How Does Progressivity Affect the Tax Cut Multiplier? *

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Abstract

How does the targeting of personal income tax cuts affect the output multiplier? This paper provides quantitative evidence using a two-asset Heterogeneous Agent New Keynesian model. The model matches data on the distributions of income, wealth, marginal tax rates and Marginal Propensities to Consume (MPCs). The labor market features search frictions and an intensive margin labor supply choice. Progressive tax cuts concentrate reductions in tax liability on relatively high-MPC households but cut marginal rates less than regressive tax cuts. The model is used to quantify the effects of major U.S. tax reforms. In the baseline calibration, the tax cut multiplier is larger for more progressive tax changes.

JEL codes: D31, E21, E22, E24, E62

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1 Introduction

Are tax cuts more effective at stimulating output and employment if they are targeted to top-income or lower-income taxpayers? Top earners face the highest marginal tax rates, suggesting that tax cuts targeted to top earners will be most effective at stimulating labor supply. But top earners have relatively low marginal propensities to consume (MPCs), in which case reductions in tax liability on top earners will be less effective at raising aggregate demand than tax cuts targeted at middle- and lower-income earners.

This paper's contribution is to *jointly* study the aggregate demand and supply-side transmission channels for tax cuts using a state-of-the-art quantitative model. A model capable of providing credible evidence must contain four key features. First, the model must match the empirical distributions of income, wealth and marginal tax rates. Second, the model must feature empirically realistic MPCs, so that changes in tax liability affect aggregate demand. Third, output and employment must be at least partly demand determined. Fourth, labor supply must be responsive to changes in marginal tax rates and wages, so that incentives to work affect economic activity.

The model is based on the seminal two-asset Heterogeneous Agent New-Keynesian (HANK) model developed by Kaplan, Moll and Violante (2018), which in turn in builds on the Aiyagari-Huggett-İmrohoroğlu incomplete-markets model. Households face uninsurable idiosyncratic risk to their employment status and labor productivity, providing scope for the model to generate a realistic distribution of income. Tax liability is determined by a non-linear tax function that provides an excellent fit to the U.S. individual income tax.

Households save in a low-return liquid asset and a high-return illiquid asset, as in Kaplan and Violante (2014). The two-asset framework enables the model to simultaneously match the empirical evidence on MPCs and the distribution of wealth. This is important because saving behavior of high income households affects investment and therefore labor demand. The model matches empirical evidence on the magnitude of MPCs and generates heterogeneity in MPCs across income groups, implying that the aggregate demand effects of tax changes differ depending on the groups to whom they are targeted. Goods prices in the model are set by monopolistically competitive firms subject to nominal rigidities, as in standard in New-Keynesian models, making output and employment responsive to changes in aggregate demand in the short run. The labor market is subject to search frictions and hours of work within an employment relationship are determined by household preferences. Thus, labor input is affected by both aggregate demand and incentives to work. Monetary policy follows a Taylor rule.

I document the distributional properties of major U.S. tax reforms and use the model to study how progressivity affects the tax cut multiplier. Major tax reforms in 1981, 2003 and 2017 cut taxes disproportionately on top earners. In contrast, the 1993 tax reform raised taxes on top earners and cut taxes on low- and middle-income earners. I use these reform episodes to construct progressive and regressive tax reform scenarios that cut taxes by 1 percent of GDP. The regressive tax cut scenario has the same distributional properties as an average of the 1981, 2003 and 2017 reforms. The progressive tax cut scenario has the same distributional properties as the 1993 reform. I also use the model to study the 1991 tax reform, which cut taxes on low- and middle-income earners and raised taxes on top-earners in a roughly revenue neutral manner.

I reach three main quantitative findings. First, across a range of model calibrations, the progressive tax cut scenario is more expansionary for output and employment than the regressive tax cut scenario. The labor supply response is relatively large for the regressive tax cut scenario because it cuts marginal tax rates relatively sharply while the aggregate demand response is relatively large for the progressive tax cut scenario because it lowers tax liability by more for households with large MPCs. I deduce that the aggregate demand channel is quantitatively more important than the labor supply channel for the transmission of tax cuts to output and employment. The exception is in calibrations with a labor supply elasticity well above that found in the microeconomic literature on the response of hours worked to temporary tax changes. Furthermore, I find that the revenue-neutral 1991 reform had a modest expansionary effect on output and employment.

Second, the transmission *mechanism* of tax cuts to economic activity depends on the progressivity of the tax change. Indirect effects operating through labor demand reinforce the partial equilibrium effect of the tax cut. Increased spending raises labor demand which, in the presence of sticky prices, compresses mark-ups and raises wages. Indirect effects are relatively more important for the progressive tax reform scenario.

Third, for the baseline calibration, the output multiplier cumulated over a five-year horizon is 0.80 for the progressive tax cut scenario and 0.43 for the regressive tax cut scenario. This range is broadly in line with the results for Representative Agent New-Keynesian (RANK) models surveyed in Ramey (2019), but lower than recent time-series evidence. Output multipliers are larger for both tax cut scenarios in calibrations that strengthen the aggregate demand channel (accommodative monetary policy and high price rigidity). Calibrations with a high labor supply elasticity increase the output multiplier for regressive reforms but reduce the output multiplier for regressive reforms.

This paper makes three main contributions to the literature. First, it shows that the output multiplier and employment effect of tax cuts is larger for U.S. tax changes that were relatively more progressive. This is important because the limited empirical literature on this question provides conflicting evidence (Zidar, 2019; Mertens and Montiel Olea, 2018). Second, the model sheds light on the *transmission mechanism* of tax cuts to economic activity, highlighting the importance of indirect effects. In contrast, the empirical literature is largely silent on mechanisms. Third, the paper enriches the labor market block of the HANK model developed by Kaplan, Moll and Violante (2018).

Related literature: This paper contributes to a growing literature using HANK models to study fiscal policy. McKay and Reis (2016) measure the effect of automatic stabilizers on U.S. business cycle dynamics, Oh and Reis (2012) study the transfer multiplier, and Hagedorn, Manovskii and Mitman (2019) measure the size of the government spending multiplier. These papers all feature heterogeneous households, incomplete-markets and nominal rigidities, however, none feature a frictional labor market, as in this paper.

Other papers have incorporated search frictions into HANK models to study: unemployment insurance (Kekre, 2019); the aggregate implications of job-to-job flows (Alves, 2019); the dependence of consumption during unemployment on the composition of liquid and illiquid assets held (Graves, 2020); and search efficiency shocks (Ravn and Sterk, 2017). However, none of these models permit adjustment of hours worked along the intensive margin. Furthermore, all except Graves (2020) use a one-asset framework.

The most closely related paper is by Ferriere and Navarro (2020), who study how the size of the government spending multiplier depends on the progressivity of (partial) contemporaneous financing via income taxes. Aside from their focus on the spending multiplier, there are important differences in the asset and labor market structures between their model and mine. Ferriere and Navarro (2020) assume an indivisible labor market with fixed hours of employment. This fits their wartime application, but is inconsistent with evidence on labor supply responses to temporary tax changes (Martinez, Saez and Siegenthaler, 2021).[1]

An earlier literature has studied tax changes in heterogeneous agent incomplete-markets models with flexible prices. Heathcote (2005) finds large effects of changes in the timing of taxes on consumption when markets are incomplete but no effect in a representative-agent model. Other papers to study taxation and social security policy in heterogeneous-agent incomplete markets models include Guner, Kaygusuz and Ventura (2012), De Nardi and Yang (2016), Kindermann and Krueger (2014) and Kitao (2008). More recently, Brinca et al. (2021) show that fiscal consolidations have larger recessive impact in high-inequality countries and rationalize this in an incomplete-markets life-cycle model in which higher income risk induces precautionary saving behavior.

A large empirical literature has estimated the macroeconomic effects of taxes. Blanchard and Perotti (2002) and Mountford and Uhlig (2009) are seminal contributions. More recently, Romer and Romer (2010), Mertens and Ravn (2014) and Cloyne (2013) used the narrative record to identify a set of plausibly exogenous tax changes for the United States and United Kingdom and find tax increases to be highly contractionary. The empirical work most closely related to this paper is by Zidar (2019) and Mertens and Montiel Olea (2018). They use the narrative methodology to investigate how tax changes targeted to different income groups affects aggregate economic activity.

[1] Another important modeling difference is their use of a one-asset model, calibrated to match the liquid wealth distribution.

I discuss these papers in detail in Section 4.

The remainder of the paper is structured as follows. Section 2 describes the model, explains its calibration and documents its key moments. Section 3 reports the baseline results, sensitivity analysis and extensions, Section 4 provides a discussion of the results and Section 5 concludes.

2 Model

2.1 Description

Households Time is continuous. There is a continuum of households who discount the future at rate ρ and die at rate ζ. Households receive a utility flow u from consumption $c_t \geq 0$ and disutility flow from supplying labor $h_t \in [0,1]$. The function u is strictly increasing and strictly concave in consumption and non-increasing and strictly convex in hours worked. Preferences are time separable:

$$\mathbb{E}_0 \int_0^\infty e^{-(\rho+\zeta)} u(c_t, h_t)\, dt \tag{1}$$

where the expectation is taken over realizations of idiosyncratic labor productivity and employment status. An employed household with labor productivity z receives labor income equal to $w_t z_t h_t$, where w_t is the wage rate. An unemployed household receives unemployment benefits $uben_t$, equal to a fraction φ (the replacement ratio) of labor income at steady-state hours, up to a maximum of \$25000, at an annual rate. The model features a frictional labor market, described below. There is no aggregate uncertainty.

Following Kaplan, Moll and Violante (2018), households can hold a liquid asset b and an illiquid asset a. Liquid assets pay an interest rate r_t^b while illiquid assets pay an interest rate r_t^a. There is no borrowing.[2] Household must pay a cost $\chi(d,a)$ to transfer funds at the rate d between liquid and illiquid assets. This implies that in equilibrium the interest rate on illiquid assets exceeds the interest rate on liquid assets.

Households differ in their employment status $E \in \{e = \text{employed}, u = \text{unemployed}\}$, labor productivity z and asset holdings (b,a). There are assumed to be perfect annuity markets. Assets of deceased households are distributed to living households in proportion to assets held. This implies households are born with zero assets. A household's holding of liquid assets evolves according to

$$\begin{aligned} \dot{b}_t \;=\; & \mathbb{1}^e \left[w_t z_t h_t + \Gamma_\Pi(z_t) - T\left(w_t z_t h_t + r_t^b b_t + \Gamma_\Pi(z_t) \right) \right] + \\ & \mathbb{1}^u \left[uben_t - T\left(uben_t + r_t^b b_t \right) \right] + r_t^b b_t - d_t - \chi(d_t, a_t) + tr_t - c_t \end{aligned} \tag{2}$$

[2] In a version of the model with borrowing and a positive interest rate wedge on negative assets, the mean MPC for employed households is counterfactually higher than the mean MPC for unemployed households. This is because unemployed households are prevalent in the borrowing region and are approximately on their Euler equation while many employed households hold small amounts of liquid wealth and are constrained in their consumption by the interest rate wedge that applies to borrowing.

where T is a non-linear tax function described below, $\mathbb{1}^e$ is an indicator function taking the value one if a household is employed, $\mathbb{1}^u$ is an indicator function taking the value one if a household is unemployed, $\Gamma_\Pi(z_t)$ are profits of intermediate goods firms paid to employed workers in proportion to labor productivity z_t, tr_t is an untaxed lump-sum transfer and c_t is consumption. Liquid savings is equal to the sum of labor income when employed, unemployment benefits when unemployed, liquid interest income, profits paid to employed workers less deposits into or withdrawals from illiquid assets and the associated transactions costs and less consumption and taxes. Taxable income for employed households is the sum of labor income $w_t z_t h_t$, liquid interest income $r_t^b b_t$ and bonus payments from intermediate goods firms $\Gamma_\Pi(z_t)$; taxable income for unemployed households is the sum of unemployment benefits and liquid interest income. Because there is no borrowing, $b_t \geq 0$. A household's holding of illiquid assets evolves according to

$$\dot{a}_t = r_t^a a_t + d_t \tag{3}$$

subject to the constraint $a_t \geq 0$. Illiquid savings comprise interest income on illiquid assets and net deposits from the liquid to illiquid assets.

The transaction cost function follows Kaplan, Moll and Violante (2018) and is given by

$$\chi(d,a) = \chi_0 |d| + \chi_1 \left| \frac{d}{max\{\underline{a},a\}} \right|^{\chi_2} max\{\underline{a},a\}. \tag{4}$$

As explained by Kaplan, Moll and Violante (2018), the linear component allows for an inaction region ($\chi_0 > 0$), and the convex component ($\chi_1 > 0, \chi_2 > 0$) ensures deposit rates are finite ($|d| < \infty$). Scaling of the convex term by illiquid asset holdings makes transaction costs proportional to the fraction of illiquid assets deposited or withdrawn, rather than the magnitude of assets transacted; $\underline{a} > 0$ is set equal to a small value to ensure deposit costs are finite with holdings of zero illiquid assets. The recursive formulation of the households' problem is given in Appendix A.1.

Tax function Tax liability for a household with taxable income y is given by the function

$$T(y) = y - \lambda y^{1-\tau}. \tag{5}$$

This flexible tax function has been widely used in heterogeneous-agent models (e.g. Persson 1983; Benabou 2002) and has been shown by Heathcote, Storesletten and Violante (2017) to provide an excellent fit to the U.S. income tax and transfer system. The parameter τ determines the progressivity of the tax code and the parameter λ determines the average tax rate. The term $(1-\tau)$ is equal to the elasticity of post-tax income with respect to pre-tax income. It is also equal to the ratio of the marginal net-of-tax rate to the average tax rate. Accordingly, higher values of τ imply a more progressive tax system. As shown by Heathcote, Storesletten and Violante (2017), the average income-weighted marginal tax rate is simply related to the average tax rate atr:

$$\int T'(y_i)\frac{y_i}{TI}d\mu_i = 1-(1-\tau)(1-atr), \tag{6}$$

where TI is aggregate taxable income.[3] Equation (6) makes clear that, for a given average tax rate, lowering marginal tax rates requires reduced progressivity (smaller τ). This is the equity-efficiency trade-off at the heart of progressive taxation.

Labor market The labor market features search and matching frictions. Perfectly competitive labor recruitment firms post vacancies v_t and match at rate m_t with unemployed workers u_t accordingly to the constant-returns-to-scale matching function $m_t = \sigma \cdot u_t^{\phi} v_t^{1-\phi}$. Worker productivity and desired labor supply is unobservable to labor recruitment firms prior to matching. Accordingly, vacancies are not segmented and labor recruitment firms match with unemployed workers of type (b,a,z) in proportion to their share of unemployed workers.[4] Labor market tightness is given by the ratio of vacancies to unemployed workers $\theta_t = v_t/u_t$. An unemployed worker meets a labor recruitment firm and becomes employed at rate

$$f_t = \sigma \cdot \theta_t^{1-\phi} \tag{7}$$

and a vacant job is filled at the rate

$$q_t = \sigma \cdot \theta_t^{-\phi}. \tag{8}$$

Job destruction occurs at the exogenous rate δ_u and households are born unemployed. Unemployment evolves according to

$$\dot{u}_t = (\delta_u + \zeta)(1-u_t) - f_t u_t. \tag{9}$$

The value function for a filled job for a labor recruitment firm with a worker of type (b,a,z_j) is given by

$$\begin{aligned} r_t^a J_t(b,a,z_j) = {} & (p_t^w - w_t)\cdot z_j \cdot h_t(b,a,z_j) + (\delta_u+\zeta)\left[V_t - J_t(b,a,z_j)\right] + \frac{\partial J_t}{\partial b}(b,a,z_j)\,\dot{b}_t \\ & + \frac{\partial J_t}{\partial a}(b,a,z_j)\,\dot{a}_t + \sum_{j'\neq j}\lambda_{j,j'}\left[J_t\left(b,a,z_{j'}\right) - J_t(b,a,z_j)\right] + \frac{\partial J_t}{\partial t} \end{aligned} \tag{10}$$

where w_t is the wage rate paid by labor recruitment firms to employed workers, p_t^w is the price received by labor recruitment firms for each unit of effective labor sold to intermediate goods producers, described below, V_t is the value function for a vacant job, and $\lambda_{j,j'}$ is the matrix of transition rates to different labor productivity levels for an employed worker. The choice of the illiquid interest rate r_t^a to discount revenues from labor recruitment firms is justified by a no-arbitrage condition described below.

