How important is Belief Heterogeneity of Households?

Kwok Yan Chiu*

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Abstract

Macroeconomic expectations are known to correlate with socioeconomic status, but this relationship is absent in most heterogeneous-agent models. I find that, specifically, households with low marginal propensities to consume (MPC) or high elasticity of intertemporal substitution (EIS) update their forecasts faster than others in response to the business cycle. I develop and estimate a heterogeneous-agent model with rational expectations that captures the empirical correlation between beliefs and household characteristics. Compared to a typical calibration that assumes no such correlation, I find that this model implies more amplification and consumption heterogeneity in response to shocks.

[Very Preliminary. Do Not Cite or Distribute.]

*Northwestern University; KwokYan.Chiu@u.northwestern.edu.
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1 Introduction

How important is belief heterogeneity of households? The heterogeneity in macroeconomic expectation suggests that households may have different abilities to form expectations about the future. This can affect transmission of demand shock to individuals consumption. Literatures following Friedman (1957) and Modigliani (2005) show that individual consumption depends on their current and future expected discount rate shock, as well as their current and future expected personal income. Information affects households expectation about future shocks and income, and thus consumption decision.

The effect of information to consumption depends on other non-belief characteristics of households such as 1) elasticity of consumption to discount rate shock, or elasticity of intertemporal substitution (**EIS**), 2) exposures of their personal income to aggregate output fluctuation (**Exposure**), 3) preferences between current and future consumption, measured by discount factor or marginal propensity to consume (**MPC**). These factors interact with the macroeconomic expectations to influence individual's consumption. This implies that the aggregate exposure to discount factor shocks and, more importantly, the aggregate MPC, a critical sufficient statistics Auclert *et al.* (2018) for shock transmissions, depend on not only the distribution of the non-belief characteristics but also the macroeconomic expectations.

This paper studies the importance of belief heterogeneity of households. First, I analyze how non-belief characteristics correlates with expectations on future one-year ahead unemployment rate changes. I impute an MPC and an Exposure to each individual in Michigan Survey of Consumer using empirical techniques in Patterson (2023) and I use stock market . Then, using the latent variables design from Bhandari *et al.* (2019) and Mankiw *et al.* (2003), I estimate the average forecast of one-year ahead unemployment rate changes for each type of households. I find that households with high EIS or low MPC tend to update their forecasts more rapidly in response to the business cycle fluctuation.

I calibrate a heterogeneous-agent model with incomplete information that produces the empirical pattern of macroeconomic expectations and I show that the model implies more amplification of demand shocks and vastly different consumption paths of each type of households, compared to a model with same non-belief characteristics but without belief heterogeneity.

Literature Das *et al.* (2020) finds that macroeconomic expectations are correlated with the socioeconomic status, such as income and education. My empirical focuses on the correlation that are more relevant in quantitative heterogeneous-agent models. Angeletos and Huo (2021), Angeletos and Lian (2022) and Auclert *et al.* (2020) incorporate information frictions to consumption-saving problems, but heterogeneity in information frictions was yet to be explored in their work. To the best of my knowledge,Guerreiro (2022) is the first to discuss the theoretical potential of macro shock amplification through correlation of beliefs and exposures to business cycle. This paper focuses on the quantitative assessment of the impact of correlation between a wide range of non-belief characteristics (Exposures, MPC and EIS) and macroeconomic expectations.

The paper proceeds as follows. Section 2 discusses empirical findings. Section 3 and 4 describe a heterogeneous-agent model with incomplete information and discuss how information plays a role. Section 6 quantifies importance of heterogeneous beliefs. Section 7 concludes.

2 Beliefs Heterogeneity in Data

In this section, I explore the correlation between non-belief characteristics and macroeconomic expectations. To do this, I construct a micro-level dataset of macroeconomic expectations, Exposures, MPCs and EISs.

Following the methodology by Patterson (2023), I estimate the exposure of personal income to business cycle for households with different ages, income and education attainments using Panel Studies of Income Dynamics (PSID). Exposures in MSC are imputed based on survey respondents' age, income and education. I take the estimate of MPCs for each income group from Patterson (2023) and impute the MPCs using their income. For the EISs, Guvenen (2006) shows that the EIS of the stockholders and non-stockholders are vastly different. I identify high or low EIS using survey respondents' answer of stock market participation.

I focus on the survey question of "Do you think that there will be more unemployment than now, about the same, or less?". Responses of this question take the forms of "more", "less" or "about the same". A challenge for using MSC data to study households' macroeconomic expectation is to transform qualitative forecasts to quantitative forecasts. I extend the method in Bhandari *et al.* (2019) and Mankiw *et al.* (2003). I assume that households from each group has a quantitative forecast around the mean forecast of the group, and they answer "more" or "less" if their quantitative forecast exceeds group-specific upper or lower thresholds.

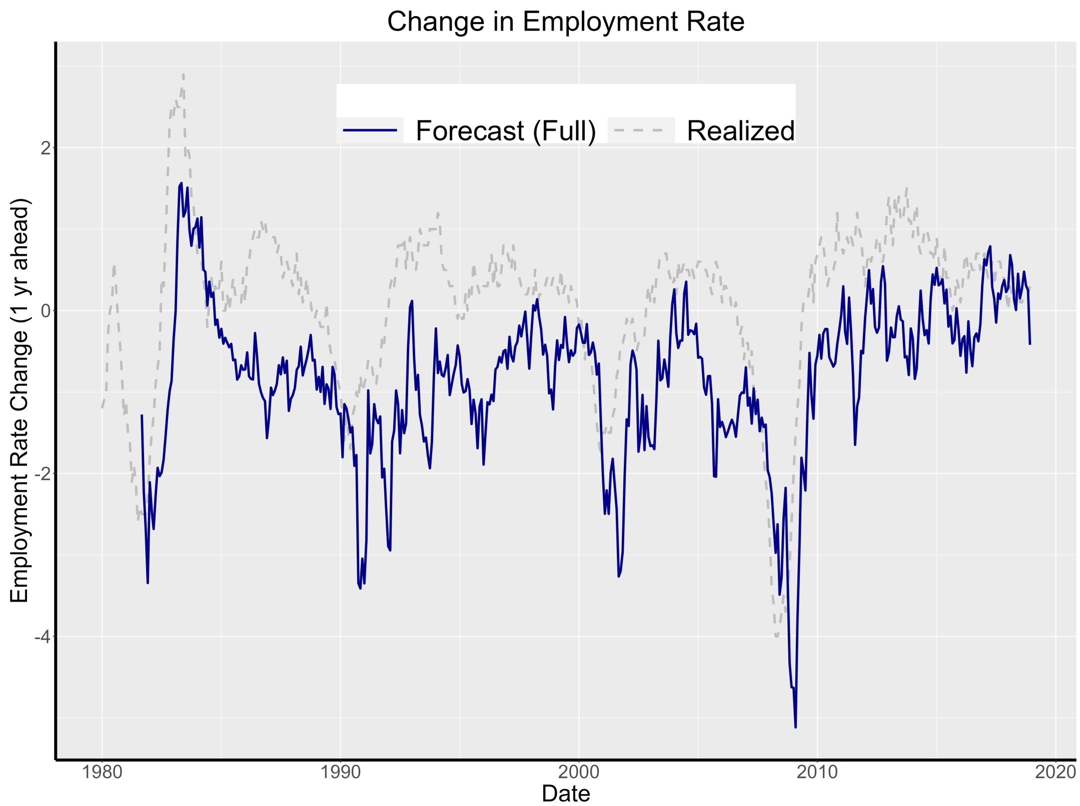


Figure 1: Average forecasted vs realized employment change in a year

Figure 1 shows that the estimated average quantitative forecast of employment changes tracks the realized change in employment rate. Consistent with findings in literature, households' forecast tends to be more pessimistic than realized macroeconomic conditions. To isolate co-movements of the forecasts and the business cycle from general optimism or pessimism, I regress group-average forecasts to realized employment rate changes.

$$\mu_{g,t} = \alpha_{0,g} + \alpha_{1,g}\Delta y_t + \epsilon_{g,t} \quad \text{with} \quad E[\epsilon_{g,t}] = 0 \tag{1}$$

$\alpha_{0,g}$ captures general optimism or pessimism for group g. $\alpha_{1,g}$ captures expectation changes in response to business cycle fluctuations. To understand how two groups (g and g') respond to business cycle fluctuations differently, we can regress differences of macroeconomic expectations between the two groups to realized employment change.

$$\mu_{g,t} - \mu_{g',t} = (\alpha_{0,g} - \alpha_{0,g'}) + (\alpha_{1,g} - \alpha_{1,g'})\Delta y_t + \epsilon_{g,t} - \epsilon_{g',t} \quad \text{with} \quad E[\epsilon_{g,t} - \epsilon_{g',t}] = 0 \qquad (2)$$

In the absence of belief heterogeneity, the regression coefficients across groups are identical. Thus, $\alpha_{0,g} - \alpha_{0,g'} = 0$ and $\alpha_{1,g} - \alpha_{1,g'} = 0$. If there is only a difference in general optimism or pessimism between groups, then only $\alpha_{1,g} - \alpha_{1,g'} = 0$. Belief heterogeneity is irrelevant to business cycle fluctuations in this case because it means that all households update their beliefs in the same way when the economy is hit by a shock. Thus, I test $H_0 : \alpha_{1,g} - \alpha_{1,g'} = 0$ to see how households update their beliefs differently.

Table 1: Forecast Differences Between Groups on Realized Employment Change

	Dependent variable:		
	(High - Low) Exposure	(High - Low) MPC	(High - Low) EIS
	(1)	(2)	(3)
Realized	−0.022	−0.049***	0.072***
	(0.019)	(0.015)	(0.015)
Constant	0.254***	−0.536***	0.411***
	(0.028)	(0.023)	(0.027)
Observations	490	490	295
R^2	0.003	0.021	0.073
Adjusted R^2	0.001	0.019	0.070
Residual Std. Error	0.618 (df = 488)	0.504 (df = 488)	0.460 (df = 293)
F Statistic	1.435 (df = 1; 488)	10.265*** (df = 1; 488)	23.233*** (df = 1; 293)

Note: *p<0.1; **p<0.05; ***p<0.01

Table 1 uncovers very different patterns across types of characteristics. The difference of forecasts between high and low Exposures groups is acyclical, even though high Exposures group is more optimistic than the low Exposures group in general. The difference of forecasts between high and low MPCs groups is countercyclical. One possibility is that low MPC households are more forward-looking and thus pay differentially more attention to future economic conditions. They are more accurate in forecasting and thus their $\alpha_{1,g}$ is larger. Finally, the difference of forecasts between high and low EIS group is procyclical. Since EIS is approximated by stock market participation, the high EIS households in the data may pay more attention to the state of economy. Therefore, they update their forecasts more rapidly to changes in economic conditions.

