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The House Price Channel of Quantitative Easing

Hannah Magdalena Seidl*

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Abstract

I study the transmission mechanism of Quantitative Easing (QE) in the form of large-scale asset purchases in the mortgage market to aggregate consumption. To this end, I develop a New Keynesian model that features heterogeneous households, a microfounded housing market, and frictional intermediation. This model helps explain the empirical evidence suggesting that QE increases aggregate consumption by raising house prices. I find that higher house prices account for around half of QE's stimulative effects, with higher labor income contributing the remaining half.

Keywords: Quantitative Easing, Heterogeneous Agents, Incomplete Markets, Sticky Wages, Housing, Asset Prices

JEL Codes: E12, E21, E44, E52

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1 Introduction

Quantitative Easing (QE) has become a standard component of central banks' toolkits in many advanced economies and is expected to remain a key policy instrument (Gopinath (2023)). In the United States, the Federal Reserve's QE programs have provided substantial macroeconomic stimulus during recessions following both the Great Financial Crisis and the COVID-19 pandemic (Adrian et al. (2024)). While the scale and composition of asset purchases under QE vary, large-scale asset purchases in the mortgage market are among the Federal Reserve's most frequently used QE tools. Empirical studies indicate that this form of QE decreases mortgage spreads (see, e.g., Hancock and Passmore (2011) and Drechsler et al. (2024)), thereby increasing house prices (Walentin (2014)). Higher house prices, in turn, stimulate aggregate consumption, as households exhibit a high elasticity of consumption to housing wealth (Mian et al. (2013)). It is therefore plausible that QE stimulates the economy, to some extent, through its effect on house prices.

Yet, the theoretical literature has not studied the transmission of QE through house prices. This is mainly because many macroeconomic models of QE are based on representative-agent or spender-saver frameworks[1] which generate counterfactually small consumption responses to house price fluctuations. This limited response arises because the consumption behavior in these models closely follows the permanent income hypothesis, according to which agents smooth consumption based on the expected net present value of their resources (Berger et al. (2018)).[2] In contrast, heterogeneous-agent New Keynesian (HANK) models[3] generate substantial consumption responses to changes in house prices. This is because, as shown by Berger et al. (2018), these models replicate the high elasticity of consumption to housing wealth observed in the data (Mian et al. (2013)) by incorporating incomplete markets and borrowing constraints. However, prior work studying QE in HANK models either abstracts from a housing market (see, e.g., Cui and Sterk (2021), Lee (2021), and Sims et al. (2022)) or assumes an exogenous process for house prices (Beraja et al. (2019)).

In this paper, I develop a HANK model with frictional financial intermediation and a microfounded housing market that captures the transmission of QE through endogenous house price movements—a novel transmission channel of QE in the literature. Specifically,

[1] See, e.g., Gertler and Karadi (2011), Gertler and Karadi (2013), and Sims and Wu (2020).

[2] Spender-saver models can generate a large consumption response from the representative spender when house prices change. However, since the spender holds very little wealth, this response has only a small impact on aggregate consumption.

[3] See, among many others, Werning (2016), Kaplan et al. (2018), Auclert et al. (2020), and McKay and Wieland (2021).

I show that QE increases house prices, which, in turn, stimulate aggregate consumption—the largest component of GDP. The model-implied aggregate effects of QE are consistent with empirical estimates by Walentin (2014): a QE shock that reduces the mortgage spread by 100 basis points on impact leads to a 1.6% increase in aggregate consumption. I find that higher house prices account for roughly half of QE's stimulative impact on aggregate consumption, with the remaining half driven by increased labor income.

I derive these findings in a New Keynesian model in a perfect foresight environment, following McKay and Wieland (2021). Households face idiosyncratic shocks to their labor productivity that cannot be fully insured, resulting in heterogeneity in their portfolios of liquid assets and housing. Housing is illiquid as its adjustment is subject to fixed costs. I assume that every household owns some housing. In addition, households face a collateral constraint that limits borrowing to a fraction of their housing value.

I extend the model by introducing a representative financial intermediary that channels funds among households. Financial intermediation is frictional, as the intermediary faces an always-binding leverage constraint, following He and Krishnamurthy (2013). Specifically, the intermediary's leverage cannot exceed a fixed ratio of its net worth, giving rise to an endogenous and time-varying borrowing spread. QE becomes relevant in this setup, as it reduces the spread, thereby stimulating consumption.

On the supply side, wages are sticky and prices are flexible. Including wage stickiness rather than price stickiness prevents countercyclical profits, which would be counterfactual. This assumption is important, as the distribution of profits affects the cyclical properties of macroeconomic aggregates in the model (see Werning (2016) and Broer et al. (2020)).

The government sector consists of monetary and fiscal policy. The central bank implements unconventional monetary policy in the from of QE. Following Gertler and Karadi (2011), QE is modeled as central bank credit intermediation. Specifically, the central bank issues interest-bearing reserves to the financial intermediary. In addition to QE, the central bank conducts conventional monetary policy by setting the nominal interest rate according to a standard Taylor rule. The fiscal authority issues liquid assets and collects labor taxes proportional to household productivity. Conventional monetary and fiscal policy are intertwined, as changes in the interest rate affect the government's budget constraint through debt payments. Following McKay and Wieland (2021), I assume that fiscal policy adjusts labor taxes to balance the effects on the government budget constraint.

My main finding is that this model generates a transmission of QE to aggregate consumption through increases in house prices. More specifically, when the central bank conducts QE, it issues interest-bearing reserves to the financial intermediary. Since these reserves are not subject to the intermediary's leverage constraint, QE relaxes this constraint, allowing the intermediary to expand lending, which reduces the mortgage spread. A lower mortgage spread decreases the user cost of housing, incentivizing households to increase their housing demand, which raises house prices.

I find that these QE-induced increases in house prices stimulate aggregate consumption, thereby completing the QE–house price–consumption nexus. My findings indicate that the transmission from house prices to aggregate consumption operates primarily through *wealthy hand-to-mouth* households (Kaplan et al. (2014))—households who belong to the top 10% of the housing wealth distribution but at the same time hold little or no liquid assets. Specifically, rising house prices increase their housing wealth, which, in turn, relaxes their collateral constraint. As a result, these households are able to convert part of their housing wealth into liquid assets and use this additional liquidity for consumption. Given their substantial share of total housing wealth, their consumption responses significantly contribute to the overall increase in aggregate consumption following QE.

Subsequently, I show that, in addition to the house price channel, QE operates through two further transmission channels. First, QE induces a general-equilibrium increase in labor income, which stimulates consumption. This effect arises because the model generates on average high marginal propensities to consume (MPCs) out of labor income, consistent with empirical evidence (see, e.g., Johnson et al. (2006) and Jappelli and Pistaferri (2010)). The importance of labor income in the transmission of QE is consistent with findings from the HANK literature on conventional monetary policy (see, e.g., Kaplan et al. (2018)).

Second, as inflation rises in response to QE, conventional monetary policy tightens, leading to an increase in the real interest rate, which dampens the expansionary effects of QE. This is first because a higher real interest rate increases the user cost of housing, reducing housing demand. This dampens the increase in house prices and, thus, the expansionary effects of QE on aggregate consumption. Moreover, the increase in the real interest rate incentivizes households to postpone consumption via intertemporal substitution, further reducing the stimulative impact of QE. In addition, higher interest rates increase government debt payments. To balance the government budget constraint, labor taxes rise, reducing households' labor income. As households have high MPCs out of labor income, this fiscal response further dampens aggregate consumption.

To quantify the relative strength of the transmission channels, I decompose the aggregate consumption response into the contribution of house prices, labor income, and interest rates. I find that higher house prices and increased labor income each account for approximately 50% of the expansionary effects of QE, while rising interest rates account for the dampening of the QE stimulus.

In response to the Great Financial Crisis (GFC), the Federal Reserve primarily purchased government-backed mortgage-backed securities (MBS). These assets involve low intermediation costs due to their high credit quality and explicit government guarantees. In contrast, following the COVID-19 shock, the Fed broadened its asset-purchase program to include agency commercial MBS (Milstein and Wessel (2024)). These assets incur higher intermediation costs because they are backed by a diverse set of commercial properties requiring more extensive evaluation of asset quality, tenant performance, and market conditions. To compare the stimulative effects of QE policies that differ in intermediation costs, I extend the model to incorporate these costs explicitly into the government budget constraint.[4] I find that higher intermediation costs dampen the stimulative effects of QE, primarily by raising government expenditures, which, in turn, induce higher labor taxes. This reduces households' disposable income, thereby limiting the increase in aggregate consumption. The extent of this dampening depends on the magnitude of the intermediation costs, highlighting the importance of accurately measuring these costs to fully understand QE's macroeconomic impact.

The paper is organized as follows. In section 2, I introduce the model, outline its calibration, and describe the solution method. In section 3, I present the aggregate effects and transmission channels of QE. In section 4, I extend the analysis by incorporating intermediation costs for the central bank. Finally, in section 5, I conclude.

2 Model

This section outlines my HANK model, a sticky-wage New Keynesian model extended by a heterogeneous-household, incomplete-market setup. My model also includes a microfounded housing sector and frictional financial intermediation.

[4] In the baseline model, intermediation costs are implicitly absorbed via the mortgage spread.

2.1 Households

The household sector is based on McKay and Wieland (2021). The economy is populated by a continuum of measure one of households. The preferences of household $i \in [0,1]$ are given by:

$$E_0 \int_{t=0}^{\infty} e^{-\rho t} \left[u\left(c_{it}, h_{it}\right) - \bar{u}_{c,t} \int_0^1 v\left(n_{ijt}\right) dj \right] dt, \tag{1}$$

where c_{it} denotes nondurable consumption, h_{it} is meant to indicate housing, n_{ijt} is labor supply of labor type $j \in [0,1]$, and ρ denotes the discount rate. I assume that every household owns housing and, thus, abstract from a rental market. This assumption is based on Greenwald and Guren (2021), who show that rental markets are highly frictional, discouraging many households from renting. In an extreme case, these frictions are so severe that the housing market consists solely of homeowners. By excluding the rental market from my model, all households are immediately affected by QE-induced increases in house prices. In contrast, if a rental market were incorporated, renters would experience the effects indirectly and with a delay as rising house prices gradually translate into higher rental costs. This would therefore smooth out the aggregate responses to QE.

