Verifying HANK.
Evidence from size-persistence tradeoff

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Abstract

This work explores size-persistence tradeoff for monetary policy in the manner most close to its original formulation by Kaplan, Moll, and Violante (2018).

Keywords: Monetary Policy, Heterogeneous Agents, New Keynesian, Consumption

JEL Codes: E21, E52, E12

1 Introduction

The prerequisite for the successful conduction of monetary response to a shock is the good understanding of Monetary Transmission Mechanism (MTM) – the way that external changes in short term rate translate into the economy. Traditionally, macroeconomic models assumed away all of the heterogeneity in agents, replacing each with a representative one Gali (2018). This representative agent models[1] are distinguished by the fact that they show the economy in a much more compact and tractable manner than heterogeneous ones. Although, assumption of insignificance of differences between households looks quite unrealistic, it is still not immediately obvious, whether heterogeneity in a particular agent traits actually enhances the predictive powers of Representative-Agent New Keynesian (RANK) models[2] and whether this result would hold to the data.

This paper conduct an econometric check of one of distinct outcomes of Heterogeneous-Agent New Keynesian (HANK) model by Kaplan et al. (2018, henceforth, KMV), namely

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[1]Further referred to under abbreviated name RANK, what stands for Representative Agent New Keynesian (model).

[2]For example, Krusell and Smith (1998) argue that "the behavior of the macroeconomic aggregates can be almost perfectly described using only the mean of the wealth distribution".

size-persistence tradeoff.

One of the most important problem in RANK is that, in equilibrium all of the agents are neither savers nor borrowers, even in the absence of financial frictions Gali (2018). This happens because every agent in the model is identical, and therefore, the only possible channel through which monetary policy could work, in theory, is the intertemporal substitution channel. But this this questioned by the fact that aggregated time-series data on consumption finds a small sensitivity of consumption to changes in the interest rate after controlling for income changes Campbell and Mankiw (1989); Canzoneri et al. (2007) – "imperfect consumption insurance". Although by itself, it cannot be concluded from this evidence that the effect of intertemporal substitution is small, because indirect effects can almost completely compensate for changes caused by substitution.

Kaplan et al. (2018) served as a way to answer the accumulated questions about modeling the economy in a neo-Keynesian manner. The key idea is that some of the households face financial frictions i.e borrowing limit, which make them more sensitive to income change and less sensitive to shock of interest rate, since household cannot smooth the unexpected temporal income shock with the increase in credit.

1.1 Trade-offs in HANK

HANK, since it was not reversely-engineered, requires not only a "check for inputs"[3] but also a "check for outputs" – the monetary policy outcomes. HANK, as formulated by KMV has two main monetary policy tradeoffs: tradeoff between size and persistence of monetary shock, and inflation-activity tradeoff. In this work we focus on the former tradeoff. It could be summarized as following: the higher the autocorrelation of monetary shock, the lower the elasticity of consumption to the expected path deviation of the rate of interest from its natural value.[4] Intuitively, persistence of highly autocorrelated shock is indifferent to non-HtMs, as it is in RANK, since the only channel of monetary transmission is intertemporal substitution, but it matters for HtM households, whose response may be dampened by the persistence of monetary shock. This effect stems from failure of Ricaridan equivalence, since when it fails, then "not only timing of fiscal policy but timing of monetary policy matters as well" Kaplan et al. (2018).

1.2 Related literature

First, this work provides additional indirect empirical support for models focused on the role of heterogeneity in household portfolio in MTM, for example Kaplan et al. (2018), Auclert (2019), Luetticke (2021) and successors. There were several studies, which empirically support

[3]The Hand-to-Mouth household existence, which was done in Kaplan et al. (2014), and in Cloyne et al. (2019).

[4]Further we sometimes refer to a difference between real rate and neutral (natural) rates of interest as the excess rate

HANK.