All in all, the empirical finding suggests that belief heterogeneity across MPC types or EIS types seem to be more salient during business cycle fluctuations.

3 Model

In this section, I describe a consumption-saving model with rich heterogeneity in non-belief characteristics (EIS, MPC and Exposure) as well as expectation formations.

3.1 Consumption

There are G types of households, indexed by $g \in \{1, 2, ..., G\}$, with corresponding population of π_g. Each consumer in group g survives with a probability of $\omega_g \in (0, 1]$ and dies with a probability $1 - \omega_g$. Differences in survival probability generate heterogeneity in patience and, therefore, heterogeneity in MPCs. The interest rate is exogenously set at R. To make the model tractable as in Angeletos and Huo (2021), Blanchard (1985) and Yaari (1965), consumers can save in actuarially fair annuities, with return of R/ω_g.

3.1.1 Household Maximization Problem

For a consumer i of type g, born in period τ, the lifetime utility for a given consumption path at birth is given by

$$\sum_{t=\tau}^{\infty} (\chi\omega_g)^{t-\tau} E_t[\Phi_{i,g,t}(C_{i,g,\tau;t})^{1+1/\sigma_g}]$$

$\Phi_{i,t}$ is a shock to discount rate. Each group has a group-specific elasticity of intertemporal substitution to match the empirical heterogeneity in EIS Guvenen (2006). The budget constraint is given by

$$C_{i,g,\tau;t} + S_{i,g,\tau;t} = \frac{R}{\omega_g} S_{i,g,\tau;t-1} + Y_{i,g,t} + T_{g,t}$$

Individual income is given by an idiocyncratic component and an aggregate component, $Y_{i,g,t} = \exp(\epsilon^y_{i,t})(Y_t)^{\lambda_g}$. λ_g is the elasticity of individual income to aggregate output, which captures the differential exposures of personal income to business cycle. $\epsilon^y_{i,t}$ is an idiocyncratic shock to income. Households only observe $\exp(\epsilon^y_{i,t})(Y_t)^{\lambda_g}$ as a whole instead of $\epsilon^y_{i,t}$ and Y_t separately.

After linearization around the steady state of $\chi_t R = 1$, optimal consumption (in log derivation from the steady state) is given by

$$
\begin{aligned}
c_{i,g,\tau;t} =& \frac{1-\chi\omega_g}{\chi\omega_g} s_{i,g,\tau;t-1} - \chi\omega_g\sigma_g\big[\phi_{i,g,t} + \sum_{k=1}^{\infty}(\chi\omega_g)^k E_{i,g,\tau;t}[\phi_{i,g,t+k}]\big] \\
&+ (1-\chi\omega_g)\big[y_{i,t} + \sum_{k=1}^{\infty}(\chi\omega_g)^k E_{i,g,\tau;t}[y_{i,t+k}]\big]
\end{aligned}
$$

where $\phi_{i,g,t}$ is log deviation of $\Phi_{i,g,t+1}/\Phi_{i,g,t}$. The growth of individual discount factor is assumed to be

$$
\phi_{i,g,t} = \phi_t + \epsilon_{i,g,t}
$$

where ϕ_t is an aggregate shock to the discount factor. In this model, it plays a role of generating business cycles. The idiocyncratic element $\epsilon_{i,g,t}$ prevents households from observing aggregate shocks directly. This will be discussed later in details in Section 3.3. The log-derivation of personal income $y_{i,t}$ is given by $y_{i,t} = \lambda_g y_t + \epsilon^y_{i,t}$. After aggregation, average optimal consumption of group g (in log derivation from the steady state) is given by

$$
c_{g,t} =(1-\beta_g)Rs_{g,t-1} - \beta_g\sigma_g\big[\phi_t + \sum_{k=1}^{\infty}(\beta_g)^k \bar{E}_{g,t}[\phi_{t+k}]\big] + (1-\beta_g)\lambda_g\big[y_t + \sum_{k=1}^{\infty}(\beta_g)^k \bar{E}_{g,t}[y_{t+k}]\big] \tag{3}
$$

where β_g is the effective discount rate that takes into account of the survival probability,

$\beta_g = \chi\omega_g$. The group level budget constraint is given by

$$c_{g,t} + s_{g,t} = \frac{1}{\chi}s_{g,t-1} + \lambda_g y_t \tag{4}$$

3.2 Market Clearing Condition

Aggregate output of this economy is demand-determined, which is the sum of the consumption of all groups.

$$y_t = \sum_g \pi_g \Big[(1-\beta_g)Rs_{g,t-1} - \beta_g\sigma_g\big[\phi_t + \sum_{k=1}^{\infty}(\beta_g)^k \bar{E}_{g,t}[\phi_{t+k}]\big] + (1-\beta_g)\lambda_g\big[y_t + \sum_{k=1}^{\infty}(\beta_g)^k \bar{E}_{g,t}[y_{t+k}]\big]\Big] \tag{5}$$

Condition 5 states that aggregate output is affected by demand shocks ϕ_t, beliefs about future demand shocks ϕ_{t+k}, and beliefs about future outputs y_{t+k}. By repeating substitution, aggregate output y_t is given by the first order beliefs as well as the higher-order beliefs on ϕ_t. In Section 4, I will describe how the model can be solved.

3.3 Uncertainty and Expectation Formation

Fundamental Uncertainty: ϕ_t follows an $AR(1)$ process

$$\phi_t = \rho\phi_{t-1} + \eta_t$$

with

$$\eta_t \sim N(0, (\tau^{\phi})^{-1})$$

Households do not observe ϕ_t directly. Instead, they observe their own realization of discount factor shocks, which is given by

$$\phi_{i,g,t+k} = \phi_t + \epsilon_{i,g,t} \tag{6}$$

where

$$\epsilon_{i,g,t} \sim N(0, (\tau_g^x)^{-1})$$

In addition, households observe their personal income $y_{i,t}$, which can be used for forecasting ϕ_t. For now, I assume that the variance of the idiocyncratic shock $\epsilon_{i,t}^y$ to be infinitely large. This avoids the complication of extracting information from endogenous signals.

Lastly, notice that since ϕ_t is unobserved and affects aggregate outputs according to equation (5), this implies that households are also uncertain about aggregate outputs y_t.

Rational Expectation: I assume households form expectations about y_t and ϕ_t using the full history of realized discount rate shocks $\{\phi_{i,t-k}\}_{k=0}^{\infty}$ and the knowledge of the model. Rationality is common knowledge. Thus, each household understands that other households are rational. As discussed before, since households use personal shocks realization $\{\phi_{i,t-k}\}_{k=0}^{\infty}$ to forecast, it implies that each household would have different opinions about the demand shock ϕ_t as well as y_t due to the market clearing condition 5. This is consistent with the data that households are uncertain about both present and future economic conditions.

3.4 Rational Expectation Equilibrium

A Rational Expectation Equilibrium of this model is given by an aggregate output process y_t that satisfies

1. Optimal consumption

$$c_{g,t} = (1-\beta_g)Rs_{g,t-1} - \beta_g\sigma_g\big[\phi_t + \sum_{k=1}^{\infty}(\beta_g)^k \bar{E}_{g,t}[\phi_{t+k}]\big] + (1-\beta_g)\lambda_g\big[y_t + \sum_{k=1}^{\infty}(\beta_g)^k \bar{E}_{g,t}[y_{t+k}]\big] \tag{7}$$

2. Market Clearing

$$y_t = \sum_g \pi_g c_{g,t} \tag{8}$$

3. Expectation is formed with signals and the knowledge of the model. Rationality is common knowledge.

4 Model Solution

Characterizing the solution of an incomplete information model is often challenging. As discussed before, higher-order beliefs of households about demand shocks are involved to compute y_t. To form expectations on these higher-order beliefs, households need to use all signals in the past, which leads to an infinite regress problem.

The solution strategy in this paper is to first form an educated guess that the process y_t follows an $MA(\infty)$ process of the fundamental η_t. Given the coefficients of the process, households only need to form predictions on the path of η_t, which can be done via a standard Kalman smoother.

The coefficients of the $MA(\infty)$ process can be pinned down by a fixed point problem in the impulse response function (IRF). This requires computing the IRF of consumption and therefore, the evolution of the beliefs. But given the coefficients of the process, only evolution of beliefs on η_t needs to be tracked which is also a standard application of the Kalman smoother.

Proposition 1 *The impulse response function for the aggregate output denoted by* $\boldsymbol{h}_y = \begin{bmatrix} \frac{dy_0}{d\eta_0} & \frac{dy_1}{d\eta_0} & \ldots \end{bmatrix}'$

is the solution of the following linear system

$$\boldsymbol{h}_{c,g} = (1-\beta_g)R\boldsymbol{L}\boldsymbol{h}_{s,g} - \beta_g\sigma_g(\boldsymbol{h}_\phi + \boldsymbol{W}_g\boldsymbol{h}_\phi) + (1-\beta_g)\lambda_g(\boldsymbol{h}_y + \boldsymbol{W}_g\boldsymbol{h}_y) \tag{9}$$

$$\boldsymbol{h}_{c,g} + \boldsymbol{h}_{s,g} = R\boldsymbol{L}\boldsymbol{h}_{s,g} + \lambda_g\boldsymbol{h}_y \tag{10}$$

$$\boldsymbol{h}_y = \sum_{g=1}^{G}\pi_g\boldsymbol{h}_{c,g} \tag{11}$$

where $\boldsymbol{h}_{c,g} = \begin{bmatrix}\frac{dc_{g,0}}{d\eta_0} & \frac{dc_{g,1}}{d\eta_0} & \dots\end{bmatrix}'$ *and* $\boldsymbol{h}_{s,g} = \begin{bmatrix}\frac{dc_{g,0}}{d\eta_0} & \frac{dc_{g,1}}{d\eta_0} & \dots\end{bmatrix}$ *are the IRFs for consumption and saving of group* g *respectively.* $\boldsymbol{L} = \begin{bmatrix}\mathbf{0}_{\infty\times 1} & \boldsymbol{I}\end{bmatrix}'$ *is the lag operator in the matrix form and* $\boldsymbol{W}_g$ *is the expectation matrix for* η_t*, where*

$$\boldsymbol{W}_g = \begin{bmatrix} m_g'\boldsymbol{M}_{g,0}^{\eta} \\ m_g'\boldsymbol{M}_{g,1}^{\eta} \\ \vdots \end{bmatrix}$$

with $m_g' = \begin{bmatrix}\beta_g & \beta_g^2 & \beta_g^3 & \dots\end{bmatrix}$ *and* $\boldsymbol{M}_{g,t}^{\eta} \equiv \begin{bmatrix} 0 & \frac{d\bar{E}_{g,t}[\eta_t]}{d\eta_0} & \frac{d\bar{E}_{g,t}[\eta_{t-1}]}{d\eta_0} & \dots \\ 0 & 0 & \frac{d\bar{E}_{g,t}[\eta_t]}{d\eta_s} & \dots \\ \vdots & \vdots & \vdots & \dots \end{bmatrix}$

The equation (9) comes from taking derivative of the optimal consumption. The $\boldsymbol{W}_g$ matrix tracks the update of the beliefs on η_t with proper weighting of the discount factors. The derivation is detailed in appendix B. The equation (11) is the market clearing condition in all periods and the equation (10) is the budget constraint.