As further described below, labor unions determine labor supply while taking household preferences into account. Additively separable preferences induce a wealth effect on labor supply: an increase in household wealth leads to higher consumption. Higher consumption lowers the marginal utility of consumption which makes leisure relatively more attractive such that labor supply decreases. For computational tractability,[5] I follow McKay and Wieland (2021) and eliminate this wealth effect on labor supply through introducing a preference shifter into household preferences, given by:

$$\bar{u}_{c,t} = \int_0^1 \frac{\partial u(c_{it}, h_{it})}{\partial c_{it}} di. \tag{2}$$

Accordingly, the preference shifter captures the marginal utility of consumption. It eliminates the wealth effect on labor supply as the disutility of labor adjusts in proportion to the marginal utility of consumption: when consumption rises, the scaled disutility of labor rises proportionally.

The utility function includes a constant elasticity of substitution (CES) consumption

[5] Removing the wealth effect simplifies the computation (see McKay and Wieland (2019) for details). The reasoning is as follows. A change in the LTV ratio affects the interest rate and, thus, household wealth. In a model with a wealth effect on labor, labor supply is then affected, which, in turn, affects again the interest rate. Removing the wealth effect breaks this feedback loop.

aggregator for consumption goods and housing, and is given by:

$$u(c,h) = \frac{\left[(1-\psi)^{\frac{1}{\xi}} c^{\frac{\xi-1}{\xi}} + \psi^{\frac{1}{\xi}} h^{\frac{\xi-1}{\xi}}\right]^{\frac{\xi(1-1/\sigma)}{\xi-1}} - 1}{1-1/\sigma}, \tag{3}$$

where ξ denotes the elasticity of substitution between housing and nondurables, ψ denotes the consumption share of housing in the preference aggregator, and σ is the inverse of the elasticity of intertemporal substitution.

Households hold liquid assets, a_{it}, and illiquid housing, h_{it}, in their portfolio. When a household adjusts its housing position, it reshuffles its portfolio (a_{it}, h_{it}) to its new value (a'_{it}, h'_{it}) according to:

$$a'_{it} + p_t h'_{it} = a_{it} + (1-f) p_t h_{it},$$

where p_t denotes the relative price of housing in terms of the consumption good, and f is a fixed cost proportional to the value of the housing stock, rendering housing illiquid.

The evolution of the housing stock is given by:

$$\dot{h}_{it} = -\delta h_{it},$$

where a dot over a variable denotes the derivative with respect to time and δ denotes the depreciation rate of housing.

The household can borrow against the value of its housing stock up to a loan-to-value limit, λ. The endogenous borrowing constraint of each household is accordingly given by:

$$a_{it} \geq -\lambda(1-f) p_t h_{it}. \tag{4}$$

When a household does not adjust its housing stock, the evolution of liquid assets is given by:

$$\dot{a}_{it} = r_t a_{it} + r_t^b a_{it} \mathbb{I}_{\{a_{it}<0\}} + y_{it} - \delta p_t h_{it}. \tag{5}$$

Hence, the change in liquid asset holdings, $\dot{a}_t$, of household i is determined by the household's labor income, y_{it}, as specified below, and the depreciation of housing composed of the depreciation rate, δ, times the value of housing, $p_t h_{it}$. If a household has positive asset holdings, it earns interest income of the amount of assets held by the household, a_{it}, times the interest rate r_t. When a household borrows, it pays on its debt the interest rate $r_t^l = r_t + r_t^b$, where r_t^b is a mortgage spread which is endogenously determined in the intermediary's problem as described in section 2.5. Hence, the household has expenditures of the amount of the interest paid on debt, r_t^l, times the amount of debt the household holds, $a_{it}\mathbb{I}_{\{a_{it}<0\}}$.

Household labor income, y_{it}, is given by:

$$y_{it} = (Y_t - \bar{\tau}_t) z_{it}, \tag{6}$$

where Y_t is aggregate income and z_{it} is the household's idiosyncratic labor productivity. Let $\bar{\tau}_t$ denote a labor tax paid by households in proportion to their labor productivity. The tax is a revenue source for the government, which uses these funds to finance government consumption G_t and interest payments on its debt, as specified in the government's budget constraint below (equation (22)).

Let $\ln z_{it}$, follow an Ornstein-Uhlenbeck process[6], given by:

$$\mathrm{d} \ln z_{it} = -\rho_z (\ln z_{it} - \ln \bar{z})\, \mathrm{d}t + \sigma_z \, \mathrm{d}\mathcal{W}_{it}^z,$$

where $\mathrm{d}\mathcal{W}_{it}$ represents a Brownian motion, ρ_z governs the degree of mean reversion of the income process, σ_z determines the variance of the income process, and $\bar{z}$ is a constant ensuring that $\int z_{it}\, di = 1$.

2.2 Final goods producers

As in McKay and Wieland (2021), a representative firm produces the final good, Y_t, using aggregate labor, L_t. The production function is given by:

$$Y_t = L_t. \tag{7}$$

Aggregate labor and aggregate wage are given by the following indices:

$$L_t = \left(\int_0^1 l_{jt}^{\frac{\phi-1}{\phi}} dj \right)^{\frac{\phi}{\phi-1}}, \tag{8}$$

$$W_t = \left(\int_0^1 W_{jt}^{1-\phi} dj \right)^{\frac{1}{1-\phi}}, \tag{9}$$

where ϕ denotes the elasticity of substitution between different types of labor, W_{jt} is the wage rate for labor type j, l_{jt}. The price of the final good, P_t, is flexible and equal to

[6] An Ornstein-Uhlenbeck process is the continuous-time counterpart of the discrete-time AR(1)-process.

marginal costs, so $P_t = W_t$. As shown in Appendix A, the demand curve for labor is given by:

$$l_{jt} = L_t \left(\frac{W_{jt}}{W_t} \right)^{-\phi}. \tag{10}$$

2.3 Labor unions

As in McKay and Wieland (2021), a set of unions determines households' labor supply, and households take labor supply and labor income as given.

Unions collect differentiated productivity-weighted labor, $z_{it}n_{ijt}$, and aggregate it to labor type j, l_{jt}, according to:

$$l_{jt} = \int_0^1 z_{it} n_{ijt} di.$$

They sell this labor to final goods producers at the nominal wage rate W_{jt}. Nominal wages are sticky, and the Rotemberg-style wage adjustment costs are given by:

$$\frac{\Psi}{2} \bar{u}_{c,t} L_t (\mu_{jt})^2,$$

where Ψ is the strength of nominal rigidities. Including the preference shifter, $\bar{u}_{c,t}$ (as defined in equation (2)), in the Rotemberg adjustment costs function ensures that wage adjustment costs are higher when the marginal utility of consumption is high, meaning that in periods of low consumption, the economy exhibits greater wage rigidity.

The growth rate of the wage for variety j, μ_{jt}, is given by:

$$dlnW_{jt} = \mu_{jt} dt. \tag{11}$$

The union chooses a wage growth rate for labor type j, μ_{jt}, that is optimal for households. Note that the individual labor supply of type j, n_{ijt}, is equally distributed across all households. The objective function of the union is given by the following equation:

$$\max_{\mu_{jt}} \int_{t=0}^{\infty} e^{-\rho t} \int_0^1 \left[u_c(c_{it}, h_{it}) \frac{W_{jt}}{P_t} l_{jt} - \bar{u}_{c,t} v(l_{jt}) - \frac{\Psi}{2} \bar{u}_{c,t} L_t (\mu_{jt})^2 \right] didt. \tag{12}$$

The first term in the brackets of the objective function represents the utility gain for households, which is real labor earnings for labor type j, $W_{jt} l_{jt} / P_t$, in terms of utility, that is, multiplied by the marginal utility of consumption of household i, $u_c(c_{it}, h_{it})$. The second term is the disutility of supplying labor of type j. As explained in section 2.1, the disutility of supplying labor is scaled by the preference shifter $\bar{u}_{c,t}$ to eliminate the wealth effects on labor supply. The last term captures the quadratic adjustment costs that arise when the wage changes. These costs depend on the size of the change, $L_t(\mu_{jt})^2$, the adjustment cost parameter, Ψ, and the preference shifter, $\bar{u}_{c,t}$, as explained above.

The union maximizes the objective function (equation (12)), with respect to labor demand (equation (10)) and the growth rate of wages (equation (11)). The union optimizes with respect to the growth rate of wages, rather than wage levels, because Rotemberg adjustment costs penalize large wage changes. This leads to gradual wage adjustments and prevents unrealistic jumps, in line with observed wage-setting behavior. The resulting optimality condition yields the following Phillips curve log-linearized around the zero inflation steady state:

$$\dot{\pi}_t = \rho\pi_t - \kappa\left(\frac{Y_t - \bar{Y}_t}{\bar{Y}_t}\right), \tag{13}$$

where $\bar{Y}_t$ is natural output, inflation, π_t, is defined as $\pi_t \equiv \frac{dlnP_t}{dt}$ and $\kappa \equiv \frac{(\phi-1)\eta}{\psi}$ is the slope of the Phillips curve, where $1/\eta$ denotes the Frisch elasticity. For details of the derivation of the Phillips curve, see Appendix B.

2.4 Housing supply

As in McKay and Wieland (2021), a representative firm produces housing, X_t, using a nondurable good, M_t, as an input, and using a constant flow of land, $\bar{D}$. The government makes land available and sells it. The production function is given by:

$$X_t = \omega M_t^{1-\zeta}\bar{D}^{\zeta}, \tag{14}$$

where ω is a constant, and ζ is the share of land in housing production.

Profit maximization yields the following relative price of housing:

$$p_t = (1-\zeta)^{-1}\omega^{-\frac{1}{1-\zeta}}\left(\frac{X_t}{\bar{D}}\right)^{\frac{\zeta}{1-\zeta}}.$$

It follows that $\frac{1-\zeta}{\zeta}$ is the supply elasticity of housing. For details of the derivation, see Appendix C.