Most of the literature exploring the empirical side of HANK uses the individual level portfolio data. Holm et al. (2020) explores the norwegian individual-level dataset in trying to investigate the full process of the transmission of monetary policy. They find that the low-liquidity households (Kaplan et al. would call them hand-to-mouth households) show strong responce to monetary shock estimated with Romer and Romer (2004) identification strategy. Another work lying in the same field is Cloyne et al. (2019), which shows that aggregate response of consumption to interest rate is mostly driven by households with a mortgage – balance sheet driven heterogeneity plays a key role in monetary policy transmission. It finds, that, in response to a negative monetary shock, the expenditure rise is highly significant for mortgagors[5], less significant for renters, and insignificant for owners with controls for different characteristics. Another empirical contribution to of literature is done by Gross et al. (2020), they document the MPC change over economic cycle, specifically its change through GFC.

This work contribute to the discussion with conformation of the size-persistence tradeoff existence, and confirmation that it has a quadratic form. Since this trade-off is the first of two KMV HANK's outcomes, this work gives us additional confidence to believe in the validity of this model essentials – the importance and significance of indirect effects of monetary policy on consumption. At the same time this work does focus on the overall effect, not trying to disentangle the direct and different indirect channels[6], since the total effect is what actually we need to verify first. Additionally we this work is one of the first, that uses newly developed way of identification of systematic monetary policy by , which allows us to estimate the aforementioned overall effect of the monetary shock, without controlling for any income related covariates – without possible .

The remainder of the paper proceeds as follows: the next section thoroughly discloses our empirical strategy for estimating the tradeoff and the difference between various new keynesian models. Than we describe data being used, further on we discuss the result , and at the end we conclude.

2 Theoretical Framework

Kaplan et al. (2018) emphasize two tradeoffs arising in HANK, that are not present in RANK and TANK (two-agent spender-saver model akin to Campbell and Mankiw (1989)). In this section I revise the tradeoff between monetary shocks size and persistence. Kaplan et al. (2018) assume that the interest rate path follows

$$r_t = \rho + e^{-\eta t}(r_0 - \rho). \tag{2.1}$$

[5]As Cloyne et al. (2019) shows, mortgagors and Wealthy HtMs as defined by Kaplan et al. (2014) are extremely overlapping groups.

[6]which could give additional multiplicative effect of the monetary policy shock

That is, in period 0 there is a shock of r equal to r_0 which mean-reverts with time to ρ at rate η. This is a continuous-time AR(1) equivalent with coefficient equal to $\exp(-\eta) < 1$.

The Euler equation in the continuous-time representative new keynesian model is

$$C_0 = \bar{C} \exp\left(-\frac{1}{\gamma}\int_0^\infty (r_s - \rho)\ ds\right).$$

And the aforementioned size is defined as

$$R_0 = \int_0^\infty (r_s - \rho)\ ds, \tag{2.2}$$

which is essentially the planned (since there are no expectation, it will come into fruition with certainty) excess of interest rate[7] And one can easily note that from the Euler equation in RANK that elasticity of consumption with respect to size is

$$\frac{-d\log C_0}{dR_0} = \frac{1}{\gamma},$$

and it is independent of particular interest rate path, assuming that the size is identical.

Using numerical methods Kaplan et al. (2018) deduce that under tax adjustment the elasticity of consumption with respect to size is dependent on the persistence of the interest rate path, $e^{-\eta}$, and it is is decreasing with it in linear fashion for TANK model and decreasing in concave fashion for HANK. Under the public debt adjustment the elasticity of consumption with respect to size is non-constant only in HANK and it decreases with persistence in concave fashion.

The fundamental difference between models in Size-Persistence tradeoff can formally be written as follows:

$$\textit{RANK:} \qquad \frac{d}{d\rho}\frac{-d\log C_0}{dR_0} = 0 \tag{2.3}$$

$$\textit{TANK with } B^g \textit{ adjustment:} \qquad \frac{d}{d\rho}\frac{-d\log C_0}{dR_0} = 0 \tag{2.4}$$

$$\textit{TANK with } T \textit{ adjustment:} \qquad \frac{d}{d\rho}\frac{-d\log C_0}{dR_0} < 0 \tag{2.5}$$

$$\textit{HANK:} \qquad \frac{d^2}{d\rho^2}\frac{-d\log C_0}{dR_0} < 0 \tag{2.6}$$

This inequalities are tested further.

[7] In words of authors "cumulative deviation of the real interest rate r_t from the natural rate ρ" (Kaplan et al., 2018).