[3]This assumes a balanced budget.

[4]If the labor market were segmented by worker productivity level there would be a skill-specific job finding rate. Solving for transition dynamics would be intractable with more than a handful of worker productivity levels.

All matches between unemployed workers and labor recruitment firms result in a filled job. Labor recruitment firms incur a flow cost s to post a vacancy. Following Pissarides (2009), labor recruitment firms must pay a fixed training cost $\Theta(b,a,z)$ upon matching with an unemployed worker of type (b,a,z).[5] This prevents the hiring cost rising sharply with labor market tightness, enabling the model to generate realistic variation in employment. There is free-entry into vacancy creation, which implies that $V_t = 0$ and that the cost of hiring equals the expected benefit of a filled job:

$$s = q_t \cdot \int \left(J_t(b,a,z) - \Theta(b,a,z)\right) d\mu_t^u(b,a,z) \tag{11}$$

where $\mu_t^u(b,a,z)$ is the distribution of unemployed workers of type (b,a,z). Aggregate hiring costs is given by the sum of vacancy posting and training costs: $\Xi_t = s \cdot v_t + m_t \cdot \int \Theta(b,a,z)\, d\mu_t^u(b,a,z)$.

With search frictions, there is surplus to an employment relationship and any wage within the bargaining set is bilaterally efficient. It is common to assume wages are set by bilateral Nash bargaining. However, this implies a potentially different wage for each employment relationship. Introducing a fourth state variable to handle this is computationally infeasible. I suppose instead that wages take the form of a piece rate. Workers receive a common fraction Ω of the match output flow and firms keep the remaining fraction $(1-\Omega)$ of the match output flow. The assumption that the piece rate is common across employment relationships implies a uniform wage rate $w_t = \Omega \cdot p_t^w$.[6] A common wage rate across employment relationships eliminates incentives for job-to-job transfers.

Final goods producers A competitive representative final-goods producer aggregates a continuum of differentiated intermediate inputs $y_{j,t}$

$$Y_t = \left(\int_0^1 y_{j,t}^{\frac{\varepsilon-1}{\varepsilon}} dj\right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{12}$$

where $\varepsilon > 1$ is the elasticity of substitution between intermediate inputs. Cost minimization by final goods producers implies that demand for each intermediate input $y_{j,t}$ as a function of its price $p_{j,t}$ is

$$y_{j,t}(p_{j,t}) = \left(\frac{p_{j,t}}{P_t}\right)^{-\varepsilon} Y_t, \tag{13}$$

where

$$P_t = \left(\int_0^1 p_{j,t}^{1-\varepsilon} dj\right)^{\frac{1}{1-\varepsilon}} \tag{14}$$

[5] I assume deviations in hiring cost from their steady-state are virtual when solving for transition dynamics. This means changes in hiring costs outside of steady-state do not enter the goods market clearing condition. This assumption is largely innocuous and is made to simplify computation of transition dynamics.

[6] This differs from Burdett and Mortensen (1998) and subsequent work allowing a unique piece rate for each employment relationship, which would also be computationally infeasible.

is the aggregate price index.

Intermediate goods producers Intermediate input $y_{j,t}$ is produced by monopolistically competitive firm j using capital $k_{j,t}$ at utilization rate u_t^K and effective units of labor $l_{j,t} \equiv z_j \cdot h_{j,t}$ according to the constant returns-to-scale production function

$$y_{j,t} = \left(u_t^K k_{j,t}\right) l_{j,t}^{1-\alpha}. \tag{15}$$

A unit of capital $k_{j,t}$ is rented by intermediate goods producer j from a competitive factor market at the price r_t^k. The level of capital capacity utilization is chosen by an investment fund, described below, from which capital is rented. Intermediate goods firm j pays a labor recruitment firm the marginal product of a unit of effective labor $p_t^w = mpl_t$ for each unit of effective labor $l_{j,t}$ employed. Cost minimization implies that all firms choose the same capital-to-labor ratio $k_{j,t}/l_{j,t}$ and that marginal cost mc_t is given by

$$mc_t = \left(\frac{r_t^k}{\alpha}\right)^{\alpha} \left(\frac{p_t^w}{1-\alpha}\right)^{1-\alpha}. \tag{16}$$

Competitive factors markets imply the prices $r_t^k = \alpha m_t \left(u_t^K K_t/L_t\right)^{\alpha-1}$ and $p_t^w = (1-\alpha)\, m_t \left(u_t^K K_t/L_t\right)^{\alpha}$, where $Y_t = \int y_{j,t} dj$, $K_t = \int k_{j,t} dj$ and $L_t = \int l_{j,t} dj$.

Intermediate goods firms face Rotemberg (1982)-type price adjustment costs. The cost to adjust prices, as a fraction of aggregate output, at the rate $\dot{p}_t/p_t$ is

$$\Phi_t\left(\frac{\dot{p}_t}{p_t}\right) = \frac{\gamma}{2}\left(\frac{\dot{p}_t}{p_t}\right)^2 Y_t, \tag{17}$$

where $\gamma > 0$. Flow profits, net of price adjustment costs, as a function of firm j's price $p_{j,t}$ is

$$\Pi_{j,t}^{int}\left(p_{j,t}\right) = \left(\frac{p_{j,t}}{P_t} - mc_t\right)\left(\frac{p_{j,t}}{P_t}\right)^{-\varepsilon} Y_t. \tag{18}$$

The path of prices $\left\{p_{j,t}\right\}_{t\geq 0}$ is chosen to maximize the discounted sum of profits

$$\int_0^\infty e^{-\int_0^t r_s^a ds}\left\{\Pi_t^{int}\left(p_{j,t}\right) - \Phi_t\left(\frac{\dot{p}_{j,t}}{p_{j,t}}\right)\right\} dt. \tag{19}$$

In a symmetric equilibrium all firms choose the same prices $p_{j,t} = P_t$. Kaplan, Moll and Violante (2018) show that quadratic adjustment costs imply the following New Keynesian Phillips curve in continuous time:

$$\left(r_t^a - \frac{\dot{Y}_t}{Y_t}\right)\pi_t = \frac{\varepsilon}{\varsigma}\left(mc_t - \overline{mc}\right) + \dot{\pi}_t \tag{20}$$

where $\pi_t = \dot{p}_t/p_t$ is the inflation rate and $\overline{mc} = (\varepsilon - 1)/\varepsilon$ is the flexible price optimum. Firms increase their price when their mark-up is below the flexible-price optimum and decrease their price when their mark-up is above the flexible-price optimum. At an optimum, the rate of price changes equates the discounted marginal benefit from changing prices with marginal price adjustment costs.

Composition of illiquid assets As in Alves et al. (2020), illiquid assets are equity claims on the assets of an investment fund. The stock of illiquid assets held by households is equal to the value of the investment fund: $Q_t = A_t \equiv \int a_t d\mu(b,a,z,E)$, where $d\mu(b,a,z,E)$ is the distribution of households of type (b,a,z,E). The investment fund holds the economy's stock of physical capital K_t, shares X_t^{int} in an equity fund owning intermediate goods producers and shares X_t^{lab} in an equity fund owning labor market recruitment firms.

Aggregate intermediate goods firm profits are given by $\Pi_t^{int} = (1-m_t)Y_t$. A fraction ω of intermediate goods firm profits are paid as dividends to the equity fund and the remaining fraction $(1-\omega)$ is paid as a worker bonus. Furthermore, the government levies a corporate income tax τ_c on intermediate goods firm profits. Accordingly, aggregate dividends paid by intermediate goods firms to the equity fund is $\omega(1-\tau_c)\Pi_t^{int}$ and aggregate worker bonuses is $\Gamma_\Pi = (1-\omega)(1-\tau_c)\Pi_t^{int}$.[7]

The value of labor market recruitment firms is equal to the value of filled jobs

$$J_t = \int J_t(b,a,z)\, d\mu_t^e(b,a,z)$$

where $\mu_t^e(b,a,z)$ is the distribution of employed workers of type (b,a,z). It is equal to the discounted value of the flow surplus on all filled jobs less recruitment expenses, plus capital gains. The flow surplus on filled jobs less recruitment expenses is $\Pi_t^{lab} = (p_t^w - w_t)L_t - \Xi_t$.

The investment fund chooses the physical capital investment rate $\iota \equiv I/K$, the rate of capital capacity utilization u^K and the rate-of-change of share holdings $\dot{X}_t^{int}$ and $\dot{X}_t^{lab}$ to maximize the value of the investment fund. Investment in physical capital is subject to adjustment costs $\Psi(\iota)$, with $\Psi(\delta_K) = 0$ and $\Psi'(\iota) > 0$, where δ_K is the depreciation rate on physical capital. The restriction that $\Psi(\delta_K) = 0$ implies capital adjustment costs do not affect the steady state. Utilization of capital at rate u^K is incurs cost $a(u^K)$, with $a'(u^K) > 0$, and it is assumed that in steady state $u^K = 1$. Let q_t^K represent the price of a unit of installed capital and q_t^{int} and q_t^{lab} represent the prices of shares in the intermediate and labor market recruitment firms. The value of the investment fund is given by

$$A_0 = \max_{\left\{\iota, \dot{X}_t^{int}, \dot{X}_t^{lab}, u^K\right\}} \int_t^\infty e^{-\int_0^t r_s^a ds} \left\{ \left[r_t^k u^K - \iota_t - \Psi(\iota) - a\left(u^K\right) \right] K_t + \omega(1-\tau_c)\Pi_t^{int} X_t^{int} - q_t^{int}\dot{X}_t^{int} + \Pi_t^{lab} X_t^{lab} - q_t^{lab}\dot{X}_t^{lab} \right\} \tag{21}$$

subject to $\dot{K}_t = (\iota - \delta_K)K_t$. The returns to the fund from holdings of physical capital, shares in the equity fund owning intermediate goods producers and shares in the equity fund owning labor

[7] Profits are counter-cyclical in the model, causing corporate tax revenue to counter-factually fall in an expansion. This has a pronounced effect on government finances and demand for liquid assets. I abstract from this by assuming in transition that deviations of monopoly profits from their steady-state level are untaxed. Accordingly, the corporate profit tax affects only the steady-state of the model.

market recruitment firms must be equal. As shown in Appendix A.2, this implies

$$\begin{aligned} r_t^a &= \frac{\left[r_t^k u^K - \iota - \Psi(\iota) - a\left(u^K\right)\right] + q_t^K(\iota - \delta) + \dot{q}_t^K}{q_t^K} \\ &= \frac{\omega(1-\tau_c)\Pi_t^{int} + \dot{q}_t^{int}}{q_t^{int}} \\ &= \frac{\Pi_t^{lab} + \dot{q}_t^{lab}}{q_t^{lab}}. \end{aligned} \tag{22}$$

Equation (22) implies that intermediate goods profits are discounted by r_t^a, justifying the choice of r_t^a as the discount rate in the Phillips curve (Equation 20) and the value of a filled job to labor market recruitment firms (Equation 10).

The capital adjustment cost function is assumed to be quadratic, as is standard:

$$\Psi(\iota) = \frac{\phi_K}{2}(\iota - \delta_K)^2.$$

The parameter ϕ_K parameterizes the degree of adjustment costs. This function has the desired properties $\Psi(\delta_K) = 0$ and $\Psi'(\iota) > 0$. The capital capacity utilization cost function is of constant-elasticity form, as in Smets and Wouters (2007):

$$a\left(u^K\right) = \sigma_a^K \left(u^K\right)^{\sigma_b^K} - \sigma_a, \tag{23}$$

where σ_b^K is the elasticity of utilization costs with respect to utilization u^K and σ_a^K is a level parameter. As shown in Appendix A.2, the requirement that $u^K = 1$ in steady state implies $\sigma_a^K = \left(r_{ss}^k / \sigma_b^K\right)$. The incorporation of variable capital capacity utilization allows output to respond to demand shocks when labor input is slow to adjust, which is the case when hours worked is inelastically supplied and the extensive margin is subject to search frictions.

Monetary authority The monetary authority sets the nominal interest rate on liquid assets according to the inertial Taylor rule

$$\frac{di_t}{dt} = -\rho_i \left(i_t - \bar{r}^b - \phi_\pi \pi_t - \phi_y log\left(Y_t/\bar{Y}\right)\right) \tag{24}$$

where $\phi_\pi > 1$ is the weight on deviations in inflation from its steady-state $\pi = 0$, ϕ_y is the weight on the log deviation in output from steady-state and ρ_i controls the degree of inertia. Given the nominal liquid interest rate and inflation, the real interest rate on liquid assets is implied by the Fisher equation $r_t^b = i_t - \pi_t$.

Government The government levies a non-linear income tax $T_t = \int T(y_t)\, d\mu_t(b,a,z)$, collects corporate taxes from intermediate goods firms $\tau_c \Pi_t^{int}$, provides unemployment benefits $uben_t$, provides a transfer tr_t and spends G_t. The government is the sole issuer of real liquid debt B_t^g of infinitesimal maturity. Negative values of B_t^g denote government debt. The government's budget constraint is

$$\dot{B}_t^g + G_t + tr_t + uben_t = T_t + \tau_c \Pi_t^{int} + r_t^b B_t^g. \tag{25}$$

Out of steady state it is assumed that tax changes are deficit financed and transfers tr_t adjust to satisfy the government's intertemporal budget constraint. The adjustment of transfers follows the fiscal rule

$$tr_t(z) = \bar{tr} + \rho_g \left(B_t^g - \bar{B}^g\right) \frac{z}{\bar{z}} \tag{26}$$

where the parameter $\rho_g = \bar{r}^b + \Delta_B$ controls the speed with which the government's debt holdings revert to the steady-state level $\bar{B}^g$. The increment to transfers $tr_t(z) - \bar{tr}$ is allocated across employed households in proportion to labor productivity. This minimizes the effect of financing on the dynamics of the model because the decline in transfers is distributed predominantly to top income earners who have relatively low MPCs. The lump-sum nature of the transfer means debt repayment does not affect incentives to work. See Appendix A.4 for further details on the fiscal rule.

2.2 Equilibrium

An equilibrium is a path of individual household decisions $\{b_t, a_t, c_t, d_t, h_t\}_{t\geq 0}$, intermediate goods firm factor demands $\{l_t, k_t\}_{t\geq 0}$, capital capacity utilization $\{u_t^K\}_{t\geq 0}$, a path of vacancy postings by labor recruitment firms $\{v_t\}_{t\geq 0}$, intermediate goods firms factor input prices $\{r_t^k, p_t^w\}_{t\geq 0}$, wages $\{w_t\}_{t\geq 0}$, returns on liquid and illiquid assets $\{r_t^b, r_t^a\}_{t\geq 0}$, the value of the investment fund $\{Q_t\}_{t\geq 0}$, the inflation rate $\{\pi_t\}_{t\geq 0}$, fiscal variables $\{T_t, tr_t, G_t, uben_t\}_{t\geq 0}$, distributions $\{\mu_t, \mu_t^u, \mu_t^e\}_{t\geq 0}$ and aggregate quantities such that at every instant t: (i) households and firms maximize their objective functions taking as given prices, taxes and transfers; (ii) the discounted value of a vacant job is equal to zero; (iii) the distributions $\{\mu_t, \mu_t^u, \mu_t^e\}_{t\geq 0}$ are consistent with aggregate household and firm decisions; (iv) the government's budget constraint holds; and (v) all market clear.

The liquid asset market clears when

$$B_t^h + B_t^g = 0 \tag{27}$$

where $B_t^h = \int b d\mu_t$ is total liquid asset holdings by households. Households aggregate holdings of illiquid assets $A_t = \int a d\mu_t$ must equal the sum of the value of physical capital and equity

$$A_t = q_t^k K_t + q_t^{int} X_t^{int} + q_t^{lab} X_t^{lab}. \tag{28}$$

Factor market clearing requires

$$K_t = \int k_{j,t} d\mu_j \tag{29}$$

and

$$L_t = \int z_t \cdot h_t(b, a, z) \, d\mu^e. \tag{30}$$

The goods market clearing condition is

$$Y_t = C_t + I_t + G_t + \chi_t + \Xi_t + \Psi_t + a\left(u_t^K\right) K_t \tag{31}$$

where Y_t is aggregate output, C_t is aggregate consumption spending, I_t is investment in physical capital, G_t is government spending, χ_t are aggregate transaction costs from depositing and withdrawing from the illiquid account, Ξ_t is aggregate hiring costs by labor recruitment firms, Ψ_t is aggregate capital adjustment costs and $a\left(u_t^K\right)K_t$ is capital capital utilization costs. Price adjustment costs Φ_t are assumed to be virtual and so do not enter the goods market clearing condition, as in Hagedorn, Manovskii and Mitman (2019). Thus, price adjustment costs affect pricing decisions of firms but do not consume real resources. This prevents price adjustment costs comprising a large share of output in simulations where there are large movements in inflation. The absence of real resources costs of price adjustment is consistent with the Calvo model.