2.5 Intermediaries

I extend the model by introducing a financial intermediary sector where the mortgage spread is determined. A continuum of perfectly competitive financial intermediaries channels funds among households. The balance sheet of a generic intermediary is given by:

$$b_t = d_t + e_t, \tag{15}$$

where b_t represents loans issued to households and is defined as $b_t \equiv a_{it}\mathbb{I}_{\{a_{it}<0\}}$. Let d_t denote household deposits, defined as $d_t \equiv a_{it}\mathbb{I}_{\{a_{it}\geq 0\}}$, and let e_t indicate equity which is in fixed supply.

Following He and Krishnamurthy (2013), I assume that intermediaries face a leverage constraint that limits the issuance of loans to a maximum fraction Φ_t of their equity holdings:

$$\Phi_t \geq \frac{b_t}{e_t}. \tag{16}$$

This constraint ensures that the total amount of loans is limited by the intermediaries' equity.

Following Justiniano et al. (2019), I assume that issuing equity is costly and determined by a cost function, given by:

$$f\left(\frac{e_t}{\bar{e}}\right) = \tau\left(\frac{e_t}{\bar{e}}\right)^{\chi},$$

where $\tau > 0$ and $\chi > 0$. Hence, the cost function is strictly increasing in the amount of equity holdings, implying that intermediaries choose to minimize their holdings of equity. As a consequence, intermediaries prefer to fund loans with deposits rather than equity, making the leverage constraint (equation (16)) always binding:

$$\Phi_t = \frac{b_t}{e_t}. \tag{17}$$

Intermediaries' profits are given by:

$$\mathcal{P}_t \equiv r_t^l b_t - r_t d_t - r_t^e\left(1 + f\left(\frac{e_t}{\bar{e}}\right)\right)e_t,$$

where r_t^e denotes the return on equity.[7]

As derived in Appendix D, the intermediaries' profit maximization problem determines

[7]Note that from a household's perspective, deposits and equity are perfect substitutes since the respective returns, r_t and r_t^e, and the liquidity are the same. Therefore, equity does not appear explicitly in the household budget constraint.

the mortgage spread—the gap between loan rates and deposit rates—given by:

$$r_t^b = r_t\left(\frac{\tau(1+\chi)}{\Phi_t}\left(\frac{b_t}{\Phi_t \bar{e}}\right)^{\chi}\right). \tag{18}$$

As reflected in equation (18), a higher leverage ratio, Φ_t, lowers the mortgage spread. In the next section, I specify the QE policy and show that QE increases the leverage ratio which lowers the mortgage spread and, thus, stimulates the economy.

I assume that any positive spread exactly offsets the costs of financial frictions such that intermediaries earn zero profits and the intermediaries' wealth remains constant. This way, QE impacts macroeconomic aggregates through intermediaries' leverage constraints, while abstracting from indirect effects arising from asset price revaluations in intermediaries' balance sheets.

2.6 Government

Monetary Policy. The monetary authority sets the nominal interest rate, i_t, according to the Taylor rule as in Kaplan et al. (2018), given by:

$$i_t = \bar{r} + \phi_\pi \pi_t, \tag{19}$$

where $\bar{r}$ is the steady-state real interest rate and ϕ_π denotes by how much monetary policy reacts to deviations in inflation, π_t. The nominal and the real interest rate are linked via the Fisher equation, given by:

$$r_t = i_t - \pi_t.$$

In addition to this conventional monetary policy instrument, the monetary authority can also resort to QE in the form of large-scale asset purchases in the mortgage market. More specifically, I follow Gertler and Karadi (2011) and assume that the central bank issues government debt to the financial intermediary, who finances its holdings of government debt by issuing loans to households. These holdings of government debt by financial intermediaries can be interpreted as interest-bearing reserves. Deposits and reserves are perfect substitutes and, thus, have the same return, r_t.

I assume that QE is a discretionary policy and that the central bank issues government bonds of the amount:

$$m_t = \psi_t s_t, \tag{20}$$

where s_t is the total amount of intermediated assets in the economy as specified below.

Let ψ_t denote the QE shock which follows an Ornstein-Uhlenbeck process, given by:

$$d\psi_t = \rho_\psi(\psi_t - \bar{\psi})dt + \sigma_\psi d\mathcal{W}_t^\psi,$$

where $\mathcal{W}_t^\psi$ is a Brownian motion, ρ_ψ denotes the persistence, and σ_ψ indicates the variance.

Following Gertler and Karadi (2011), I assume that the leverage constraint does not apply to reserves, which reflects that, unlike loans, reserves do not face binding regulatory constraints. As a result, the overall amount of loans intermediated in the economy, s_t, increases through QE and is given by:

$$s_t = b_t + m_t. \tag{21}$$

Plugging in equations (17) and (20) and rearranging yields:

$$\begin{aligned} s_t &= \Phi_t e_t + \psi_t s_t \\ \Leftrightarrow \frac{s_t}{e_t} &= \frac{1}{1-\psi_t}\Phi_t. \end{aligned}$$

As a consequence, the leverage ratio that intermediaries face with QE, $\Phi_t^{QE} \equiv \frac{s_t}{e_t}$, is higher than the leverage ratio without QE, Φ_t. The reason is that $\psi_t \in [0,1]$ such that the multiplier $\frac{1}{1-\psi}$ is greater than 1, leading to $\Phi_t^{QE} > \Phi_t$.

Fiscal Policy. The government budget constraint is given by:

$$\bar{\tau}_t = r_t A_t + G_t, \tag{22}$$

where A_t are liquid assets issued by the government, G_t is exogenous government consumption, and $\bar{\tau}_t$ is a proportional labor tax as described in section 2.1. A change in the real interest rate affects the government budget constraint through its effects on the government's debt payments. Following McKay and Wieland (2021), I assume that the fiscal authority adjusts labor taxes to balance the effects on the government budget, which affects households' disposable income. As households have on average high MPCs out of labor income, the fiscal response matters for the aggregate effects of QE.

2.7 Market clearing conditions

The non-durable goods market clearing condition is given by:

$$Y_t = \int_0^1 c_{it} \, \mathrm{d}i + M_t + G_t + r_t^b \int_0^1 a_{it} I_{(a_{it}<0)} \mathrm{d}i.$$

The housing market clearing condition is given by:

$$X_t = \int_0^1 \left(\frac{\mathrm{d}h_{it}}{\mathrm{d}t} - \delta h_{it} \right) \mathrm{d}i + f \int_0^1 I_{h'_{it} \neq h_{it}} h_{it} \, \mathrm{d}i.$$

The bond market clearing condition is given by:

$$A_t = \int_0^1 a_{it} \, \mathrm{d}i.$$

By Walras' law, aggregate labor demand equals aggregate labor supply.

2.8 Calibration

Table 1 shows the calibration of the model. As it is standard in the literature, I set the inverse elasticity of intertemporal substitution, σ, to 1. The parameter ξ governs the elasticity of substitution between housing and consumption. As in McKay and Wieland (2021), I set it to 0.5 to match the average ratio of the nominal value of the housing stock and annual nondurable consumption.

The discount rate and the share of housing in the consumption aggregation are calibrated to match the ratio of net assets to GDP and housing to consumption, respectively. I follow McKay and Wieland (2021) and target 0.92 as the ratio of net assets to GDP, and 1.92 as the ratio of housing to consumption. The depreciation of housing is set to 2.3%, which matches the quarterly value for housing depreciation divided by the total housing stock as in the Bureau of Economic Analysis Fixed Asset tables. Following McKay and Wieland (2021), I set the steady-state real interest rate to 1.5%. This reflects the average ex-post real federal funds rate during the period of 1991–2007. Similarly, the steady-state mortgage spread is set to 1.7%, corresponding to the difference between the 30-year mortgage rate and the 10-year Treasury rate over the same period (McKay and Wieland (2021)). The size of the fixed cost is measured in terms of the value of the housing stock and governs the adjustment frequency of housing. I use an annual adjustment probability of 15% as found by Bachmann and Cooper (2014) which corresponds to a quarterly fixed

Table 1: Calibration of the model

Parameter	Description	Value
ρ	Discount rate	0.085
σ	Inverse elasticity of intertemporal substitution	1
ψ	Housing consumption share	0.327
ξ	Elasticity of substitution between housing and consumption	0.5
$\bar{r}$	Steady-state interest rate	0.015
$\bar{r}^b$	Steady-state mortgage spread	0.017
δ	Depreciation rate	0.023
f	Fixed cost	0.038
ρ_z	Income persistence	0.09
σ_z	Income standard deviation	0.216
λ	Loan-to-value ratio	0.8
G/Y	Government spending share	0.2
ζ	Inverse housing supply elasticity	0.23
κ	Slope of the Phillips curve	0.03
ϕ_π	Real rate response to inflation	1.25
ρ^{QE}	QE persistence	0.9

cost of 3.75%. The calibration of the income process in continuous time corresponds to the discrete-time version in Floden and Lindé (2001). More specifically, the persistence, ρ_z, is set to 0.09 and the standard deviation, σ_z, is set to 0.2. The loan-to-value ratio, λ, is set to 0.8 in line with a 20% down payment requirement as in McKay and Wieland (2021). As in McKay and Wieland (2021), the share of land in the production of housing is used to calibrate the housing supply elasticity. The land share of new houses and of existing ones is estimated to be 11% and 36%, respectively (see Davis and Heathcote (2007)) whose averages results in 23.5%. The ratio of government spending to output is set to 0.2 as it is standard in the literature. The monetary authority sets the interest rate according to a Taylor rule. The response to inflation, ϕ_π, is set to 1.25 as in Kaplan et al. (2018).

The Phillips curve slope, expressed in terms of annualized inflation per unit of the quarterly output gap, is set to 0.03, which falls within the range of empirical estimates (Mavroeidis et al. (2014)). I assume that the QE shock follows an Ornstein-Uhlenbeck process. I assume a quarterly persistence ρ^{QE} of 0.9. The size of the QE-shock is calibrated such that it results in a decline in the mortgage spread of 100 basis points on impact as found in the literature (Hancock and Passmore (2011)).

