

The New Keynesian Transmission Mechanism: A Heterogeneous-Agent Perspective*

Tobias Broer[†] Niels-Jakob Harbo Hansen[‡] Per Krusell[§]

Erik Öberg[¶]

September 27, 2018

Abstract

We present a tractable heterogeneous-agent version of the New Keynesian (NK) model that allows us to study the interaction between inequality and monetary policy. Though formulated as a precautionary-saving model à la Huggett-Aiyagari, its reduced form is a two-agent model with a highly concentrated wealth distribution. When prices are sticky and wages flexible, as in the textbook representative-agent model, monetary policy affects the distribution of consumption, but has no effect on output as workers choose not to change their hours worked in response to wage movements. This highlights a transmission mechanism of the textbook model that we find implausible: in response to a monetary stimulus, the representative worker's labor supply is greatly affected by the profits she receives. First, the lower profits induced by higher wages raise labor supply through a wealth effect and, second, the mere presence of profits reduces the negative income effect of a wage rise. When wages are rigid, in contrast, our model exhibits plausible responses of output and hours worked to monetary policy shocks.

*We are very grateful for comments from the editor, three anonymous referees, Adrien Auclert, Florin Bilbiie, John Cochrane, Martin Eichenbaum, Jordi Galí, Jean-Baptiste Michau, Valerie Ramey, Matthew Rognlie, Ivàn Werning, and participants at numerous seminars. All errors are our own. The views expressed in this paper are those of the authors and do not necessarily represent the views of the IMF, its Executive Board, or IMF management. Erik Öberg and Niels-Jakob Harbo Hansen acknowledge financial support from Handelsbanken's Research Foundations.

[†]IIES and CEPR: tobias.broer@iies.su.se.

[‡]IMF: nhansen@imf.org.

[§]IIES, CEPR, and NBER: per.krusell@iies.su.se.

[¶]Uppsala University, UCLS: erik.oberg@nek.uu.se.

1 Introduction

How is monetary policy transmitted to aggregate real activity? This question is usually addressed using models relying on the approximating assumption of a representative agent, whose wealth equals the economy's capital stock and whose income equals the sum of all wages and profits. However, beginning with the early study by Johnson et al. (2006), there is mounting evidence that households respond differently to changes in income and wealth; see, e.g., Misra and Surico (2014), Krueger et al. (2016) and references therein. These differential responses, moreover, are typically viewed to be systematic across some underlying characteristics of households, such as employment status and wealth. From this perspective, it becomes a first-order issue to examine how monetary policy propagates to aggregate output in a heterogeneous-agent economy, through its effects on prices and the determination of different income sources. Monetary policy, in particular, can lead to a redistribution of resources across households because, through sluggish adjustment of prices and wages, it can affect real wages and real profits differently, both of which we know are very unevenly distributed across the economy. This paper proposes a simple framework for studying these issues. The key finding, in short, is that unlike in the corresponding representative-agent economy, the source of nominal rigidity matters greatly for the transmission of monetary policy to output.

Our model nests the textbook New Keynesian with the workhorse incomplete-markets model of Huggett (1993) and Aiyagari (1994), and may therefore be labeled a Heterogeneous-agent New Keynesian (HANK) model (an abbreviation proposed by Kaplan et al. (2018)). We are not the first to construct and solve such a model: a burgeoning literature has already produced a series of interesting and complementary hypotheses using similar HANK models.¹ However, because these models typically feature a wealth distribution that responds endogenously to aggregate shocks, solving them requires quantitative techniques whose complexity may present a challenge when trying to identify the mechanisms at work. A key value added of our framework is that it admits analytical solutions and is as simple to use as the textbook,

¹See, e.g., Auclert (2017), Kaplan et al. (2018), McKay et al. (2016), and Gornemann et al. (2016) on monetary policy and Den Haan et al. (2017), Ravn and Sterk (2017), McKay and Reis (2015), Guerrieri and Lorenzoni (2017), and Heathcote and Perri (2017) on related aspects of the business cycle.

Representative-agent New Keynesian (RANK) model. In particular, our framework identifies a small set of variables whose co-movements characterize the transmission of monetary policy to inequality and aggregate activity. This makes the comparison of the model’s implications to data from real economies particularly easy.

Specifically, we augment the textbook RANK model with a stylized form of heterogeneity that captures two key features of the data: households are not perfectly insured against idiosyncratic income risk; and wealth holdings are extremely concentrated, as recently documented by Wolff (2014), Piketty and Zucman (2015), Kuhn and Rios-Rull (2015), and Saez and Zucman (2016). For this, we assume that households can smooth idiosyncratic shocks to their labor productivity only by investing in non-contingent bonds, and that firm ownership is confined to a small group of “capitalists”. Following Krusell et al. (2011); Werning (2015); McKay and Reis (2017) and Ravn and Sterk (2018), we assume a tight limit on household borrowing, which enables us to summarize the dynamics of our simple HANK model by a set of linear equations, isomorphic to the corresponding textbook RANK model.

We demonstrate that in our simple HANK model, the aggregate dynamics following a monetary shock depend greatly on whether the aggregate nominal rigidity stems from stickiness in the price- or in the wage-setting process. Specifically, when prices are rigid and wages are flexible, monetary policy has large redistributive effects between capitalists and workers, but there is no effect of monetary policy on aggregate output. With a rigid wage setting, in contrast, monetary policy has smaller redistributive effects, but now the transmission to output is active. These findings contrast sharply with the corresponding textbook RANK model, where firms are owned by all households and idiosyncratic risks are fully insured. In that model, whether wages are rigid or not does not qualitatively change the response of aggregate quantities after a monetary shock (although it does change the size of that response).

Why are wage rigidities so crucial for monetary transmission in our model? With rigidities only in the goods market, workers respond to wages according to their labor supply curve. With the kind of preferences used in the macroeconomic literature (see King et al. (1988)) and without profit income accruing to workers, the income and substitution effect from changes in the wage level cancel out.² Consequently, changes

²The preferences in King et al. (1988) are often described as *balanced-growth preferences* as they deliver

in the wage level will not affect employment, and output becomes invariant to monetary policy. This does not mean, however, that monetary policy is neutral with respect to real variables. To the contrary, there are strong redistributive effects. As is well-known regarding this class of models (see, e.g., Christiano et al. (1997)), profits respond counter-cyclically to monetary policy shocks, and in our HANK model this makes capitalists poorer while workers become richer in response to a surprise cut in the nominal interest rate. In sum, monetary policy cannot affect output, but there are effects on the distribution of consumption.

In contrast, with rigid wages, workers are constrained to supply the quantity of labor demanded in the short run. Wage rigidity disconnects the response of worker employment, and hence output, from the response of worker income, and mechanically ties it to the response in aggregate consumption demand following the monetary policy shock. In addition, a rigid wage setting dampens the response of real wages to the shock, and the income split between labor and profit income stays approximately constant, such that profits now respond pro-cyclically. Accordingly, there are limited redistributive effects, and aggregate consumption demand is aligned with consumption demand of each of the two household groups. In sum, our HANK model with rigid wages exhibits a plausible transmission of a monetary loosening to increases in prices and quantities, including its implication that profits are pro-cyclical.

Our results invite the hypothesis that it is the degree of rigidity in the labor market, as opposed to in the product market, that is key to evaluating the strength of the monetary transmission mechanism. This claim has empirical support in the evidence from calendar-varying vector autoregressions, showing that the magnitude and persistence of the output response to monetary policy shocks decrease in the calendar periods in which wages are renegotiated (Olivei and Tenreyro, 2007, 2010; Björklund et al., 2018). Moreover, using a medium-scale DSGE model, Christiano et al. (2005) show that wage rigidities play a critical role in accounting for observed inertia in inflation and persistence in output following a monetary policy shock.

a balanced growth path for all macroeconomic variables under the restriction of a constant labor supply. Boppart and Krusell (2016) recently argue that a better approximation to the data is that hours fall at a constant (but small) rate and offer an enlargement of balanced-growth preferences that is consistent with this behavior and where income effects slightly outweigh substitution effects. Such preferences would only change our main conclusions here slightly (they would actually strengthen them).

Our results also highlight what we believe to be an under-appreciated feature of the transmission mechanism in the standard RANK model with price rigidities only.³ In particular, both the counter-cyclical response of profits and their steady-state size play a key role for the employment and output response to monetary policy shocks in this environment. With preferences in the King-Plosser-Rebelo class, it is the deviation of total income from labor income that determines the response of labor supply. When households receive profit payments lump-sum, such a deviation can occur: in response to an increase in goods demand and wages, firm profits fall, making the households poorer, thus generating the required increase in labor supply that meets the higher demand. Moreover, the larger is the steady-state profit share, the more potent is this channel. In our view, this transmission mechanism is implausible, and clearly at odds with the pro-cyclical response of profits to monetary policy shocks we see in the data (Christiano et al., 2005).