2.3 Calibration

First, a large block of parameters pertaining to preferences, production, the labor market and government policy are calibrated based on relevant literature. Second, the labor productivity process is specified and parameters are chosen to match the moments of the male earnings distribution targeted by Kaplan, Moll and Violante (2018). Lastly, a subset of parameters are internally calibrated to match moments of the wealth distribution and the mean marginal income tax rate. The values of the calibrated parameters are reported in Table 1 and explained below. The model is solved using the numerical methods detailed in Achdou et al. (2020).

Demographics and preferences The quarterly death rate ζ is set equal to $1/180$, implying an average life of 45 years. Instantaneous utility is separable over consumption and hours worked:

$$u(c,h) = \frac{c^{1-\gamma}}{1-\gamma} - \varphi\frac{h^{1+1/\eta}-1}{1+1/\eta} \tag{32}$$

where $1/\gamma$ is the intertemporal elasticity of substitution (IES) and η is the Frisch elasticity of labor supply. The parameter φ controls the level of labor disutility and is chosen to target mean hours of work.

The IES is set equal to one (log utility over consumption). The relevant target for η is an intensive-margin Frisch elasticity of labor supply. This is because the model will be used to study temporary tax changes and there is no labor force participation decision for households in the model. Chetty et al. (2011) survey the literature and report an intensive-margin Frisch elasticity of labor supply equal to 0.54. However, this is a structural elasticity after adjusting for adjustment frictions. The attenuation of behavioral responses due to adjustment frictions is relevant for studying labor supply responses to *temporary* tax changes.

The most compelling and relevant evidence for calibrating η comes from earnings responses to temporary income tax holidays. Martinez, Saez and Siegenthaler (2021) study earnings responses to two-year long income tax holidays in Switzerland using cross-canton variation in the timing of the tax holidays. They estimate an intertemporal elasticity of labor supply substitution of $\eta = 0.025$.[8] Further, they find no evidence of adjustment along the extensive margin, which is consistent with the absence of a participation margin in my model. Other studies of income tax holidays in Iceland have found larger earnings responses, but these studies are less credible because all taxpayers in Iceland experienced the income tax holiday at the same time, making it difficult to remove business cycle effects (Sigurdsson, 2021; Stefansson, 2019; Bianchi, Gudmundsson and Zoega, 2001). A small *real* earnings response to tax changes is consistent with evidence from the public finance literature (Saez, Slemrod and Giertz, 2012; Kleven and Schultz, 2014). I set $\eta = 0.025$ in the baseline analysis and use a larger values in the sensitivity analysis.[9] Appendix Table A1 summarizes relevant studies for calibrating η.

Production The capital share α is set to 0.33 and the capital depreciation rate δ_K is set equal to 0.07 per annum, consistent with United States National Accounts data. Final goods producers' elasticity of demand across intermediate goods ε is set equal to 10, implying a mark-up of 11 percent and that intermediate goods profits comprise 10 percent of output in steady state. Following Kaplan, Moll and Violante (2018), the price adjustment cost parameter ς is set equal to 100, implying the slope of the Phillips curve ς/ε is 10. I consider larger and smaller value of ς in the sensitivity analysis.

Labor market The quarterly job destruction rate δ_u is set to 0.1, in line with the values calculated by Hall and Milgrom (2008) and Shimer (2012). The matching function elasticity with respect to unemployed workers ϕ is set to 0.5, within the plausible range of values reported by Petrongolo and Pissarides (2001), and the matching function efficiency parameter σ is internally calibrated to target a steady-state ratio of vacancies to unemployed workers (labor market tightness) of $\theta = 0.6$. The vacancy posting cost s is implied by a target steady-state unemployment rate of 5 percent. The fixed cost component of hiring $\Theta(b, a, z)$ is set such that it comprises 90 percent of total hiring costs in the steady-state, close to the value estimated by Christiano, Eichenbaum and Trabandt (2016). The piece rate Ω is set equal to 0.96, such that in the representative agent version of the model the steady-state match surplus is equally split between workers and labor recruiters. See Appendix A.3 for details.

Fiscal policy The tax progressivity parameter τ is set equal to 0.181, equal to the value estimated by Heathcote, Storesletten and Violante (2017) for the United States. The average tax rate parameter λ is internally calibrated to target the mean marginal income tax rate of 0.34 reported by Heathcote, Storesletten and Violante (2017) for the United States. The replacement ratio is set to 0.4, up to a maximum of \$25,000 at an annual rate, and untaxed lump-sum transfers are equal to 1

[8] They estimate larger responses for top earners but argue that they driven by tax avoidance rather than labor supply.

[9] In the model, hours of work is the only margin along which households can adjust their labor supply. However, the empirical public finance literature focuses on the response of labor or taxable income, which summarize all margins of adjustment. Accordingly, for calibration purposes, hours in the model should be thought of as a composite including all other additional margins through which a household can adjust their earnings, such as effort.

percent of steady-state output. The combined value of lump-sum transfers, unemployment benefits and households with negative income tax liability is 8 percent of steady-state output. Government spending is 13 percent of output in the steady state. The rate at which government debt reverts to steady-state Δ_B is set equal to 0.1, implying a half-life of 7 quarters for a deviation of government debt from its steady-state level. Slower adjustment of debt is analyzed in the sensitivity analysis.

Monetary policy The coefficient on inflation in the Taylor rule ϕ_π is set equal to 1.5 and the degree of inertia in the nominal interest rate ρ_i is set equal to 0.5. These values are within the range used in the New-Keynesian model literature. In the baseline analysis I assume the monetary authority attempts to stabilize only inflation and set the coefficient on the output gap ϕ_y equal to zero. I make this assumption because the tax changes studied affect potential output through labor supply responses. Furthermore, the assumed intent of the tax cuts studied is to stimulate output. The sensitivity analysis studies responses when $\phi_y > 0$. The steady-state liquid interest rate is set equal to 2 percent per annum.

Labor productivity process The continuous-time labor productivity process is based on that developed by Kaplan, Moll and Violante (2018), modified for the introduction of unemployment. There are two components to the labor productivity process. The first process is the jump-drift process from Kaplan, Moll and Violante (2018) that captures large but infrequent changes in earnings. The second process is a two-point ($n_{z,2} = 2$) Markov process that captures smaller but more frequent changes in earnings, such as bonuses. Shocks to the first process are assumed to occur at the same rate when employed and unemployed, but upward jumps to the second process occur only when employed, generating transitory earnings losses from unemployment. The assumption of constant job destruction and job finding rates across skill types puts rich interactions between unemployment risk, duration and scarring effects of unemployment beyond the scope of the model. The earnings process for the model is generated by the product of the labor productivity process and employment status.

Formally, the process for the first component of the log labor productivity process $z_{1,it}$ is

$$dz_{1,it} = -\beta_1^z z_{1,it} + d\mathscr{Z}_{1,it} \tag{33}$$

where $d\mathscr{Z}_{1,it}$ is a process that at rate λ_1^z experiences jumps drawn from a mean zero normal distribution with standard deviation σ_1^z and drifts back to zero at rate β_1^z. The second component of the log labor productivity process $z_{2,it}$ is a two-point Markov process of width Δ_2^z that experiences upward jumps at rate $\lambda_{2,up}^z$ when employed and downward jumps at rate $\lambda_{2,dn}^z$ when employed or unemployed. The combination of these two log processes gives the log labor productivity process

$$z_{i,t} = z_{1,it} + z_{2,it}. \tag{34}$$

Table 2a reports simulated moments of the earnings process against the target moments from Kaplan, Moll and Violante (2018). The parameter estimates for the earnings process are reported in Table 2b. The incorporation of unemployment into the earnings process imposes additional structure on the earnings process relative to Kaplan, Moll and Violante (2018). Despite this, the continuous time earnings process fits the target moments almost as well. The continuous time process for labor productivity is discretized for incorporation into the model. There are assumed to be $n_{z,1} = 9$ points for the first component of the labor productivity process, with the bounds and grid spacing estimated to maximize fit of the simulated moments of the earnings process to the data. In total, there are $n_y = 36$ points to the earnings process ($n_{z_1} \times n_{z_2} = 18$ labor productivity states $\times$ employed/unemployed status). Note that there is an employed and unemployed state for each skill level, preserving a distribution of productivities among the unemployed. The third column in Table 2a reports the simulated moments of the discretized process. The discretized process maintain a good fit to most moments of the earnings data.

Distribution of intermediate goods firm profits and capital adjustment costs Intermediate goods firm profits are countercyclical in the model, because the mark-up over marginal cost $(1-m_t)$ declines when inflation and output rise. This depresses investment when profits are fully distributed to illiquid assets. Accordingly, in the baseline model, a fraction of intermediate goods firm profits are paid as dividends to the equity fund to neutralize the effect of countercyclical mark-ups on investment. The remaining fraction of intermediate goods firm profits are paid as a bonus to workers. In the sensitivity analysis I consider a profit distribution scheme in which intermediate goods firm profits are paid in full as dividends to the investment fund.

Aggregate flows into the illiquid account, net of depreciation, hiring costs and deposits, is

$$r_t^k u_t^K K_t + \omega (1-\tau_c) \Pi_t^{int} + (p_t^w - w_t) L_t, \tag{35}$$

where $(p_t^w - w_t) L_t$ is the aggregate flow match surplus of labor recruitment firms. Using the competitive factor prices $r_t^k = \alpha m_t \left(Y_t / u_t^K K_t\right)$ and $p_t^w = (1-\alpha) m_t (Y_t / L_t)$ and the piece-rate wage function $w_t = \Omega p_t^w$, aggregate flows into the illiquid account can be re-expressed as

$$\omega (1-\tau_c) Y_t + [\alpha - \omega (1-\tau_c) + (1-\Omega)(1-\alpha)] m_t Y_t. \tag{36}$$

The profit distribution scheme that neutralizes the effect of countercyclical intermediate goods firm profits on investment is

$$\omega^{neutral} = \frac{1}{1-\tau_c} (\alpha + (1-\Omega)(1-\alpha)).$$

This scheme ensures that investment rises proportionally with output in the model.

The capital adjustment cost function parameter is set to $\phi_K = 25$ in the baseline calibration, as in Alves et al. (2020). The elasticity of capital capacity utilization to the rental rate of capital, $\sigma_{K,B}$ is set equal to 2, following Smets and Wouters (2007).[10] I consider alternative calibrations in the

[10] Note that the capital capacity utilization elasticity ψ reported by Smets and Wouters (2007) is related to $\sigma_{K,B}$ by $\sigma_{K,B} = 1/(1-\psi)$.

sensitivity analysis.

Internally calibrated parameters The discount rate ρ, the parameters of the illiquid deposit adjustment cost function (χ_0, χ_1, χ_2) and the average tax rate parameter λ are internally calibrated to match target moments of the wealth distribution and the mean marginal income tax rate. Table 3a shows that the model closely matches the targeted moments.

Fit of the model to non-targeted moments Consistent with the data, the distributions of wealth in the model are highly concentrated, and the illiquid wealth distribution is more concentrated than the liquid wealth distribution (Table 3b and Figures A1a and A1b). However, the model somewhat understates the degree of concentration for liquid wealth and overstates the degree of concentration for illiquid wealth. The fit of the model to the distributions of wealth is comparable but not quite as good as the fit provided by the model of Kaplan, Moll and Violante (2018). The difference is attributable to the incorporation of a less flexible income process in the presence of unemployment.

All households face the same exogenous risk of becoming unemployed and transitioning from unemployment to employment in the model. However, some households will remain employed or unemployment longer that others, creating dispersion in wealth by employment status (Table 3a). On average, employed households are less likely to have low liquid wealth $(b \simeq 0)$ or low total asset holdings.

The distribution of taxable income is a little less concentrated in the model than the data because the model is not able to capture the concentration at the very top of the income distribution. However, the Gini coefficient for the taxable income distribution in the model is close to the data.

Figure 1a plots marginal and average tax rates as a function of income. The tax function $T(y)$ should be interpreted as a combined tax and transfer function (Heathcote, Storesletten and Violante, 2017). Households with incomes below about \$10,000 (28 percent of all households by number and 8 percent income weighted) receive net transfers from the government. Importantly, the tax and transfer system reduces the taxable income Gini coefficient by a similar amount in the model and the data (Table 3b, Figure 1b).

2.4 MPCs, MPEs and Labor Supply Responses

MPCs The model is consistent with empirical evidence on MPCs (Johnson, Parker and Souleles, 2006; Parker et al., 2013). For a one-time \$500 increase in liquid wealth the mean quarterly (annual) MPC is 0.15 (0.41) (Table 4). Households with large MPCs are those with low liquid wealth (Figure 2a). MPCs differ substantially by employment status. For a one-time \$500 increase in liquid wealth, the quarterly (annual) mean MPC for unemployed households is 0.36 (0.54), compared with 0.14 (0.38) for employed households. This is consistent with the evidence from Kekre (2019), who uses the 2010 Italian Survey of Household Income to estimate a 25 percentage point higher MPC for unemployed than employed workers.[11]

The two-asset structure of the model and the heterogeneity of the wealth distributions generate variation in MPCs across the taxable income distribution. The quarterly mean MPC for households in the bottom 90 percent of the taxable income distribution is three times larger than the mean MPC for households in the top 10 percent of the taxable income distribution (Table 4).[12] By income decile, the MPC is declining with income, except around the middle of the income distribution (Figure 2b). The non-monotonicity around the middle of the income distribution reflects there being many households with similar incomes (in the $40,000 range) and the mix of income and employment shocks they face.

MPEs The MPE is the amount by which a household reduces their earnings in response to a one-time increase in (liquid) wealth. While a large body of empirical evidence points to large MPCs, around 0.25 quarterly and 0.5 annually, the available evidence indicates much smaller MPEs, of around 0.00-0.04 annually (Auclert, Bardóczy and Rognlie, 2020). The model is able to generate MPEs consistent with the data. For a one-time $500 increase in liquid wealth the mean quarterly (annual) MPE is 0.00 (-0.01). The small mean MPE in the model is a result of households having relatively inelastic labor supply (η small). In contrast, models in which η is large cannot simultaneously match the empirical evidence on MPCs, MPEs and fiscal multipliers, which Auclert, Bardóczy and Rognlie (2020) label a trilemma.[13]

Labor Supply Responses The labor supply response to a change in the net-of-tax wage rate is heterogeneous in wealth and income. To quantify this, I compute the partial equilibrium labor supply response on impact for each employed household (b,a,z) to a uniform transitory 1 percent change in the net-of-tax wage rate.[14] The response of labor supply to a change in the net-of-tax rate falls as liquid wealth declines toward zero (Figure 3b). This reflects households with low liquid wealth having above-average (but still small) MPEs. Similarly, labor supply responses are also somewhat muted for households with low illiquid wealth (Figure 3c). By income, labor supply is most responsive at the top of the income distribution but heterogeneity by income level is modest (Figure 3d).

Implications for the targeting of tax cuts MPCs are declining in income, suggesting the aggregate demand channel for the transmission of tax cuts will be relatively stronger for more

[11] Evidence on the response of consumption at unemployment benefit exhaustion is also consistent with relatively large MPCs for the unemployed (Ganong and Noel, 2019).

[12] For the bottom 25 percent of the income distribution, the mean MPC is a little larger for a one-time transfer equal to one percent of taxable income compared with a flat $500 transfer. This is because MPCs are decreasing in the size of the transfer (due to the nature of deposit adjustment costs) and a transfer proportional to income provides smaller transfers to those with low incomes and high MPCs.

[13] Non-separable preferences that diminish wealth effects on labor supply (e.g. Greenwood, Hercowitz and Huffman 1988) raise complementary between consumption and labor supply, implying unrealistically large fiscal multipliers (Auclert, Bardóczy and Rognlie, 2020).

[14] The shock has a half-life of 1 quarter.

progressive tax cuts. However, progressive tax cuts lower mean (income-weighted) marginal tax rates by less than regressive tax cuts (see Equation 6). This is because reducing marginal tax rates faced by lower-income earners also cuts tax liability for higher-income earners (without reducing marginal rates) and therefore constrains the mean reduction in marginal tax rates per dollar of tax revenue foregone.[15] Thus, more progressive tax cuts will have a stronger aggregate demand response but a weaker aggregate supply response. The overall effect depends on the relative strength of the aggregate demand and labor supply transmission channels, and general equilibrium forces, which I study quantitatively in the next section.