3 Empirical Strategy

3.1 Systematic Monetary Policy Identification

I follow Hack et al. (2023) approach of systematic monetary policy identification that is based on the use of Hawk-Dove balance as a measure of systematic monetary policy. I assume that the monetary policy rule is

$$r_t - \rho_t = \tilde{\phi}_t \mathbb{E}\left[\pi_{t+1} \mid \mathcal{I}_t\right] + \varepsilon_t,$$

where r_t is the real rate of interest, ρ_t is the natural rate of interest, $\tilde{\phi}_t = \phi + \phi_t$ is the systematic monetary policy – that is, the response of the monetary authority to the expected change in inflation and $\mathbb{E}_t \pi_{t+1}$ is the expectations of monetary authority about the inflation in period $t+h$. This simple monetary policy rule can be viewed as simplified time-varying version of Romer and Romer (2004) regression rule, or as modified by introducing time-variability McKay and Wolf (2023) "simple Taylor rule".[8]

I estimate the following state-dependent local projection model

$$r_{t+h} - \rho_{t+h} = \alpha^h + \beta^h \hat{\pi}_t + \gamma^h \hat{\pi}_t \left(Hawk_t - \overline{Hawk}\right) + \delta^h \left(Hawk_t - \overline{Hawk}\right) + \zeta^h Z + e^h_{t+h}, \quad (3.1)$$

for $h = 0, \ldots, H$ forecast horizons. r_{t+h} is federal funds rate (bridged with Wu and Xia (2016) in ZLB period) and ρ_{t+h} is the Laubach and Williams (2003) natural interest rate.[9] $\hat{\pi}_t$ is the measure of the FED expectation of future inflation. I use the average of the one- and two-quarters tealbook inflation forecast forecast following Coibion and Gorodnichenko (2011). $Hawk_t$ is the quarterly Hawk-Dove index of Hack et al. (2023), which is based on the Istrefi (2019); Bordo and Istrefi (2023) estimation of individual policy preference of FOMC members, and $\overline{Hawk}$ stand for the mean of this variable. This variable is instrumented with $\left(Hawk_t^{IV} - \overline{Hawk}^{IV}\right)$. The instrument is based on the rotation of FOMC board membership among 11 FRB presidents, which follows mechanical scheme and thus independent of the economic situation.

The vector of controls, Z, consists of the 4 lags of the dependent variable, $r_{t+h} - \rho_{t+h}$, and 4 lags of the Tealbook expected inflation, $\hat{\pi}_t$.

3.2 Size-Persistence Tradeoff Estimation

The coefficient β^h captures the average response of monetary authority to an increase in its expected inflation, γ^h captures the differential response depending on the preferences of the FOMC. The systematic part of monetary policy can then be written as

$$\tilde{\phi}_t = \phi_t + \bar{\phi} = \hat{\beta}^h_t + \hat{\gamma}^h \left(Hawk_t - \overline{Hawk}\right) + \bar{\phi},$$

[8] McKay and Wolf (2023) use $r_t = \phi \pi_t + v_{0,t} + v_{1,t-1}$ where $v_{0,t}$ is a conventional contemporaneous monetary policy shock and $v_{1,t-1}$ is a pre-announced "news shock", as the base monetary policy rule.

[9] I use Holston et al. (2023) updated version of the Laubach and Williams (2003) natural rate estimation.

for the IV-LP estimated estimated vectors of coefficients β_t^h and γ_t^h. It is also a marginal response of "excess interest rate", $r_t - \rho_t$, to an increase in inflation. That is, $\tilde{\phi}_t$ is the predicted response of FOMC to a unit increase in $\hat{\pi}_t$ is

$$\widehat{(r_{t+h} - \rho_{t+h})} = \hat{\beta}_t^h + \hat{\gamma}^h \left(Hawk_t - \overline{Hawk} \right) + \bar{\phi}, \qquad h = 1, 2, \ldots, H \tag{3.2}$$

Then, based on the estimated impulse-response function we can calculate analogues of size and persistence as follows: size, R_0, is the mean of predicted responses,[10] and persistence, $e^{-\mu} = \nu$, is the first sample autocorrelation of $\widehat{(r_{t+h} - \rho_{t+h})}$.