Connection to Higher-Order Belief: The equations (9), (10), and (11) pin down the IRF for the aggregate output

$$\boldsymbol{h}_y = \boldsymbol{M}_\phi\boldsymbol{h}_\phi + \boldsymbol{M}_y\boldsymbol{h}_y \tag{12}$$

The exact formula for $\boldsymbol{M}_\phi$ and $\boldsymbol{M}_y$ are in the appendix B. Via repeated substitution, the IRF of the aggregate output is given by the IRFs of the ϕ

$$\boldsymbol{h}_y = \boldsymbol{M}_\phi \boldsymbol{h}_\phi + \boldsymbol{M}_y \boldsymbol{M}_\phi \boldsymbol{h}_\phi + \boldsymbol{M}_y^2 \boldsymbol{M}_\phi \boldsymbol{h}_\phi + \dots$$

This is analogous to the result in Beauty Contest that the equilibrium quantity is often the sum of higher-order beliefs (Angeletos and Lian (2022), Angeletos and Lian (2018), and Angeletos and Huo (2021)). The aggregate output can be neatly solved by inverting a matrix

$$\boldsymbol{h}_y = (\boldsymbol{I} - \boldsymbol{M}_y)^{-1} \boldsymbol{M}_\phi \boldsymbol{h}_\phi$$

Connection to Intertemporal MPC: In case of no imperfect information, it can be shown that matrix $\boldsymbol{M}_y$ reduces to a standard iMPC matrix in Auclert *et al.* (2018). The joint distribution of signal precisions, Exposures and MPCs determines the elements of $\boldsymbol{M}_y$.

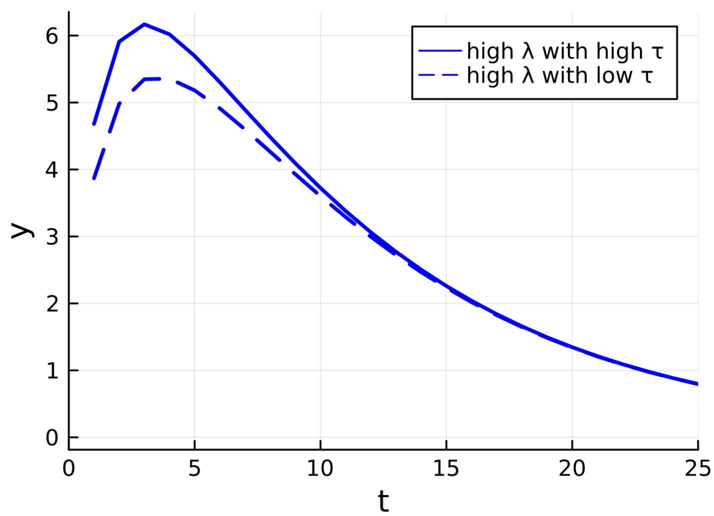
5 Role of Information Allocation

How does information interact with other household characteristics? I compare the IRFs for a discount factor shock ϕ_t under two economies with different information allocations. I set up an economy consisting of two groups of households with distinct non-belief characteristics and distinct signal precisions. Then, I compare it with another economy with same distribution of non-belief characteristics but opposite allocation of signal precisions. When high Exposure or low MPC or high EIS households receive higher quality signals, the output response is amplified.

5.1 Exposure and Information

Households' consumption depends on their future expected personal income. When the aggregate output increases, if high Exposure households have better information, they are more aware of future high increase of personal income. Alternatively, if the low Exposure households have better information, they are more aware of future increase of personal income but the increase in their expected life-time personal income is smaller due to the low Exposure. Therefore, allocating more information to high Exposure households causes bigger increases in consumption, which effectively increases the aggregate MPC of this economy.

Figure 2: Effect of information allocation to output under heterogeneity in cyclicality

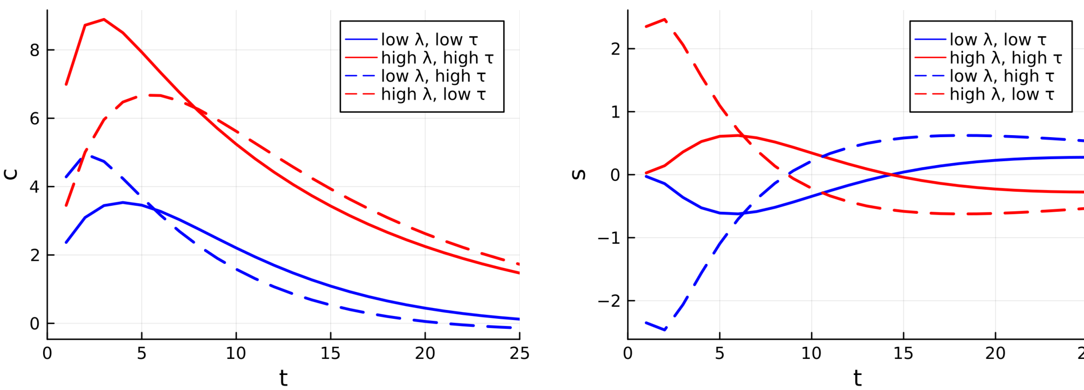


As shown in Figure 2, the economy with high exposure households receiving more precise signals has a higher output response. This is the channel highlighted by Guerreiro (2022).[1] From Figure 3, when there is a positive demand shock, in the economy of high Exposure having better information (solid line), high Exposure households increase consumption massively, compared to high Exposure households in the alternative econ-

[1]Guerreiro (2022) uses cognitive discounting instead of dynamic noisy signals. Both of them dampen the GE response.

omy.

Figure 3: Effect of information allocation to consumption and saving under heterogeneity in cyclicality



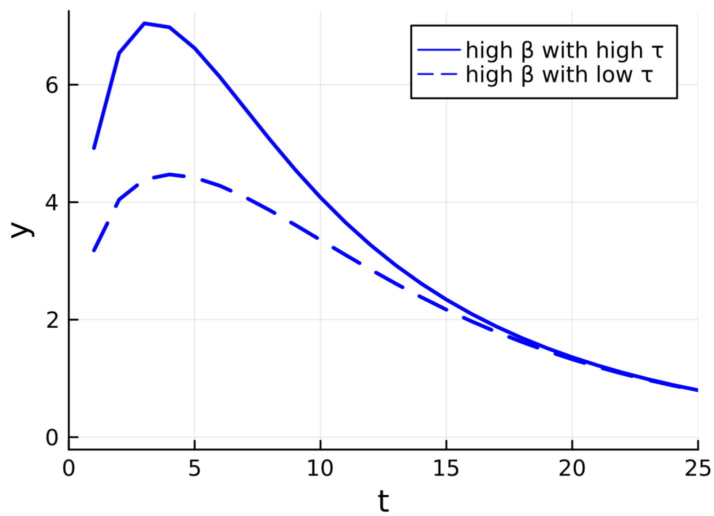
5.2 MPC and Information

MPC affects how forward-looking a household is in a consumption-saving decision. The higher the MPC, the more the consumption depends on expectations of future variables. The effect of information comes in two ways. First, when there is a positive discount factor shock, if low MPC (high discount factor) households have better information, their expectation about future discount factor shock adjusts more rapidly and their consumption response is larger because they put more weights on future variables. If high MPC (low discount factor) households have better information, their expectation adjusts quickly, but their consumption response is limited.

Second, in case of an increase in aggregate output, if low MPC (high discount factor) households have better information, their expectation about future aggregate income increases rapidly and their consumption response is more persistent. Instead, if high MPC (low discount factor) households have better information, their expectation about future aggregate income increases rapidly but their consumption response concentrates on the short run. The effective aggregate MPC can go to both directions.

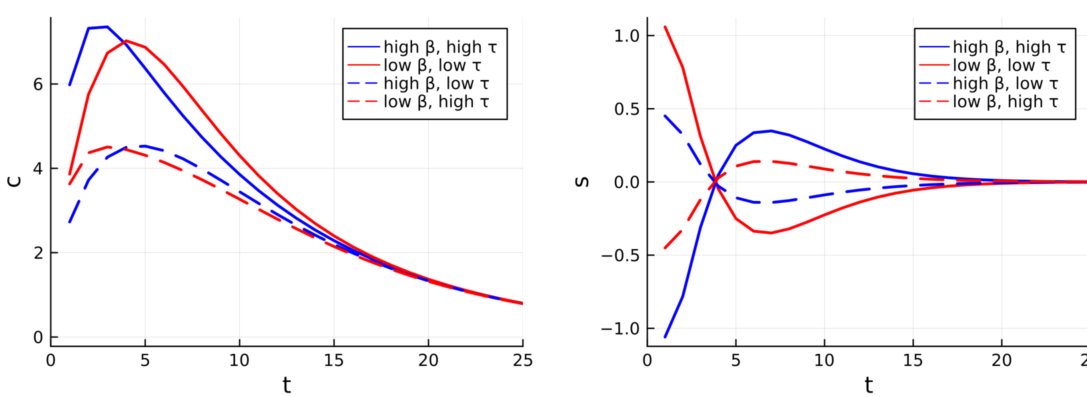
In other words, allocating more information between households with different MPCs has a definite effect on the direct exposure to demand shock $\boldsymbol{M}_r$ but a ambiguous effect on the effective MPC matrix $\boldsymbol{M}_y$

Figure 4: Effect of information allocation to output under heterogeneity in MPC



As shown in Figure 2, the economy with low MPC households receiving more precise signals produce a higher output response. In Figure 7, the allocation of information has a huge impact to the consumption of each group.