Closely related to our analysis is the recent paper by Ravn and Sterk (2018), who analyze business-cycle dynamics under similar assumptions that imply a degenerate wealth distribution of workers and a homogeneous capitalist. In contrast to our work, they do not focus on the distribution of profit income across workers in response to monetary shocks, but construct a richer model with endogenous fluctuations in unemployment risk to highlight how incomplete markets may change the determinacy properties of interest rate rules, produce self-fulfilling beliefs and sizable risk premia, and also qualitatively change the aggregate dynamics at the zero lower bound. We regard their analysis as complementary to the perspective presented here.

Also related to our work is a set of papers using two-agent New Keynesian (TANK) models. Due to the tight borrowing limit, the reduced-form log-linear representation of our simple HANK model is similar to that of a TANK model where workers are distinct from capitalists but without any within-group heterogeneity. In particular, it is similar to Bilbiie (2008)'s TANK model, where all households work but only a fraction λ of them participates in the bond market and receive profit income.⁴ Bilbiie shows that in his model the value of λ changes both the strength of the monetary transmis-

³The standard RANK model often serves as a benchmark for business cycle and policy analysis in the NK literature (see, e.g., Lorenzoni (2009), Christiano et al. (2011), and Werning (2011)).

⁴Other, more recent studies analyzing NK models with two types of agents are Walsh (2017), Bilbiie (2018), and Galí and Debortoli (2017).

sion mechanism and the determinacy properties of the equilibrium. He then uses these results to discuss the positive and normative implications for monetary policy in environments and periods of low asset-market participation. We instead point out that the transmission mechanism of the textbook NK model with rigid prices is implausible, as highlighted by the observation that hours worked are constant in our simple HANK model. The same result is also true in Bilbiie's model when $\lambda \rightarrow 0$, i.e., when (almost) all workers do not receive any profit income.⁵

In Section 2, we present the baseline version of our simple HANK model, with rigid prices but without rigid wages, and study its responses to a monetary shock. In Section 3, we augment the model with rigid wages and redo the impulse-response analysis. Section 4 concludes.

2 A model with rigid prices

Our model nests two common frameworks used for macroeconomic analysis. On the firm side, it has the essential features of a New Keynesian model, with monopolistic firms that can reset prices subject to the Calvo (1983) friction. In its setup, we follow Galí (2009), chapter 3, closely. On the household side, it has the essential features of an incomplete-markets model à la Huggett (1993), in which households can only imperfectly insure themselves against idiosyncratic labor productivity shocks by means of trading in a risk-free bond subject to a borrowing constraint.

Two assumptions are worth highlighting. First, we assume that households are of two types, *workers* and *capitalists*. These households are ex-ante identical in all aspects except in that the capitalists own the firms and derive income from firm dividends, whereas workers only receive wage income.⁶ This assumption serves two purposes: it captures the notion that equity ownership is extremely concentrated (see, e.g., Kuhn

⁵Our models also differ in the structure of the asset market. In Bilbiie's model the bond market participants also receive profit income, while in our model the profit-receiving capitalists decide not to participate but some workers do. However, whether capitalists participate in the bond market or not is inconsequential for the constant-hours result in our model, as it follows directly from intratemporal optimization under KPR preferences, whenever the equilibrium entails that worker consumption equals labor income.

⁶In an earlier version of our paper, the distinction between workers and capitalists was the only source of heterogeneity in the model.

and Rios-Rull (2015)) and it helps us to isolate the role of firm profits for the equilibrium dynamics in response to a monetary policy shock.

Second, we follow Krusell et al. (2011); Werning (2015); McKay and Reis (2017) and Ravn and Sterk (2018) and assume that the borrowing constraint restricts households from borrowing altogether. With a zero net supply of bond assets, this assumption implies a degenerate equilibrium bond wealth distribution, and the consumption allocation coincides with that of autarky. With this assumption, we can maintain all the essential features of a standard incomplete-markets model while still retrieving analytical solutions for the log-linearized equilibrium.

A time period should be interpreted as a quarter of a year. We focus on the log-linear approximation around a steady state where aggregate variables and price indices are constant, but household-specific variables may fluctuate. In line with this first-order approach, we focus on small aggregate shocks. As for notation, we will for any variable X_t denote its steady-state value with \bar{X} , its natural logarithm with x_t , and its log deviation from steady state with \hat{x}_t . We will refer to these deviations as “gaps”.⁷ We start by describing the setup of our HANK model and then compare it to the corresponding RANK model.

2.1 Households

Households are indexed by j . There is a continuum of ex ante identical workers on the unit line $[0, 1]$ and a continuum of identical capitalists on the interval $(1, 1 + m_c]$, with $0 < m_c \ll 1$. All households face a fixed cost of working ϑ . Household j receives an idiosyncratic labor productivity shock A_{jt} that yields an effective labor supply $A_{jt}N_{jt}$, for any given number of hours worked N_{jt} . Within each period, all shocks are realized before households and firms make their choices. We assume that A_{jt} has a finite support and follows a Markov process that is identical and independent across households and has a unique ergodic distribution whose mean we normalize to 1.

⁷It is common to describe the log-linear equilibrium in terms of deviations from the flexible-price equilibrium rather than in deviations from the steady state. In this paper, the only source of exogenous disturbances is shocks to the nominal interest rate, and since the model features long-run monetary neutrality, the two measures coincide.

Workers. Workers choose C_{jt} , N_{jt} and B_{jt} to maximize the objective

$$E_t \sum_{k=0}^{\infty} \beta^k \left(\log(C_{jt}) - \frac{N_{jt}^{1+\varphi}}{1+\varphi} - \vartheta * \mathbb{I}_{N_{jt}>0} \right), \quad (1)$$

subject to the budget constraint

$$P_t C_{jt} + Q_t B_{jt} = W_{jt} N_{jt} + B_{jt-1}, \quad (2)$$

and the borrowing constraint

$$B_{jt} \geq 0. \quad (3)$$

We assume that the fixed cost ϑ is small enough so that all workers choose to work. The solution to the worker problem is then characterized by two optimality conditions:

$$Q_t = \beta E_t \left\{ \frac{C_{jt+1}^{-1}}{C_{jt}^{-1}} \frac{P_t}{P_{t+1}} + \eta_{jt} \right\}, \quad (4)$$

$$\frac{W_{jt}}{P_t} = MRS_{jt}, \quad (5)$$

where $MRS_t = \frac{N_{jt}^\varphi}{C_{jt}^{1-\varphi}}$ and $\eta_{j,t} \geq 0$ is the Kuhn-Tucker multiplier on the zero-borrowing constraint (3).

Capitalists. The capitalist problem is the same as that of workers, apart from their budget constraint: capitalists are the only ones who can own intermediate good firm shares, of which they are endowed an equal amount $1/m_c$ in $t = 0$. We assume that their portfolio is well-diversified and that their mass m_c is small enough that they choose not to work, which makes capitalists immune to idiosyncratic risk and implies that they will make identical decisions in all periods. We denote aggregate profits with D_t . As described below, any capitalist j will consume her profit income $\frac{D_t}{m_c}$ hand-to-mouth in equilibrium. Given this condition, capitalist j will choose not to work if

$$\log \left(\frac{D_t}{m_c} \right) > \log \left(\frac{D_t}{m_c} + \frac{W_{jt}}{P_t} N_{jt}^* \right) - \frac{N_{jt}^{*1+\varphi}}{1+\varphi} - \vartheta, \quad (6)$$

where N_t^* is the labor supply implied by a condition analogous to (5), i.e., disregarding the fixed cost from working. It is clear that for every $D_t > 0$, there exists an $m_c^*(D_t)$ such that for every $m_c < m_c^*(D_t)$ condition (6) is satisfied. In line with our focus on small aggregate shocks, and therefore small fluctuations in D_t , we assume that $m_c < \min\{m_c^*(D_t)\}$. So capitalists never work.

2.2 Firms

The final good sector. There is a representative firm that takes all prices as given and produces the final good Y_t by combining a continuum of intermediate goods Y_{it} through the Dixit-Stiglitz aggregator with elasticity of substitution ϵ_p :

$$Y_t = \left(\int_0^1 Y_{it}^{\frac{\epsilon_p-1}{\epsilon_p}} di \right)^{\frac{\epsilon_p}{\epsilon_p-1}}. \quad (7)$$

Cost-minimization implies a demand curve for intermediate goods:

$$Y_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\epsilon_p} Y_t, \quad (8)$$

where the aggregate price index is defined as $P_t = \left[\int_0^1 P_{it}^{1-\epsilon_p} di \right]^{\frac{1}{1-\epsilon_p}}$.