3 Results

3.1 Tax cut scenarios

The tax cut scenarios fed into the model are based on historical tax reforms in the United States. The five previous major reform episodes are reported in Table 5. I summarize the progressivity of tax reforms using the top-10 (T10) percent and bottom-90 (B90) percent shares, for consistency with the empirical literature (Zidar, 2019). The T10 and B90 income shares in the model are close to the data (Table 3b).

The 1981, 2003 and 2017 reforms disproportionately cut taxes on top earners. For example, for the 2017 reform, the total static cost to revenue of the tax cut was 1.06 percent of GDP, of which 0.51 percent of GDP and 48 percent of the total tax cut went to the T10 percent of income earners. Thus, on average, people in the T10 percent received a tax cut almost 10 times as large as people in the B90 percent. The fraction of the tax cut received by the T10 percent was 53 percent for the 1981 reform and 61 percent for the 2003 reform. The 1991 reform was approximately revenue neutral, cutting taxes on the B90 and raising taxes by an almost equivalent amount on the T10. The 1993 reform increased taxes on the T10 percent and provided a smaller tax cut to the B90 percent.

These reforms are used to construct *progressive* and *regressive* tax cut scenarios. In both cases, the total reduction in income tax liability is 1 percent of GDP, assuming no behavioral response by households or general equilibrium effects (static scoring). The 1981, 2003 and 2017 reforms are regressive and similar in their distribution of tax cuts to the T10 percent. Thus, the *regressive* tax cut scenario is constructed as an average of the 1981, 2003 and 2017 reforms, after scaling each to have a static revenue cost of 1 percent of GDP. The average share of the tax cut to the T10 percent across these reforms is 55 percent. Thus, in the regressive scenario, there is a 0.55 percent of GDP tax cut for the T10 percent and a 0.45 percent of GDP tax cut for the B90 percent.

There has been no progressive tax cut scenario in the recent past. The 1991 and 1993 reforms were progressive, but did not cut taxes. Instead, I construct a tax cut scenario that has the same

[15] For example, a bottom bracket tax cut lowers tax liability for everyone, but only cuts marginal rates for low income earners.

distributional properties as the 1993 tax increase. Specifically, in the *progressive* scenario the B90 percent receive a tax cut of 1.27 percent of GDP and the T10 percent receive a tax increase of 0.27 percent of GDP. In a later exercise, I quantify the effect of a revenue neutral tax change based on the 1991 tax reform.

In the model, the *progressive* shift is constructed by choosing the parameters of the tax function $\{\lambda, \tau\}$ to lower total income tax revenue of 1 percent of GDP and reduce static tax liability on the T10 (B90) percent by 0.55 (0.45) percent of GDP; the *regressive* shift is constructed by choosing $\{\lambda, \tau\}$ to lower total tax liability by the same amount but increase (decrease) tax liability on the T10 (B90) percent by 0.27 (1.27) percent of GDP (Figure 4).

The mean marginal tax rate rises by 1.2 percent under the *progressive* scenario and falls by 2.8 percent under the *regressive* scenario. For the *progressive* scenario, tax liability rises on average by \$3,105 (0.9 percent of taxable income) for the T10 percent and falls on average by \$1,622 (3.8 percent of taxable income) for the B90 percent. For the *regressive* shift, tax liability falls on average by \$6,325 (1.9 percent of taxable income) for the T10 percent and by \$575 (1.3 percent of taxable income) for the B90 percent. Accordingly, the *progressive* scenario decreases incentives to work but distributes disposable income to lower-income households, who have relatively large MPCs. In contrast, the *regressive* scenario increases incentives to work but concentrates the reduction in tax liability on top earners. These scenarios capture the equity-efficiency trade-off inherent in tax reforms.

The shift in the tax function is assumed to be persistent but transitory. Mertens and Montiel Olea (2018) show for the U.S. that tax reforms affecting marginal tax rates on average had a half-life of about 2.5 years in the post-war period, as a result of bracket creep, expiration clauses and policy reversals. I assume that the tax function exponentially decays back to the baseline function. That is, for scenario j, $\lambda_{j,t} = \lambda_{ss} - \Delta\lambda_j e^{-\rho t}$ and $\tau_{j,t} = \tau_{ss} - \Delta\tau_j e^{-\rho t}$, where $\Delta\lambda_j$ and $\Delta\tau_j$ are the changes in the tax function parameters for scenario j that lower tax liability by 1 percent of GDP on impact. I assume a half-life of two years (8 quarters) for the tax shocks ($\rho = -ln(0.5)/8$).

3.2 Baseline results

The results primarily contrast the output and employment effects of the temporary progressive and regressive tax cut scenarios described in Section 3.1. The progressive tax cut scenario cuts tax liability on the B90 percent but increases the income-weighted mean marginal tax rate. The increase in disposable income raises aggregate demand and indirectly raises labor demand. However, this is partly offset by decreased incentives to work. The increase in labor demand and reduction in labor supply raises the real wage and inflation (Figure 5). The rise in inflation causes the liquid return to initially decline, while the illiquid return falls. Output, consumption and investment rise (Figure 5). The rise in output is a result of lower unemployment, higher investment and higher capital capacity utilization. The increase in labor demand raises the price per effective unit of labor received by labor recruitment firms, raising the return to vacancy creation.

Output multipliers are calculated as the present discounted value of the change in output divided by the present discounted value of the change in tax revenue. For the progressive tax cut scenario, the multiplier is 0.64 over the first two years, rising to 0.80 over five years (Table 6). The output multiplier is larger when computed over longer horizons because the response of output to the tax cut is more persistent than the change in tax revenue.

The regressive tax change reduces total static tax liability by the same amount as the progressive tax change but cuts marginal tax rates and distributes the reduction in tax liability disproportionately to top earners. Accordingly, the regressive tax change induces a positive labor supply response but a weaker aggregate demand response. The positive labor supply response moderates the rise in the wage rate (Figure 5). Investment initially rises by less under the regressive tax cut scenario because aggregate demand and therefore capital utilization is lower. But after the first few quarters the response of investment is almost the same under both scenarios. The positive labor supply response and relatively weak aggregate demand response results in lower inflation and a smaller decline in the markup under the regressive tax cut scenario. This results in a smaller rise in the price per effective unit of labor received by labor recruitment firms relative to the wage rate, reducing vacancy creation relative to the progressive scenario. This is less than offset by increased labor supply, which raises output produced per filled job and increases the return to vacancy creation. Accordingly, unemployment falls by less for the regressive tax cut scenario than the progressive tax cut scenario. The output multiplier is 0.37 over the first two years and 0.43 over the first five years (Table 6). Although only static tax liability changes are constructed to be the same for the progressive and regressive tax cut scenarios, the dynamic revenue effects are also almost identical (Figure 5). The larger labor supply response in the regressive tax cut scenario is offset by a lower wage rate.

The plausibility of the unemployment response in the model can be gauged by comparison with Okun's law. Averaged over the first five years, the Okun's law coefficient is 2.4 for the progressive tax shock scenario and 2.3 for the regressive tax shock scenario. In other words, the mean percentage rise in output is 2.3-2.4 times larger than the mean percentage point reduction in unemployment over the first five years. These Okun's law coefficients are broadly consistent with empirical evidence for the U.S. (Ball, Leigh and Loungani, 2017).[16]

Decomposition The mechanisms at work can better understood by a decomposition of the equilibrium consumption and labor responses into partial and general equilibrium effects. The partial equilibrium (direct) effect is computed by feeding the tax shock alone into the household problem

[16]Although reassuring, this comparison provides only a broad plausibility check because estimates of Okun's law are typically based on averages for different time periods rather than responses of output and unemployment to identified shocks.

and aggregating across households. The general equilibrium (indirect) effects are computed by sequentially feeding the equilibrium time paths for prices into the household problem.[17]

The progressive tax cut induces a larger direct consumption response than the regressive tax cut scenario (Figure 6). This is because the progressive tax cut scenario cuts tax liability by more for the B90 percent, who have relatively large MPCs (Figures 2b and 4). The aggregate demand stimulus raises wages and lowers unemployment, indirectly raising consumption. Partly offsetting this, bonus income falls because the rise in the markup lowers intermediate goods firm profits. Tighter monetary policy in response to increased inflation significantly dampens consumption. The indirect effects on consumption are weaker under the regressive tax cut scenario due to the weaker aggregate demand response and positive labor supply response.

For equilibrium labor input, the reduction in unemployment more than offsets lower labor supply (the direct effect) for the progressive tax cut scenario. For the regressive tax cut scenario, close to one-third of the equilibrium response of labor is due to increased incentives (direct effect) and the remaining two-thirds by lower unemployment. Changes in prices on net explain little of the equilibrium labor response.

3.3 Alternative calibrations

This sub-section considers the sensitivity of the baseline results to variation in key parameters.

Labor supply: Raising the Frisch elasticity of labor supply increases the response of hours worked to changes in marginal tax rates. The progressive tax cut scenario raises the mean marginal tax rate while the regressive tax cut scenario lowers it. Accordingly, a higher labor supply elasticity raises the output multiplier for the regressive tax cut scenario and lowers it for the progressive tax cut scenario. Quantitatively, the output multipliers are similar for two tax cut scenarios when the Frisch elasticity is raised to $\eta = 0.1$ (Table 6). But the regressive tax cut scenario is more expansionary when the incentive effects of taxes are very large ($\eta = 0.25$). Increasing the labor supply elasticity results in a larger partial equilibrium labor supply response to cuts in the marginal tax rate but increases the disinflationary effect of the tax cut and therefore weakens the indirect aggregate demand effect (Table 7).

Capital adjustment costs: The baseline model assumes a moderate level of capital adjustment costs. An increase in investment raises labor demand, benefiting all households. But an increase in the price of capital alone provides gains predominately to wealthy households and does not directly increase labor demand. Quantitatively, the output and employment effects of the model are insensitive to a doubling in the size of capital adjustment costs (Table 6). This is because in equilibrium higher capital adjustment costs depress investment but boost consumption, in approximately offsetting amounts.

[17] The employment response is classified as an indirect effect because it reflects the hiring behavior of labor recruitment firms to equilibrium prices and quantities.

Capital utilization costs: Variable capital utilization allows output to respond to changes in aggregate demand when labor input adjusts slowly due to search frictions and is insensitive to the net wage. Doubling the elasticity of capital utilization costs, $\sigma_{K,B}$, reduces the output multiplier by a little more than half for the regressive tax cut scenario and a little less than half for the progressive tax cut scenario. The progressive tax cut scenario remains more expansionary.

Distribution of monopoly profits: It is well understood that the distribution of monopoly profits plays an important role in the transmission of shocks in HANK models (Alves et al., 2020; Kaplan, Moll and Violante, 2018; Broer et al., 2020). The baseline model uses a profit distribution scheme $\left(\omega^{neutral}\right)$ that neutralizes the effect of counter-cyclical intermediate goods firm profit flows into the liquid and illiquid accounts (see Section 2.3), ensuring investment moves proportionally to output. While this profit distribution scheme neutralizes the effect of mark-ups on investment, it results in counter-cyclical *bonus* income to households. Lower bonus income depresses consumption but higher investment raises labor demand and therefore consumption.[18] The net effect on output is ambiguous.

Quantitatively, the labor demand channel is stronger: the output multiplier falls for both tax cut scenarios falls when intermediate goods profits are fully distributed to the investment fund (Table 6). However, the decline is relatively larger for the progressive tax cut scenario because the aggregate demand response, and therefore the rise in the mark-up, is relatively greater. The progressive tax cut scenario remains more expansionary.

Intermediate goods price rigidity and monetary policy: The degree of intermediate goods price rigidity and the monetary policy rule control the strength of the model's aggregate demand channel. When price adjustment costs are high, the Phillip curve is steep, strengthening the aggregate demand channel of the model, because inflation and the real liquid interest rate are less sensitive to movements in output. Conversely, the response of output to an increase in labor supply is dampened by high price adjustment costs, because goods prices cannot decline as quickly to absorb the increase in supply. Halving (tripling) the degree of intermediate goods price rigidity substantially lowers (raises) the output multiplier, particularly for the progressive tax cut scenario (Table 6). Reducing the monetary response to inflation ($\phi_\pi = 1.25$) decreases the crowding-out effect of monetary policy and raises the output multiplier and unemployment response, particularly for the progressive tax cut scenario (Table 6). However, if the monetary authority targets an unchanged level of output, the output and employment responses are lower, particularly for the progressive tax cut scenario (Table 6). Across all these alternative calibrations for goods price rigidity and monetary policy, the progressive tax cut scenario is more expansionary.

Labor search parameters: In baseline calibration, fixed hiring costs comprise 90 percent

[18]Note that in Broer et al. (2020) there is no capital and recipients of monopoly profits (capitalists) consume all their income each period. This eliminates effect of profit distribution on labor demand via investment.

to total hiring costs, guided by the estimate from Christiano, Eichenbaum and Trabandt (2016). Parameterizing hiring costs to be only half of total hiring costs reduces the unemployment response around sixfold for both tax cut scenarios. This is because the marginal cost of hiring a worker rises sharply with labor market tightness when vacancy posting costs comprise a large share of total hiring costs. The output multiplier declines for both tax cut scenarios, but relatively more for the regressive tax cut scenario because the extensive margin employment response is relatively more important. The progressive tax cut scenario remains more expansionary than the regressive tax cut scenario. The smaller employment response means direct effects comprise a larger share of the equilibrium changes in labor and consumption (Table 7).

When the job destruction rate is low, employment is insensitive to short-lived changes in the flow match surplus accruing to recruiters. Quantitatively, halving the job destruction rate reduces the output multiplier by about 0.1 for the progressive tax cut scenario and by about 0.05 for the regressive tax cut scenario (Table 6). The decline in the output multiplier is relatively modest because the tax changes studied are persistent relative to the mean length of an employment relationship.

Fiscal rule: Accumulated government debt is gradually repaid by a lump-sum tax on employed households in proportion their labor productivity. The lump-sum nature of the tax means it has no incentive effects. The incidence of the tax predominantly on high income earners with relatively low MPCs minimizes the aggregate demand effects of the transfer. However, the speed of debt repayment affects the level of government debt and the liquid interest rate; a higher liquid interest rate crowds out consumption. Quantitatively, halving the speed of debt repayment ($\Delta_B = 0.05$) reduces the output multiplier in the first year, particularly for the progressive tax cut scenario, but has a modest effect thereafter (Table 6). The composition of the direct and indirect effects for labor input are little changed (Table 7). However, for consumption, the indirect dampening effect of monetary policy on consumption rises due to the higher liquid interest rate.

3.4 Size of tax change

The nature of the deposit cost function makes the consumption response non-linear in the size of a tax cut. For small shocks, the cost of adjusting the liquid and illiquid asset portfolio may not exceed the consumption smoothing benefit. This implies larger MPCs for small than large shocks, strengthening relative size of the the aggregate demand channel in response to small shocks. However, the difference is quantitatively small. Reducing the size of the tax cut on impact from 1 percent of GDP to 0.1 percent of GDP raises the output multiplier by about 0.05 for the progressive tax cut scenario and about 0.01 for the regressive tax cut scenario (Table 6).

3.5 Revenue-neutral tax changes

The 1991 tax reform differed from other major reforms in being essentially revenue neutral, in static terms. Taxes were cut on the B90 percent and increased on the T10 percent in almost equal amounts (Table 5). Figure 7 plots the impulse responses for a simulation of the 1991 reform. The redistribution of tax liability from the B90 percent to the T10 percent raises the income-weighted mean marginal tax rate but cuts taxes on people with relatively high MPCs. Consistent with the findings above, the aggregate demand channel for the transmission of tax cuts is relatively stronger than the aggregate supply channel. Output, consumption, investment and employment rise. The equilibrium change in prices and quantities causes tax revenue to fall initially but rise thereafter. This scenario shows that a progressive shift in the tax function, such as in 1991 in the U.S., can both reduce income inequality and provide a temporary fiscal stimulus.

4 Discussion

I now discuss my main findings in light of the quantitative and empirical literature on tax change multipliers. Using a large-scale estimated DSGE model, typical of those used in policy institutions, Coenen et al. (2012) find labor income tax multipliers of 0.2-0.4. Using medium-scale estimated DSGE models, Zubairy (2014) and Sims and Wolff (2018) estimate labor tax multipliers of 0.7-1.0 and 1, respectively. My estimates are within the ranges from these papers.