Figure 5: Effect of information allocation to consumption and saving under heterogeneity in MPC



5.3 EIS and Information

EIS affects how susceptible a household is to a shock to discount rate. When there is a positive discount factor shock, if high EIS households have better information, their expectation about the future discount factors adjust more rapidly and their consumption response is bigger since they are more susceptible to shocks to discount rate. Relative to the other two channels, this operates only through M_r.

Figure 6: Effect of information allocation to output under heterogeneity in EIS

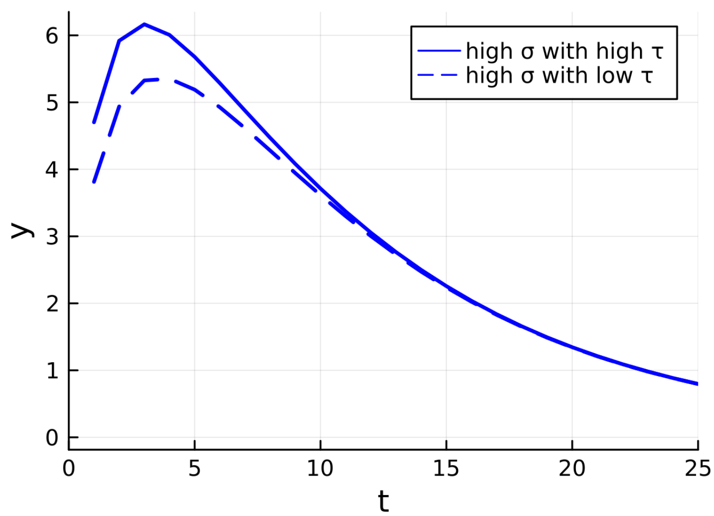
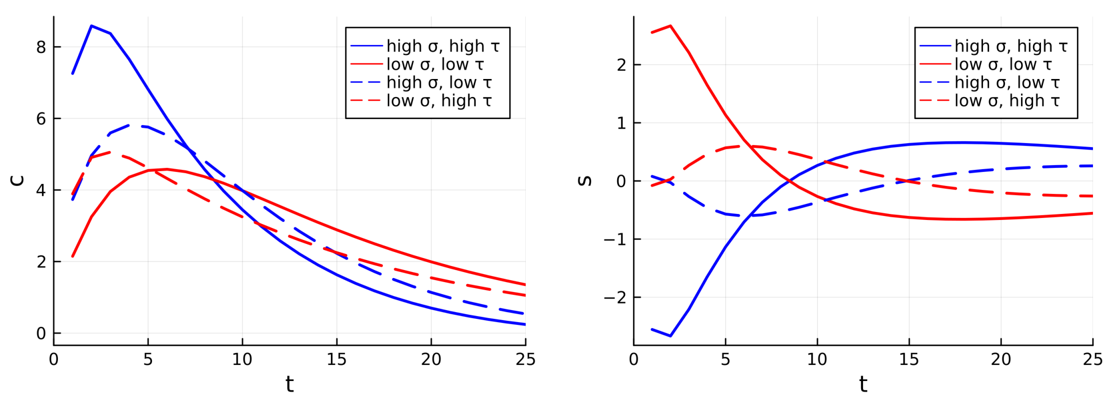


Figure 7: Effect of information allocation to consumption and saving under heterogeneity inEIS



6 Quantitative Exercise

This section investigates the importance of belief heterogeneity through a fully calibrated model. I divide the population into eight groups. Each group is characterized by high or low MPC, EIS and Exposure. I estimate the correlation of each group's forecast to business cycle fluctuations. Table 2 shows the parameters for the eight groups.

	σ_g	β_g	λ_g	$\alpha_{1,g}$	π_g
1	1.00	0.49	2.32	0.29	0.02
2	1.00	0.49	0.69	0.19	0.20
3	0.10	0.49	2.32	0.12	0.03
4	0.10	0.49	0.69	0.12	0.28
5	1.00	0.95	2.32	0.18	0.12
6	1.00	0.95	0.69	0.23	0.28
7	0.10	0.95	2.32	0.09	0.02
8	0.10	0.95	0.69	0.13	0.05

Table 2: Calibration of the Eight Groups

The group with high EIS, high MPC and high exposure (Group 1) changes their forecast most rapidly in response to the business cycle fluctuations. However, it is one of the smallest group whose impact to the economy is limited. The group with low EIS, high MPC and low exposure (Group 4) and the group with high EIS, low MPC and low exposure (Group 6) highlight the importance of belief heterogeneity. Each of them represents over a quarter of population and their beliefs fluctuates differently along the business cycle.

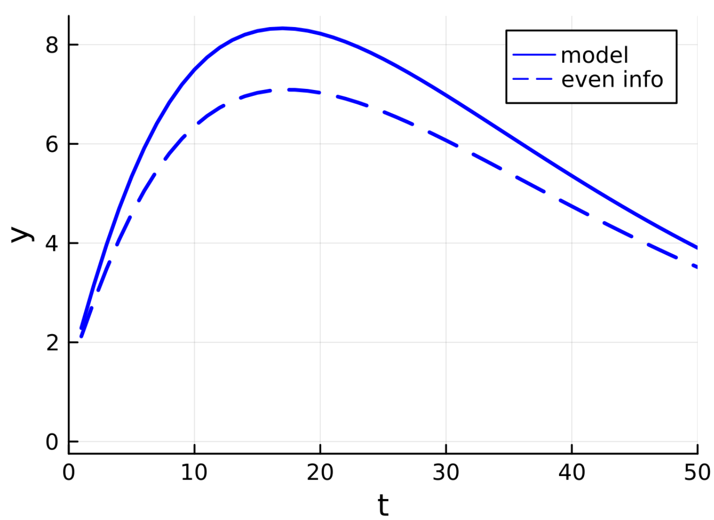
I calibrate the signal precision τ_g^x for each group to match the empirical regression coefficient between group forecast on unemployment changes and realized unemployment changes. This requires computing the analogous regression coefficient in the model. The computation of such coefficient can be performed efficiently, which is documented in Appendix B.5 in detail. $\rho = 0.96$ and $\tau_\eta = 1/4$ are picked to match the time-series properties of the unemployment rate from 1980 to 2019. The calibrated τ_g^x is listed below.

$$\begin{bmatrix} 0.0032 & 0.0013 & 0.00067 & 0.00065 & 0.0012 & 0.0019 & 0.00044 & 0.00071 \end{bmatrix}$$

6.1 Effect of Belief Heterogeneity

How important is belief heterogeneity? In this section, I compare the impulse response function of a demand shock in the calibrated model with an equal information model that has no belief heterogeneity. To construct this equal information model, I reallocate the information set such that for every combination of MPC, EIS and Exposure, there are eight subgroups with signal precision and shares matched to the overall population. This effectively creates $8 \times 8 = 64$ groups and removes the correlation between non-belief characteristics (MPC, EIS and Exposure) and signal quality.

Figure 8: Effect of information allocation to output



As shown in Figure 8, the calibrated economy with belief heterogeneity significantly amplifies the demand shock compared to the economy with equal distribution of information. Figure 9 shows that all eight types of households have higher consumption than the average counterpart in the equal information economy. To understand the mechanism, I decompose the effect of the shock into a direct channel through the demand shock

(PE effect) and an indirect channel through the feedback of income (GE effect).

First, the direct effect is more pronounced in the calibrated economy. This is because high EIS and low MPC households are more informed about the economy in the data. In the equal information economy, when more information is reallocated from high EIS and low MPC households (Group 6) to low EIS and high MPC group (Group 4), the former responds less to the shock while the latter responds roughly the same. Even though Group 7 and Group 8 respond more under the equal information economy in Figure 10, their total share is too small. This leads to an overall increase in PE effect.

Second, the GE effect is also bigger in the calibrated economy. Figure 11 shows that all groups have higher consumption response through the GE effect. To understand the mechanism better, I calculate the GE effects under the same path of output.

In Figure 12, information has very little effect to the high MPC groups, because their consumption mostly follows the current output. The only exception is households with low MPC and high EIS (group 6). When they are more informed, they shifted their spending earlier, which pushes up the aggregate output in the earlier periods. This eventually feeds back to high MPC groups. All in all, the belief heterogeneity has a significant impact to transmission of the demand shock.

7 Conclusion

To conclude, I argue that belief heterogeneity of households is important. Empirically, I show that low MPC and high EIS households adjust their macroeconomic expectations more rapidly in response to the business cycle. Through a heterogeneous-agent incomplete information model, I show that this difference is quantitatively important as information allocation has a huge impact to amplification of demand shocks as well as consumption heterogeneity.