The intermediate good sector. Intermediate goods are produced by a continuum of firms, indexed by i , with CRS technology $Y_{it} = N_{it} = \int_{j=0}^1 A_{jt} N_{jit} dj$, where A_{jt} is the productivity of household j . Each firm i takes the nominal wages $\{W_{jt}\}$ and the average price level P_t as given. The labor market is competitive, such that

$$\frac{W_{jt}}{A_{jt}} = \frac{W_{kt}}{A_{kt}} \quad \forall j, k. \quad (9)$$

For future reference, we define the average wage level as

$$\begin{aligned} W_t &= \int_{j=0}^{1+m_c} \frac{W_{jt}}{A_{jt}} dj \\ &= \int_{j=0}^1 \frac{W_{jt}}{A_{jt}} dj, \end{aligned} \quad (10)$$

where the second step follows from capitalists choosing not to work. Together with (9), (10) implies that $\frac{W_{jt}}{A_{jt}} = W_t$ for all j .

The intermediate good producers set their prices to maximize the expected discounted profits subject to the goods demand curve (8), using the stochastic discount factor of their owners, i.e., the capitalists, which is, in the steady state, simply β . The intermediate good producers can only reset their prices with probability $1 - \theta_p$ in every period. From these assumptions, we find that (1) in the steady state, prices are set as a constant fraction $M = \frac{\epsilon_p}{\epsilon_p-1}$ over marginal cost and the steady-state labor share is consequently $\bar{S} = \frac{\epsilon_p-1}{\epsilon_p}$; and (2) in the first-order approximation around the steady state,

there is a log-linear relationship between inflation and the deviation of the average marginal cost from the steady state, that is, a *Phillips curve*:

$$\pi_t^p = \beta E_t \pi_{t+1}^p + \lambda_p \hat{m}c_t, \quad (11)$$

where π_t^p is the inflation rate, $\hat{m}c_t$ is the log deviation in average real marginal cost, and $\lambda_p \equiv \frac{(1-\theta_p)(1-\beta\theta_p)}{\theta_p}$. Note that with a CRS production technology, deviations in the average real marginal cost equal the deviation in the average real wage: $\hat{m}c_t = \hat{\omega}_t$, where $\omega_t = w_t - p_t$.

2.3 Government

There is no government consumption nor taxation and the fiscal authority maintains a balanced budget. There is a central bank that sets the interest rate according to a log-linear Taylor rule:

$$\hat{i}_t = \phi_\pi \pi_t^p + \nu_t, \quad (12)$$

where $i_t = -\log Q_t$.

2.4 Equilibrium implications

Bonds are in zero net supply and there is no investment in physical capital. The markets for goods and bonds clear when

$$Y_t = \int_{j=0}^{1+m_c} C_{jt} dj, \quad (13)$$

$$0 = \int_0^{1+m_c} B_{jt} dj. \quad (14)$$

Since households cannot borrow ($B_{jt} \geq 0$), (14) implies that all households, workers and capitalist alike, consume their per-period income. For all workers j , this means that $C_{jt} = \frac{W_{jt}}{P_t} N_{jt}$ in all periods t . Substituting this condition into (5), we see that the workers' labor supply choice is independent of A_{jt} and that $N_{jt} = N_{kt}$ for all $j, k \in [0, 1]$. In consequence, aggregate labor supply coincides with individual labor supply: $N_t = \int_s A_{st} N_{st} ds = N_{jt}$ for all j . Using this together with the definition of W_t , we find that worker j 's consumption equals her idiosyncratic productivity times average consumption:

$$C_{jt} \equiv \frac{W_{jt}}{P_t} N_{jt} = A_{jt} \frac{W_t}{P_t} N_t = A_{jt} C_t, \quad (15)$$

where $C_t = \int_{j=0}^1 C_{jt} = \frac{W_t}{P_t} N_t$. Thus, in a log-linear approximation around the steady state we have that

$$\hat{c}_t = \hat{w}_t + \hat{n}_t. \quad (16)$$

Inserting (15) into the Euler equation (4), we find that

$$Q_t = \beta E_t \left\{ \left(\frac{A_{jt+1} C_{t+1}}{A_{jt} C_t^{-1}} \right)^{-1} \frac{P_t}{P_{t+1}} + \eta_{jt} \right\}. \quad (17)$$

From the capitalist problem, the corresponding equilibrium condition is

$$Q_t = \beta E_t \left\{ \frac{D_{t+1}^{-1}}{D_t^{-1}} \frac{P_t}{P_{t+1}} + \eta_{jt} \right\}. \quad (18)$$

We assume that idiosyncratic shocks are large compared to aggregate shocks. In consequence, $\max\{E_t \left(\frac{A_{jt+1} C_{t+1}}{A_{jt} C_t^{-1}} \right)^{-1} \frac{P_t}{P_{t+1}}\} > E_t \left\{ \frac{D_{t+1}^{-1}}{D_t^{-1}} \right\} \frac{P_t}{P_{t+1}}$ for all realizations of the aggregate shock. Thus any $Q_t \geq Q_t^*$, where

$$Q_t^* = \beta^{eff} E_t \left\{ \frac{C_{t+1}^{-1}}{C_t^{-1}} \frac{P_t}{P_{t+1}} \right\}, \quad (19)$$

and

$$\beta^{eff} = \beta \max \left\{ E_t \left[\left(\frac{A_{st+1}}{A_{st}} \right)^{-1} \right] \right\} > \beta, \quad (20)$$

implies zero net demand for bonds and is thus consistent with equilibrium. However, any $Q_t > Q_t^*$ is incompatible with an equilibrium with an arbitrarily small positive asset supply, for which there must be at least one household who voluntarily has positive bond holdings (“the marginal saver”). Motivated by the non-robustness of these equilibria, we restrict attention to the equilibrium with $Q_t = Q_t^*$.⁸ Consequently, the steady-state interest rate in the economy with idiosyncratic risk is below $\frac{1}{\beta}$, its value in the textbook RANK model. Log-linearizing condition (19) yields

$$\hat{c}_t = E_t \hat{c}_{t+1} - (\hat{i}_t - E_t \pi_{t+1}). \quad (21)$$

To complete the characterization of the log-linear dynamics we aggregate and log-linearize the labor-supply condition (5). Using that $W_{jt} = A_{jt} W_t$, $N_{jt} = N_t$ and $C_{jt} =$

⁸Adding more structure on the Markov process for A_{jt} , we could identify the marginal saver with households at a particular point of the idiosyncratic productivity distribution. For example, when A_{jt} is i.i.d. over time, we would have $\beta^{eff} = \beta \left\{ E_t \left[\left(\frac{A_{jt+1}}{A_{max}} \right)^{-1} \right] \right\}$.

$A_{jt}C_t$ in (5) yields

$$\begin{aligned} \frac{A_{jt}W_t}{P_t} &= N_{jt}^\varphi A_{jt}C_t \\ \Leftrightarrow \frac{W_t}{P_t} &= N_t^\varphi C_t. \end{aligned}$$

Log-linearizing yields

$$\hat{\omega}_t = \varphi \hat{n}_t + \hat{c}_t. \quad (22)$$

Summary: The log-linearized equilibrium can thus be summarized as follows.

$$\text{Phillips : } \pi_t^p = \beta E_t \pi_{t+1}^p + \lambda_p \hat{\omega}_t, \quad (23)$$

$$\text{IS : } \hat{c}_t = E_t \hat{c}_{t+1} - (\hat{i}_t - E_t \pi_{t+1}), \quad (24)$$

$$\text{Taylor rule : } \hat{i}_t = \phi_\pi \pi_t^p + \nu_t, \quad (25)$$

$$\text{Labor supply : } \hat{\omega}_t = \varphi \hat{n}_t + \hat{c}_t, \quad (26)$$

$$\text{Market clearing : } \hat{c}_t = \hat{\omega}_t + \hat{n}_t. \quad (27)$$

In our model, the consumption allocation coincides with that of autarky and, as such, the response of aggregate variables to monetary policy shocks does not interact with the distribution of idiosyncratic labor productivity risk. Consequently, the log-linear dynamics in our simple HANK model are identical to a two-agent New Keynesian (TANK) model where workers face no idiosyncratic income risk and where the capitalist is assumed not to participate in the bond market.⁹

Our assumptions do not mean that idiosyncratic labor productivity risk has no role in our analysis. To the contrary, its presence affects which of the households are participating in the bond market and, consequently, which consumption aggregate enters the IS curve (24). In our model, because the incomes of capitalists are insured from idiosyncratic shocks whereas the incomes of workers are not, the precautionary demand for assets is higher among the latter group. In equilibrium, the marginal participant in the bond market is therefore a worker, while the capitalists consume their income hand-to-mouth. In a TANK setup, it may seem natural to assume that the capitalist rather than the worker should be participating in the bond market, but such a setup

⁹Such a TANK model was constructed in an earlier version of this paper, which is available upon request.

does not correspond to the model presented here. In our view, a key benefit of our model over a corresponding TANK setup is to provide a micro-founded theory for participation in the bond market.