2.9 Model solution

As McKay and Wieland (2021), I solve the model building on the continuous-time methods developed by Achdou et al. (2022) for the steady state and on the Sequence-Space-Jacobian method by Auclert et al. (2021) for the aggregate dynamics. The full details for the computation are provided in Appendix A of McKay and Wieland (2021).

Steady State. I solve for the steady-state equilibrium based on the continuous-time methods developed by Achdou et al. (2022). They show that heterogeneous-agent models boil down to a Hamilton-Jacobi-Bellman (HJB) equation for the optimal choices of a household taking the distribution of households over the three state variables (income, assets, and housing) and prices as given, and a Kolmogorov Forward (KF) equation, which describes the evolution of this distribution based on households' optimal choices. Since the model includes housing subject to fixed costs, individuals solve stopping time problems (Stokey (2008)). Due to the stopping time problem, the value function solves a HJB Variational Inequality (HJBVI, Øksendal (1995)) rather than a HJB equation. The HJBVI characterizes household's optimal consumption and saving behavior by comparing the value function with and without adjustment. I define a grid over the state variables and use the finite difference method to solve for the HJBVI. More specifically, this method approximates derivatives by computing differences between function values at discrete points. The approximation is conducted with a larger point of the value function—the forward difference, or a smaller point— the backward difference. Based on the upwind scheme, I choose whether the forward or the backward difference is used. Specifically, the forward difference is used whenever the drift of the state variable is positive, and, vice versa, the backward difference is used whenever the drift of the state variable is negative. To give an example, if a household is accumulating savings (that is, the drift is positive), the forward difference is used. I then iterate to obtain the value function at each grid point. This solution gives the optimal policies, which are then used to compute the distribution of households over the three state variables—the KF equation.

Aggregate dynamics. I solve for the aggregate dynamics using the Sequence-Space-Jacobian approach by Auclert et al. (2021). This is a perfect-foresight solution with respect to aggregate shocks, which implies that the model does not feature aggregate but only idiosyncratic uncertainty arising from shocks to households' labor income. As shown by Boppart et al. (2018), due to certainty equivalence, the dynamics of the perfect-foresight solution are equivalent to those obtained from the solution of the linearized rational expectations model, as in Reiter (2009) and Ahn et al. (2018).

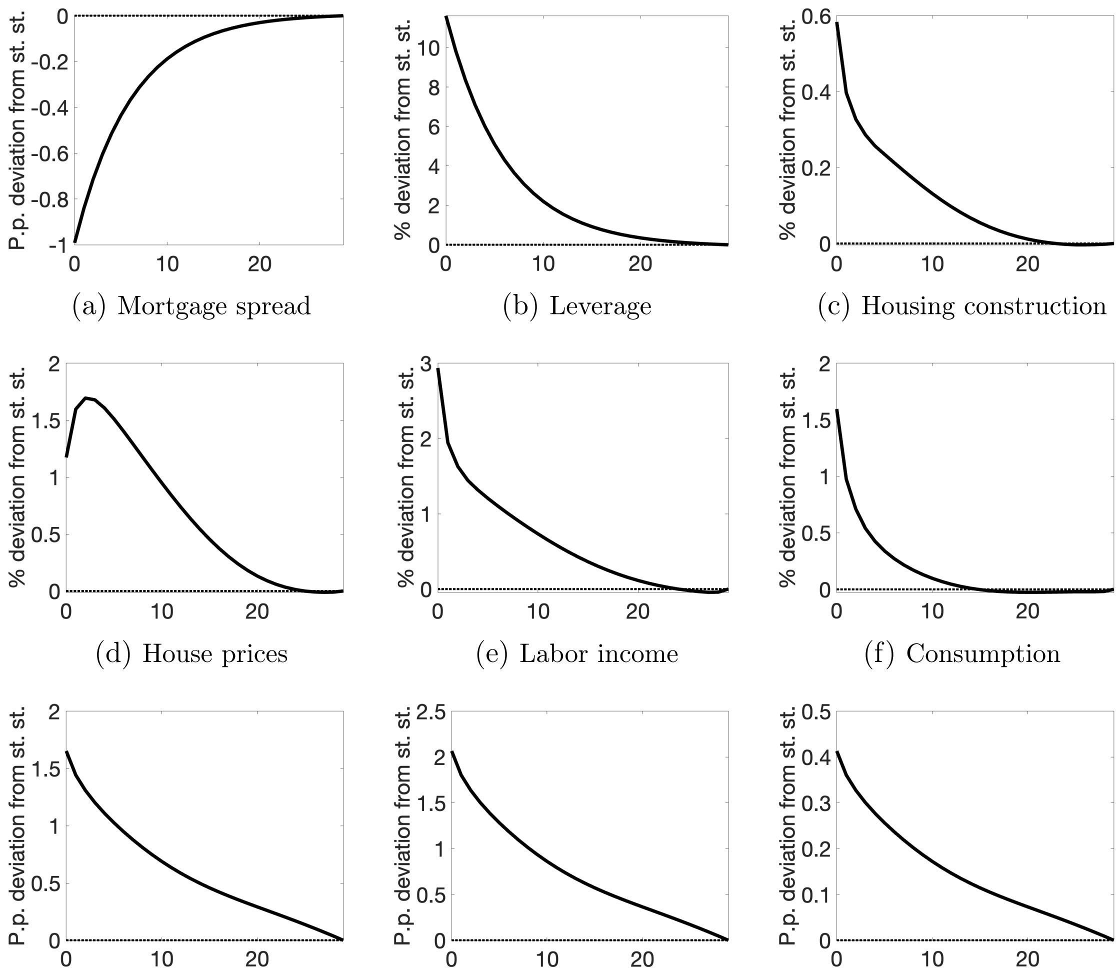
The Sequence-Space-Jacobian method derives the first-order approximation of equilibrium responses to anticipated shocks by reformulating the equilibrium as a system of linear equations within the space of perfect-foresight sequences. The key feature of this method is the use of Sequence-Space Jacobians, which link changes in aggregate variables to variations in prices and aggregate shocks. The first step in the computation is to calculate the partial equilibrium Jacobians, which capture how changes in aggregates are related to changes in prices or shocks. Specifically, I solve for the HJBVI marching backward in time and assume that the shock has vanished at the starting point of the calculation, which is the point in time that is furthest away, $t = T$. I then solve for the KF equation marching forward in time. This process is repeated for all periods, from $t = 0$ to $t = T$, to construct the entire Jacobian matrix. Accordingly, each entry of the Jacobian represents the change in an aggregate variable in response to a change in prices. The rows of the matrix capture how the aggregate variable evolves over time in response to a price change in a given period, while the columns show how the aggregate variable in a specific period responds to price changes over time. Specifically, the first entry of the row shows how the aggregate variable responds to a price change in period one, the second row shows how the aggregate variable responds to a price change in period two, and so on. The general equilibrium Jacobians are solved for by incorporating the endogenous price and income changes that satisfy the market clearing conditions.

3 The transmission mechanism of Quantitative Easing

I now analyze the transmission mechanism of QE to aggregate consumption in my HANK model. Figure 1 shows the impulse response functions (IRFs) in response to a QE shock. I choose the size of the QE shock such that it decreases the mortgage spread by 100 basis points in line with the estimate by Hancock and Passmore (2011). In response to this QE shock, aggregate consumption increases by 1.6% (panel 1f). This model-implied response of aggregate consumption exactly matches the empirical estimate by Walentin (2014) obtained in a structural vector autoregressive model.

Figure 2 decomposes the aggregate consumption response of panel 1f into the contribution of house prices (dark blue dashed lines), labor income (light blue dash-dotted lines), and interest rates (red dotted lines). It reflects that higher house prices and higher labor income each account for roughly 50% of the stimulative effects of QE, while the higher interest rate dampens the expansionary effects of QE.

Figure 1: The macroeconomic effects of a QE shock



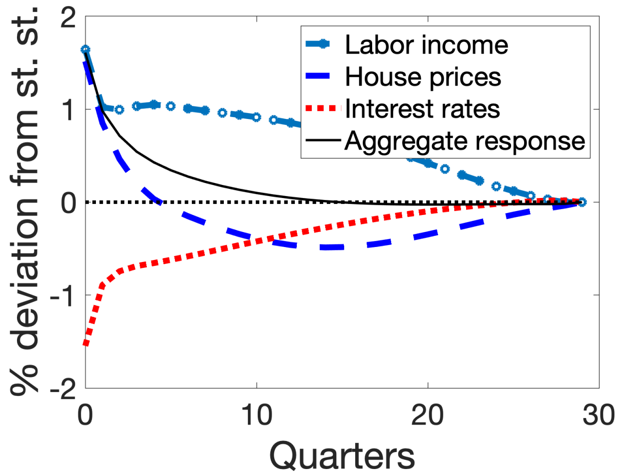
(a) Mortgage spread (b) Leverage (c) Housing construction

(d) House prices (e) Labor income (f) Consumption

(g) Inflation (h) Nominal interest rate (i) Real interest rate

Note: Impulse response functions of macroeconomic aggregates in general equilibrium to a QE shock targeted to decrease the mortgage spread by 1 percentage point under perfect foresight. Horizontal axes denote quarters.

Figure 2: Transmission channels of quantitative easing



Note: The figure shows the decomposition of the aggregate consumption response into the contribution of labor income, house prices, and the interest rate.

3.1 Transmission through house prices

I now analyze the transmission of QE to aggregate consumption through increasing house prices—a novel transmission channel of QE in the literature. I first analyze the transmission of QE to house prices and subsequently the transmission of house prices to aggregate consumption.

Transmission of QE to house prices. By conducting QE, the central bank issues interest-bearing reserves to the financial intermediary. Since these reserves are not subject to the leverage constraint, QE increases the leverage by 11.6% as reflected by panel 1b. A higher leverage lowers the mortgage spread as it is a function of the amount of loans intermediated in the economy (see equation (18)).

