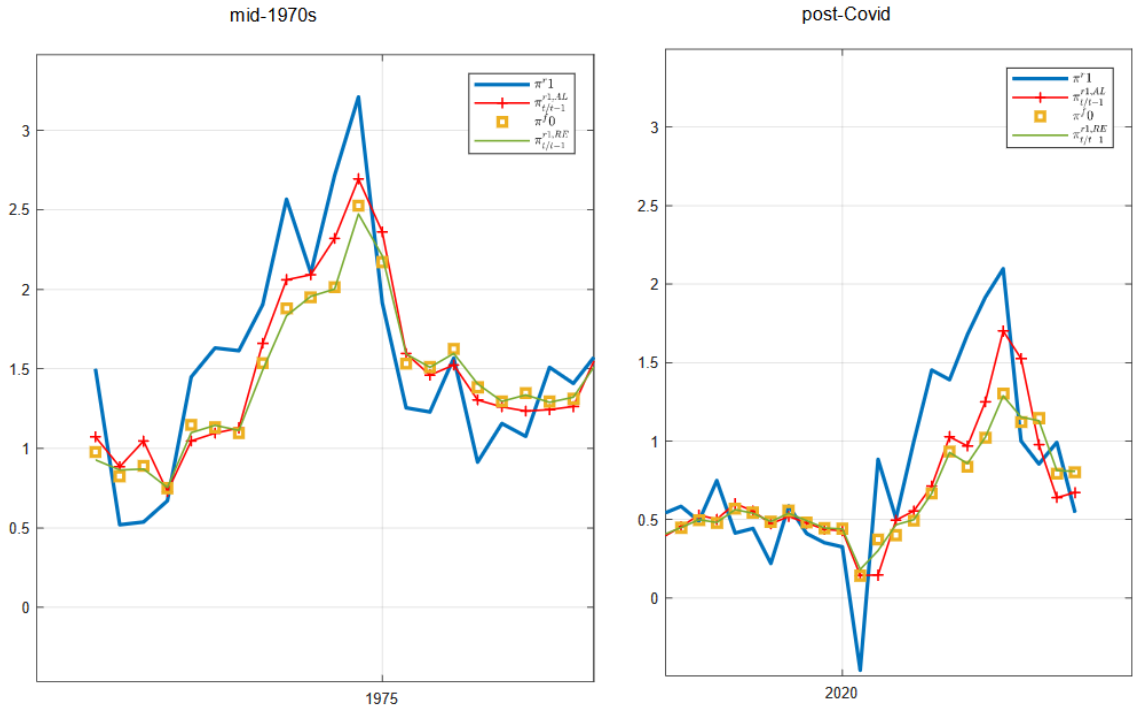
- Complex nature of the recent surge in inflation: supply shocks (supply chain disruptions, tight labor markets, energy prices, war in Ukraine), demand-side factors, structural changes in the post-covid period
- In mid-70s and after Covid: SPF systematically underpredicts inflation



- Why our setup is suitable for studying the recent inflation experience:
  - with separately identified persistent and transitory components of markup shocks we can offer more refined analysis of the nature of the inflation shocks
  - with time-varying transmission mechanism of AL model, we are able to detect changes in data-generating process and shock propagation