2.5 Comparison to the textbook RANK model

How does the equilibrium system described by equations (23)-(27) compare to the corresponding textbook RANK model, where a representative agent provides all labor and owns all firms? The following equations summarize the textbook RANK model (see Galí (2009), chapter 3).¹⁰

$$\text{Phillips : } \pi_t^p = \beta E_t \pi_{t+1}^p + \lambda_p \hat{\omega}_t, \quad (28)$$

$$\text{IS : } \hat{c}_t = E_t \hat{c}_{t+1} - (\hat{i}_t - E_t \pi_{t+1}), \quad (29)$$

$$\text{Taylor rule : } \hat{i}_t = \phi_\pi \pi_t^p + \nu_t, \quad (30)$$

$$\text{Labor supply : } \hat{\omega}_t = \varphi \hat{n}_t + \hat{c}_t, \quad (31)$$

$$\text{Market clearing : } \hat{c}_t = \bar{S}(\hat{\omega}_t + \hat{n}_t) + (1 - \bar{S})\hat{d}_t, \quad (32)$$

where $\hat{\omega}_t, \hat{c}_t, \hat{n}_t$ refer to the log deviations of the real wage, consumption, and labor supply of the representative agent, respectively (whereas in our simple HANK model, the same letters refer to the weighted averages of these variables in the worker population). Note that by substituting the equilibrium conditions $\hat{c}_t = \hat{y}_t = \hat{n}_t$ and (31) into (28) and (29), this system can be compressed into a 3-equation representation. We maintain the 5-equation representation as this allows for more transparent comparison with our simple HANK model.

As seen by comparing (23)-(27) to (28)-(32), the only difference between our simple HANK model and the textbook model is the market clearing condition. In the simple HANK model the log deviation in worker consumption equals the log deviation in the average wage bill, as in equilibrium the tight borrowing constraint prevents workers and capitalists from sharing resources through asset trade. In the textbook model, in contrast, all deviations of individual income from aggregate output are insured, and

¹⁰The only deviations here from the RANK model described in Galí (2009), chapter 3, are that our production function is linear rather than concave and that our policy rate does not respond to the output gap.

the log deviation in the representative household's consumption equals the weighted log deviation of both wage and profit income.

It is worth noting that the IS curve is the same in the two models. As seen from equation (19), the steady-state interest rate is lower in our HANK model compared to the textbook RANK model, where $Q = \frac{1}{\beta}$. This is due to the precautionary savings motive present in the HANK model, leading workers to demand more assets for any given level of the interest rate than they do in the textbook model. The response of consumption to fluctuations in the present and future interest rates is not, however, affected. As discussed in Werning (2015), it is of course true that in partial equilibrium, aggregate consumption becomes less sensitive to future interest rates in the incomplete markets setting as, eventually, all agents face a binding borrowing constraint. However, equation (19) reflects the *general equilibrium elasticity*, which also depends on the “second-round” consumption response of the constrained agents to the income shift generated by the first round consumption response of the unconstrained agents. With CRRA preferences and individual labor income proportional to aggregate labor income, the partial equilibrium dampening and the general equilibrium amplification effects exactly cancel out. As also discussed in Werning (2015), alternative assumptions regarding preferences, the cyclical supply of assets, and cyclical fluctuations in income risk could change this result.

2.6 Impulse response functions to a monetary shock

We now consider the implications of an innovation in the monetary policy rate in our model and compare the results to those in the textbook model. For the monetary policy shock, we assume that innovations follow the process

$$\nu_t = \rho_\nu \nu_{t-1} + \epsilon_{\nu t},$$

with $Var(\epsilon_{\nu t}) = 0.0025^2$. We take the parameter values from Galí (2009), chapter 3, shown in Table 1. For these values, the Blanchard-Kahn conditions of both models are satisfied and both models thus have a unique stable solution.

Parameter		Value
Discount factor	β	0.99
Frisch elasticity	φ	1
Elast. of substitution	ϵ_p	6
1-Reset probability	θ	2/3
Taylor coefficient	ϕ_π	1.5
Persistence of monetary policy shock	ρ_v	1/2

Table 1: Parameter values used for computing the impulse-response functions

The impulse-response functions following the monetary policy shock are plotted in Figure 1.

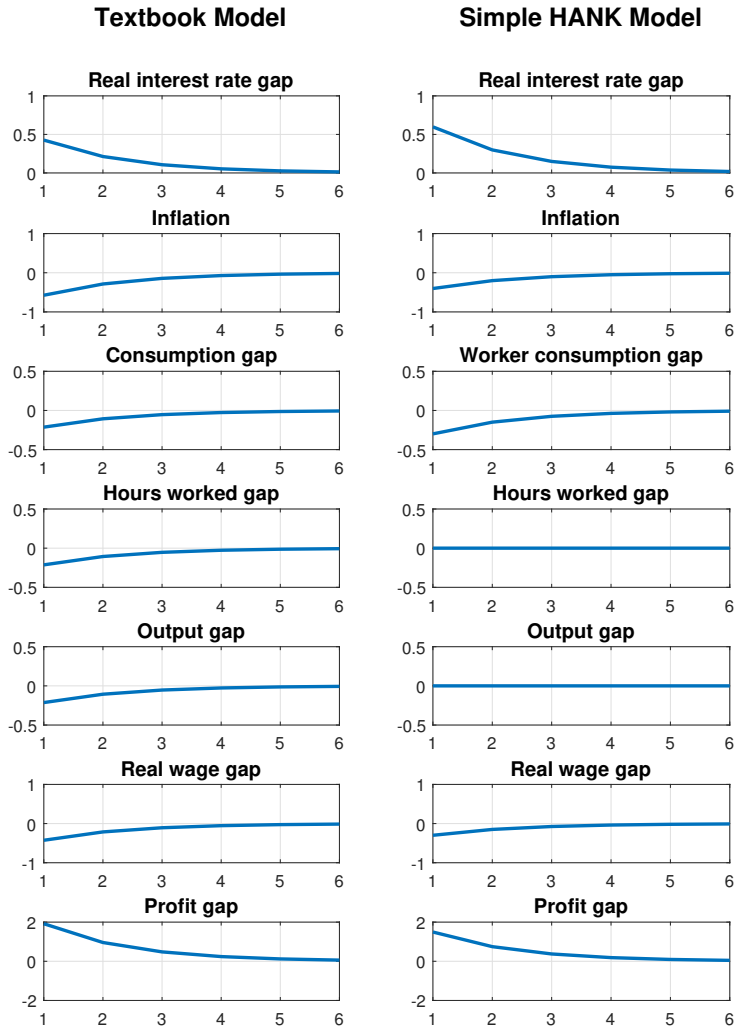


Figure 1: Equilibrium responses, measured as percentage deviations from the steady state, to a positive 25 basis-point shock in the policy rate. Left-hand panel: textbook RANK model; right-hand panel: our simple HANK model. Inflation and interest rates: yearly rates; other variables: quarterly rates.

As can be seen in Figure 1, both models give very similar responses in terms of the

real interest rate gap, inflation, real wages, and profits. Thus, a part of the transmission mechanism seems very similar across the two models. However, in the textbook RANK model, there is a substantial negative response in output and hours worked, whereas in our simple HANK model, there is no response at all in these variables.

What explains these findings? We start by analyzing the responses in the HANK model. Looking at the right-hand side of Figure 1, we see that in response to the surprise increase in the nominal interest rate, the real interest rate increases. From the IS curve (24), we then know that the worker consumption gap must follow an upward-sloping path, and thus has to fall discretely in the initial period of the shock. The worker income gap must follow the same path, as worker consumption equals worker income in equilibrium. Hence, either wages, hours worked, or both must initially fall. We see that only real wages fall; hours worked do not move.