If size and persistence are calculated, we can then inspect the relationship between them. Namely, I estimate the following linear models

$$\log Consumption = \alpha_0 + \alpha_1 R_0 + \alpha_2 \nu + \beta_1 R_0 \nu \tag{3.3}$$

$$\log Consumption = \alpha_0' + \alpha_1' R_0 + \alpha_2' \nu + \beta_1' R_0 \nu + \beta_2' R_0 \nu^2 \tag{3.4}$$

The hypotheses of models in equations 2.3 to 2.6 on page 4 map into the tests of the signs of coefficients as follows:[11]

$$\mathbb{H}_0 : \beta_1 = 0 \quad vs \quad \mathbb{H}_a : \beta_1 > 0 \quad \Longleftrightarrow$$
$$\text{RANK or TANK with } B^g \text{ adjustment} \quad vs \quad \text{TANK with } T \text{ adjustment or HANK.}$$

and

$$\mathbb{H}_0 : \beta_2' = 0 \quad vs \quad \mathbb{H}_a : \beta_2' > 0 \quad \Longleftrightarrow \text{ RANK or TANK} \quad vs \quad \text{HANK.}$$

Note that since the estimates of coefficients of in models 3.3 to 3.4 on this page are derived based on other estimates, the tests need to be based on bootstrap percentile-type confidence intervals and p-values.

I use block bootstrap with geometrically distributed block lengths with mean 16. The geometric distribution of block length decreases the dependence of block-bootstrap procedure on the block length, at the same time it does not deprive it from the main advantage, it still preserves heteroskedasticity and autocorrelation structures of data.

The bootstrap p-values are calculated for the non-studentized statistic $T = \hat{\theta} - \theta_0$, where $\hat{\theta}$ is the coefficient estimate and θ_0 is its hypothesized value. The bootstrap version of this statistic is $T^*(b) = \hat{\theta}^*(b) - \hat{\theta}$, where b is the bootstrap index and $\hat{\theta}^*(b)$ is the individual bootstrap

[10] Note that Kaplan et al. (2018) use another definition of size, they use an integral shown in 2.2 on page 4. I modify it by using a discrete-time analog, limiting the timespan of desired rate path by H, and scaling it by H. This transformation increases the associated coefficient by H, which is done in order to obtain the coefficients comparable for different choices of H.

[11] Note that the elasticity of consumption with respect to size, R_0, is $-d \log Consumption / dR_0$, so positive coefficients in the regressions are equivalent to negative effects on log consumption.

estimate. Then the bootstrap two-sided test p-value is

$$p^* = \frac{1}{B}\sum_{b=1}^{B} \mathbf{1}\left\{\left|\hat{\theta}^*(b) - \hat{\theta}\right| > \left|\hat{\theta} - \theta_0\right|\right\},$$

and bootstrap p-value for one-sided test $\mathbb{H}_0\theta = \theta_0$ against the alternative $\mathbb{H}_0\theta > \theta_0$ is

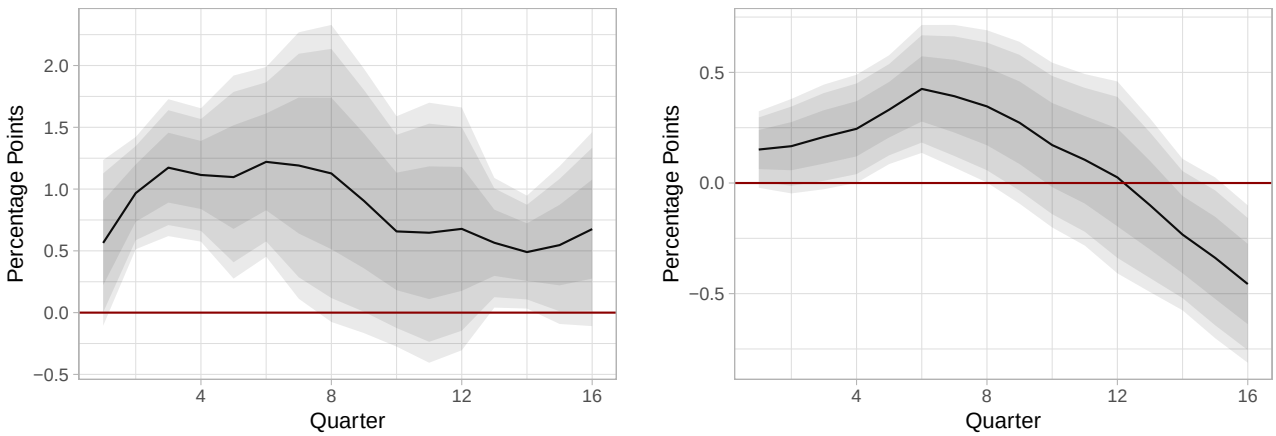
$$p^* = \frac{1}{B}\sum_{b=1}^{B} \mathbf{1}\left\{\hat{\theta}^*(b) - \hat{\theta} > \hat{\theta} - \theta_0\right\}.$$