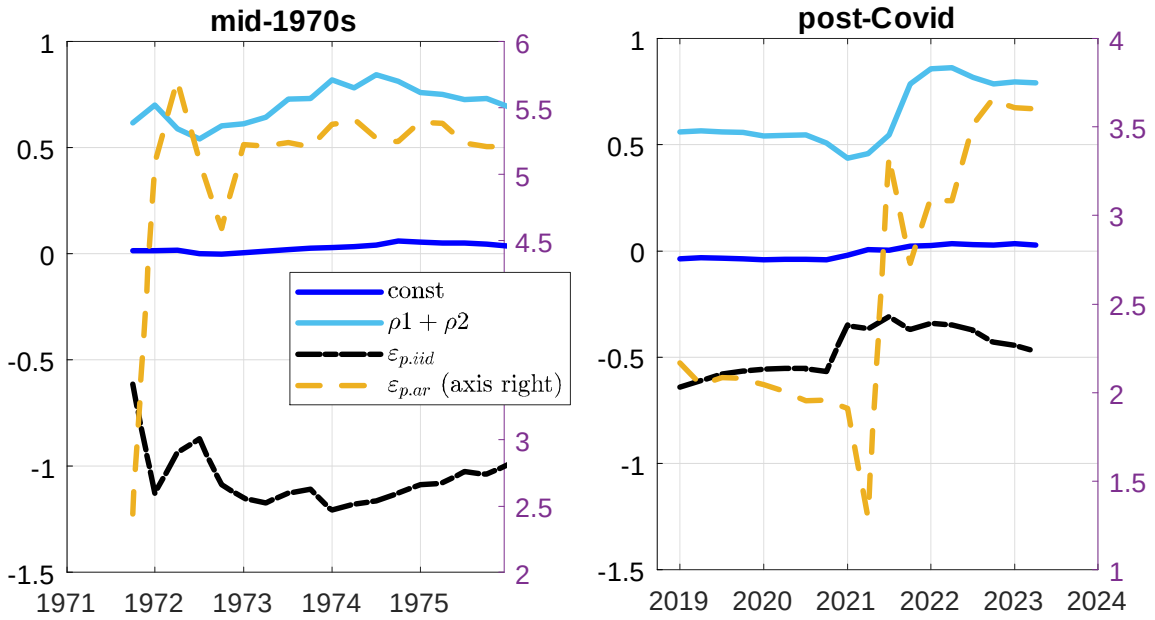
Inflation predictions: RE, AL and SPF

- We evaluate our models on the extended sample (up to 2023q2), fixing the parameters at the level estimated on the main pre-covid sample
- In 70s and post-Covid: AL predicts systematically higher inflation (smaller underprediction) than RE model and SPF
- Role of modified transmission mechanism due to belief updating:
  - AL model can capture shift in DGP of inflation
  - AL better identifies the persistent nature of inflation shocks