Much of the recent time-series literature uses the narrative record for identification, and has found estimates of the output multiplier between 2 and 3, with effects building over time (Romer and Romer, 2010; Cloyne, 2013; Mertens and Ravn, 2014). Thus, there is substantial disagreement on the labor tax multiplier between DSGE models and a suite of empirical papers using the narrative methodology (Ramey, 2019). A potential reconciliation between DSGE models and narrative studies is a strong aggregate demand channel for the transmission of tax cuts, which is lacking in DSGE models because MPCs are unrealistically small. Romer and Romer (2010, p. 799) comment that their results are “largely silent concerning whether the output effects operate through incentives and supply behavior or through disposable income and demand stimulus”. However, my findings do not support this possibility. Despite the model used in this paper having empirically realistic MPCs, the aggregate demand channel is not strong enough to generate multipliers of 2-3, except in extreme calibrations.

Zidar (2019) uses the Romer and Romer (2010) narrative record and variation in the income distribution across U.S. states to estimate the responses of state output and employment to tax changes targeted to the T10 and B90 percent of the income distribution. He finds that a 1 percentage point of state GDP cut in tax liability targeted to the B90 percent of the income distribution raises state employment growth by 3.4 percentage points over the following two years. However, he finds that the same sized tax cut targeted to the T10 percent of the income distribution has a small and insignificant effect on employment. Zidar’s (2019) results are qualitatively but not quantitatively consistent with my findings. Zidar’s (2019) results represent reduced-form responses to changes in tax liability, so it is difficult to discern mechanisms. However, Zidar (2019) concludes that his estimated effects are too large to be explained by consumption responses alone, given micro evidence on MPCs, and that substantial labor supply responses are likely to be an important mechanism. Thus, reconciling my findings quantitatively with Zidar (2019) would require substantially larger labor supply elasticities than estimated from micro data.

Mertens and Montiel Olea (2018) use the narrative record to identify measures of exogenous variation in personal marginal income tax rates, rather than tax liability. Their aggregate estimates indicate that a temporary 1 percentage point reduction in the marginal net-of-tax rate raises output by about $\frac{1}{2}$ percentage point for each of the next five years.[19] Further, Mertens and Montiel Olea (2018, p. 1805) show that "marginal rate changes lead to very similar income responses regardless of the change in the average tax rate." and that counterfactual reforms affecting average but not marginal rates have a negligible effect on output. They deduce that incentive effects rather than aggregate demand stimulus is the main transmission mechanism for U.S. federal income tax changes. This can be explained by their estimate of an elasticity of taxable income around one, which is substantially larger than estimates from the micro literature using cross-sectional identification (Saez, Slemrod and Giertz, 2012).

5 Conclusion

This paper has used a state-of-the-art Heterogeneous Agent New Keynesian model to study whether tax cuts are more expansionary if they are relatively more progressive or regressive. The progressive tax cut scenario closely matches the distributional properties of the 1981, 2003 and 2017 U.S. tax reforms. The regressive tax scenario has the distribution properties of the 1993 U.S. tax reform. More regressive tax cuts lead to a larger reduction in mean marginal tax rates, but distribute a larger share of tax cuts to top earners who have relatively low MPCs. This presents a trade-off between the labor supply and aggregate demand channels for the transmission of tax cuts. Quantitatively, I find that an increase in the progressivity of a tax cut makes it more expansionary.

The size of the output multipliers vary considerably depending on their targeting across the income distribution. For the baseline scenarios analyzed, they lie in the range between 0.4-0.8. This is consistent with the representative-agent New Keynesian literature, but below the range of narrative-based empirical evidence (Ramey, 2019). I conclude that the incorporation of an empirically realistic aggregate demand channel for the transmission of tax cuts, absent from RANK models, cannot account for the discrepancy between the model-based and empirical evidence.

There is scope to extend the model and analysis in several directions. First, it would be valuable to understand the effects of changes in corporate taxes in HANK models. Empirically, Mertens and Ravn (2013) find evidence of smaller output effects for corporate than personal income taxes. A difficulty to confront is the empirically-inconsistent counter-cyclicality of profits in New Keynesian

[19] Mertens and Montiel Olea (2018) report elasticities of taxable income with respect to the marginal net-of-tax rate rather than output multipliers. They find short-run tax elasticities of 1.2.

models.

Second, labor productivity is the only source of heterogeneity in the model. This implies a close relationship between labor income and wealth, precluding top-earners from having high non-labor income relative to total income. Augmenting the model to include rate-of-return heterogeneity correlated with wealth and heterogeneous preferences for saving could prove fruitful. Labor supply responses of wealthy households may decline if labor income comprises a smaller share of total income.

Third, studying anticipated tax changes in HANK models may yield new insights. Empirical evidence indicates that announced but not yet implemented tax cuts are contractionary (Mertens and Ravn, 2012). For monetary policy, McKay, Nakamura and Steinsson (2016) show that forward guidance is less powerful in the presence of incomplete markets and borrowing constraints. It may also be the case that preannounced tax changes have smaller effects in HANK than representative agent DSGE models because households' consumption and labor supply decisions may be less forward-looking.

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Table 1: List of Calibrated Parameters

Description		Value	Target
Demographics and preferences			
ζ	Death rate	1/180	Avg. lifespan of 45 years
$\frac{1}{\gamma}$	Intertemporal elasticity of substitution	1	–
η	Frisch intensive-margin elasticity of labor supply	0.025	Martinez, Saez and Siegenthaler (2021)
φ	Labor supply disutility: level parameter	10	Average hours worked $\simeq 0.9$
ρ	Discount rate (p.a.)	6.2%	Internally calibrated
Production			
ε	Intermediate goods demand elasticity	10	mark-up of 11 percent
ς	Price adjustment cost	100	Slope of Phillips curve $\varepsilon/\varsigma = 0.1$
α	Capital share	0.33	National accounts
δ_K	Physical capital depreciation rate (p.a.)	0.07	National accounts
ϕ	Capital adjustment cost function parameter	25	Alves et al. (2020)
$\sigma_{K,B}$	Capital utilization cost parameter	2	Smets and Wouters (2007)
Labor market			
δ_u	Job destruction rate (quarterly)	0.1	Hall and Milgrom (2008); Shimer (2012)
ϕ	Matching function elasticity	0.5	Petrongolo and Pissarides (2001)
σ	Matching function efficiency	2.59	Steady-state labor market tightness $\theta = 0.6$
Ω	Piece rate	0.96	Equal split of match surplus in rep. agent version
$\Theta(b,a,z)$	Fixed hiring costs	$0.9 \times \bar{J}(b,a,z)$	Christiano, Eichenbaum and Trabandt (2016)
s	Vacancy posting costs as percent of GDP	0.2%	Steady-state unemployment rate of 5 percent
Fiscal policy			
τ	Tax progressivity	0.181	Heathcote, Storesletten and Violante (2017)
λ	Average tax parameter	0.815	Mean marginal tax rate of 34 percent
τ_c	Corporate profits tax	0.3	–
$uben$	Replacement ratio (up to $25,000 p.a. maximum)	0.4	UI replacement rate of 40 percent
tr/Y	Lump-sum transfers to GDP	0.01	Transfer GDP share of 1 percent
Δ_B	Government debt speed of adjustment	0.1	Half-life of 7 quarters
Monetary policy			
ϕ_π	Taylor rule coefficient on inflation	1.5	Benchmark NK model
ϕ_y	Taylor rule coefficient on output gap	0	–
ρ_i	Persistence	0.5	Alves et al. (2020)
$\bar{r}^b$	Steady-state real liquid interest rate (p.a.)	2%	–
Transaction cost function			
χ_0	Fixed-cost parameter	0.04	Internally calibrated
χ_1	Level component	0.81	Internally calibrated
χ_2	Convex component	1.40	Internally calibrated
$\underline{a}$	Min a in denominator	$500	–

Table 2: Earnings Process

(a) Estimation Fit

	Data	Model Estimated	Model Discretized
Variance: annual log earnings	0.70	0.70	0.78
Variance: 1-yr change	0.23	0.20	0.19
Kurtosis: 1-yr change	17.8	17.0	14.5
Variance: 5-yr change	0.46	0.51	0.52
Kurtosis: 5-yr change	11.6	11.1	10.1
Frac. 1-yr change < 10 percent	0.54	0.53	0.51
Frac. 1-yr change < 20 percent	0.71	0.67	0.63
Frac. 1-yr change < 50 percent	0.86	0.82	0.82

(b) Parameter estimates

	Parameter	Value
Process 1		
Arrival rate:	λ_1^z	0.007
Mean reversion:	β_1^z	0.011
Innovation s.d.:	σ_1^z	1.59
Process 2		
Arrival rate up:	$\lambda_{2,up}^z$	0.046
Arrival rate down:	$\lambda_{2,dn}^z$	0.355
Width:	Δ_2^z	1.12

Notes: Panel (a) compares simulated moments of the fitted earnings process against the data. Data moments are from Kaplan, Moll and Violante (2018). Panel (b) lists the estimated parameters of the earnings process.

Table 3: Empirical Moments

(a) Targeted Moments

	Targeted		Memo:	
	Data	Model: Total	Model: Emp.	Model: Unemp.
Mean illiquid assets	2.92	2.92	2.93	2.77
Mean liquid assets	0.26	0.26	0.27	0.22
Frac. with $b \simeq 0$ and $a = 0$	0.10	0.10	0.10	0.20
Frac. with $b \simeq 0$ and $a > 0$	0.20	0.20	0.20	0.25
Average marginal tax rate	0.34	0.34	–	–

(b) Non-targeted Moments

	Liquid wealth		Illiquid Wealth		Taxable Income	
	Data	Model	Data	Model	Data	Model
Top 1 percent share	47	21	33	40	25	14
Top 10 percent share	86	67	70	88	55	46
Bottom 90 percent share	14	33	30	12	45	54
Bottom 50 percent share	-4	2	3	0	7	19
Gini coefficient	0.98	0.78	0.81	0.90	0.51	0.52
Gini coefficient: post tax	–	–	–	–	0.39	0.42

Notes: Panel (a) reports targeted empirical moments and those produced by the model. It also shows values separately by employment status. Panel (b) reports non-targeted empirical and model-generated moments. Sources: Data wealth moments are from Kaplan, Moll and Violante (2018), originally sourced from SCF (2004). Taxable income share data are from IRS Statistics of Income Table 3 for tax year 2017. Income Gini data are from OECD Income Distribution Database, 2013: http://dx.doi.org/10.1787/888933533625.

Table 4: Quarterly Mean MPCs, MPEs and Hours Worked by Taxable Income Percentile

	MPC: $500		MPE: $500		Hours
	Qtly	Annual	Qtly	Annual	worked
Top 1 percent	0.04	0.14	0.00	-0.01	0.95
Top 10 percent	0.05	0.17	0.00	-0.01	0.94
Bottom 90 percent	0.17	0.43	0.00	-0.01	0.88
Bottom 50 percent	0.21	0.51	0.00	-0.01	0.84
Bottom 25 percent	0.23	0.52	0.00	-0.01	0.75
Employed	0.14	0.38			
Unemployed	0.36	0.54			
Mean	0.15	0.41	0.00	-0.01	0.89
Weighted mean					0.93

Notes: Table reports quarterly and annual MPCs and MPEs out of a one-time unexpected $500 increase in liquid wealth. *Weighted mean* refers to taxable income-weighted mean.

Table 5: Distributional Effects of Historical Tax Reforms

	Reform	ΔTax: Percent of GDP		
	year	All	B90	T10
Historical Tax Reform Episodes				
Economic Recovery Tax Act of 1981 (ERTA 1981)	1982	-0.69	-0.32	-0.37
Omnibus Budget Reconciliation Act of 1991 (OBRA 1991)	1991	-0.01	-0.16	0.15
Omnibus Budget Reconciliation Act of 1993 (OBRA 1993)	1993	0.24	-0.07	0.31
Jobs and Growth Tax Relief Reconciliation Act of 2003 (JGTRRA 2003)	2003	-0.80	-0.31	-0.49
Tax Cuts and Jobs Act of 2017 (TCJA 2017)	2018	-1.06	-0.55	-0.51
Modeled scenarios:				
Progressive		-1.00	-1.27	0.27
Regressive		-1.00	-0.45	-0.55
Revenue neutral		0.00	-0.15	0.15

Notes: Table reports the mechanical size of tax changes, as a percent of GDP, for historical US tax reform episodes. *Reform year* denotes the first full year of the reform and the year for which revenue effects are shown. *B90* and *T10* report the revenue effect for the bottom 90 percent of tax units and T10 for the top 10 percent of tax units, respectively. Data for the first four reform episodes are from (Zidar, 2019) and data for the TCJA 2017 are from Tax Policy Center (2018), Table T18-0027. *Modeled scenario* are the scenarios used in the quantitative model.

Table 6: Output Multipliers and Unemployment Response

				Output multiplier: to horizon h			Change in unemp. rate	
				$h=4Q$	$h=8Q$	$h=20Q$	Mean	Peak
	(1)	Baseline	Progressive	0.63	0.64	0.80	-0.12	-0.23
			Regressive	0.35	0.37	0.43	-0.07	-0.11
Labor supply	(2)	$\eta=0.1$	Progressive	0.52	0.53	0.69	-0.12	-0.21
			Regressive	0.56	0.60	0.67	-0.09	-0.14
	(3)	$\eta=0.25$	Progressive	0.38	0.38	0.55	-0.11	-0.19
			Regressive	0.87	0.93	1.01	-0.12	-0.17
Capital adjustment costs	(4)	$\phi_K=50$	Progressive	0.63	0.66	0.82	-0.13	-0.24
			Regressive	0.36	0.38	0.44	-0.08	-0.12
Capital utilization	(5)	$\sigma_{K,B}=4$	Progressive	0.31	0.28	0.35	-0.09	-0.22
			Regressive	0.20	0.21	0.26	-0.06	-0.10
Profit distribution	(6)	$\omega=1$	Progressive	0.45	0.47	0.60	-0.07	-0.12
			Regressive	0.29	0.31	0.37	-0.05	-0.08
Price stickiness	(7)	$\varsigma=50$	Progressive	0.34	0.31	0.37	-0.06	-0.14
			Regressive	0.25	0.26	0.30	-0.05	-0.08
	(8)	$\varsigma=300$	Progressive	1.57	1.72	2.08	-0.26	-0.44
			Regressive	0.61	0.65	0.73	-0.12	-0.19
Monetary policy	(9)	$\phi_\pi=1.25$	Progressive	1.08	1.11	1.31	-0.19	-0.37
			Regressive	0.49	0.51	0.57	-0.09	-0.16
	(10)	$\phi_y=0.5$	Progressive	0.46	0.48	0.58	-0.09	-0.17
			Regressive	0.17	0.19	0.24	-0.04	-0.05
Labor recruitment	(11)	$\Theta=0.5\times J$	Progressive	0.41	0.38	0.45	-0.02	-0.05
			Regressive	0.23	0.23	0.26	-0.01	-0.02
	(12)	$s=0.05$	Progressive	0.54	0.54	0.66	-0.09	-0.16
			Regressive	0.30	0.32	0.39	-0.06	-0.09
Fiscal rule	(13)	$\Delta_B=0.05$	Progressive	0.41	0.58	0.78	-0.12	-0.19
			Regressive	0.25	0.28	0.44	-0.07	-0.08
Shock size	(14)	$\Delta T=0.1\%$	Progressive	0.68	0.70	0.85	-0.01	-0.02
			Regressive	0.36	0.38	0.44	-0.01	-0.01

Notes: The table reports present-discounted-value multipliers for output by horizon. The liquid interest rate r^b is used to calculate the present discounted value of output and tax revenues. (1) reports results for the baseline model; (2-3) increases the Frisch elasticity of labor supply to 0.1 and 0.25; (4) doubles capital adjustment costs to $\phi_K=50$; (5) doubles the elasticity of capital capacity utilization costs; (6) distributes all intermediate goods firm profits to the investment fund; (7) halves the degree of intermediate goods price rigidity; (8) triples the degree of intermediate goods price rigidity; (9) lowers the weight on inflation in the Taylor rule; (10) increases the weight on output in the Taylor rule from 0 to 0.5; (11) reduces the fixed hiring cost component to half the value of a filled job; (12) halves the job destruction rate; (13) halves the speed at which government debt is repaid through lump-sum transfers; (14) reduces the size of the shock to 0.1 percent of GDP, compared with 1 percent of GDP in the baseline analysis.