The reason for the lack of response in hours worked is our preference specification: we use the King-Plosser-Rebelo utility function, employed in most of the applied macroeconomic literature and originally proposed in King et al. (1988). These preferences are constructed so that hours have no trend in the long run, despite wage growth, and this is accomplished with an interior choice of hours only if income and substitution effects cancel. In a model where the consumer/worker only receives labor income, as in the present setting, this insight carries over straightforwardly. Formally, insert the market-clearing condition (27) into the intratemporal optimality condition (26):

$$\begin{aligned} \varphi \hat{n}_t + \hat{c}_t &= \hat{\omega}_t \quad \text{and} \quad \hat{c}_t = \hat{\omega}_t + \hat{n}_t \\ \Rightarrow \quad \varphi \hat{n}_t + \hat{\omega}_t + \hat{n}_t &= \hat{\omega}_t \\ \Leftrightarrow \quad \hat{n}_t &= 0. \end{aligned}$$

Clearly, regardless of the Frisch elasticity, hours will not change.¹¹ Since hours worked are unresponsive, the fall in worker consumption matches the fall in wages. Because wages fall, so does the marginal cost of production, which leads to a fall in inflation and an increase in profits. The counter-cyclical response of profits, however, has no

¹¹With the slightly larger preference class derived in Boppart and Krusell (2016) and a parameter restriction implying that hours fall over the long run if wages grow, we would see hours rise in response to a drop in wages. Thus, a monetary policy tightening would make output go up, and hence make the transmission mechanism in the HANK model even more different than that in the textbook RANK model.

direct effect on equilibrium output since it is directly consumed by the capitalists, who do not provide any labor services. Although aggregate consumption is unaffected by monetary policy, its distribution is: as wages fall and profits rise in response to a monetary tightening, the consumption of workers decreases and that of capitalists increases.

Having explained the responses in our simple HANK model, it is now easy to understand the responses in the textbook model. As in the HANK model, the real interest rate gap increases, which leads to a fall in the consumption gap. There is also a fall in the real wage gap and an increase in the profit gap. However, hours worked and the output gap now decrease. To explain this, we again insert the market-clearing condition (32) into the intratemporal optimality condition (31):

$$\begin{aligned}
& \varphi \hat{n}_t + \hat{c}_t = \hat{\omega}_t \quad \text{and} \quad \hat{c}_t = \bar{S}(\hat{\omega}_t + \hat{n}_t) + (1 - \bar{S})\hat{d}_t \\
\Rightarrow & \quad \varphi \hat{n}_t + \bar{S}(\hat{\omega}_t + \hat{n}_t) + (1 - \bar{S})\hat{d}_t = \hat{\omega}_t \\
\Leftrightarrow & \quad \hat{n}_t = \frac{1 - \bar{S}}{\varphi + \bar{S}}(\hat{\omega}_t - \hat{d}_t).
\end{aligned} \tag{33}$$

Equation (33) allows us to make two related observations: hours can respond and the size of the response depends on the steady-state labor share. In particular, $\frac{1-\bar{S}}{\varphi+\bar{S}}$ is decreasing in the labor share \bar{S} and equals 0 when $\bar{S} = 1$. If the labor share is 100 percent, KPR preferences imply that hours worked are unresponsive to monetary policy. When the labor share is less than 100 percent, the response of total income can potentially deviate from the response of labor income and so hours worked become responsive as well. The magnitude of the response is determined by how much the response of profits deviates from the response of real wages. To generate the response in output consistent with the path of the nominal interest rate and inflation, profits become counter-cyclical.

Intuitively, the increase in profits makes the representative household choose to work less: an income (wealth) effect. Moreover, the wage change has a direct effect on hours worked now since the worker also receives profit income, making the income effect of wage changes weaker than the substitution effect. The fall in wages thus depresses hours from this perspective as well.

The textbook RANK model is thus capable of generating negative responses of employment and output to a positive innovation in the policy rate because 1) the households that supply labor also receive profit income and 2) because profit income responds less pro-cyclically than do wages (in fact, the former is counter-cyclical in the

model whereas the latter is pro-cyclical). Although logically clear, this transmission mechanism does not seem empirically well grounded for two reasons. The first is the one emphasized here: few households have substantial non-labor income (see, e.g., Gornemann et al. (2016)) and hence one would not expect workers to be much affected by movements in profits.

The second reason is the one already pointed to in the literature: profits are strongly pro-cyclical, not counter-cyclical, in the data and the available evidence is also that they fall after a monetary policy tightening (see Christiano et al. (2005)). Thus, although the textbook RANK model offers very plausible reduced-form responses to monetary policy that are aligned with intuition, the transmission mechanism whereby this is achieved is implausible: it is very hard to justify empirically. Our simple HANK model highlights this deficiency by showing that, once the assumption of a representative agent is replaced by a stylized form of heterogeneity and incomplete markets, the monetary business cycle disappears. The next section shows that an alternative version of our model, in contrast, where wages are also rigid, features a standard monetary business cycle.

While our analysis focuses on the transmission of monetary policy shocks in a particularly simple heterogeneous-agent version of the standard NK model, the sensitivity of equilibrium dynamics to distributional assumptions is a more general feature of models with an interior labor supply choice. In our model, constant labor supply is a direct implication of intratemporal optimization by workers. Labor supply is thus constant in response to most shocks, including those to total factor productivity (TFP), independently of assumptions about price setting by firms. It is therefore also true in the corresponding flexible price, or real business cycle (RBC), version of our model. Our results thus relate to earlier debates on the correspondence between commonly used business cycle models and business cycle facts. Specifically, both traditional Keynesian and RBC models have been criticized for their implied strong comovement of hours worked and real wages, which contrasts with the small correlation found in U.S. data (Christiano and Eichenbaum, 1992) that is roughly consistent with our findings. More recently, Galí (1999) noted, in accordance with some empirical findings, that hours contract after a positive TFP shock in the representative-agent version of the NK model, in contrast to the standard RBC model, and interpreted this as evidence for the impor-

tance of rigid prices in the transmission of technology shocks. Our analysis suggests that this result, too, depends on an income effect of profits, and hence that the degree of price stickiness does not affect the TFP-hours correlation in the heterogenous-agent setting that we consider here.

3 A model with rigid wages

In Section 2, we saw that monetary policy was not neutral in our simple HANK model. Wages and profits responded differently to a monetary policy shock, redistributing consumption between workers and capitalists. However, as the standard balanced-growth preference specification prescribes that the substitution and income effects from wage changes exactly offset each other, labor supply and aggregate output were unaffected. Taking preferences as given, we infer that to have business cycle fluctuations in labor usage in our model, there must be a time-varying wedge between the wage level and the workers' marginal rate of substitution.

In this section, we allow for such a wedge by introducing rigid wage setting to our model. Such rigidities have considerable empirical support (see, e.g., Taylor (2016) and references therein) and, since they require workers to temporarily deviate from their long-run labor supply curve, they can potentially deliver a mechanism through which labor usage and output respond to monetary policy. Importantly, since flexible wages were crucial for the cyclical properties of firm profits in our benchmark model, such a transmission mechanism may not inherit the problematic role of profits and the sensitivity to distributional assumptions from the standard model. We introduce wage rigidity into our model in a rather standard fashion: by assuming that each household provides a differentiated type of labor service and can reset its wage subject to a Rotemberg (1982)-type adjustment cost. For a crude version of how such a model will work, first consider an extreme form of adjustment cost: wages are constrained to always remain at their steady-state level (and workers are obliged to always meet labor demand). With constant returns to scale, marginal costs as well as the output shares of profits and earnings are then unaffected by monetary policy shocks. This implies that worker and capitalist consumption, as well as total output, all satisfy the same Euler equation. Aggregate dynamics are thus the same as in the corresponding simple

representative agent version and are not sensitive to distributional assumptions.

Moving to the proper model of wage rigidity, assume that household j receives an idiosyncratic labor productivity shock A_{jt} . With adjustment costs, heterogeneity in A_{jt} would typically lead to heterogeneous wage choices and a wage distribution whose dynamics are very difficult to characterize analytically. To keep the analysis tractable we therefore focus on the case of idiosyncratic productivity shocks that are i.i.d. over time. Also, we assume that within each period, households choose whether to participate in the labor market and set their wages after the aggregate shock is realized but before the idiosyncratic shocks have been drawn. Together, as we will see, this implies that all households are identical at the time of wage determination, and therefore choose the same wage path. Trade in the goods and bond market occurs at the end of the period. With this timing, the wage setting problem becomes tractable and we can derive analytical solutions to the log-linear equilibrium. As a result, the equilibrium dynamics are now also characterized by a *wage Phillips curve*, relating current wage inflation to future wage inflation and the average markup over the marginal rate of substitution.

There are other forms of wage setting frictions in the literature. In the context of DSGE models, the most commonly employed construct is the Calvo structure originally proposed by Erceg et al. (2000). In our model, as in the textbook New Keynesian model, this structure delivers a wage Phillips curve isomorphic to the one we find using the Rotemberg adjustment cost. The Rotemberg adjustment-cost version is chosen because it delivers an analytical form for the IS curve, unlike for the case of a Calvo wage friction. In the latter, namely, the history of wage re-settings matters for a worker's consumption trajectory, thus making it unclear who the marginal saver is and hence the whole wage distribution is relevant. In the former, in contrast, all households set the same wage in all periods, and hence there is no need to keep track of the wage distribution when constructing the IS curve.