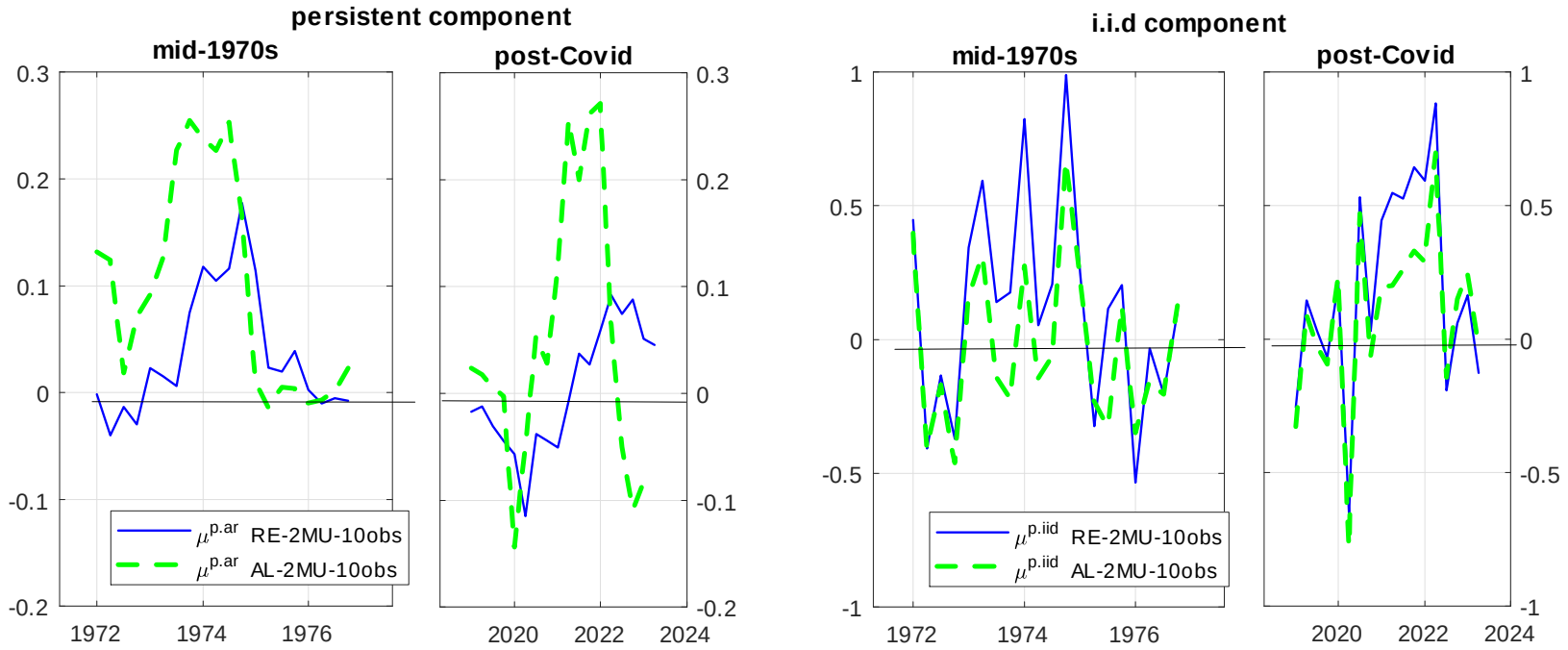
Time-variation: Belief dynamics

- Modified transmission mechanism under AL is due to time-varying nature of agents' beliefs
  - Constant: generates time-varying estimate of the perceived inflation target
  - Persistence and shock components: capture time-varying sensitivity to shocks
- Model-based expectations are more flexible to adjust to forecast errors
- => improved identification of persistent and transitory drivers of inflation
- PLM beliefs for inflation:



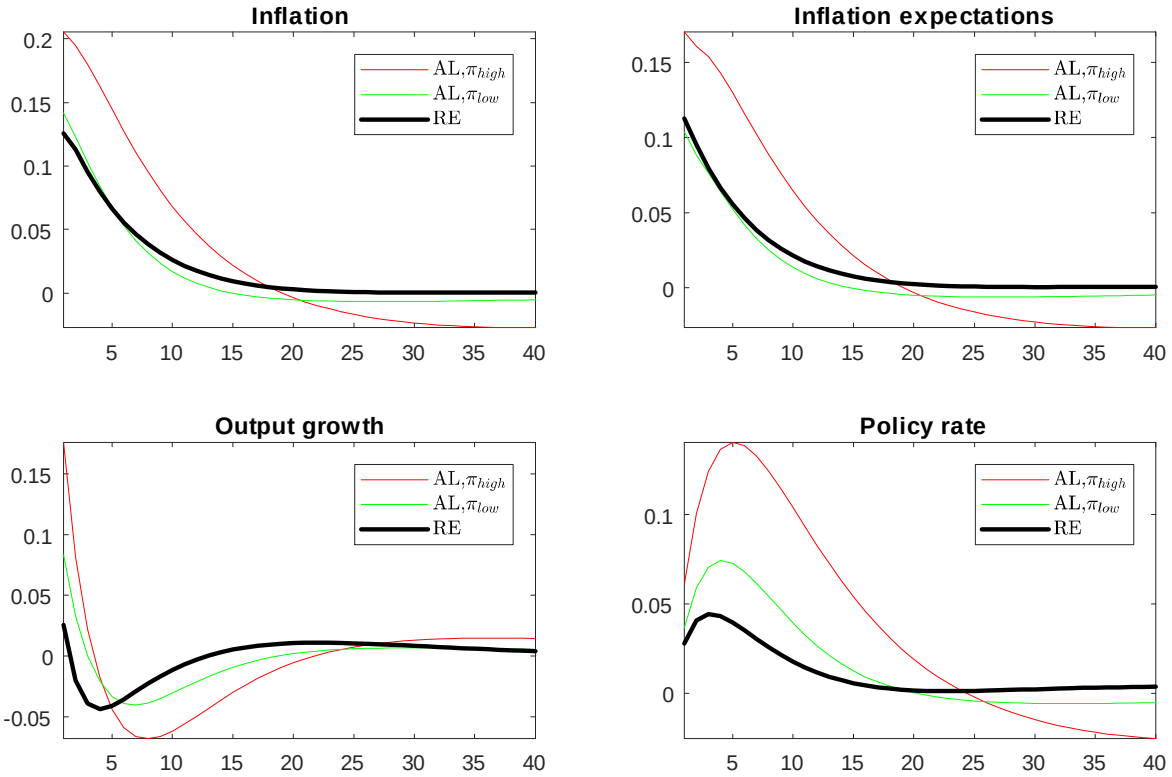
Identification: shock components

- AL model identifies more important role of the persistent markup shock component in the beginning of 70s and 2021-2022
- RE model explores a systematic pattern of the transitory component:
  - sustained inflation surprises in 1970s and after 2021q2 are interpreted as a sequence of large and systematically positive *i.i.d.* mark-up shocks, which have increased inflation but not the SPF expectations
- Components of identified price mark-up shocks:



IRFs to persistent mark-up shock

- Modified transmission mechanism due to time variation: Non-linear (average) responses to persistent mark-up shock in periods of high and low inflation
- In period of high and persistent inflation: supply shocks produce more powerful impact; higher risk of deanchoring of the inflation expectations



Discussion I

- Two important questions:
  - Why was inflation missed during the two episodes: systematic underprediction of inflation in mid-1970s and in the post-Covid period?
  - Was underprediction due to certain changes in the nature of the underlying shocks that have forced the forecasters to be wrong in similar ways?
- In both periods: inflation was affected by unusual sequence of shocks
  - due to repeated innovations, i.i.d shock began to behave in a persistent manner
- RE model interpretation:
  - agents saw through large i.i.d component (transitory energy shocks)
  - $=>$ systematic underprediction of inflation
  - SPF forecasters behaved as rational agents and perceived the economy as stable data-generating process
- This interpretation is consistent with the stance prevailing in the beginning of the inflation surge among the policymakers and academics:

Discussion II

- Fed Chair Powell, August 2021: "The absence so far of broad-based inflation pressures"
- Ball et al (2021): "underlying inflation could rise to about 2.5-3% by 2023" ; "there is little risk of a 1960s-type inflationary spiral"

- => Agents failed to distinguish between repeated transitory and persistent cost-push innovations
  - due to the complex mixture of shocks and temporary change in the data generating process of inflation
- AL agents were more successful in identifying the more persistent nature of inflation via the higher perceived inflation persistence and increased role of autocorrelated markup component in their PLM
- The better fit of AL model indicates that such an identification is better supported by the data
- AL model inflation expectations exhibit greater sensitivity to higher realized inflation than SPF

Conclusions

- We propose a procedure to incorporate and efficiently explore the timely information from inflation survey forecasts in DSGE-models
- With the help of timely survey data we improve identification of important fundamental shocks driving inflation. Survey forecasts improve the predictive power of DSGE-models
- Models with alternative expectation formation mechanism can overcome certain limitations of RE-models:
  - updating of the belief models can generate time-varying estimates of the perceived inflation target, persistence and sensitivity to shocks
  - can capture main features of observed agents forecasts and at the same time produce more efficient model-based predictions
  - AL agents were more successful in identifying the persistent nature of the recent inflation increase
- In this way, the model provides a more informative analysis of inflation dynamics