Table 7: Decomposition of the Effect of Tax Shocks

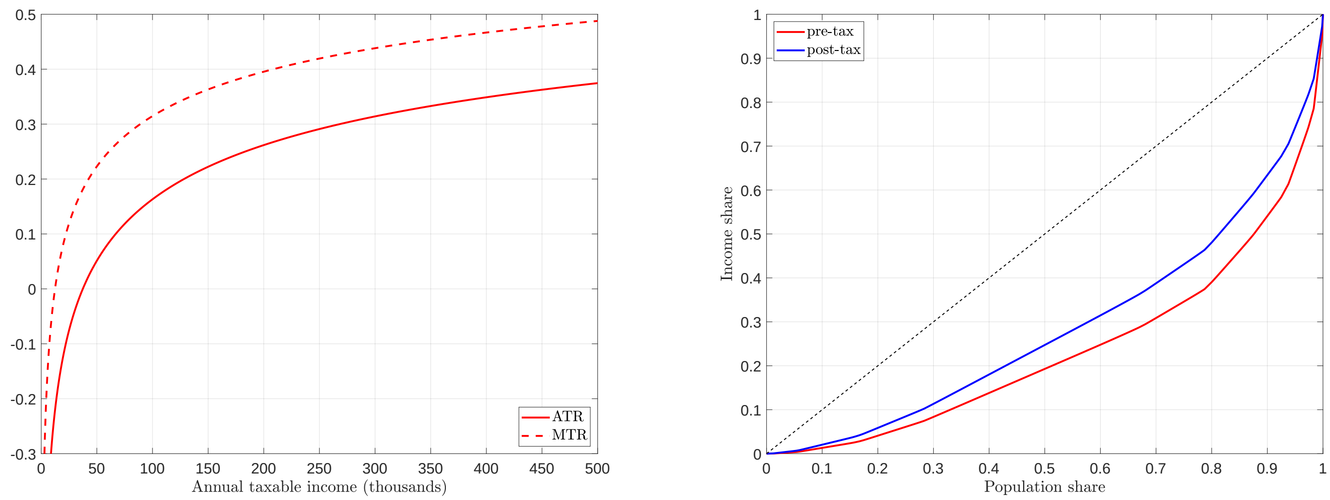
			Percent change in C due to:					Percent change in L due to:				
			Direct	Indirect				Direct	Indirect			
			tax shock	*w* and *bonus*	*ur*	r^a, Q and q^k	r^b	*tax shock*	*w* and *bonus*	*ur*	r^a, Q and q^k	r^b
	(1)	Baseline	Prog.	114	19	13	9	-54	-25	8	112	0	6
			Reg.	78	16	16	26	-35	28	3	67	0	2
Labor supply	(2)	$\eta = 0.1$	Prog.	120	24	14	6	-61	-153	49	167	-1	38
			Reg.	64	8	13	27	-12	53	3	43	-1	2
	(3)	$\eta = 0.25$	Prog.	129	34	15	0	-75	-2325	818	976	4	632
			Reg.	57	3	11	28	1	71	-1	33	-3	-1
Cap. adj. costs	(4)	$\phi_K = 50$	Prog.	105	17	13	14	-48	-23	7	112	0	5
			Reg.	69	13	15	32	-29	27	2	70	-1	2
Capital utilization	(5)	$\sigma_{K,B} = 4$	Prog.	197	13	17	-7	-116	-34	14	110	0	10
			Reg.	131	9	23	22	-83	33	4	60	0	3
Profit distribution	(6)	$\omega = 1$	Prog.	130	43	9	-27	-53	-51	7	132	2	10
			Reg.	86	31	13	4	-34	34	2	62	0	2
Price stickiness	(7)	$\varsigma = 50$	Prog.	175	18	10	1	-99	-62	11	133	0	17
			Reg.	104	13	15	27	-59	37	2	58	0	3
	(8)	$\varsigma = 300$	Prog.	66	20	15	17	-17	-11	6	104	0	1
			Reg.	53	17	16	26	-12	19	4	78	-1	1
Monetary policy	(9)	$\phi_\pi = 1.25$	Prog.	85	20	14	15	-32	-15	7	106	0	3
			Reg.	65	17	16	26	-23	22	3	73	-1	1
	(10)	$\phi_y = 0.5$	Prog.	134	18	12	6	-67	-35	8	118	0	8
			Reg.	122	11	15	27	-73	45	1	51	0	3
Labor recruitment	(11)	$\Theta = 0.5 \times J$	Prog.	162	27	4	0	-89	-212	65	188	0	57
			Reg.	120	24	5	24	-72	62	6	28	-1	5
	(12)	$s = 0.05$	Prog.	124	21	12	8	-65	-35	11	116	0	9
			Reg.	85	16	17	27	-44	32	3	63	0	2
Fiscal rule	(13)	$\Delta_B = 0.05$	Prog.	155	21	16	4	-92	-32	7	114	0	10
			Reg.	147	18	22	20	-105	30	2	63	0	5

Notes: The table reports decompositions of the impulse responses of consumption and labor. Decompositions are for average responses over the first 40 quarters. (1) reports results for the baseline model; (2-3) increases the Frisch elasticity of labor supply to 0.1 and 0.25; (4) doubles capital adjustment costs to $\phi_K = 50$; (5) doubles the elasticity of capital capacity utilization costs; (6) distributes all intermediate goods firm profits to the investment fund; (7) halves the degree of intermediate goods price rigidity; (8) triples the degree of intermediate goods price rigidity; (9) lowers the weight on inflation in the Taylor rule; (10) increases the weight on output in the Taylor rule from 0 to 0.5; (11) reduces the fixed hiring cost component to half the value of a filled job; (12) halves the job destruction rate; (13) halves the speed at which government debt is repaid through lump-sum transfers.

Figure 1: Taxable Income

(a) Tax Rates

(b) Lorenz curve

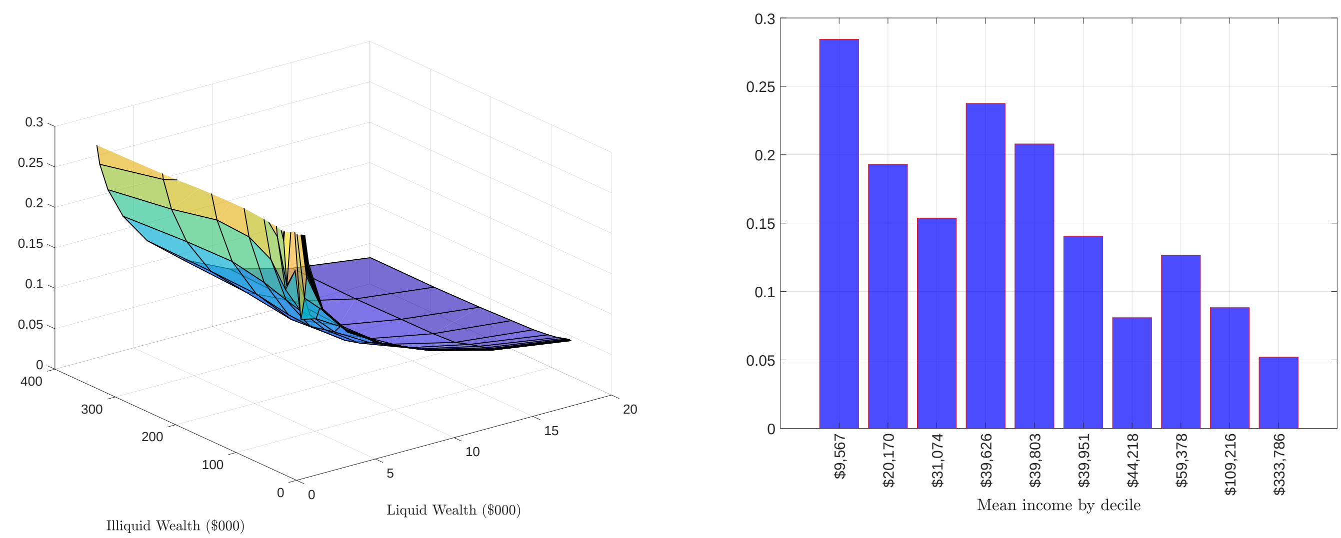


Notes: Panel (a) plots average (ATR) and marginal (MTR) tax rates as a function of taxable income. Panel (b) plots the Lorenz curve for pre- and post-tax taxable income, together with the 45-degree line

Figure 2: MPC Heterogeneity

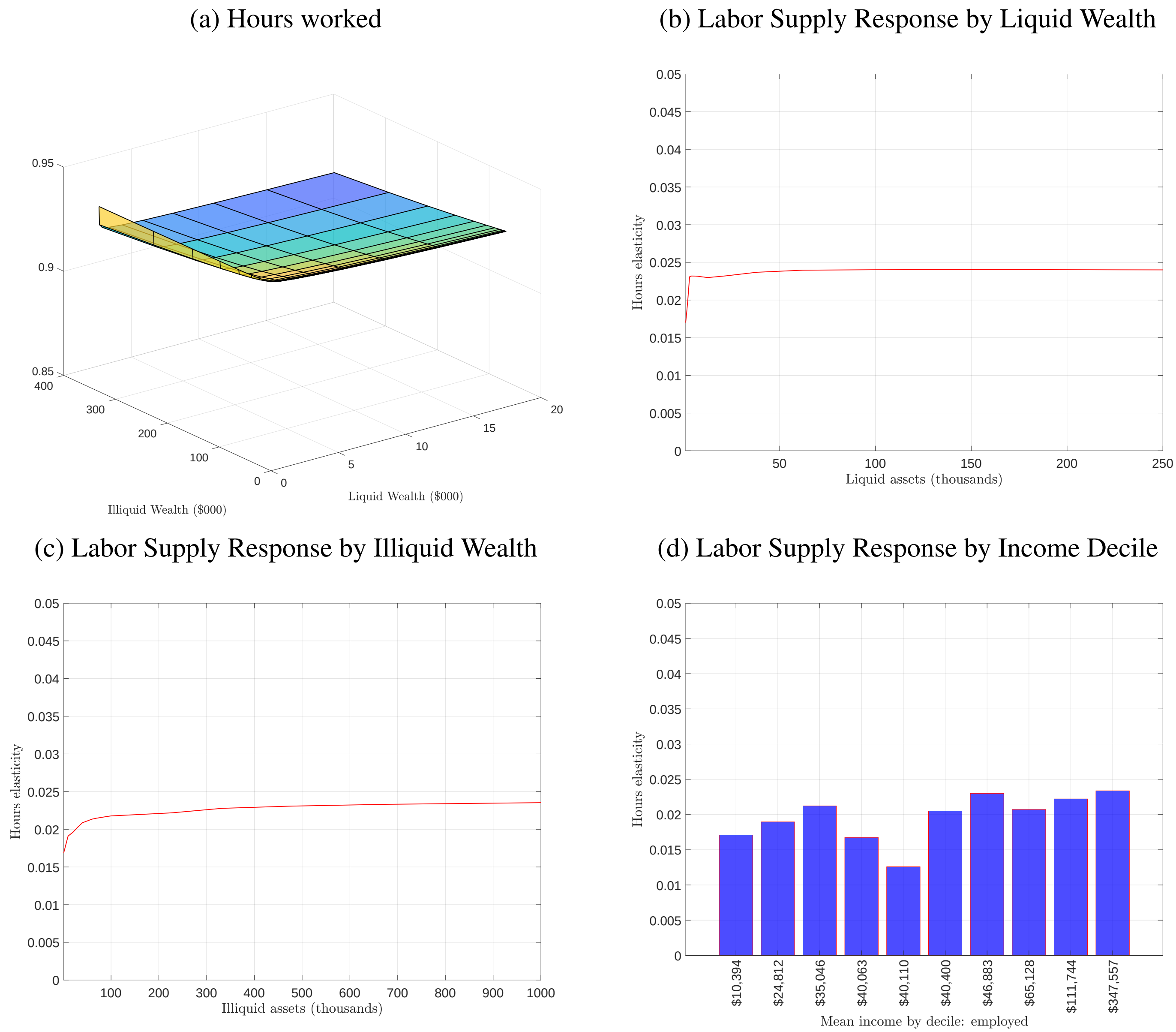
(a) MPC by Wealth Holding

(b) MPC by Income Decile



Notes: Panel (a) shows the mean quarterly MPC (averaged over skill level z) for a household with liquid assets b and illiquid assets a for a one-time $500 increase in liquid wealth. Panel (b) shows mean quarterly MPCs by income decile.

Figure 3: Labor Supply Response Heterogeneity

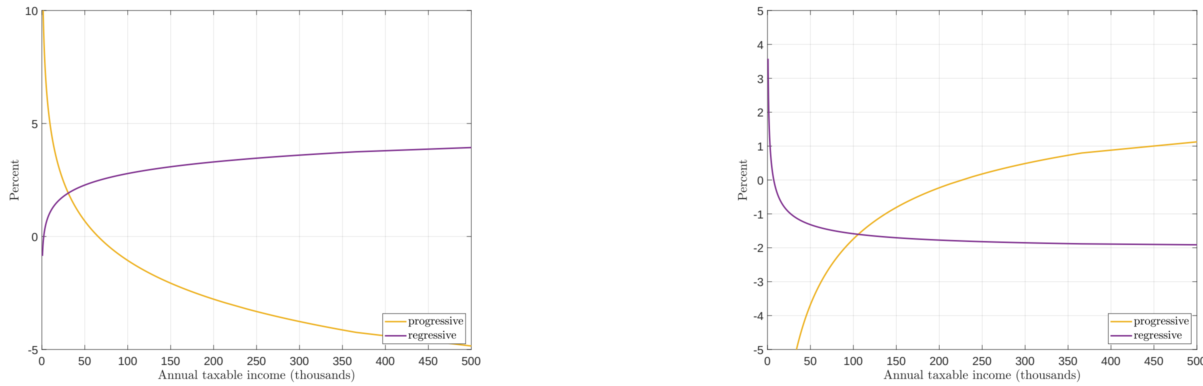


Notes: Panel (a) shows mean hours worked (averaged over skill level z) for an employed household with liquid assets b and illiquid assets a; Panel (b) shows the percentage change in hours worked on impact in response to a transitory one-percent change in the net-of-tax wage rate (the hours elasticity) by liquid wealth; Panel (c) shows the hours elasticity by illiquid wealth holding; and Panel (d) shows the hours elasticity by income decile for employed households.