3.1 Intermediate good firms

As in Section 2, intermediate goods are produced by a continuum of firms, indexed by i , with CRS technology $Y_{it} = N_{it}$. What is new, however, is that labor inputs are now

only imperfectly substitutable through the Dixit-Stiglitz aggregator

$$N_{it} = \left(\int_{j=0}^1 (A_{jt} N_{ijt})^{\frac{\epsilon_w - 1}{\epsilon_w}} dj \right)^{\frac{\epsilon_w}{\epsilon_w - 1}}, \quad (34)$$

where A_{jt} is the productivity of household j and $\epsilon_w > 1$ is the elasticity of substitution. In (34), we have anticipated the result that capitalists continue to not supply labor. Each firm i takes the nominal wages W_{jt} and the average price level P_t as given. Intratemporal cost minimization implies the labor demand curve

$$N_{ijt} = \frac{1}{A_{jt}} \left(\frac{W_{jt}}{A_{jt}} \right)^{-\epsilon_w} N_{it}, \quad (35)$$

where the wage index is defined as

$$W_t = \left[\int_{j=0}^1 \left(\frac{W_{jt}}{A_{jt}} \right)^{1-\epsilon_w} dj \right]^{\frac{1}{1-\epsilon_w}}. \quad (36)$$

Besides the change of the production function, the price setting problem of the intermediate good firms is identical to that in previous section and gives rise to the same Phillips curve for price inflation:

$$\pi_t^p = \beta E_t \pi_{t+1}^p + \lambda_p \hat{\omega}_t. \quad (37)$$

3.2 Households

Both workers and capitalists face the same problem as described in the previous section apart from one aspect: conditional on participating in the labor market, they set their wage W_{jt} subject to an adjustment cost that is quadratic in the wage adjustment and proportional to their labor income.

Workers. As in the previous section, the equilibrium allocation will coincide with that of autarky. Workers will thus always participate in the labor market in every period. A participating worker in period t chooses C_{jt+k} , N_{jt+k} , W_{jt+k} to maximize the objective

$$E_t \sum_{k=0}^{\infty} \beta^k \left(\log C_{jt+k} - \frac{N_{jt+k}^{1+\varphi}}{1+\varphi} - \vartheta \right) \quad (38)$$

subject to the budget constraint

$$P_{t+k} C_{jt+k} + Q_{t+k} B_{jt+k} = W_{jt+k} N_{jt+k} + B_{jt+k-1} - \frac{\xi}{2} \left(\frac{W_{jt+k}}{W_{jt+k-1}} - 1 \right)^2 W_{jt+k} N_{jt+k}, \quad (39)$$

the borrowing constraint

$$B_{jt+k} \geq 0, \quad (40)$$

and the labor demand curve (35). The last term in the budget constraint (39) is the adjustment cost for changing the wage level. The adjustment cost is quadratic in the growth rate of the wage change and proportional to current labor income, implying that for a given wage growth rate, the income loss is a constant fraction of current labor income.¹²

The solution of the wage setting problem is characterized by the optimality condition

$$\begin{aligned} E_{t+k} \left\{ \left(\frac{C_{jt+k}^{-1} N_{jt+k}}{P_{t+k}} \right) \left(\epsilon_w MRS_{jt+k} \frac{1}{\frac{W_{jt+k}}{P_{t+k}}} + (1 - \epsilon_w) \right) \right. \\ \left. - \xi \left(\frac{W_{jt+k}}{W_{jt+k-1}} - 1 \right) \left(\frac{W_{jt+k}}{W_{jt+k-1}} + \frac{1 - \epsilon_w}{2} \left(\frac{W_{jt+k}}{W_{jt+k-1}} - 1 \right) \right) \right. \\ \left. + \beta \frac{C_{jt+k+1}^{-1}}{C_{jt+k}^{-1}} \frac{P_{t+k}}{P_{t+k+1}} \xi \left(\frac{W_{jt+k+1}}{W_{jt+k}} - 1 \right) \frac{W_{jt+k+1}}{W_{jt+k}} \frac{W_{jt+k+1} N_{jt+k+1}}{W_{jt+k} N_{jt+k}} \right\} = 0, \quad (41) \end{aligned}$$

where $MRS_{jt+k} = \frac{N_{jt+k}^\varphi}{C_{jt+k}^{1-\varphi}}$. Notice that in the zero-inflation steady state, where aggregate variables are constant but agents still face idiosyncratic risk, equation (41) reduces to

$$0 = E_t C_{jt}^{-1} N_{jt} \left[\frac{W_{jt}}{P_t} - M_w MRS_{jt} \right], \quad (42)$$

where $M_w = \frac{\epsilon_w}{\epsilon_w - 1}$.

Capitalists. As in the previous section, capitalists differ from workers only in that they are endowed with $1/m_c$ of a diversified portfolio of intermediate good firm shares at $t = 0$. Again, we assume that their mass m_c is sufficiently small for capitalists to prefer not to participate in the labor market. Given the autarky allocation, the formal condition for this for capitalist j is

$$\log \left(\frac{D_t}{m_c} \right) > \log \left(\frac{D_t}{m_c} + \frac{W_{jt}^*}{P_t} N_{jt}(W_{jt}^*) \right) - \frac{N_{jt}(W_{jt}^*)^{1+\varphi}}{1+\varphi} - \vartheta, \quad (43)$$

¹²In the context of Rotemberg adjustment costs, it is common to assume that the quadratic penalty is proportional to nominal output. With a representative agent, nominal output is also that agent's current income, which corresponds to the setup in our HANK model, where the quadratic penalty is proportional to the workers' current income.

where W_{jt}^* is the wage chosen conditional on participating and $N_{jt}(W_{jt}^*)$ is the implied choice of labor from the demand curve (35). As before, for any $D_t > 0$, there exists a $m_c^*(D_t)$ such that for any $m_c < m_c^*(D_t)$, condition (43) holds. Again, we assume that $m_c < \min\{m_c^*(D_t)\}$ so that capitalists never work.

3.3 Equilibrium implications

The market-clearing conditions are the same in this model as in the previous section. Since bonds are in zero net supply and households cannot borrow ($B_{jt} \geq 0$), this implies that all households consume their per-period income. Thus,

$$C_{jt} = \left(1 - \frac{\xi}{2} \left(\frac{W_{jt}}{W_{jt-1}} - 1\right)^2\right) \frac{W_{jt}}{P_t} N_{jt}, \quad (44)$$

for all workers j in all periods t . In the Appendix, we show that by aggregating (44) across households, individual household consumption is related to aggregate consumption through

$$C_{jt} = \frac{\left(\frac{W_{jt}}{A_{jt}}\right)^{1-\epsilon_w}}{\int_s \left(\frac{W_{st}}{A_{st}}\right)^{1-\epsilon_w} ds} C_t, \quad (45)$$

where

$$C_t = \int C_{jt} dj = \left(1 - \frac{\xi}{2} (\Pi_t^w - 1)^2\right) \frac{W_t}{X_t^w P_t} N_t, \quad (46)$$

and $X_t^w = \int_j \left(\frac{W_{jt}}{A_{jt}}\right)^{-\epsilon_w} dj$ is a measure of the dispersion in wages adjusted for differences in worker productivity. Due to the CES labor aggregator in the production function, the pass-through of individual productivity shocks to individual wages and consumption depends on the elasticity of substitution ϵ_w , in contrast to the flexible-wage model where this pass-through was one-for-one as evident from Equation (15).

The wage-inflation Phillips curve. We search for a symmetric solution to (41), in which $W_{it+k} = W_{jt+k} = W_{t+k}^*$ for all i, j . In the Appendix, we show that by using the definition of the average wage level (36), the market-clearing condition (44) and the aggregation result (45), the optimality condition (41) can be written in terms of

aggregate variables:

$$\begin{aligned}
0 = & K_1 \epsilon_w \frac{MRS_t}{\frac{W_t}{P_t}} + (1 - \epsilon_w) \\
& - \xi (\Pi_t^w - 1) \left(\Pi_t^w + \frac{1 - \epsilon_w}{2} (\Pi_t^w - 1) \right) \\
& + \beta \xi E_t \left[(\Pi_{t+1}^w - 1) \Pi_{t+1}^w \frac{(1 - \frac{\xi}{2} (\Pi_t^w - 1)^2)}{(1 - \frac{\xi}{2} (\Pi_{t+1}^w - 1)^2)} \right], \tag{47}
\end{aligned}$$

where $\Pi_t^w = \frac{W_t}{W_{t-1}}$ is the wage inflation rate and K_1 is a constant that depends on the dispersion of worker productivity. In the Appendix, we also show that log-linearizing this condition around the zero-inflation steady state delivers the wage Phillips curve, relating the current wage inflation to future wage inflation and deviations of the average real wage from the average marginal rate of substitution:

$$\pi_t^w = \beta E_t \pi_{t+1}^w - \lambda_w (\hat{\omega}_t - (\hat{c}_t + \varphi \hat{n}_t)), \tag{48}$$

where $\lambda_w = \frac{\epsilon_w - 1}{\xi}$.