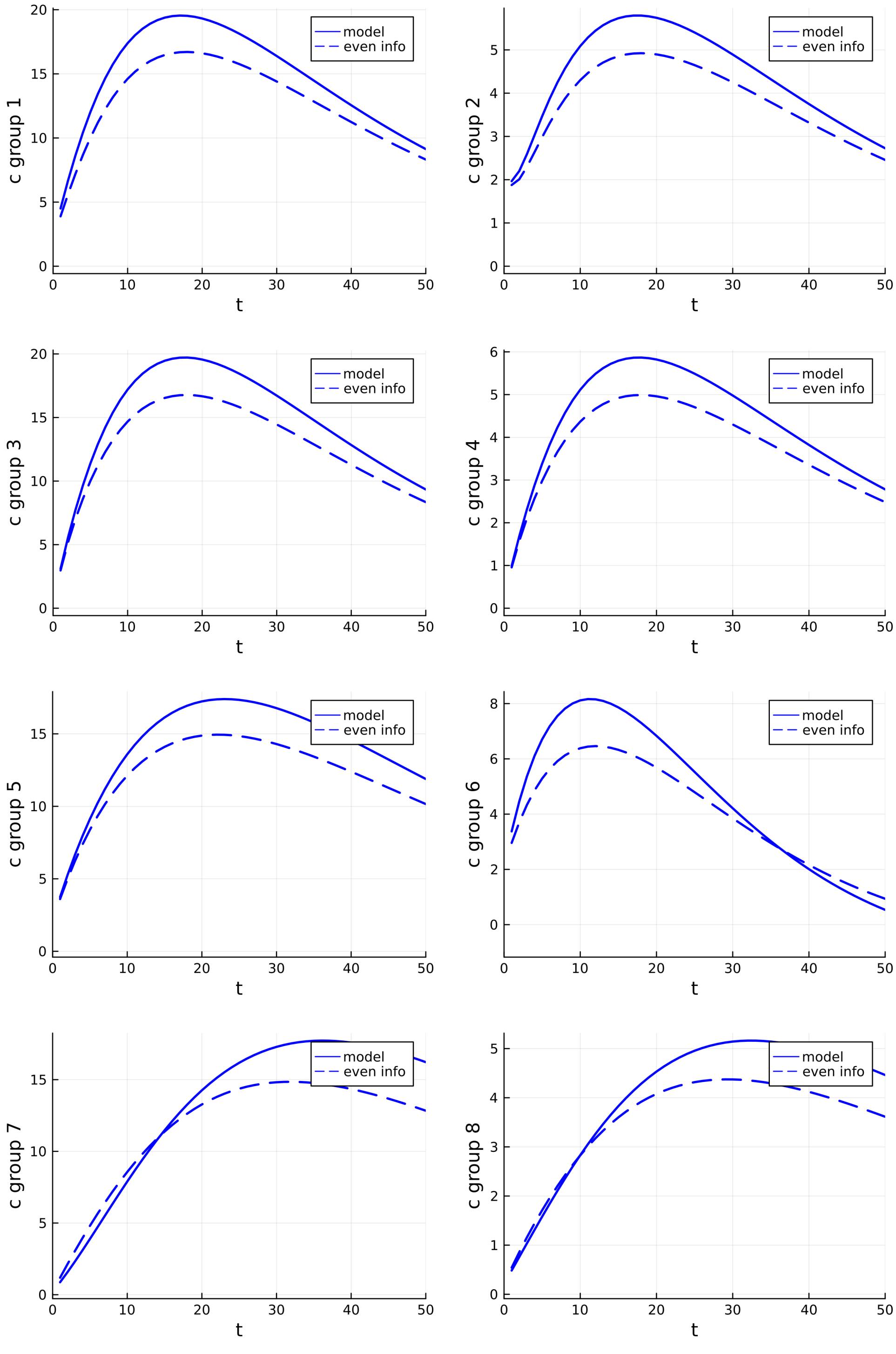


Figure 9: Consumption response for all eight groups

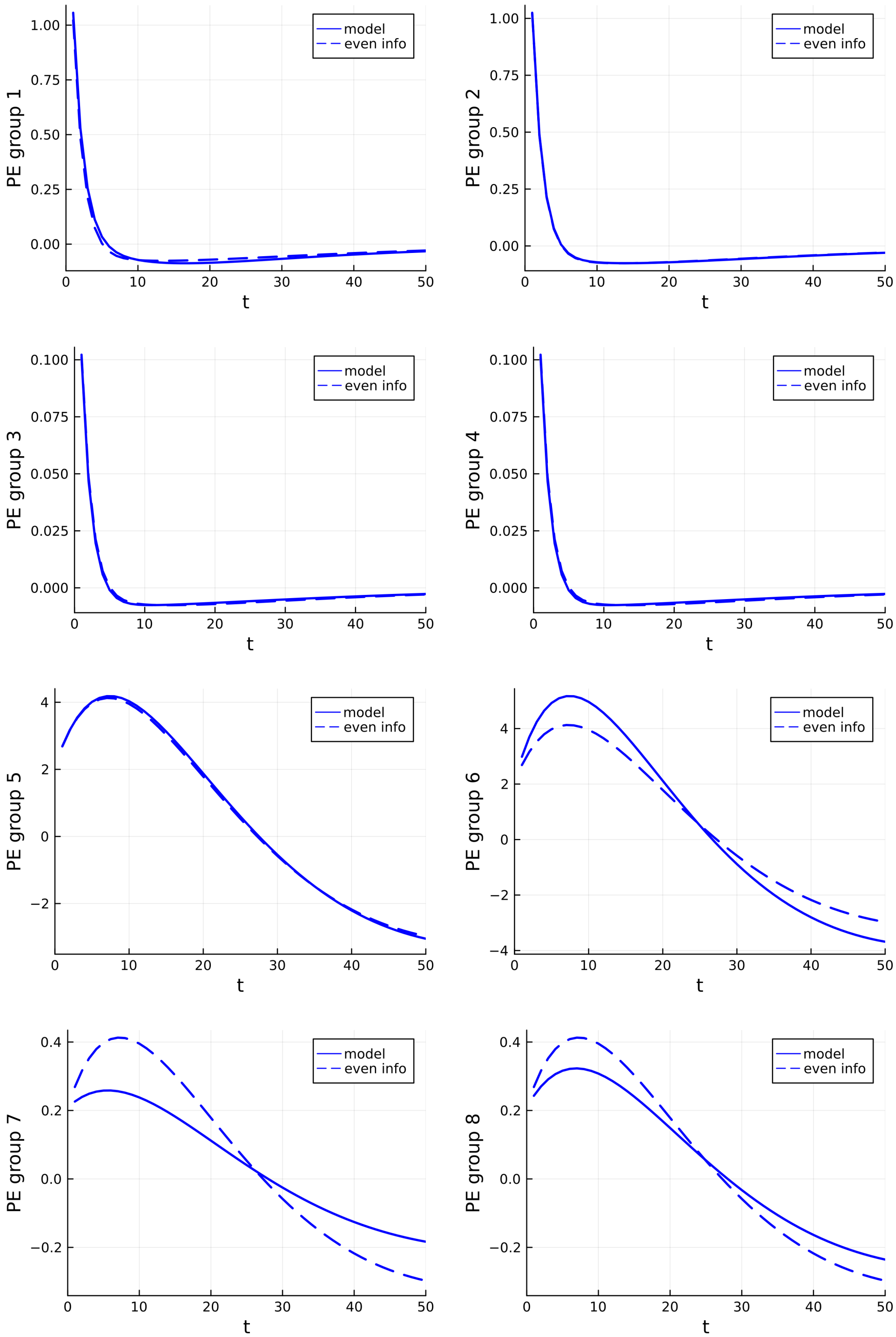


Figure 10: Direct effect for all eight groups

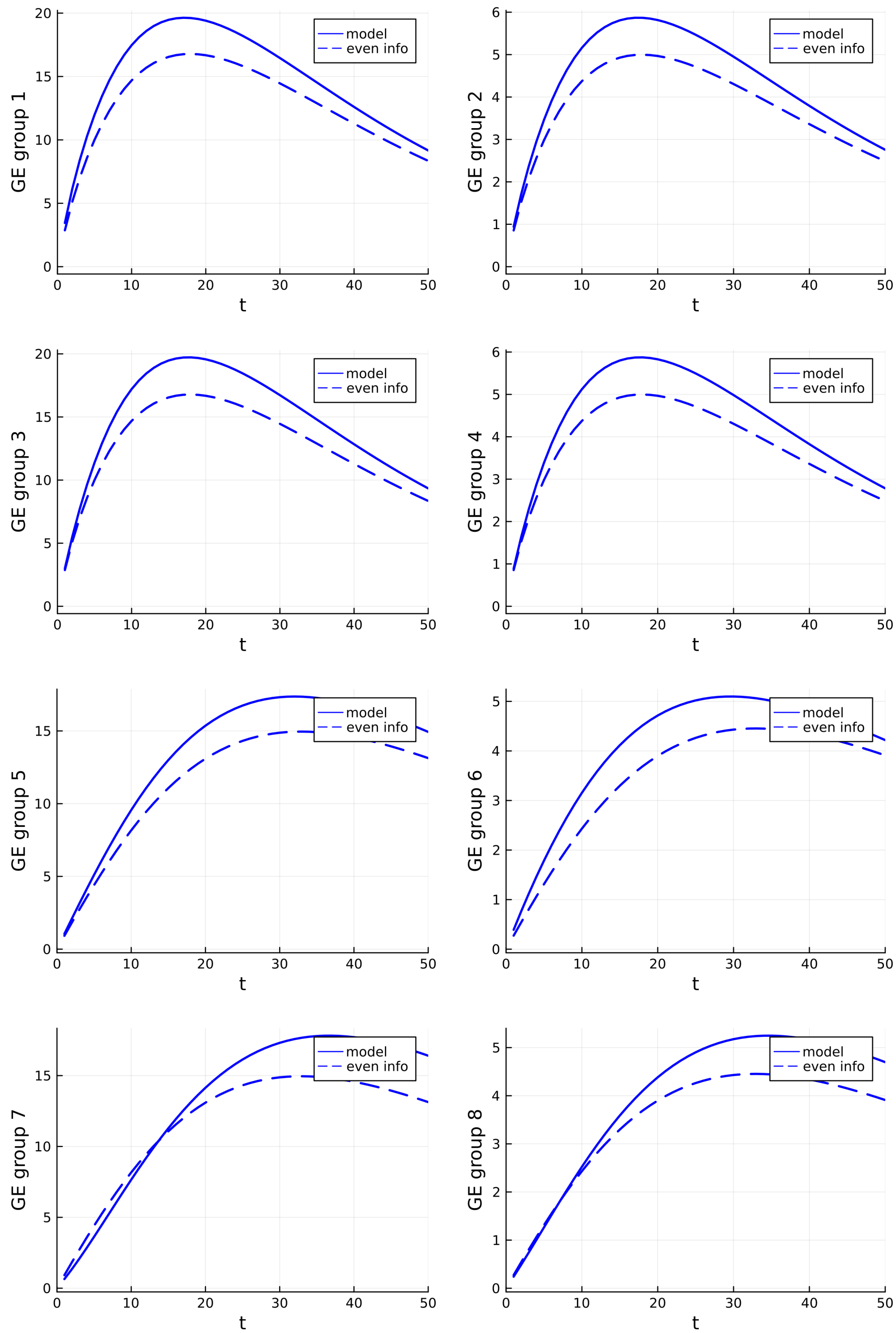


Figure 11: Indirect effect for all eight groups

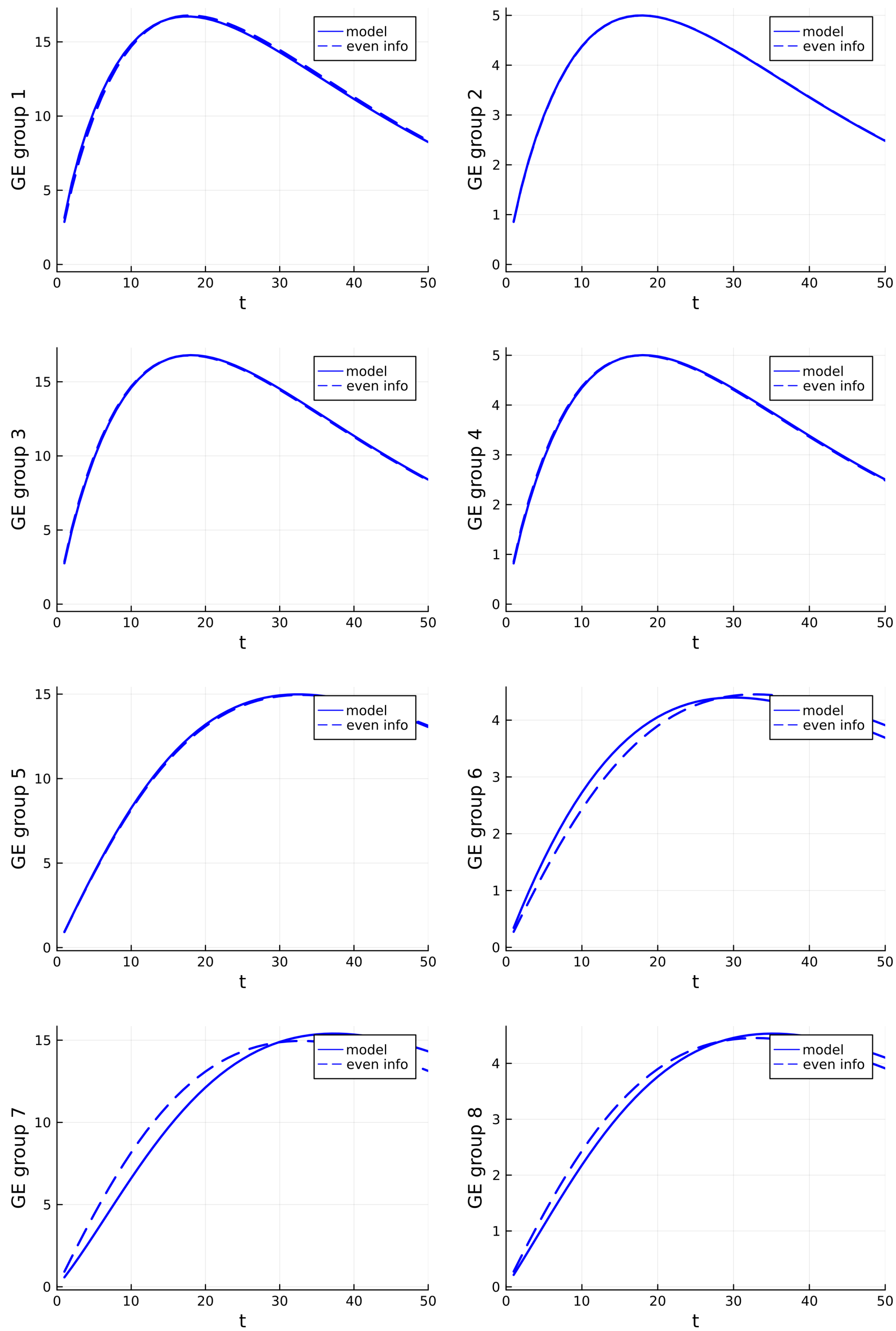


Figure 12: Indirect effect for all eight groups (same $\boldsymbol{h}_y$)

A Log-linearization

This section documents the detail of log-linearizing the household problem. The derivation is similar to the one in Bilbiie (2020).

We begin by deriving its deterministic steady state without any shock. Let the Lagrange multiplier on the budget constraint to be $(\chi\omega_g)^{t-\tau}\mu_t$. The FOCs are

$$(1/\sigma_g + 1)\Phi_{i,t}(C_{i,g,\tau;t})^{1/\sigma_g} = \mu_t$$
$$-\mu_t + \frac{R}{\omega_g}\mu_{t+1}\chi\omega_g = 0$$

This implies the usual Euler equation of

$$(C_{i,g,\tau;t})^{1/\sigma_g} = R\chi\frac{\Phi_{i,t+1}}{\Phi_{i,t}}(C_{i,g,\tau;t+1})^{1/\sigma_g}$$

In the steady state of $R_t\chi = 1$ and $\Phi_t = 1$. The consumption is simply constant.

We log-linearize the solution around a steady state $\chi_t R = 1$ and $C_t = Y_t$. For the budget constraint

$$dC_{i,g,\tau;t} + dS_{i,g,\tau;t} = \frac{R}{\omega_g}dS_{i,g,\tau;t-1} + \lambda_g(Y_t)^{\lambda_g - 1}dY_t$$
$$c_{i,g,\tau;t} + s_{i,g,\tau;t} = \frac{1}{\chi\omega_g}s_{i,g,\tau;t-1} + \lambda_g Y^{\lambda_g - 1}y_t$$
$$c_{i,g,\tau;t} + s_{i,g,\tau;t} = \frac{1}{\chi\omega_g}s_{i,g,\tau;t-1} + \lambda_g y_t + \epsilon^y_{i,t}$$

where $c_{i,g,\tau;t}$ is the log-derivation from the steady state of $C_{i,g,\tau;t}$ and $s_{i,g,\tau;t}$ is the absolute derivation from the steady state $dS_{i,g,\tau;t}/Y$.

The budget constraint holds for all t. Thus, the life-time budget constraint is given by

$$c_{i,g,\tau,t} + \sum_{k=1}^{\infty}(\chi\omega_g)^k E_t[c_{i,g,\tau;t+k}] = \frac{1}{\chi\omega_g}s_{i,g,\tau;t-1} + \lambda_g y_t + \epsilon^y_{i,t} + \sum_{k=1}^{\infty}(\chi\omega_g)^k\lambda_g E_t[y_{i,t+k}]$$

For the Euler equation,

$$
\begin{aligned}
(C_{i,g,\tau;t})^{1/\sigma_g} &= R\chi\frac{\Phi_{i,t+1}}{\Phi_{i,t}}C_{i,g,\tau;t+1}^{1/\sigma_g} \\
\implies \log(C_{i,g,\tau;t}) &= \log(R\chi) + \sigma_g\log(\frac{\Phi_{i,t+1}}{\Phi_{i,t}}) + \log(C_{i,g,\tau;t+1}) \\