A lower mortgage spread transmits to higher house prices through decreasing the user cost of housing. To provide intuition for this transmission, I derive in a stylized model version with no adjustment costs and fully collateralizable housing an analytical expression for the user cost of housing (see Appendix E), given by:

$$\left(\frac{\psi}{1-\psi}\frac{c}{h}\right)^{\frac{1}{\xi}} = p(r + r^b + \delta) - \dot{p}. \tag{23}$$

Equation (23) states that the marginal rate of substitution between nondurable consumption and housing, $\left(\frac{\psi}{1-\psi}\frac{c}{h}\right)^{\frac{1}{\xi}}$, equals the user cost of housing, $r_t^d \equiv p(r + r^b + \delta) - \dot{p}$, which captures the opportunity cost of holding housing for an instant. It shows that the mortgage spread, r^b, directly affects the user cost of housing. In particular, a lower spread decreases the user cost of housing. A reduction in the user cost incentivizes households to increase their housing demand.

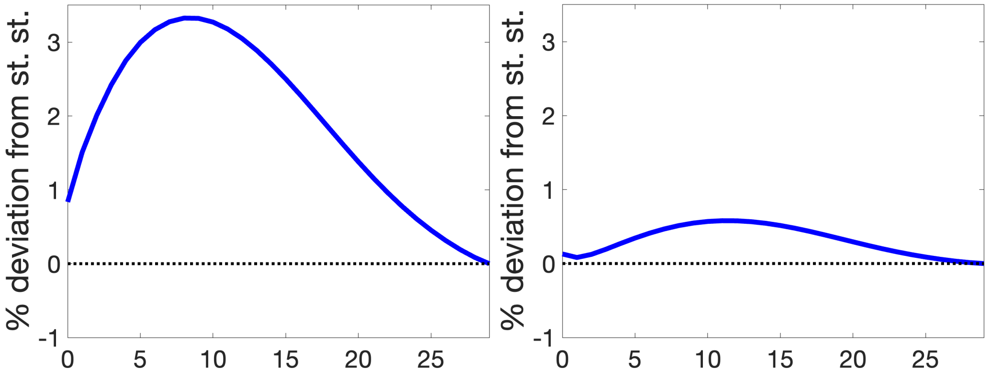
This intuition holds in the full model version with illiquid housing. More specifically, when housing is subject to fixed costs, households adjust their housing stock once it hits an adjustment threshold. As shown by McKay and Wieland (2022), the user cost of housing is a key ingredient that determines this adjustment threshold. More specifically, a lower user cost of housing incentivizes households to pull forward their housing purchases, which increases the demand for housing and, through general equilibrium, housing construction. Accordingly, housing construction increases by 0.6% (panel 1c) and house prices increase with a peak response of 1.7% (panel 1d).

Transmission of house prices to aggregate consumption. I now analyze the transmission of higher house prices to aggregate consumption. The blue dashed line in figure 2 shows that aggregate consumption substantially increases as a result of the QE-induced higher house prices. Specifically, it depicts the change in aggregate consumption resulting from the increase in house prices, ΔC^p, which is computed as the difference between the aggregate consumption response, ΔC, and a counterfactual scenario with constant house prices, $\Delta C^{\bar{p}}$:

$$\Delta C^p = \Delta C - \Delta C^{\bar{p}}.$$

To provide further intuition for the transmission of higher house prices to consumption, I decompose the evolution of the value of the housing stock and of aggregate consumption along the housing wealth distribution. I find that higher house prices stimulate aggregate consumption due to the consumption response of the upper part of the housing wealth distribution. Specifically, figure 3 presents the responses of housing wealth and consumption for the top 10% of the housing wealth distribution. Panel 3a shows that the value of the housing stock of the top 10% of this distribution increases with a peak response of 3.3%. Panel 3b shows that these households increase their consumption in response to the QE shock with a peak response of 0.6%. When comparing both panels, it becomes evident that households change their consumption in every period proportional to how much their housing wealth changes. To quantify this relationship, I compute the elasticity

Figure 3: Transmission of house prices to aggregate consumption



(a) Value of the housing stock top 10%　(b) Consumption top 10%

Note: Panel 3a shows the dynamic response of the value of the housing stock of the top 10% of the housing wealth distribution. Panel 3b shows the change in consumption of this housing wealth group. Both responses are in % deviations from steady state. Horizontal axes denote quarters.

of consumption to housing wealth for the top 10% given by:

$$\nu_t = \frac{\partial \mathrm{c}_i^{T10}(t)}{\partial \mathrm{ph}_i^{T10}(t)}, \tag{24}$$

where $\mathrm{c}_i^{T10}(t)$ denotes the consumption of the top 10% of the housing wealth distribution and $\mathrm{ph}_i^{T10}(t)$ denotes their housing wealth. Averaging these elasticities over the time periods until the IRFs return to steady state yields a value of 0.2, which is consistent with the empirical estimate by Guren et al. (2021).

My model generates these quantitatively large housing wealth elasticities because it features *wealthy hand-to-mouth* households (Kaplan et al. (2014)). These households own substantial housing wealth, placing them in the top 10% of the housing wealth distribution, yet they hold little to no liquid assets and are liquidity constrained. As higher house prices relax their collateral constraints (see equation (4)), these households convert an additional portion of their housing wealth into liquid assets—specifically, by the amount that their borrowing capacity expands. This additional liquidity is then spent on consumption. Given their significant housing wealth, the resulting increase in liquidity is substantial, leading to a rise in aggregate consumption.

3.2 Transmission through labor income

I now analyze that QE stimulates aggregate consumption through increasing labor income. The light blue dash-dotted line in figure 2 shows the contribution of labor income to the expansionary effects of QE. More specifically, it depicts the change in aggregate consumption due to the change of labor income, ΔC^y, by computing the difference between the aggregate consumption response in the baseline model, ΔC, and the counterfactual in which labor income is constant, $\Delta C^{\bar{y}}$:

$$\Delta C^y = \Delta C - \Delta C^{\bar{y}}.$$

QE increases labor income through general equilibrium effects. More specifically, QE-induced higher house prices stimulate nondurable consumption and, consequently, output. The expansion in output leads to an increase in labor demand. As a result, labor income increases by 2.9% as shown in panel 1e.

Higher labor income stimulates aggregate consumption by increasing households' disposable income, out of which households have—consistent with empirical evidence (see, e.g., Jappelli and Pistaferri (2010))—on average high MPCs. In particular, the aggregate MPCs in my model over the first year are 10.1%. These high MPCs arise because the model features a substantial fraction of liquidity-constrained households that respond strongly to income fluctuations. As shown in figure 3, higher labor income accounts for roughly half of the expansionary effects of QE.

3.3 Transmission through interest rates

I now analyze that another transmission channel of QE is that monetary policy tightens, which dampens the expansionary effects of QE. More specifically, in addition to conducting QE, the central bank sets the nominal interest rate based on a Taylor rule. As annualized inflation increases by 1.7 percentage points in response to the QE shock (panel 1g), the central bank raises the annualized nominal interest rate by 2.1 percentage points (panel 1h) and the annualized real interest rate increases by 0.4 percentage points (panel 1i).

To quantify the effects of a higher real rate for the stimulative effects of QE, I compute a counterfactual in which the monetary authority sets the nominal interest rate such that the real interest rate remains constant. The difference of the consumption response in the baseline model, ΔC, and the consumption response with a constant real rate, $\Delta C^{\bar{r}}$, quantifies the dampening on aggregate consumption due to monetary tightening:

$$\Delta C^r = \Delta C - \Delta C^{\bar{r}}. \tag{25}$$

The red dotted line in figure (2) plots this difference, ΔC^r. It reflects that the higher real rate dampens the expansionary effects of QE.

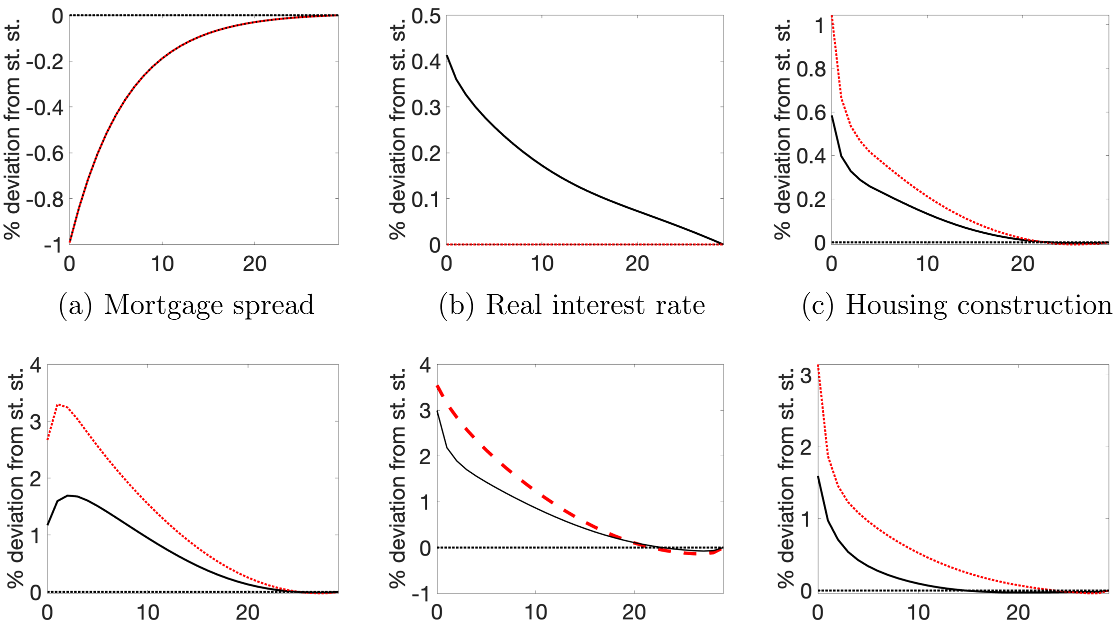
I now explain the intuition for this dampening. Figure 4 shows the IRFs of key variables of my model with both scenarios: the black solid lines correspond to the baseline model in which the real rate increases and the red dotted lines correspond to the counterfactual with a constant real rate (see panel 4b) in response to the same QE shock (4a). Panel 4f shows that while consumption increases by 3.1% in the counterfactual with a constant real interest rate, it increases by 1.6% in the baseline model. Hence, the monetary tightening in response to the expansionary effects from the looser LTV ratio substantially mutes the consumption response.