Figure 4: Changes in Marginal and Average Tax Rates by Income

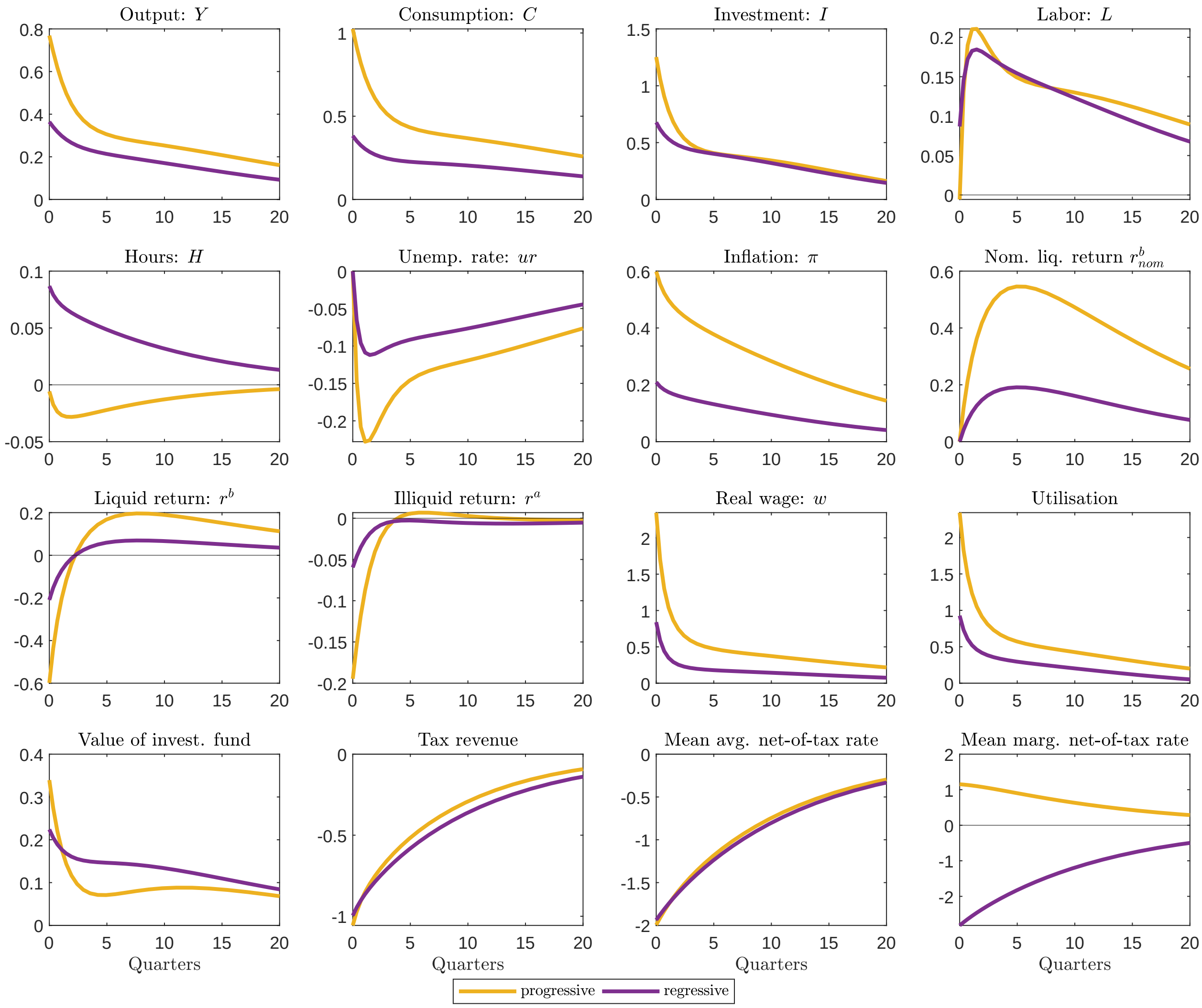
(a) Percent change in marginal net-of tax rate

(b) Percent change in average tax rate



Notes: Panel (a) shows the percentage change in the mean marginal net-of-tax tax rate (1 - marginal tax rate) by level of taxable income for the *progressive* and *regressive* tax shocks. Panel (b) does the same for the average tax rate.

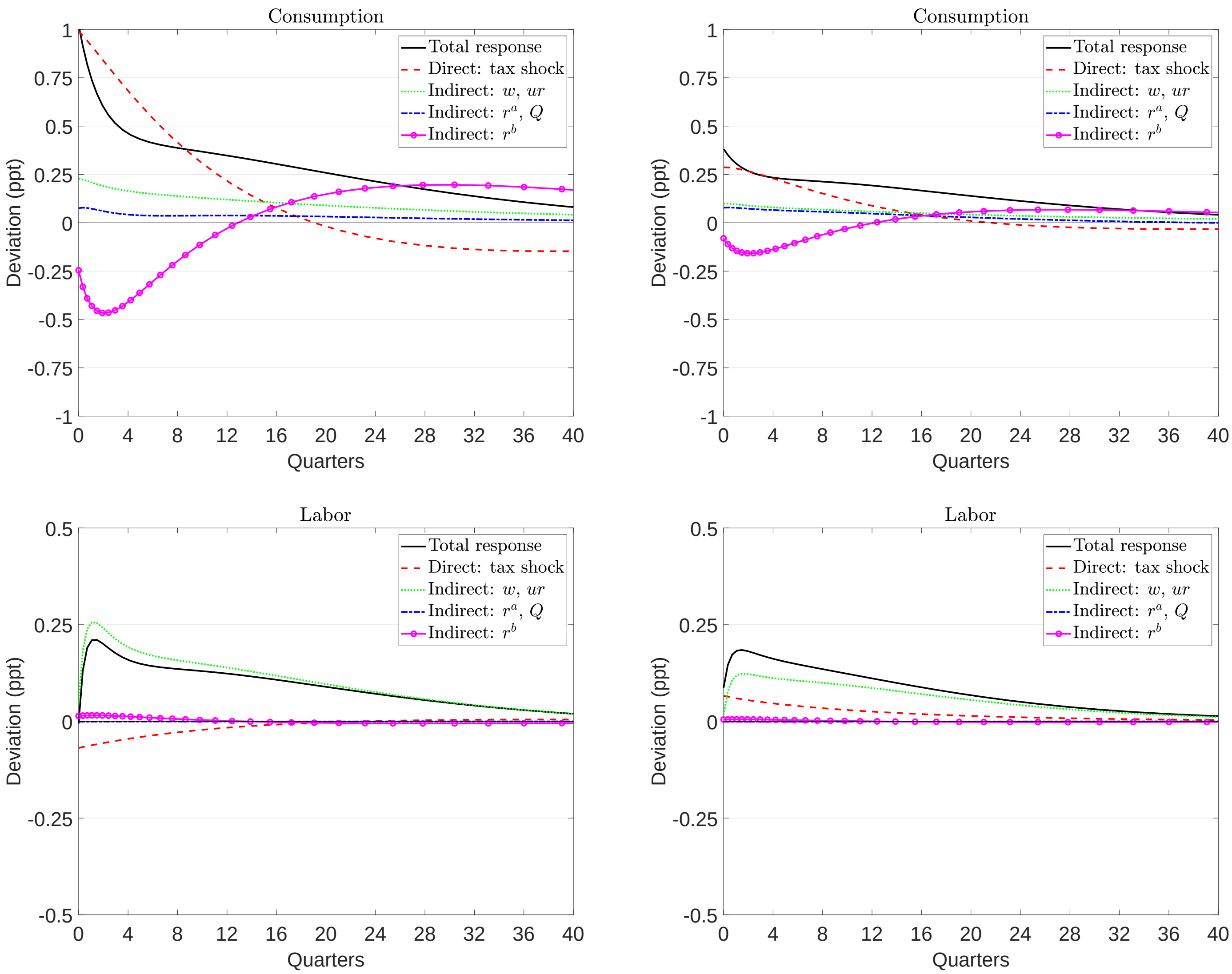
Figure 5: Impulse Responses to Tax Shocks: Baseline Model



Notes: The figure shows impulse responses of the baseline model to the *progressive* and *regressive* tax shocks.

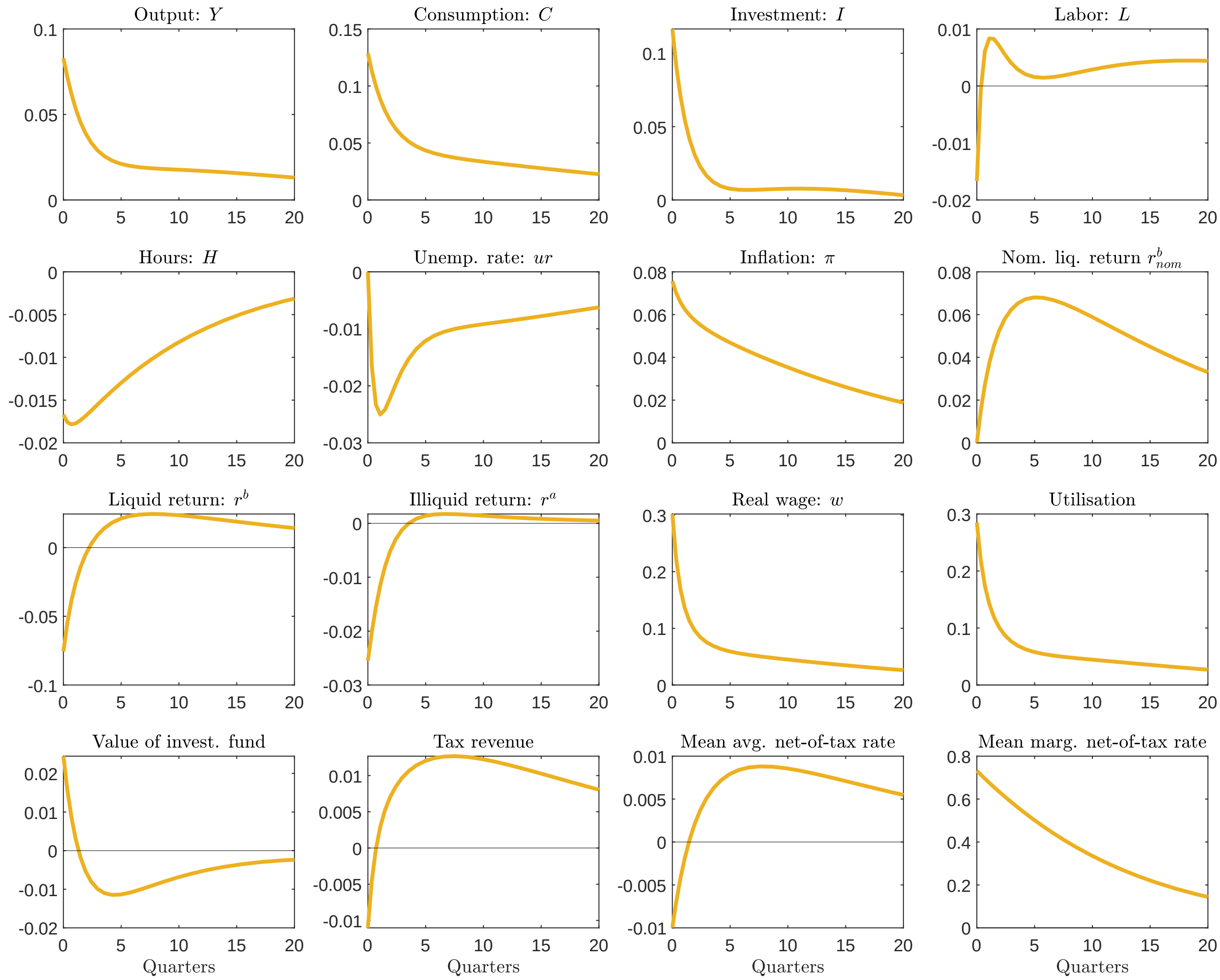
Figure 6: Impulse Response Function Decomposition: Baseline Model

(a) Progressive (b) Regressive



Notes: This figure decomposes the impulse responses of consumption C and labor L into direct and indirect effect. Panel (a) shows results for the *progressive* tax shock and Panel (b) for the *regressive* tax shock.

Figure 7: Revenue-Neutral Tax Change: 1991 reform



Notes: This figure show responses to a static revenue-neutral shift in the tax function, replicating the 1991 U.S. tax reform.

Online Appendix

A Additional details on the model

A.1 Recursive formulation

This section presents the Hamilton-Jacobi-Bellman (HJB) and Kolmogorov forward equations for the households' problem.

A.1.1 Steady state

HJB: The steady-state HJB for an employed household is given by

$$\begin{aligned}(\rho+\zeta)\,V^e(b,a,z) = &\max_{\{c,h,d\}} u(c,h)\\ &+\frac{\partial V^e}{\partial b}\left[wzh - T\left(wzh + r^b b + \Gamma_\Pi(z)\right) + r^b b + \Gamma_\Pi(z) - d - \chi(d,a) - c\right]\\ &+\frac{\partial V^e}{\partial a}\left[r^a a + d\right]\\ &+\frac{\partial V^e}{\partial z}(-\beta z) + \sum_{j'\neq j}\lambda^e_{j,j'}\left[V^e\left(b,a,z_{j'}\right) - V^e\left(b,a,z_j\right)\right]\\ &+\delta_u\left[V^u(b,a,z) - V^e(b,a,z)\right]\\ &\text{subject to}\\ &b\geq 0, a\geq 0, h\in[0,1]\end{aligned} \tag{A.1}$$

where $\lambda^e_{j,j'}$ is the Poisson rate at which transitions from skill level z_j to $z_{j'}$ occur when employed and β is the drift rate of the (log) skill level. The remaining notation is the same as in the main text. The HJB for an unemployed household is given by

$$\begin{aligned}(\rho+\zeta)\,V^u(b,a,z) = &\max_{\{c,d\}} u(c,0)\\ &+\frac{\partial V^e}{\partial b}\left[uben - T\left(uben + r^b b\right) + r^b b - d - \chi(d,a) - c\right]\\ &+\frac{\partial V^e}{\partial a}\left[r^a a + d\right]\\ &+\frac{\partial V^u}{\partial z}(-\beta z) + \sum_{j'\neq j}\lambda^u_{j,j'}\left[V^u\left(b,a,z_{j'}\right) - V^u\left(b,a,z_j\right)\right]\\ &+f\left[V^e(b,a,z) - V^u(b,a,z)\right]\\ &\text{subject to}\\ &b\geq 0, a\geq 0\end{aligned} \tag{A.2}$$

where $\lambda^u_{j,j'}$ is the Poisson rate at which transitions from skill level z_j to $z_{j'}$ occur when unemployed and β is the drift rate of the (log) skill level. The first-order conditions for c, h and d, respectively, for an employed household are

$$
\begin{aligned}
u_c(c,h) &= \frac{\partial V^e}{\partial b} \\
-u_h(c,h) &= wz\left(1 - T'\left(wzh + r^b b + \Gamma_\Pi(z)\right)\right)\frac{\partial V^e}{\partial b} \\
\frac{\partial V^e}{\partial b}\left(1+\chi_d(d,a)\right) &= \frac{\partial V^e}{\partial a}
\end{aligned}
$$

and the first-order conditions for c and d, respectively, for an unemployed household are

$$
\begin{aligned}
u_c(c,0) &= \frac{\partial V^u}{\partial b} \\
\frac{\partial V^u}{\partial b}\left(1+\chi_d(d,a)\right) &= \frac{\partial V^u}{\partial a}.
\end{aligned}
$$

KFE: The Kolmogorov forward equation describes the joint evolution of liquid wealth b, illiquid wealth a, skills z and employment status $E \in \{e,u\}$. The optimal liquid and illiquid saving policy functions for a household of type (b,a,z,E) is given by

$$
\begin{aligned}
s^b(b,a,z,E) =& \mathbb{1}^e\left[wzh + \Gamma_\Pi(z) - T\left(wzh + r^b b + \Gamma_\Pi(z_t)\right)\right] + \\
& \mathbb{1}^u\left[uben - T\left(uben + r^b b\right)\right] + r^b b - d - \chi(d,a) + tr - c
\end{aligned}
$$

and

$$
s^a(b,a,z,E) = r^a a + d
$$

and the associated density of households of type (b,a,z,E) is $d\mu(b,a,z,E)$. The stationary distribution for (b,a,z,E) satisfies

$$
\begin{aligned}
0 =& -\partial_b\left(s^b(b,a,z,E)\,d\mu(b,a,z,E)\right) \\
& -\partial_a\left(s^a(b,a,z,E)\,d\mu(b,a,z,E)\right) \\
& -\partial_z\left(-\beta z d\mu(b,a,z,E)\right) \\
& -\sum_{j'\neq j}\lambda^e_{j,j'}\left[d\mu\left(b,a,z_j,e\right) - d\mu\left(b,a,z_{j'},e\right)\right] \\
& -\sum_{j'\neq j}\lambda^u_{j,j'}\left[d\mu\left(b,a,z_j,u\right) - d\mu\left(b,a,z_{j'},u\right)\right] \\
& -\delta_u\left(d\mu\left(b,a,z_j,e\right) - d\mu\left(b,a,z_j,u\right)\right) \\
& -f\left(d\mu\left(b,a,z_j,u\right) - d\mu\left(b,a,z_j,e\right)\right) \\
& -\zeta\left(d\mu(b,a,z,E) + \delta(b-b_0)\,\delta(a-a_0)\,d\mu^u(z)\right)
\end{aligned}
\tag{A.3}
$$

where b_0 and a_0 are liquid and illiquid assets at birth, δ denotes the Dirac delta function and $d\mu(z)$ is the stationary distribution of z for unemployed households.