\implies E_{i,g,\tau;t}[c_{i,g,\tau;t+1}] &= c_{i,g,\tau;t} + \sigma_g\phi_{i,t} \\
\implies E_{i,g,\tau;t}[c_{i,g,\tau;t+k}] &= c_{i,g,\tau;t} + \sigma_g\phi_{i,t} + \sigma_g\sum_{j=1}^{k-1}E_{i,g,\tau;t}[\phi_{t+j}]
\end{aligned}
$$

where ϕ_{imt} is the log deviation of $\frac{\Phi_{i,t+1}}{\Phi_{i,t}}$.

Combining the two equations together to obtain the optimal consumption function

$$
\begin{aligned}
&\frac{1}{1-\chi\omega_g}c_{i,g,\tau;t} + \sigma_g\frac{\chi\omega_g}{1-\chi\omega_g}\phi_t + \sigma_g\sum_{k=1}^{\infty}\frac{(\chi\omega_g)^{k+1}}{1-\chi\omega_g}E_{i,g,\tau;t}[\phi_{t+k}] = \frac{1}{\chi\omega_g}s_{i,g,\tau;t-1} + \lambda_g y_t + \sum_{k=1}^{\infty}(\chi\omega_g)^k\lambda_g E_{i,g,\tau
\end{aligned}
$$

$$
\begin{aligned}
\implies c_{i,g,\tau;t} =& \frac{1-\chi\omega_g}{\chi\omega_g}s_{i,g,\tau;t-1} - \chi\omega_g\sigma_g\big[\phi_{i,t} + \sum_{k=1}^{\infty}(\chi\omega_g)^k E_{i,g,\tau;t}[\phi_{i,t+k}]\big] \\
&+ (1-\chi\omega_g)\lambda_g\big[y_{i,t} + \sum_{k=1}^{\infty}(\chi\omega_g)^k E_{i,g,\tau;t}[y_{i,t+k}]\big]
\end{aligned}
$$

The average consumption of group g in period t is given by

$$
c_{g,t} = (1-\omega_g)\sum_{j=0}^{\infty}(\omega_g)^j\int c_{i,g,t-j,t}di
$$

and the total annuity held by the end of the period $t-1$ is given by

$$
(1-\omega_g)\sum_{j=0}^{\infty}(\omega_g)^j s_{g,t-1-j,t-1}
$$

which has only ω_g of them remain in the next period. Thus, the aggregate annuity held by group g at the beginning of t is

$$\omega_g s_{g,t-1} = (1-\omega_g)\sum_{j=0}^{\infty}(\omega_g)^j s_{g,t-1-j,t-1} \tag{13}$$

Let $\beta_g = \chi\omega_g$ be the effective discount factor. The optimal consumption function is

$$c_{g,t} =(1-\beta_g)Rs_{g,t-1} - \beta_g\sigma_g\big[\phi_t + \sum_{k=1}^{\infty}(\beta_g)^k \bar{E}_{g,t}[\phi_{t+k}]\big] + (1-\beta_g)\lambda_g\big[y_t + \sum_{k=1}^{\infty}(\beta_g)^k \bar{E}_{g,t}[y_{t+k}]\big] \tag{14}$$

The group level budget constraint is given by

$$c_{g,t} + s_{g,t} = \frac{1}{\chi}s_{g,t-1} + \lambda_g y_t$$

B Deriving the IRFs

Guess that the solution of the model is an $MA(\infty)$ process of η_t. Specifically,

$$y_t = h_y(L)\eta_t = h_{y,0}\eta_t + h_{y,1}\eta_{t-1} + h_{y,2}\eta_{t-2} + ... \tag{15}$$

Notice that the Impulse Response Function for a one-time shock η_t is IRF$(s) = h_s$. Next step is to construct the IRF for consumption.