The first channel through which a higher real interest rate dampens aggregate consumption is intertemporal substitution because a higher rate incentivizes households to postpone consumption. In the counterfactual, this channel is absent as the real rate does not change.

In addition, the dampening effect of a higher real interest rate works through house prices. A higher real rate dampens housing demand, and, through general equilibrium, housing construction and house prices, as a higher real rate increases the user cost of housing (see equation (23)). To be precise, while in the baseline model, housing construction and house prices increase by 0.6% and 1.2%, respectively, they increase by 1.0% and 2.7% in the constant real rate scenario (see panels 4c and 4d). In line with the intuition from section (3.1), a lower increase in house prices dampens the stimulative effects of QE on aggregate consumption.

Finally, a higher real rate dampens aggregate consumption through the fiscal response. In particular, a higher real rate increases the debt payments of the government. To balance the effects on the government budget constraint, labor taxes increase such that the labor income of households decreases. In contrast, in the model with a constant real rate, the LTV shock does not affect the interest rate payments of the government, such that labor taxes remain constant. As a consequence, as shown by panel 4e, labor income increases by 2.9% in my baseline model while in the counterfactual with a constant real rate, labor income increases by 3.5%. As households have on average high MPCs out of labor income, aggregate consumption is higher in the model with the constant real rate than in the baseline model.

Figure 4: The dampening effects of a higher real rate



(a) Mortgage spread (b) Real interest rate (c) Housing construction

(d) House prices (e) Labor income (f) Consumption

Note: Impulse response functions of macroeconomic aggregates to a QE shock targeted to lower the mortgage spread by 100 basis points on impact. The black solid lines show the baseline results. The red dotted lines show the counterfactual with a constant real interest rate. Horizontal axes denote quarters.

4 Intermediation Costs and the Effectiveness of QE

In response to the Great Financial Crisis, the Federal Reserve intervened in the mortgage market primarily by purchasing government-backed mortgage-backed securities (MBS). These assets have low intermediation costs due to their high credit quality and explicit government guarantees. In contrast, following the COVID-19 shock, the Fed broadened its asset-purchase program to include agency commercial MBS (Milstein and Wessel (2024)). These assets incur higher intermediation costs because they are backed by a diverse set of commercial properties that demand more evaluation of asset quality, tenant performance, and market conditions.

To compare the stimulative effects of QE policies that differ in intermediation costs, I now incorporate these costs explicitly into the government budget constraint.[8] The modified government budget constraint is given by:

$$\bar{\tau}_t = r_t A_t + G_t + \phi_t^{ec} m_t, \tag{26}$$

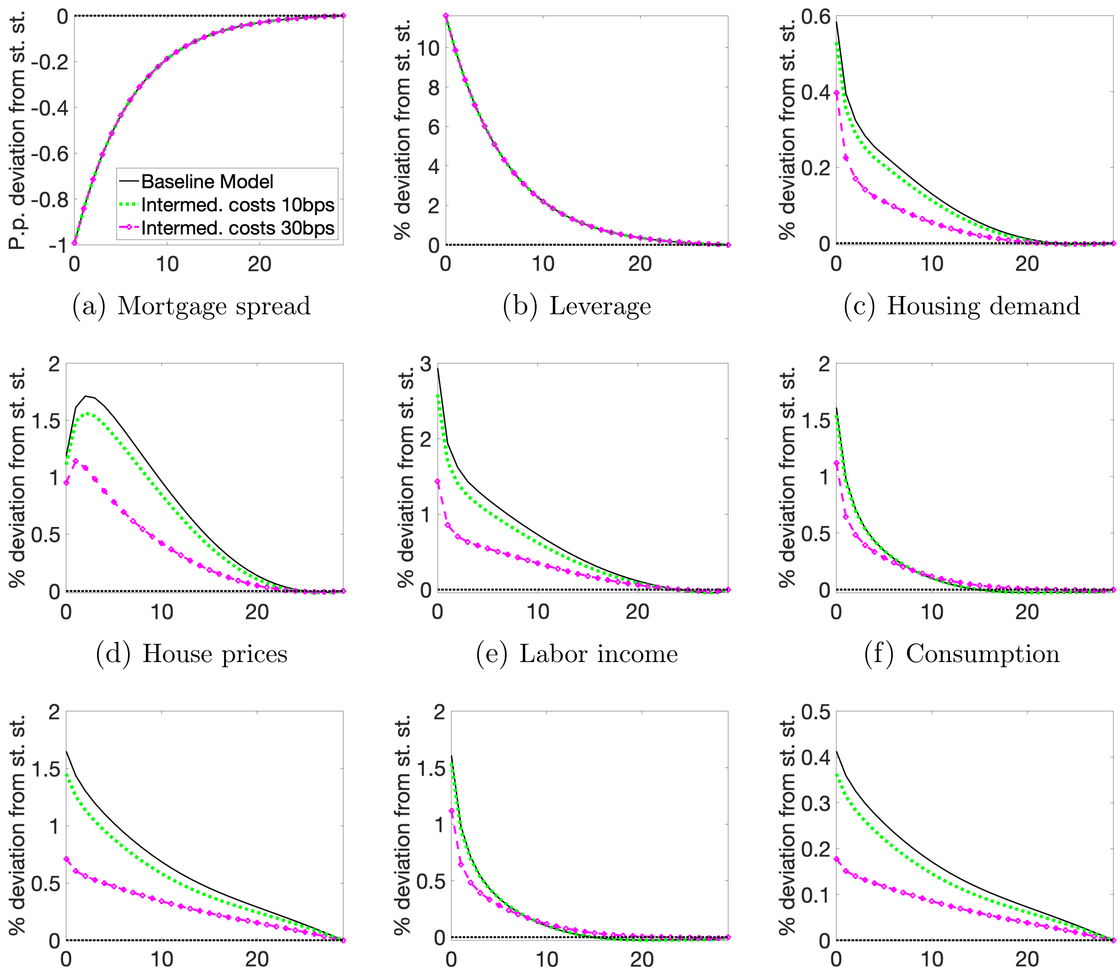
where ϕ_t^{ec} represents the intermediation costs incurred by the central bank.

Figure 5 illustrates the outcomes. The black lines show the baseline results in which the expansionary impact of QE is not mitigated by extra intermediation costs. When a moderate intermediation cost of 10 basis points is introduced (green lines, following Gertler and Karadi (2011)), the IRFs for aggregate consumption remain nearly unchanged: while consumption increases by 1.6% in the baseline, it increases by 1.5% with intermediation costs. However, when intermediation costs increase to 30 basis points (pink lines), the expansionary effects of QE on consumption are noticeably dampened: aggregate consumption rises by only 1.1% (versus 1.6% in the baseline model).

This dampening occurs because higher intermediation costs raise government expenditures (see equation (26)). As a consequence, labor taxes increase to balance the budget which decreases households' disposable income (panel 5e). More specifically, while labor income increases by 2.9% in the baseline model, it increases by only 1.4% in the model with intermediation costs. Since households have on average high MPCs out of labor income, aggregate consumption increases by less than in the baseline model. In addition, house prices increase by less with higher intermediation costs (see panel 5d) which further dampens the expansionary effects of QE in line with the intuition from out baseline analysis.

[8] Note that in the baseline model, intermediation costs are implicitly passed on to households via the mortgage spread.

Figure 5: Macroeconomic dynamics in response to a QE shock in a model version with increased intermediation costs



(a) Mortgage spread (b) Leverage (c) Housing demand

(d) House prices (e) Labor income (f) Consumption

(g) Inflation (h) Nominal interest rate (i) Real interest rate

Note: Impulse response functions of macroeconomic aggregates to a QE shock targeted to lower the mortgage spread by 100 basis points on impact in a model version with intermediation costs of 10 basis points (green dotted lines) and 30 bps (pink dash-dotted lines). The black solid lines show the baseline results. Horizontal axes denote quarters.

The substantial divergence in IRFs between the scenarios with different intermediation costs underscores the importance of accurately measuring these costs for a comprehensive understanding of QE's effectiveness. Future research should empirically estimate these costs.

5 Conclusion

In this paper, I study the effects of QE in the form of large-scale asset purchases in the mortgage market to aggregate consumption. I develop a HANK model with lumpy housing adjustment and frictional financial intermediation. I show that one important channel of QE is to increase house prices which, in turn, transmit to higher aggregate consumption. I highlight that a general-equilibrium increase in labor income and the interest rate response of the central bank are further transmission channels.

In light of the recent surge in inflation, central banks have resorted to quantitative tightening (QT). Unlike QE, which involves large-scale asset purchases, QT entails the gradual unwinding of these purchases. In future work, I aim to provide empirical evidence on whether QT increases the mortgage spread and, consequently, depresses house prices. In the next step, I plan to extend my model to compare the macroeconomic implications of central banks resorting to both QE and QT. In this paper, I assume that the wealth of financial intermediaries remains constant. However, both QE and QT affect asset prices, thereby changing the wealth of financial intermediaries. My conjecture is that the effects on financial intermediaries' balance sheets are asymmetric, with QT having a larger impact than QE. This reasoning is based on the financial accelerator literature, which suggests that negative shocks to financial variables can have disproportionately larger effects than positive shocks. Capturing these asymmetries would require a non-linear solution method. Recent work by Fernández-Villaverde et al. (2023) has provided important tools for conducting such an analysis.