4 Results

The estimated mean and differential response to a unit increase in inflation can be found in 1. The differential response is shown under the deviation of $Hawk_t$ from its mean equal to 2/12, which is slightly higher than one standard deviation, and a standard choice in Hack et al. (2023). The average and differential responses of $r_t - \rho_t$ tend to be smaller compared to the estimations for federal funds rate of Hack et al. (2023). However, they still are larger than zero up to 8th quarter. The coefficients for several selected quarters can be seen in Table A.1 on page 11.

Figure 1. Policy Response to Inflation and FOMC Hawkishness

(a) Average Response (β^h) **(b)** Differential Response (γ^h)



Notes: This figure reports the responses of the $r_t - \rho_t$ to an increase in the Tealbook inflation forecast of 1 p.p. above sample average. The subfigure 1a reports the response for the *HAWK* index equal to the sample average and 1b is the addition to the response in case there are 2 (out of 12 in total) additional consistent hawks in the FOMC. The shaded areas correspond to 68%, 90% and 95% confidence bands calculated with Newey-West HAC estimator with Andrews-selected truncation parameter.

Based on the impulse responses above I restrict the horizon for the size and persistence calculation to the 8th quarter, i.e. in equation 3.2 on the previous page I set H to be equal to 8. The estimates of coefficients of the models (3.3) and (3.4) can be seen in table 1 on the following page.

Table 1. Size-Persistence Tradeoff

	Dependent variable:	
	log(*consumption*)	
	(1)	(2)
Size (R_0)	−0.687	−0.114
	(−1.141, −0.125)	(−1.495, 1.078)
	[0.011]{0.997}	[0.857]{0.578}
Persistence (ν)	−0.100	1.223
	(−0.694, 0.691)	(−3.598, 4.968)
	[0.746]{0.673}	[0.517]{0.246}
ν^2		−1.042
		(−4.271, 4.336)
		[0.517]{0.766}
$R_0 \times \nu$	0.765	−1.628
	(−0.175, 1.526)	(−6.095, 4.186)
	[0.0754]{0.0247}	[0.522]{0.759}
$R_0 \times \nu^2$		2.435
		(−4.017, 6.784)
		[0.340]{0.145}
Constant	10.608	10.224
	(10.06, 10.96)	(9.13, 11.33)
	[0.0]{0.0}	[0.0]{0.0}
Observations	198	198
R^2	0.338	0.343
Adjusted R^2	0.328	0.326
Residual Std. Error	0.245	0.245

Note: The inference is derived from Block bootstrap with 10,000 replications and block lengths geometrically distributed with mean 16. 95% percentile intervals are in parenthesis. Bootstrap p-values for the two-sided hypothesis ($\mathbb{H}_0 : \theta = 0$ vs $\mathbb{H}_0 : \theta \neq 0$) are in square brackets, p-values for the one-sided hypothesis ($\mathbb{H}_0 : \theta = 0$ vs $\mathbb{H}_0 : \theta > 0$) are in curly brackets.