B.1 IRF for $c_{g,t}$

For $t = 0, 1, 2, \dots$

$$
\begin{aligned}
\frac{dc_{g,t}}{d\eta_0} =& (1-\beta_g) R \frac{ds_{g,t-1}}{d\eta_0} \\
& - \beta_g \sigma_g \Big[\frac{d\phi_t}{d\eta_0} + \sum_{k=1}^{\infty} (\beta_g)^k \frac{d\bar{E}_{g,t}[\phi_{t+k}]}{d\eta_0} \Big] \\
& + (1-\beta_g) \lambda_g \Big[\frac{dy_t}{d\eta_0} + \sum_{k=1}^{\infty} (\beta_g)^k \frac{d\bar{E}_{g,t}[y_{t+k}]}{d\eta_0} \Big]
\end{aligned}
$$

Collecting the IRF of the consumption of group g gives

$$
\boldsymbol{h}_{c,g} = (1-\beta_g) R \boldsymbol{L} \boldsymbol{h}_{s,g} - \beta_g \sigma_g (\boldsymbol{h}_\phi + \begin{bmatrix} m_g' \boldsymbol{E}^\phi_{g,1} \\ m_g' \boldsymbol{E}^\phi_{g,2} \\ \vdots \end{bmatrix}) + (1-\beta_g) \lambda_g (\boldsymbol{h}_y + \begin{bmatrix} m_g' \boldsymbol{E}^y_{g,1} \\ m_g' \boldsymbol{E}^y_{g,2} \\ \vdots \end{bmatrix})
$$

where $\boldsymbol{h}_{c,g}$ is the IRF of the consumption for group g, $\boldsymbol{h}_{c,g} = \begin{bmatrix} \frac{dc_{g,0}}{d\eta_0} & \frac{dc_{g,1}}{d\eta_0} & \frac{dc_{g,2}}{d\eta_0} & \dots \end{bmatrix}.$, $\boldsymbol{h}_\phi = \begin{bmatrix} \frac{d\phi_0}{d\eta_0} & \frac{d\phi_1}{d\eta_0} & \frac{d\phi_2}{d\eta_0} & \dots \end{bmatrix}$, $\boldsymbol{h}_y$ is the IRF of the output, $\boldsymbol{h}_y = \begin{bmatrix} \frac{dy_0}{d\eta_0} & \frac{dy_1}{d\eta_0} & \frac{dy_2}{d\eta_0} & \dots \end{bmatrix}$, and $\boldsymbol{h}_{s,g}$ is the IRF for the saving in group g. $\boldsymbol{h}_{s,g} = \begin{bmatrix} \frac{ds_{g,0}}{d\eta_0} & \frac{ds_{g,1}}{d\eta_0} & \frac{ds_{g,2}}{d\eta_0} & \dots \end{bmatrix}$. $\boldsymbol{L}$ is the lag operator in matrix form $\boldsymbol{L} = \begin{bmatrix} 0_{1\times\infty} \\ I \end{bmatrix}$

The $\boldsymbol{E}^\phi_{g,t}$ and $\boldsymbol{E}^y_{g,t}$ are the IRF for the average forecast of the future ϕ_{t+k} and y_{t+k} repectively using the information at time t.

$$
\begin{aligned}
\boldsymbol{E}^\phi_{g,t} &= \begin{bmatrix} \frac{d\bar{E}_{g,t}[\phi_{t+1}]}{d\eta_0} & \frac{d\bar{E}_{g,t}[\phi_{t+2}]}{d\eta_0} & \dots \end{bmatrix}' \\
\boldsymbol{E}^y_{g,t} &= \begin{bmatrix} \frac{d\bar{E}_{g,t}[y_{t+1}]}{d\eta_0} & \frac{d\bar{E}_{g,t}[y_{t+2}]}{d\eta_0} & \dots \end{bmatrix}'
\end{aligned}
$$

Finally, the forecast at each horizon is weighted by the proper discount factors given by

$$m_g' = \begin{bmatrix} \beta_g & \beta_g^2 & \beta_g^3 & \dots \end{bmatrix}$$

B.2 Expectation Vector

Since we assume y_t and ϕ_t to be an $MA(\infty)$ process of η_t, we can express $\boldsymbol{E}_{g,t}^y$ in terms of $\boldsymbol{h}_y$. For $k \geq 0$

$$E_{i,g,t}[y_{t+k}] = h_0 \underbrace{E_{i,g,t}[\eta_{t+k}]}_{=0} + h_1 \underbrace{E_{i,g,t}[\eta_{t+k-1}]}_{=0} + \dots + h_k E_{i,g,t}[\eta_t] + h_{k+1} E_{i,g,t}[\eta_{t-1}] + \dots$$

Taking average and differentiating with η_0 yield

$$\frac{d\bar{E}_{g,t}[y_{t+k}]}{d\eta_0} = h_k \frac{d\bar{E}_{g,t}[\eta_t]}{d\eta_0} + h_{k+1} \frac{d\bar{E}_{g,t}[\eta_{t-1}]}{d\eta_0} + \dots$$

The expectation vector $\boldsymbol{E}_{g,t}^y$ can be written as

$$\boldsymbol{E}_t^y \equiv \begin{bmatrix} \frac{d\bar{E}_t[y_{t+1}]}{d\eta_0} \\ \frac{d\bar{E}_t[y_{t+2}]}{d\eta_0} \\ \vdots \end{bmatrix} = \underbrace{\begin{bmatrix} 0 & \frac{d\bar{E}_t[\eta_t]}{d\eta_0} & \frac{d\bar{E}_t[\eta_{t-1}]}{d\eta_0} & \dots \\ 0 & 0 & \frac{d\bar{E}_t[\eta_t]}{d\eta_s} & \dots \\ \vdots & \vdots & \vdots & \dots \end{bmatrix}}_{\equiv \boldsymbol{M}_t^\eta} \boldsymbol{h}_y$$

where $\boldsymbol{M}_t^\eta$ captures the IRF to the expectation of all the past η_t. To compute $\boldsymbol{M}_t^\eta$, one can use a standard Wiener-Hopf filter

$$\bar{E}_{g,t}[\eta_{t-k}] = \frac{\gamma_g \tau_{g,u}}{\rho \tau_\eta} (L^k + \gamma_g L^{k-1} + \dots + \gamma_g^{k-1} L + \gamma_g^k)(1 + \gamma_g L + \gamma_g^2 L^2 + \dots)\eta_t \tag{16}$$

where $\gamma_g = \frac{1}{2}\big[\rho + \frac{1}{\rho}(1 + \tau_g^x/\tau^\phi) - \sqrt{(\rho + \frac{1}{\rho}(1 + \tau_g^x/\tau^\phi))^2 - 4}\big]$. The coefficients of the process in 16 represent the IRF for the $\bar{E}_{g,t}[\eta_{t-k}]$, which can be used to fill up $\boldsymbol{M}_t^\eta$

To simplify the notation, we let

$$\boldsymbol{W}_g \equiv \begin{bmatrix} m_g' \boldsymbol{M}_0^\eta \\ m_g' \boldsymbol{M}_1^\eta \\ \vdots \end{bmatrix}$$

B.3 Final System

The consumption IRF becomes

$$\boldsymbol{h}_{c,g} = (1-\beta_g)R\boldsymbol{L}\boldsymbol{h}_{s,g} - \beta_g\sigma_g(\boldsymbol{h}_\phi + \boldsymbol{W}_g\boldsymbol{h}_\phi) + (1-\beta_g)\lambda_g(\boldsymbol{h}_y + \boldsymbol{W}_g\boldsymbol{h}_y)$$

The IRF of the group level budget constraint and the market clearing condition comes from taking the derivative with respect to η_0. Collecting all of them into a vector yields

$$\boldsymbol{h}_{c,g} + \boldsymbol{h}_{s,g} = R\boldsymbol{L}\boldsymbol{h}_{s,g} + \lambda_g\boldsymbol{h}_y$$

and

$$\boldsymbol{h}_y = \sum_g \pi_g \boldsymbol{h}_{c,g}$$

B.4 Solving the IRF for y_t

The IRF for the wealth is the compounded IRF of saving

$$\boldsymbol{h}_{s,g} = (1 - R\boldsymbol{L})^{-1}(\lambda_g\boldsymbol{h}_y - \boldsymbol{h}_{c,g})$$

$$\boldsymbol{h}_{c,g} = (1-\beta_g)\underbrace{R\boldsymbol{L}(1-R\boldsymbol{L})^{-1}}_{\equiv \boldsymbol{A}}(\lambda_g \boldsymbol{h}_y - \boldsymbol{h}_{c,g}) - \beta_g\sigma_g(\boldsymbol{h}_\phi + W_g\boldsymbol{h}_\phi) + (1-\beta_g)\lambda_g(\boldsymbol{h}_y + W_g\boldsymbol{h}_y)$$

$$(\boldsymbol{I} + (1-\beta_g)\boldsymbol{A})\boldsymbol{h}_{c,g} = -\beta_g\sigma_g(\boldsymbol{I} + \boldsymbol{W}_g)\boldsymbol{h}_\phi + (1-\beta_g)\lambda_g(\boldsymbol{A} + \boldsymbol{I} + \boldsymbol{W}_g)\boldsymbol{h}_y$$

$$\boldsymbol{h}_{c,g} = -\beta_g\sigma_g\boldsymbol{B}_g(\boldsymbol{I} + \boldsymbol{W}_g)\boldsymbol{h}_\phi + (1-\beta_g)\lambda_g\boldsymbol{B}_g(\boldsymbol{A} + \boldsymbol{I} + \boldsymbol{W}_g)\boldsymbol{h}_y$$

with $\boldsymbol{B}_g = (\boldsymbol{I} + (1-\beta_g)\boldsymbol{A})^{-1}$. Let $\boldsymbol{M}_\phi = \sum_g^G \pi_g(-\beta_g\sigma_g\boldsymbol{B}_g(\boldsymbol{I} + \boldsymbol{W}_g))$ and $\boldsymbol{M}_y = \sum_g^G \pi_g(1-\beta_g)\lambda_g\boldsymbol{B}_g(\boldsymbol{A} + \boldsymbol{I} + \boldsymbol{W}_g)$ Now, we have a system for pinning down the $\boldsymbol{h}_y$

$$\boldsymbol{h}_y = \sum_g^G \pi_g\boldsymbol{h}_{c,g} = \boldsymbol{M}_\phi\boldsymbol{h}_\phi + \boldsymbol{M}_y\boldsymbol{h}_y$$

B.5 Calculating the Theoretical Regression Coefficient

C Data Description

More details for the data part

D Estimating μ

The Michigan Survey records only the qualitative responses, “increase", “no change" or “decrease". I extended the method in Carlson and Parkin (1975), Mankiw *et al.* (2003) and Bhandari *et al.* (2019) to estimate the average quantitative belief of each subgroup.