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Appendix A Derivation of the labor demand curve

The demand curve for labor of final goods producers is derived in the following. The labor aggregation index is given by:

$$L_t = \left(\int_0^1 l_{jt}^{\frac{\phi-1}{\phi}} dj \right)^{\frac{\phi}{\phi-1}},$$

and the wage index is given by:

$$W_t = \left(\int_0^1 W_{jt}^{1-\phi} dj \right)^{\frac{1}{1-\phi}}.$$

Optimizing behavior of the final goods producer implies the following maximization problem:

$$\max_{L_{jt}} L_t = \left(\int_0^1 l_{jt}^{\frac{\phi-1}{\phi}} dj \right)^{\frac{\phi}{\phi-1}} \quad \text{subject to} \quad \int_0^1 W_{jt} L_{jt} dj = Z_t,$$

where Z_t is any given level of labor costs. The corresponding Lagrangian is given by:

$$\mathcal{L} = \left(\int_0^1 l_{jt}^{\frac{\phi-1}{\phi}} dj \right)^{\frac{\phi}{\phi-1}} - \lambda_t \left(\int_0^1 W_{jt} l_{jt} dj - Z_t \right).$$

The first-order condition with respect to a particular labor unit k is given by:

$$\frac{\phi}{\phi-1} \left(\int_0^1 l_{jt}^{\frac{\phi-1}{\phi}} dj \right)^{\frac{\phi}{\phi-1}-1} \frac{\phi-1}{\phi} l_{kt}^{\frac{\phi-1}{\phi}-1} - \lambda_t W_{kt} = 0,$$

and with respect to a particular labor unit i:

$$\frac{\phi}{\phi-1} \left(\int_0^1 l_{jt}^{\frac{\phi-1}{\phi}} dj \right)^{\frac{\phi}{\phi-1}-1} \frac{\phi-1}{\phi} l_{it}^{\frac{\phi-1}{\phi}-1} - \lambda_t W_{it} = 0.$$

Dividing the two first-order conditions by each other yields:

$$\left(\frac{l_{kt}}{l_{it}} \right)^{\frac{\phi-1}{\phi}-1} = \frac{W_{kt}}{W_{it}}$$
$$\leftrightarrow l_{kt} = W_{kt}^{-\phi} W_{it}^{\phi} l_{it}$$
$$\leftrightarrow l_{jt} = W_{jt}^{-\phi} W_{it}^{\phi} l_{it}$$

When plugging the optimality condition into the constraint one obtains:

$$Z_t = \int_0^1 W_{jt} W_{jt}^{-\phi} W_{it}^{\phi} l_{it} dj = W_{it}^{\phi} l_{it} \int_0^1 W_{jt}^{1-\phi} dj = W_{it}^{\phi} l_{it} W_t^{1-\phi}$$
$$\leftrightarrow l_{it} = \left(\frac{W_{it}}{W_t}\right)^{-\phi} \frac{Z_t}{W_t} \leftrightarrow l_{jt} = \left(\frac{W_{jt}}{W_t}\right)^{-\phi} \frac{Z_t}{W_t}$$

In a last step, I show that $\int_0^1 W_{jt} l_{jt} dj = W_t L_t$, and therefore, $\frac{Z_t}{W_t} = L_t$.

$$L_t = \left(\int_0^1 \left(\left(\frac{W_{jt}}{W_t}\right)^{-\phi} \frac{Z_t}{W_t}\right)^{\frac{\phi-1}{\phi}} dj\right)^{\frac{\phi}{\phi-1}}$$
$$= \frac{Z_t}{W_t} W_t^{\phi} \left(\int_0^1 (W_{jt}^{1-\phi}) dj\right)^{\frac{\phi}{\phi-1}} = \frac{Z_t}{W_t} W_t^{\phi} W_t^{-\phi} = \frac{Z_t}{W_t}$$

Thus, the demand curve for labor is given by:

$$l_{jt} = L_t \left(\frac{W_{jt}}{W_t}\right)^{-\phi}. \tag{A.1}$$

Appendix B Derivation of the Phillips Curve

The optimization problem of the unions gives rise to the Phillips curve as in McKay and Wieland (2021). The union's objective function is composed of the equally-weighted utility of households less adjustment costs, given by:

$$\max_{\mu_{it}} \int_{t=0}^{\infty} e^{-\rho t} \int_0^1 \left[u_c(c_{it}, h_{it}) \frac{W_{jt}}{P_t} l_{jt} - \bar{u}_{c,t} v(l_{jt}) - \frac{\Psi}{2} \bar{u}_{c,t} L_t (\mu_{jt})^2\right] \mathrm{d}i \ \mathrm{d}t, \tag{A.2}$$

subject to labor demand (equation A.1) and to the growth rate of wages given by

$$d \ln W_{jt} = \mu_{jt} \ \mathrm{d}t.$$

The first-order conditions are given by:

$$\lambda_{jt} = \Psi \mu_{jt} \bar{u}_{c,t} L_t$$

and:

$$\mathrm{d}\lambda_{jt} - \rho \lambda_{jt} \ \mathrm{d}t = -(1-\phi) \bar{u}_{c,t} \left(\frac{W_{jt}}{P_t}\right)^{1-\phi} \left(\frac{W_t}{P_t}\right)^{\phi} L_t \ \mathrm{d}t - \phi L_t \left(\frac{W_{jt}}{W_t}\right)^{-\phi} \bar{u}_{c,t} v_L \left(l_{jt}\right) \mathrm{d}t.$$

Imposing symmetry and market clearing yields:

$$\begin{aligned}
\Psi \mu_t \bar{u}_{c,t} Y_t &= \lambda_t \\
\mathrm{d}\lambda_t - \rho\lambda_t \,\mathrm{d}t &= -(1-\phi)\bar{u}_{c,t} Y_t \,\mathrm{d}t - \phi \bar{u}_{c,t} Y_t v_L Y_t \mathrm{d}t \\
\pi_t &= \mu_t.
\end{aligned}$$

The non-linear Phillips curve is given by:

$$\mathrm{d}\pi_t = \left[\rho - \frac{\mathrm{d}\bar{u}_{c,t}}{\bar{u}_{c,t}} - \frac{\mathrm{d}Y_t}{Y_t}\right] \pi_t \,\mathrm{d}t - \frac{\phi - 1}{\Psi}\left[\frac{\phi}{\phi - 1} v_L Y_t - 1\right] \mathrm{d}t.$$

Log-linearizing around the zero-inflation steady state gives:

$$\mathrm{d}\pi_t = \rho\pi_t \,\mathrm{d}t - \frac{\phi}{\Psi}\eta\left(\frac{Y_t - \bar{Y}}{\bar{Y}}\right)\mathrm{d}t,$$

where $\frac{1}{\eta}$ is the Frish elasticity. Letting $\kappa = \frac{\phi\eta}{\Psi}$ yields equation (13).

Appendix C Derivation of the relative price of housing

Firms that supply housing maximize profits:

$$\Pi_t = P_t^H X_t - P_t M_t - P_t^D \bar{D},$$

where P_t^H is the price of housing, P_t is the price of the final good, and P_t^D is the price of land. The housing production function is given by:

$$X_t = \omega M_t^{1-\zeta} \bar{D}^{\zeta},$$

where $\omega > 0$ is a constant, $\zeta \in (0,1)$ is the elasticity of housing output with respect to land, M_t is the input of intermediate goods, and $\bar{D}$ represents the fixed amount of land.

The firm's maximization problem can be expressed as:

$$\max_{M_t} \Pi_t = P_t^H \omega M_t^{1-\zeta} \bar{D}^{\zeta} - P_t M_t - P_t^D \bar{D}.$$

The firm does not choose $\bar{D}$, as land supply is fixed by the government. Taking the derivative of Π_t with respect to M_t, the first-order condition is given by:

$$P_t^H \omega (1-\zeta) M_t^{-\zeta} \bar{D}^{\zeta} = P_t.$$

Dividing through by P_t, I define the relative price of housing $p_t = \frac{P_t^H}{P_t}$ and rewrite the first-order condition as:

$$p_t \omega (1-\zeta) M_t^{-\zeta} \bar{D}^{\zeta} = 1.$$

Rearranging, the relative price of housing is expressed as:

$$p_t = \frac{1}{\omega(1-\zeta)M_t^{-\zeta}\bar{D}^{\zeta}}.$$

To eliminate M_t, I substitute the housing production function:

$$X_t = \omega M_t^{1-\zeta}\bar{D}^{\zeta}.$$

Solving for M_t, I obtain:

$$M_t = \left(\frac{X_t}{\omega\bar{D}^{\zeta}}\right)^{\frac{1}{1-\zeta}}.$$

Substituting this expression into the equation for p_t, I get:

$$p_t = \frac{1}{\omega(1-\zeta)\left[\left(\frac{X_t}{\omega\bar{D}^{\zeta}}\right)^{\frac{1}{1-\zeta}}\right]^{-\zeta}\bar{D}^{\zeta}}.$$

Simplifying the exponent term yields:

$$\left(\frac{X_t}{\omega\bar{D}^{\zeta}}\right)^{\frac{1}{1-\zeta}}{}^{-\zeta} = \left(\frac{X_t}{\omega\bar{D}^{\zeta}}\right)^{-\frac{\zeta}{1-\zeta}}.$$

Thus, the relative price of housing is given by:

$$p_t = \frac{1}{\omega(1-\zeta)\bar{D}^{\zeta}}\left(\frac{\omega\bar{D}^{\zeta}}{X_t}\right)^{\frac{\zeta}{1-\zeta}}.$$

Combining terms gives:

$$p_t = (1-\zeta)^{-1}\omega^{-1}\bar{D}^{-\zeta}\omega^{\frac{\zeta}{1-\zeta}}\bar{D}^{\frac{\zeta^2}{1-\zeta}}X_t^{-\frac{\zeta}{1-\zeta}}.$$

Finally, collecting powers of ω and $\bar{D}$, the optimality condition for the relative price of housing is given by:

$$p_t = (1-\zeta)^{-1}\omega^{-\frac{1}{1-\zeta}}\left(\frac{X_t}{\bar{D}}\right)^{\frac{\zeta}{1-\zeta}}.$$