5 Robustness

tba

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A Additional Results

Table A.1. Response of FOMC to increase in expected inflation

	Dependent variable:						
	$r_{t+h} - \rho_{t+h}$					First Stage	
	$h = 2$	$h = 4$	$h = 6$	$h = 8$	$h = 10$	$HAWK_t - \overline{HAWK}$	—"— $\times\hat{\pi}$
	(1)	(2)	(3)	(4)	(5)	(6)	
$\hat{\pi}_t$	0.968***	1.114***	1.220***	1.127*	0.657	0.054	0.121
	(0.232)	(0.275)	(0.392)	(0.613)	(0.476)	(0.036)	(0.090)
$(HAWK_t - \overline{HAWK})$	−2.071	−2.344	−3.686*	−1.612	0.537		
	(1.314)	(1.753)	(2.214)	(2.657)	(2.791)		
$\left(HAWK_t^{IV} - \overline{HAWK}^{IV}\right)$						0.738***	0.803***
						(0.069)	(0.170)
$\hat{\pi}_t(HAWK_t - \overline{HAWK})$	0.999	1.470**	2.552***	2.077**	1.029		
	(0.653)	(0.748)	(0.885)	(1.054)	(1.140)		
$\hat{\pi}_t\left(HAWK_t^{IV} - \overline{HAWK}^{IV}\right)$						−0.101***	0.148***
						(0.021)	(0.051)
$r_{t-1} - \rho_{t-1}$	0.779***	0.747***	0.252	0.310**	−0.059	0.010	−0.007
	(0.125)	(0.169)	(0.167)	(0.151)	(0.147)	(0.018)	(0.045)
$r_{t-2} - \rho_{t-2}$	−0.068	−0.124	0.133	−0.003	0.015	−0.011	−0.073
	(0.135)	(0.221)	(0.163)	(0.189)	(0.144)	(0.026)	(0.065)
$r_{t-3} - \rho_{t-3}$	0.244***	−0.208	−0.002	−0.345***	−0.206**	0.005	0.033
	(0.078)	(0.156)	(0.104)	(0.122)	(0.091)	(0.026)	(0.064)
$r_{t-4} - \rho_{t-4}$	−0.141	0.216	0.147	0.265	0.139	0.019	−0.014
	(0.105)	(0.147)	(0.221)	(0.189)	(0.196)	(0.018)	(0.043)
$\hat{\pi}_{t-1}$	0.070	−0.156	0.002	−0.258	0.040	−0.026	−0.133
	(0.371)	(0.204)	(0.351)	(0.249)	(0.216)	(0.053)	(0.129)
$\hat{\pi}_{t-2}$	−0.420*	−0.161	−0.369	−0.521	−0.039	0.005	0.082
	(0.240)	(0.442)	(0.302)	(0.343)	(0.222)	(0.053)	(0.130)
$\hat{\pi}_{t-3}$	−0.323	−0.175	−0.377	−0.074	−0.196	−0.014	−0.046
	(0.431)	(0.215)	(0.276)	(0.164)	(0.255)	(0.053)	(0.130)
$\hat{\pi}_{t-4}$	−0.230	−0.500	−0.550	0.024	0.478	0.040	0.337***
	(0.327)	(0.361)	(0.551)	(0.486)	(0.411)	(0.038)	(0.094)
Constant	−0.185	−0.176	0.264	−0.152	−1.160	−0.223***	−0.747***
	(0.640)	(0.826)	(0.949)	(1.073)	(1.115)	(0.037)	(0.091)
Observations	192	190	188	186	184	194	194
R^2	0.841	0.751	0.650	0.597	0.576	0.669	0.794
Adjusted R^2	0.832	0.735	0.628	0.571	0.549	0.649	0.781
Residual Std. Error	1.465	1.845	2.195	2.371	2.438	0.211	0.520
F Statistic						33.438	63.673
Weak Instrument F	74.0	73.4	73.2	66.2	58.7		
	81.5	80.8	80.7	78.3	74.62		
Wu-Hausman	2.252	1.914	10.0***	8.8***	2.0		

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

B Data

FRED. I measure consumption expenditure as chained 2017 dollars, seasonally adjusted personal consumption expenditures per capita (A794RX0Q048SBEA) calculated by the U.S. Bu-

reau of Economic Analysis (quarterly). To measure r_t I take the minimum of the shadow federal funds rate (Wu and Xia, 2016) and effective federal funds rate (DFF).

Natural Rate Estimates. Natural rate of interest used is estimated by Laubach and Williams (2003) and re-estimated by Holston et al. (2023) to bridge the Covid period.