Other equilibrium conditions. Because all households set the same wage and individual productivity A_{jt} is independently distributed over time and households, the measure of productivity-adjusted wage dispersion X_t^w is a constant. Using this when log-linearizing (46) around the zero-inflation steady state, we obtain

$$\hat{c}_t = \hat{\omega}_t + \hat{n}_t. \tag{49}$$

We have assumed that households can trade in the bond market only at the end of the period, after the idiosyncratic shocks are realized. Hence, the intertemporal optimality condition of the household's problem is identical to that in Section 2, that is, equation (4). Again focusing on small aggregate shocks, the marginal saver is still a worker. Because individual worker income is proportional to aggregate labor income, the aggregate IS curve is also identical to that in Section 2. The steady-state interest rate, however, now also reflects that the pass-through of idiosyncratic productivity shocks to consumption depends on the substitutability of labor inputs in the production function. To see this, use the result that all households set the same wage and substitute (45) into the Euler equation (4) of the marginal saver to find

$$Q_t = \beta^{eff} E_t \left\{ \frac{C_{t+1}^{-1}}{C_t^{-1}} \frac{P_t}{P_{t+1}} \right\}, \tag{50}$$

where

$$\beta^{eff} = \beta E_t \left(\frac{A_{max}}{A_{st+1}} \right)^{\epsilon_w - 1}. \quad (51)$$

From (51) we see that the steady-state interest rate decreases as the elasticity of substitution of labor inputs increases, reflecting the fact that the pass-through of idiosyncratic productivity shocks to consumption increases, as seen in (45), which increases the precautionary demand for assets.

To complete the characterization of the log-linear dynamics, we also need an accounting identity for the evolution of the average real wage:

$$\hat{\omega}_t = \hat{\omega}_{t-1} + \pi_t^w - \pi_t^p. \quad (52)$$

Summary. The log-linearized equilibrium is summarized by:

$$\text{Phillips : } \pi_t^p = \beta E_t \pi_{t+1}^p + \lambda_p \hat{\omega}_t, \quad (53)$$

$$\text{Wage Phillips : } \pi_t^w = \beta E_t \pi_{t+1}^w - \lambda_w (\hat{\omega}_t - (\hat{c}_t + \varphi \hat{n}_t)), \quad (54)$$

$$\text{Wage accounting : } \hat{\omega}_t = \hat{\omega}_{t-1} + \pi_t^w - \pi_t^p, \quad (55)$$

$$\text{IS : } \hat{c}_t = E_t \hat{c}_{t+1} - (\hat{i}_t - E_t \pi_{t+1}), \quad (56)$$

$$\text{Taylor rule : } \hat{i}_t = \phi_\pi \pi_t^p + \nu_t, \quad (57)$$

$$\text{Market clearing : } \hat{c}_t = \hat{\omega}_t + \hat{n}_t. \quad (58)$$

3.4 Comparison to the textbook model

As before, it is useful to compare the dynamic system described by equations (53)–(58) to that of the corresponding textbook RANK model. The wage Phillips curve is derived in Appendix ?? and is identical to that in our simple HANK model. The wage accounting equation is, of course, identical as well. The rest of the equations are unaffected by the wage adjustment cost and taken directly from the RANK model

described in Section 2.

$$\text{Phillips : } \pi_t^p = \beta E_t \pi_{t+1}^p + \lambda_p \hat{\omega}_t, \quad (59)$$

$$\text{Wage Phillips : } \pi_t^w = \beta E_t \pi_{t+1}^w - \lambda_w (\hat{\omega}_t - (\hat{c}_t + \varphi \hat{n}_t)), \quad (60)$$

$$\text{Wage accounting : } \hat{\omega}_t = \hat{\omega}_{t-1} + \pi_t^w - \pi_t^p, \quad (61)$$

$$\text{IS : } \hat{c}_t = E_t \hat{c}_{t+1} - (\hat{i}_t - E_t \pi_{t+1}), \quad (62)$$

$$\text{Taylor rule : } \hat{i}_t = \phi_\pi \pi_t^p + \nu_t, \quad (63)$$

$$\text{Market clearing : } \hat{c}_t = \bar{S}(\hat{\omega}_t + \hat{n}_t) + (1 - \bar{S})\hat{d}_t. \quad (64)$$

As before, when log-linearized around their respective steady states, the only differences between the RANK model and our simple HANK model are the market-clearing conditions (58) and (64). The consumption aggregate that enters the IS curve in our HANK model equals aggregate worker income, whereas the same aggregate equals total income in the RANK model. Any differential response of the two models will stem from differential responses of profits and wages to the monetary policy shock. As we shall see, however, the factor shares of total income will barely be affected by monetary policy when wages are sufficiently rigid.

3.5 Impulse response functions to a monetary shock

Calibration. We need to choose the values for two new parameters: ϵ_w and ξ . We follow Galí (2009), Ch. 6, and set $\epsilon_w = 6$. The parameter ξ does not have a direct interpretation in the data. To calibrate ξ , we rely on the first-order equivalence between our wage Phillips curve (54) and the wage Phillips curve retrieved in the same model with the Calvo wage setting friction proposed by Erceg et al. (2000). In the appendix, we derive the wage Phillips curve with the Calvo friction, and solve for ξ so that the slope of this Phillips curve equals that of (54). Galí (2009) suggests a quarterly resetting probability of $1/4$, which translates into $\xi \approx 700$. For these values, the Blanchard-Kahn conditions of our model are satisfied and the model thus has a unique stable solution.

Impulse-response functions. We now consider the implications of an innovation in the monetary policy rate. The impulse-response functions (IRFs) of our simple HANK model and the RANK model are plotted in Figure 2, juxtaposed to the IRFs of the same models taken to their flexible-wage, perfectly-competitive labor market limits

($\xi = 0, \epsilon_w \rightarrow \infty$) in the left column. The latter parameterization produces the same model as that considered in Section 2 and the IRFs are identical to those in Figure 1.

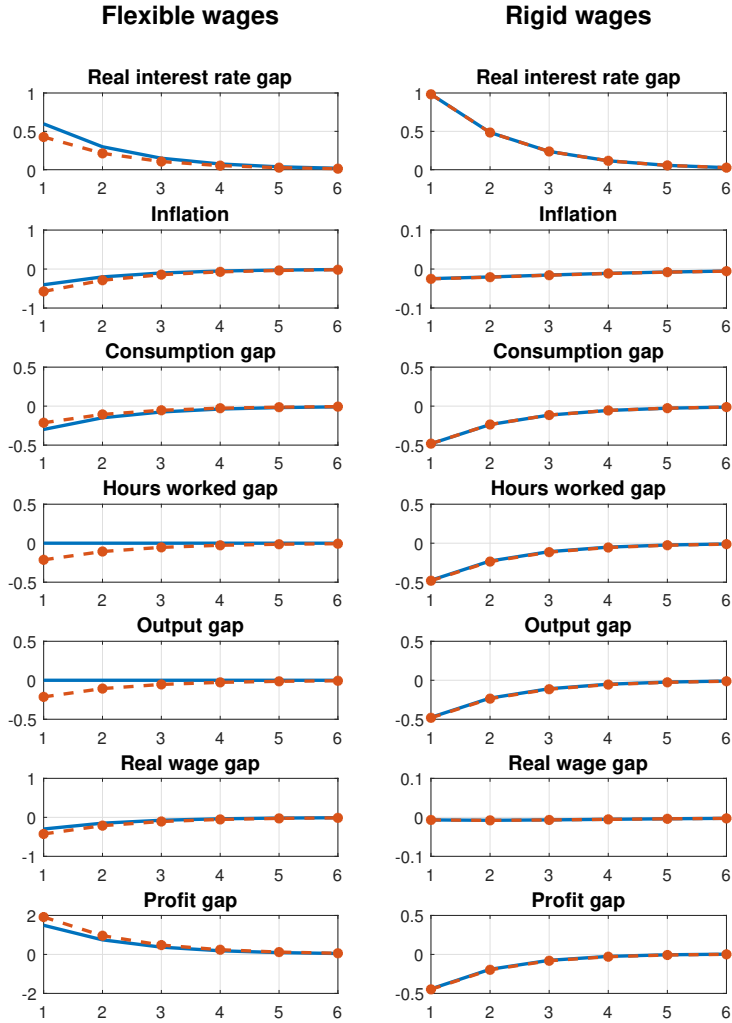


Figure 2: Equilibrium responses, measured as percentage deviations from the steady state, to a positive 25 basis-point shock in the policy rate. Blue solid lines: our HANK model. Red dashed lines with circle markers: the textbook RANK model. Left-hand panel: flexible wage setting. Right-hand panel: rigid wage setting. The “Consumption gap” refers to the worker consumption gap, in the case of our HANK model, and the aggregate consumption gap, in the RANK model. Inflation and interest rates: yearly rates; other variables: quarterly rates.