Appendix D Derivation of the intermediary's first-order condition

The intermediary maximizes its profits function, given by:

$$\mathcal{P}_t \equiv r_t^l b_t - r_t d_t - r_t^e\left(1 + f\left(\frac{e_t}{\bar{e}}\right)\right)e_t,$$

subject to the leverage constraint:

$$b_t = \Phi_t e_t.$$

Using $b_t = \phi_t e_t$, $d_t = b_t - e_t$, and $f(e_t) = \tau\left(\frac{e_t}{\bar{e}}\right)^\chi$ as well as the leverage constraint yields:

$$\mathcal{P}_t = r_t^l \phi_t e_t - r_t(\phi_t e_t - e_t) - r_t^e\left(1 + \tau\left(\frac{e_t}{\bar{e}}\right)^\chi\right)e_t.$$

The first-order condition with respect to equity is given by:

$$\frac{\partial \mathcal{P}_t}{\partial e_t} \overset{!}{=} 0 \Leftrightarrow r_t^e\left(1 + \tau(1+\chi)\left(\frac{e_t}{\bar{e}}\right)^\chi\right) - r_t = r_t^l \Phi_t - r_t \Phi_t.$$

Using $r_t^e = r_t$ yields:

$$r_t\left(1 + \tau(1+\chi)\left(\frac{e_t}{\bar{e}}\right)^\chi\right) - r_t + r_t\Phi_t = r_t^l \Phi_t.$$

Dividing by Φ_t and rearranging yields:

$$\begin{aligned}
r_t^l &= \frac{r_t}{\Phi_t}\left(1 + \tau(1+\chi)\left(\frac{e_t}{\bar{e}}\right)^\chi\right) - \frac{1}{\Phi_t}r_t + r_t \\
\Leftrightarrow r_t^l &= \frac{r_t}{\Phi_t}\left(1 + \tau(1+\chi)\left(\frac{e_t}{\bar{e}}\right)^\chi\right) - \frac{1}{\Phi_t}r_t + r_t \\
\Leftrightarrow r_t^l &= \frac{r_t}{\Phi_t}\left(1 + \tau(1+\chi)\left(\frac{e_t}{\bar{e}}\right)^\chi\right) + \frac{\Phi_t - 1}{\Phi_t}r_t.
\end{aligned}$$

Using $e_t = \frac{b_t}{\Phi_t}$ and $r_t^l = r_t^b + r_t \leftrightarrow r_t^b = r_t^l - r_t$ yields equation (18):

$$\begin{aligned}
r_t^l &= \frac{r_t}{\Phi_t}\left(1 + \tau(1+\chi)\left(\frac{b_t}{\Phi_t \bar{e}}\right)^\chi\right) + \frac{\Phi_t - 1}{\Phi_t}r_t \\
\Leftrightarrow r_t^l &= \frac{1}{\Phi_t}r_t + \frac{\Phi_t - 1}{\Phi_t}r_t + r_t\frac{\tau(1+\chi)}{\Phi_t}\left(\frac{b_t}{\Phi_t \bar{e}}\right)^\chi \\
\Leftrightarrow r_t^l &= r_t\left(1 + \frac{\tau(1+\chi)}{\Phi_t}\left(\frac{b_t}{\Phi_t \bar{e}}\right)^\chi\right) \\
\Leftrightarrow r_t^b &= r_t\left(\frac{\tau(1+\chi)}{\Phi_t}\left(\frac{b_t}{\Phi_t \bar{e}}\right)^\chi\right).
\end{aligned}$$

Appendix E Derivation of the user cost of housing

In this section, I derive the user cost of housing for borrowers in a frictionless model, that is, without fixed costs and with housing which is fully collaterizable as in McKay and Wieland (2022).

The budget constraint is given by:

$$\dot{a} = ra + r^b a \mathbb{I}_{\{a<0\}} - c + y - px.$$

The evolution of the housing stock is given by:

$$\dot{d} = x - \delta d.$$

The Hamiltonian is given by:

$$\mathcal{H} = u(c,h) + \lambda(ra + r^b a \mathbb{I}_{\{a<0\}} - c + y - px) + \mu(x - \delta h).$$

Plugging in the utility function, $u(c,h) = \frac{\left[(1-\psi)^{\frac{1}{\xi}} c^{\frac{\xi-1}{\xi}} + \psi^{\frac{1}{\xi}} h^{\frac{\xi-1}{\xi}}\right]^{\frac{\xi(1-1/\sigma)}{\xi-1}} - 1}{1-1/\sigma}$, and taking first-order conditions yields:

$$\frac{d\mathcal{H}}{dc} = 0 \Leftrightarrow \underbrace{\frac{\xi(1-\frac{1}{\sigma})}{\xi-1} \frac{\left[(1-\psi)^{\frac{1}{\xi}} c^{\frac{\xi-1}{\xi}} + \psi^{\frac{1}{\xi}} h^{\frac{\xi-1}{\xi}}\right]^{\frac{\xi(1-1/\sigma)}{\xi-1}-1}}{1-1/\sigma} (1-\psi)^{\frac{1}{\xi}} \frac{\xi-1}{\xi} c^{\frac{-1}{\xi}}}_{u_c} = -\lambda \tag{C.1}$$

$$\frac{d\mathcal{H}}{dx} = 0 \Leftrightarrow -p\lambda + \mu = 0 \Leftrightarrow p\lambda = \mu \tag{C.2}$$

$$\frac{d\mathcal{H}}{da} = \rho\lambda - \dot{\lambda} \Leftrightarrow r\lambda + r^b\lambda = \rho\lambda - \dot{\lambda} \tag{C.3}$$

$$\frac{d\mathcal{H}}{h} = \rho\mu - \dot{\mu} \Leftrightarrow \underbrace{\frac{\xi(1-\frac{1}{\sigma})}{\xi-1} \frac{\left[(1-\psi)^{\frac{1}{\xi}} c^{\frac{\xi-1}{\xi}} + \psi^{\frac{1}{\xi}} h^{\frac{\xi-1}{\xi}}\right]^{\frac{\xi(1-1/\sigma)}{\xi-1}-1}}{1-1/\sigma} (\psi)^{\frac{1}{\xi}} \frac{\xi-1}{\xi} h^{\frac{-1}{\xi}}}_{u_h} - \mu\delta = \rho\mu - \dot{\mu} \tag{C.4}$$

Dividing equation C.4 by μ and rearranging yields:

$$\frac{\frac{\xi(1-\frac{1}{\sigma})}{\xi-1}\frac{\left[(1-\psi)^{\frac{1}{\xi}}c^{\frac{\xi-1}{\xi}}+\psi^{\frac{1}{\xi}}h^{\frac{\xi-1}{\xi}}\right]^{\frac{\xi(1-1/\sigma)}{\xi-1}-1}}{1-1/\sigma}(\psi)^{\frac{1}{\xi}}\frac{\xi-1}{\xi}h^{\frac{-1}{\xi}}}{\mu}-\delta=\rho-\frac{\dot{\mu}}{\mu}\ \mid \text{ plugging in (C.2)}$$

$$\Leftrightarrow\frac{\frac{\xi(1-\frac{1}{\sigma})}{\xi-1}\frac{\left[(1-\psi)^{\frac{1}{\xi}}c^{\frac{\xi-1}{\xi}}+\psi^{\frac{1}{\xi}}h^{\frac{\xi-1}{\xi}}\right]^{\frac{\xi(1-1/\sigma)}{\xi-1}-1}}{1-1/\sigma}(\psi)^{\frac{1}{\xi}}\frac{\xi-1}{\xi}h^{\frac{-1}{\xi}}}{p\lambda}-\delta=\rho-\frac{\dot{\lambda}}{\lambda}-\frac{\dot{p}}{p}\ \mid \text{ plugging in } r+r^b=\rho-\frac{\dot{\lambda}}{\lambda}$$

$$\Leftrightarrow\frac{\frac{\xi(1-\frac{1}{\sigma})}{\xi-1}\frac{\left[(1-\psi)^{\frac{1}{\xi}}c^{\frac{\xi-1}{\xi}}+\psi^{\frac{1}{\xi}}h^{\frac{\xi-1}{\xi}}\right]^{\frac{\xi(1-1/\sigma)}{\xi-1}-1}}{1-1/\sigma}(\psi)^{\frac{1}{\xi}}\frac{\xi-1}{\xi}h^{\frac{-1}{\xi}}}{p\lambda}-\delta=r+r^b-\frac{\dot{p}}{p}\ \mid \text{ plugging in (C.1)}$$

$$\Leftrightarrow\frac{\frac{\xi(1-\frac{1}{\sigma})}{\xi-1}\frac{\left[(1-\psi)^{\frac{1}{\xi}}c^{\frac{\xi-1}{\xi}}+\psi^{\frac{1}{\xi}}h^{\frac{\xi-1}{\xi}}\right]^{\frac{\xi(1-1/\sigma)}{\xi-1}-1}}{1-1/\sigma}(\psi)^{\frac{1}{\xi}}\frac{\xi-1}{\xi}h^{\frac{-1}{\xi}}}{p\frac{\xi(1-\frac{1}{\sigma})}{\xi-1}\frac{\left[(1-\psi)^{\frac{1}{\xi}}c^{\frac{\xi-1}{\xi}}+\psi^{\frac{1}{\xi}}h^{\frac{\xi-1}{\xi}}\right]^{\frac{\xi(1-1/\sigma)}{\xi-1}-1}}{1-1/\sigma}(1-\psi)^{\frac{1}{\xi}}\frac{\xi-1}{\xi}c^{\frac{-1}{\xi}}}-\delta=r+r^b-\frac{\dot{p}}{p}\ \mid \text{ simplifying and } +\delta \text{ yields}$$

$$\Leftrightarrow\left(\frac{\psi}{1-\psi}\frac{c}{h}\right)^{\frac{1}{\xi}}=r+r^b+\delta-\frac{\dot{p}}{p}\ \mid\ \text{ multiplying by } p \text{ yields}$$

$$\Leftrightarrow\left(\frac{\psi}{1-\psi}\frac{c}{h}\right)^{\frac{1}{\xi}}=p(r+r^b+\delta)-\dot{p}$$

which correponds to equation (23).