Individual i in group g makes a forecast $y^f_{i,g,t}$ about an macroeconomic variable y_t. The forecast $y^f_{i,g,t}$ follows a distribution

$$y^f_{i,g,t} \sim N(\mu_{g,t}, \sigma^2_{g,t})$$

Our goal is to estimate the group average forecast, $\mu_{g,t}$ and use it to study the relationship with y_t.

Following the assumptions in the literature, I assume that households answer "increase" or "decrease" only when their forecast exceeds the thresholds. Let $y^*_{i,g,t}$ be the response to the survey

$$y^*_{i,g,t} = \begin{cases} \text{“increase"} & \text{if } y^f_{i,g,t} > a \\ \text{“no change"} & \text{if } -a \leq y^f_{i,g,t} \leq a \\ \text{“decrease"} & \text{if } y^f_{i,g,t} < -a \end{cases}$$

Thus,

$$P(y^*_{i,g,t} = \text{“increase"}) = 1 - \Phi(\frac{a - \mu_{g,t}}{\sigma^2_{g,t}})$$

and

$$P(y^*_{i,g,t} = \text{“decrease"}) = \Phi(\frac{-a - \mu_{g,t}}{\sigma^2_{g,t}})$$

We have two data point to pin down $\{a, \mu_{g,t}, \sigma_{g,t}\}$ so we still need one more data point. Both SPF and Michigan Survey asked the respondents to give a quantitative forecast for inflation. In addition, forecasters in SPF were asked to forecast other macroeconomic variables, such as unemployment. Following Bhandari *et al.* (2019), we assume that the ratio of cross-sectional dispersion of forecasts between the survey respondents in SPF and Michigan Survey is constant across other macroeconomic variables. This allows us to infer the overall dispersion of the forecasts in Michigan Survey. a is picked to match this value.

E Forecast by Groups

E.1 Time Series of Forecasts by Groups

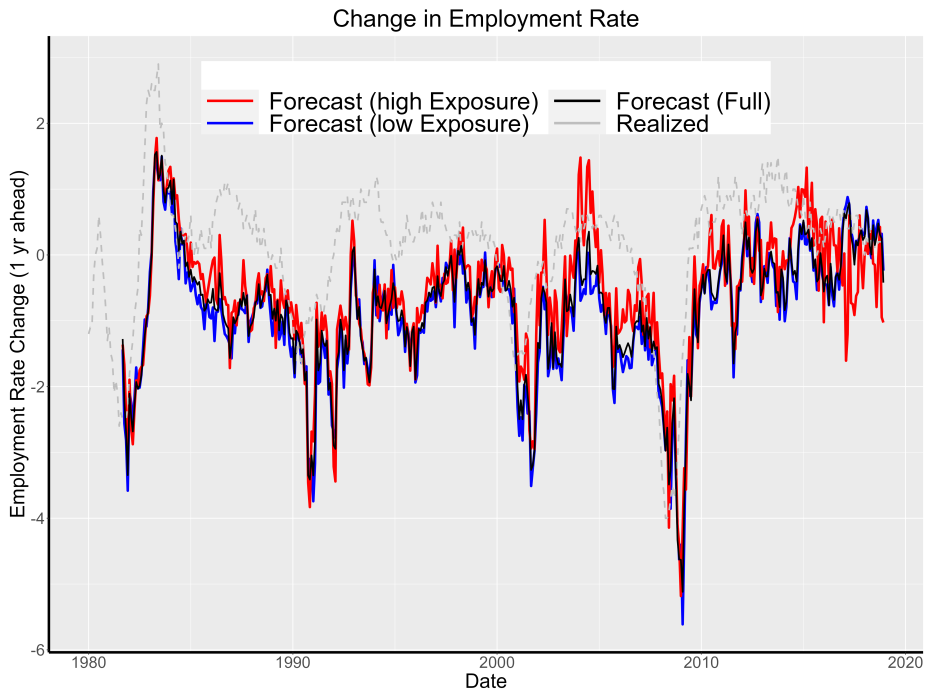


Figure 13: Forecasts by Exposures group

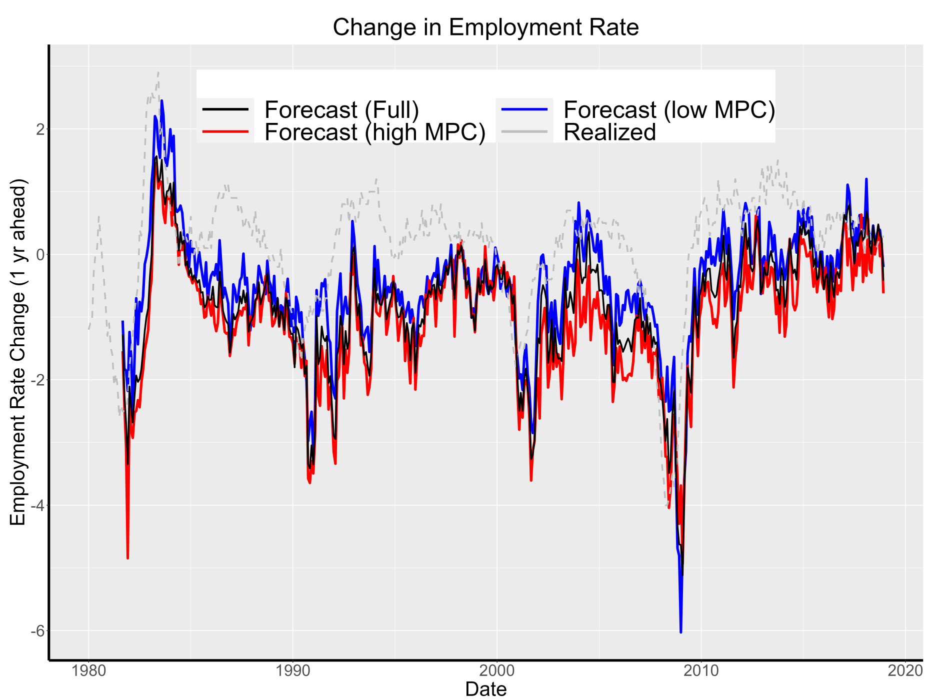


Figure 14: Forecasts by MPCs group

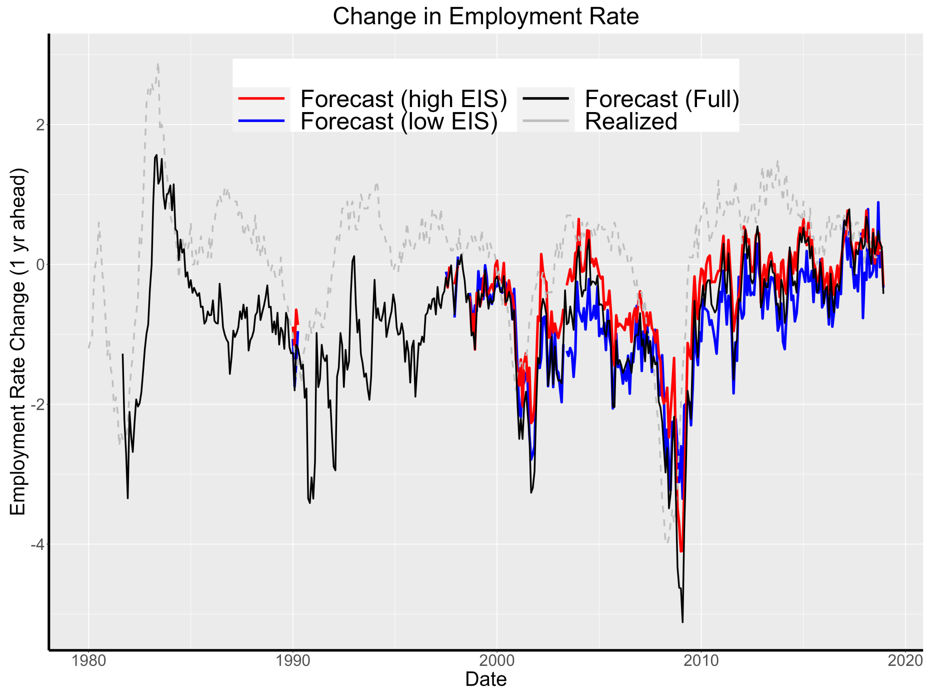


Figure 15: Forecasts by EISs (Proxy by Stock Market Participation) group

E.2 Regression of Forecasts by Groups

Table 3: Forecast by Exposures on Realized Employment Change

	Dependent variable:		
	Full	High Exposure	Low Exposure
	(1)	(2)	(3)
Realized	0.278***	0.264***	0.286***
	(0.028)	(0.031)	(0.029)
Constant	−0.760***	−0.563***	−0.817***
	(0.043)	(0.047)	(0.044)
Observations	490	490	490
R^2	0.164	0.129	0.166
Adjusted R^2	0.162	0.128	0.165
Residual Std. Error (df = 488)	0.943	1.031	0.965
F Statistic (df = 1; 488)	95.790***	72.536***	97.364***
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 4: Forecast by MPCs on Realized Employment Change

	Dependent variable:		
	Full	High MPC	Low MPC
	(1)	(2)	(3)
Realized	0.278***	0.247***	0.296***
	(0.028)	(0.029)	(0.028)
Constant	−0.760***	−0.978***	−0.442***
	(0.043)	(0.043)	(0.042)
Observations	490	490	490
R^2	0.164	0.131	0.190
Adjusted R^2	0.162	0.130	0.189
Residual Std. Error (df = 488)	0.943	0.956	0.917
F Statistic (df = 1; 488)	95.790***	73.748***	114.763***
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 5: Forecast by EISs on Realized Employment Change

	Dependent variable:		
	Full	High EIS	Low EIS
	(1)	(2)	(3)
Realized	0.278***	0.202***	0.130***
	(0.028)	(0.026)	(0.025)
Constant	−0.760***	−0.337***	−0.748***
	(0.043)	(0.046)	(0.045)
Observations	490	295	295
R^2	0.164	0.171	0.084
Adjusted R^2	0.162	0.168	0.081
Residual Std. Error	0.943 (df = 488)	0.797 (df = 293)	0.766 (df = 293)
F Statistic	95.790*** (df = 1; 488)	60.401*** (df = 1; 293)	27.032*** (df = 1; 293)
Note:			*p<0.1; **p<0.05; ***p<0.01

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