To understand the behavior of our HANK model with wage rigidities, note that our calibration implies that workers’ real wages adjust only very little in response to a monetary tightening. With a linear production technology, firms’ marginal costs are therefore approximately unaffected by monetary policy, which strongly dampens the inflation response relative to the model with flexible wage setting. The need for policy-

makers to counteract a fall in inflation, which partly undoes the monetary tightening when wages are flexible, is thus reduced and both the nominal and real interest rates rise more strongly. Accordingly, the consumption gap in the model with rigid wages responds more strongly on impact but follows a path that is similar to that with only price rigidities, as seen by comparing the blue solid lines in each column of Figure 2.

The effects of monetary policy on output and hours worked, in contrast, are completely different with rigid wages. Without an active choice of hours worked, labor supply mechanically follows the demand for total consumption. With marginal costs largely unaffected by monetary policy, profits and labor income are approximately constant fractions of total output, respectively, and equal to capitalist and worker consumption in equilibrium. Importantly, profits now respond pro-cyclically and, accordingly, aggregate consumption demand responds proportionally to worker consumption demand, whose path is determined by the worker's Euler equation (56).

With rigid wages, the output and consumption responses in our simple HANK model thus capture the conventional view of the effect of monetary policy: in response to a monetary tightening, both components fall and slowly converge back to their steady-state values. This pattern sharply contrasts with that found in the same model with a flexible wage setting. We regard this crucial role of wage rigidities in our model as a particularly appealing feature of our model, as it is in line with the evidence from calendar-varying vector autoregressions, showing that the magnitude and persistence of the output response to monetary policy shocks decrease in the calendar periods in which wages are renegotiated (Olivei and Tenreyro, 2007, 2010; Björklund et al., 2018).

While idiosyncratic risk did not affect the transmission of monetary policy in the rigid price version of our simple HANK model, heterogeneity in factor incomes was crucial, and strongly affected by a monetary tightening, as a negative wage gap redistributed income from workers to capitalists. By comparing the blue solid and red dashed circle-marked lines in the right-hand side panel of Figure 2, we see that, through its implication of almost constant real wages, our calibration significantly reduced the importance of heterogeneity for aggregate transmission: the monetary business cycle is more or less the same as that in the textbook RANK model. The impact of monetary policy on inequality is also reduced, as the output shares of profits and labor income

are approximately constant. Importantly, the strength of the monetary transmission as well as the distributive trade-off are both functions of the degree of wage rigidity fed into the model, and may thus vary across time periods and economies with different labor market institutions.

4 Concluding remarks

In this paper, we have proposed a heterogeneous-agent version of the New Keynesian model. The heterogeneity was kept stylized, but rich enough to capture two key dimensions of the data: first, that labor incomes are volatile and unequal; and second, that wealth holdings are highly concentrated. The stylized nature of the model allowed us to obtain an analytical log-linear representation similar to that of the representative-agent model familiar from textbooks. We have used the model to analyze how heterogeneity affects the responses of aggregate quantities and prices to a monetary shock, and how monetary policy affects the distribution of resources in the economy.

Our main conclusion from this analysis is that when taking household heterogeneity into account, the monetary transmission mechanism depends greatly on whether nominal frictions arise from price or wage rigidity. When only prices are rigid, the distributional effect of monetary policy interventions is large, as they move wage and profit income in opposite directions. Total labor usage and output, however, are unaffected, since income and substitution effects of wage changes on labor supply cancel each other out. In other words, there is no effect of monetary policy on aggregate quantities in the rigid-price-only version of our model.

When we add rigid wages to our model, the distributional effect is smaller, as wages, and therefore the shares of labor and profit income in total output, respond less. Labor usage becomes “demand-determined” in this case and the standard transmission mechanism, whereby a monetary tightening reduces total output, is restored. This crucial role of wage rigidity for the monetary transmission mechanism is in line with the empirical evidence (Olivei and Tenreyro, 2007, 2010; Björklund et al., 2018) and contrasts with the representative-agent version of the New Keynesian model, where the qualitative response of aggregate quantities is independent of the sources of nominal rigidity.

We also uncovered what we think is a second unappealing feature of the standard textbook New Keynesian model with a representative-agent, rigid prices, and flexible wages. Although the reduced-form link from monetary policy to output seems plausible in that framework, it relies on a transmission mechanism that is implausible: output falls in response to a monetary tightening because mark-ups and total profits rise, increasing the representative working household's income and thus her demand for leisure, amounting to a fall in labor supply. Together with the marginal role of wage rigidity for monetary transmission, this finding suggests that the simple representative-agent New Keynesian model with sticky prices is a somewhat problematic benchmark for monetary policy analysis. In our view, a simple heterogeneous-agent version of the model, like the one developed here, with sticky wages in addition to sticky prices is a more appropriate benchmark setting: not only does it recognize the striking inequality in wealth and income composition in the data, but it allows us to better understand the microfoundations of the monetary policy transmission and, in so doing, account for key distinguishing implications of price and wage stickiness for this transmission.¹³

Our analysis invites further research along several dimensions. First, the main claims of this paper are of course confined to a specific class of New Keynesian models. In particular, the non-response of output to monetary policy in our simple HANK model without wage rigidities, and *mutatis mutandis* the crucial role of the representative-agent assumption for the standard model, could potentially be affected by other features not considered here. Obvious candidates include physical capital, investment adjustment costs, and consumption habits. Further analysis of these features may uncover that some of them are more important for the transmission mechanism than previously believed. If so, they should therefore also be in focus in textbooks and simple policy models, in our view. In its current standing, the textbook representative-agent New Keynesian model with only price stickiness does not have these features and must at best be interpreted with great caution. For these reasons, we would welcome further

¹³As we have also shown, the implications of our model for aggregate variables and inequality are close to those of the simple RANK model when wages are rigid, hence making the RANK model with sticky wages a much more appropriate benchmark in the class of RANK models. When wages are somewhat more flexible, however, the RANK model becomes more implausible and for this reason we prefer our HANK model as a benchmark.

investigation into simple HANK models, as the one proposed here, to incorporate such richer features.

Second, the tractability of our model was achieved by studying the limit of no risk sharing, achieved through the joint conditions of no borrowing and zero net supply of assets, following Krusell et al. (2011); Werning (2015); McKay and Reis (2017) and Ravn and Sterk (2018). We of course very much welcome quantitative analysis considering the intermediate case between full and no risk sharing, which allows matching the heterogeneity in consumption and savings behavior observed in the data with greater precision. A burgeoning literature studying the implications of such models is already under way (see, e.g., Auclert (2017); McKay et al. (2016); Gornemann et al. (2016); Kaplan et al. (2018)). Interestingly, Kaplan et al.'s quantitative analysis of an economy with capital whose features are carefully calibrated to capture microeconomic evidence from the United States on wealth and consumption (including the distribution of households across liquid and illiquid assets and the average marginal propensity to consume out of income shocks) also finds that assumptions about the distribution of firm profits matter greatly for the transmission of monetary policy.¹⁴ A relevant question in this context is to what extent the implications of more quantitative HANK models can be summarized within the simple model that we have proposed here. Galí and Debortoli (2017) finds that there are parameters for which their TANK model behaves very similarly to a fully specified quantitative HANK model in response to a monetary shock, which points to the possibility that models with reduced forms of heterogeneity may be able to capture most of the relevant interaction between inequality and monetary policy. Needless to say, much more analysis, theoretical and empirical, is necessary in the area exploring the interactions between monetary policy and consumer heterogeneity, and we surely look forward to taking an active part in it.

¹⁴The authors control the degree of profit sharing by introducing a parameter ω which equals the fraction of firm profits distributed to firm owners, with the remainder being distributed lump-sum to all households in proportion to their labor productivity. When this profit sharing is removed, by increasing ω from its benchmark value of 0.33 to 1, the elasticity of output to a monetary policy shock declines from 4 to 0.1.

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