A.1.2 Transition

HJB: The HJB for an employed household in transition is given by

$$
\begin{aligned}
(\rho+\zeta)V_t^e(b,a,z) = & \max_{\{c,h,d\}} u(c,h) \\
& + \frac{\partial V_t^e}{\partial b}\left[w_t zh - T\left(w_t zh + r_t^b b + \Gamma_{\Pi,t}(z)\right) + r_t^b b + \Gamma_{\Pi_t}(z) - d - \chi(d,a) - c\right] \\
& + \frac{\partial V_t^e}{\partial a}\left[r_t^a a + d\right] \\
& + \frac{\partial V_t^e}{\partial z}(-\beta z) + \sum_{j'\neq j} \lambda_{j,j'}^e \left[V_t^e\left(b,a,z_{j'}\right) - V_t^e\left(b,a,z_j\right)\right] \\
& + \delta_u\left[V_t^u(b,a,z) - V_t^e(b,a,z)\right] \\
& + \frac{\partial V_t^e}{\partial t} \\
& \text{subject to} \\
& b \geq 0, a \geq 0, h \in [0,1].
\end{aligned}
\tag{A.4}
$$

The HJB for an unemployed household in transition is given by

$$
\begin{aligned}
(\rho+\zeta)V_t^u(b,a,z) = & \max_{\{c,d\}} u(c,0) \\
& + \frac{\partial V_t^e}{\partial b}\left[uben_t - T\left(uben_t + r_t^b b\right) + r_t^b b - d - \chi(d,a) - c\right] \\
& + \frac{\partial V_t^e}{\partial a}\left[r_t^a a + d\right] \\
& + \frac{\partial V_t^u}{\partial z}(-\beta z) + \sum_{j'\neq j} \lambda_{j,j'}^u \left[V_t^u\left(b,a,z_{j'}\right) - V_t^u\left(b,a,z_j\right)\right] \\
& + f_t\left[V_t^e(b,a,z) - V_t^u(b,a,z)\right] \\
& + \frac{\partial V_t^u}{\partial t} \\
& \text{subject to} \\
& b \geq 0, a \geq 0.
\end{aligned}
\tag{A.5}
$$

The first-order conditions for c, h and d are analogous to those for the household problem in the steady state.

KFE: The distribution for (b,a,z,E) in transition $d\mu_t(b,a,z,E)$ satisfies

$$
\begin{aligned}
\partial_t\left(d\mu_t(b,a,z,E)\right) = &- \partial_b\left(s_t^b(b,a,z,E)\,d\mu_t(b,a,z,E)\right)\\
&- \partial_a\left(s_t^a(b,a,z,E)\,d\mu_t(b,a,z,E)\right)\\
&- \partial_z\left(-\beta z d\mu_t(b,a,z,E)\right)\\
&- \sum_{j'\neq j}\lambda^e_{j,j'}\left[d\mu_t\left(b,a,z_j,e\right) - d\mu_t\left(b,a,z_{j'},e\right)\right]\\
&- \sum_{j'\neq j}\lambda^u_{j,j'}\left[d\mu_t\left(b,a,z_j,u\right) - d\mu_t\left(b,a,z_{j'},u\right)\right]\\
&- \delta_u\left(d\mu_t\left(b,a,z_j,e\right) - d\mu_t\left(b,a,z_j,u\right)\right)\\
&- f_t\left(d\mu_t\left(b,a,z_j,u\right) - d\mu_t\left(b,a,z_j,e\right)\right)\\
&- \zeta\left(d\mu_t(b,a,z,E) + \delta(b-b_0)\,\delta(a-a_0)\,d\mu_t^u(z)\right).
\end{aligned}
\tag{A.6}
$$

A.2 Investment fund

The investment fund own the economy's capital stock and shares in intermediate goods firms and labor market recruitment firms. The investment fund chooses the rate of investment in physical capital, the rate of capital utilization and the rate of purchases of shares in intermediate and labor market recruitment firms. Denote the value of the investment fund at time t by $A_t\left(K,X^{int},X^{lab}\right)$, where K is the stock of physical capital held, X^{int} is the number of shares held in intermediate goods firms and X^{lab} is the number of shares held in labor market recruitment firms. Let q_t^K denote the price of a unit of installed capital and q_t^{int} and q_t^{lab} denote the share price of intermediate goods and labor market recruitment firms, respectively. Furthermore, let u^K denote the rate of capital utilization. The value function satisfies the Hamilton-Jacobi-Bellman equation

$$
\begin{aligned}
r_t^a A_t\left(K,X^{int},X^{lab}\right) = \max_{\left\{\iota,\dot{X}^{int},\dot{X}^{lab},u^K\right\}} &\left[r_t^k u^K - \iota - \Psi(\iota) - a\left(u^K\right)\right]K\\
&+ \omega\left(1-\tau_c\right)\Pi_t^{int}X_t^{int} - q_t^{int}\dot{X}_t^{int}\\
&+ \Pi_t^{lab}X_t^{lab} - q_t^{lab}\dot{X}_t^{lab}\\
&+ \partial_K A_t\left(K,X^{int},X^{lab}\right)(\iota-\delta)K\\
&+ \partial_{X^{int}} A_t\left(K,X^{int},X^{lab}\right)\dot{X}_t^{int}\\
&+ \partial_{X^{lab}} A_t\left(K,X^{int},X^{lab}\right)\dot{X}_t^{lab}\\
&+ \partial_t A_t\left(K,X^{int},X^{lab}\right)
\end{aligned}
\tag{A.7}
$$

The first-order conditions for the investment fund's choices ι, u^K, $\dot{X}^{int}$ and $\dot{X}^{lab}$ are

$$\begin{aligned}
[\iota] \qquad & 1+\Psi'(\iota) = \partial_K A_t\left(K, X^{int}, X^{lab}\right) \\
\left[u^K\right] \qquad & r_t^k = a'\left(u^K\right) \\
\left[\dot{X}_t^{int}\right] \qquad & q_t^{int} = \partial_{X^{int}} A_t\left(K, X^{int}, X^{lab}\right) \\
\left[\dot{X}_t^{lab}\right] \qquad & q_t^{lab} = \partial_{X^{lab}} A_t\left(K, X^{int}, X^{lab}\right)
\end{aligned}$$

Guess that the value of the fund is linear in the value of each asset type held: $A_t\left(K, X^{int}, X^{lab}\right) = q_t^K K + q_t^{int} X^{int} + q_t^{lab} X^{lab}$. Using this guess, the first-order conditions for ι, $\dot{X}^{int}$ and $\dot{X}^{lab}$ are

$$\begin{aligned}
[\iota] \qquad & 1+\Psi'(\iota) = q_t^K \\
\left[\dot{X}_t^{int}\right] \qquad & q_t^{int} = q_t^{int} \\
\left[\dot{X}_t^{lab}\right] \qquad & q_t^{lab} = q_t^{lab}.
\end{aligned}$$

The first-order conditions for share holdings hold for any values of q_t^{int} and q_t^{lab}. Substituting the guess for the value functions and the first-order conditions into the HJB gives

$$\begin{aligned}
r_t^a\left[q_t^K K + q_t^{int} X^{int} + q_t^{lab} X^{lab}\right] = {} & \left[r_t^k u^K - \iota - \Psi(\iota) - a\left(u^K\right)\right] K + \omega\left(1-\tau_c\right)\Pi_t^{int} X_t^{int} + \Pi_t^{lab} X_t^{lab} \\
& + q_t^K(\iota - \delta) K \\
& + \dot{q}_t^K K + \dot{q}_t^{int} X^{int} + \dot{q}_t^{lab} X^{lab}
\end{aligned} \tag{A.8}$$

This must hold for all K, X^{int} and X^{lab}, hence,

$$\begin{aligned}
r_t^a &= \frac{\left[r_t^k u^K - \iota - \Psi(\iota) - a\left(u^K\right)\right] + q_t^K(\iota-\delta) + \dot{q}_t^K}{q_t^K} \\
r_t^a &= \frac{\omega\left(1-\tau_c\right)\Pi_t^{int} + \dot{q}_t^{int}}{q_t^{int}} \\
r_t^a &= \frac{\Pi_t^{lab} + \dot{q}_t^{lab}}{q_t^{lab}}.
\end{aligned} \tag{A.9}$$

Using the functional form for the capital capacity utilization cost function (Equation 23), the first-order condition for u^K is

$$a'\left(u^K\right) = \sigma_a^K \sigma_b^K \left(u^K\right)^{\sigma_b - 1} = r_t^k. \tag{A.10}$$

In the steady state $u^K = 1$, implying

$$\sigma_a^K = \frac{r_{ss}^k}{\sigma_b^K}. \tag{A.11}$$

A.3 Piece rate

The piece rate Ω is chosen such that in the representative-agent version of the model workers and labor recruitment firms equally share the steady-state match surplus. The value of a filled job to a labor recruitment firm is

$$r^a J = (1-\Omega)\, p^w \bar{z}\bar{h} + (\delta_u + \zeta)\,(V - J), \tag{A.12}$$

where $\bar{z}$ and $\bar{h}$ are mean productivity and hours, respectively. Free-entry into vacancy creation implies $V = 0$. The value function for an employed worker is

$$(\rho+\zeta)\, V^e = (1-\bar{\tau})\,\Omega p^w \bar{z}\bar{h} - \frac{v\left(\bar{h}\right)}{u_c\left(\bar{c}\right)} + \delta_u\left(V^u - V^e\right), \tag{A.13}$$

where $\bar{\tau}$ is the mean tax rate, $v(h)$ is disutility of hours worked and $u_c(\bar{c})$ is the marginal utility of mean consumption $\bar{c}$. The value function for an unemployed worker is

$$(\rho+\zeta)\, V^u = (1-\bar{\tau})\,\bar{\varphi}\Omega p^w \bar{z}\bar{h} - \frac{v(0)}{u_c\left(\bar{c}\right)} + f\left(V^e - V^u\right), \tag{A.14}$$

where $\bar{\varphi}$ is the mean replacement ratio. Equation (A.12) can be re-arranged to give the recruitment firm's match surplus:

$$J - V = \frac{(1-\Omega)\, p^w \bar{z}\bar{h}}{r^a + \delta_u + \zeta} \tag{A.15}$$

and Equations (A.13) and (A.14) can be re-arranged to give the worker's match surplus:

$$V^e - V^u = \frac{(1-\bar{\tau})(1-\bar{\varphi})\,\Omega p^w \bar{z}\bar{h} - \left(\left(v\left(\bar{h}\right) - v(0)\right)/u_c\left(\bar{c}\right)\right)}{\rho + \zeta + \delta_u + f}. \tag{A.16}$$

An equal split of the match surplus implies $(J-V) = (V^e - V^u)$. Hence, choosing Ω such that the ratio

$$\frac{V^e - V^u}{J - V} = \left(\frac{(1-\bar{\tau})(1-\varphi)\,\Omega p^w \bar{z}\bar{h} - \left(\left(v\left(\bar{h}\right) - v(0)\right)/u_c\left(\bar{c}\right)\right)}{(1-\Omega)\, p^w \bar{z}\bar{h}}\right) \cdot \left(\frac{r^a + \delta_u + \zeta}{\rho + \zeta + \delta_u + f}\right) \tag{A.17}$$

equals one. In the steady state: unemployment u is constant and (9) implies $f = (\delta_u + \zeta)(1-u)/u$; $r^a \simeq \rho$; and with only labor income mean consumption is

$$\bar{c} = (1-\bar{\tau})\,\Omega p^w \bar{z}\bar{h}\,(1 - u(1-\bar{\varphi})) \tag{A.18}$$

With log utility for consumption $u_c(c) = 1/c$ and

$$\frac{V^e - V^u}{J - V} \simeq \frac{(1-\bar{\tau})\,\Omega\left((1-\bar{\varphi}) - \left(v\left(\bar{h}\right) - v(0)\right)(1 - u(1-\bar{\varphi}))\right)}{(1-\Omega)} \cdot \left(\frac{\rho + \delta_u + \zeta}{\rho + (\zeta + \delta_u)/u}\right). \tag{A.19}$$

The parameter values in Table 1, together with $\bar{\tau} \simeq 0.2$ and $\bar{\varphi} \simeq 0.1$, taking into account the upper limit on unemployment benefit payments, implies $\Omega \simeq 0.96$.

A.4 Fiscal rule

The law of motion for government debt is

$$\dot{B}_t^g = r_t^b B_t^g + T_t + \tau_c \Pi_t^{int} - G_t - tr_t - uben_t. \tag{A.20}$$

In the steady state $\dot{B}_t^g = 0$. Letting an overbar denote steady-state values,

$$\dot{B}_t^g = r_t^b B_t^g - \bar{r}^b \bar{B}^g + (T_t - \bar{T}) + \tau_c \left(\Pi_t^{int} - \bar{\Pi}^{int}\right) - \left(G_t - \bar{G}\right) - (tr_t - \bar{tr}) - \left(uben_t - \overline{uben}\right). \tag{A.21}$$

Transfers are assumed to adjust to bring debt back to steady-state levels following a shock:

$$tr_t = \bar{tr} + \rho_g \left(B_t^g - \bar{B}^g\right). \tag{A.22}$$

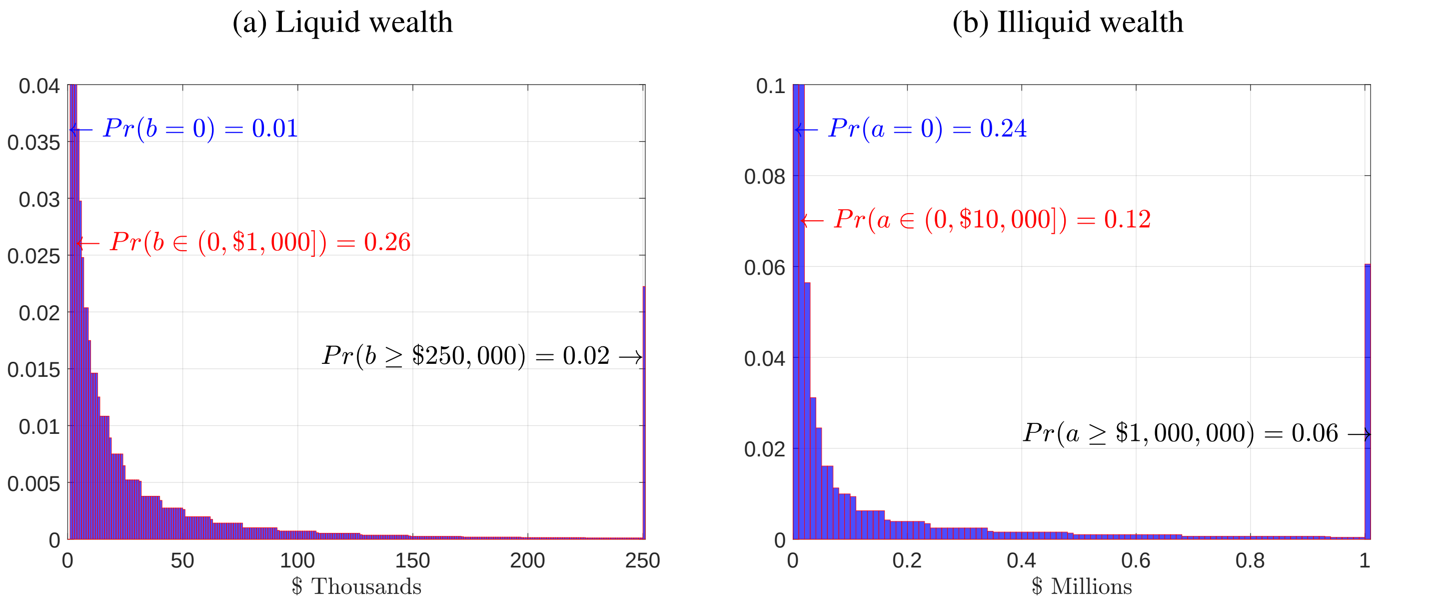
Combining Equations (A.21) and (A.22) gives the law of motion for debt under the fiscal rule:

$$\dot{B}_t^g = \left(r_t^b - \rho_g\right) B_t^g - \left(\bar{r}^b - \rho_g\right) \bar{B}^g + (T_t - \bar{T}) + \tau_c \left(\Pi_t^{int} - \bar{\Pi}^{int}\right) - \left(G_t - \bar{G}\right) - \left(uben_t - \overline{uben}\right). \tag{A.23}$$

Table A1: Literature on Labor Supply Responses to Taxes

Study	Finding and comments
Martinez, Saez and Siegenthaler (2021)	Study of staggered two-year long Swiss income tax holidays. Frisch intertemporal elasticity of 0.025 for wage earners. Elasticities of 0.1-0.25 for high earners and the self-employed, likely driven by tax avoidance. No effects on the extensive margin. Variation in timing of tax holidays across Swiss cantons permits controls for the business cycle. Administrative earnings data matched to Census data.
Bianchi, Gudmundsson and Zoega (2001)	Study of one-year income tax holiday in Iceland in 1987. Frisch elasticity of 0.42 along the extensive margin and 0.67 for earnings. Small survey dataset; study may not fully control for effect of the business cycle.
Sigurdsson (2021)	Study of one-year income tax holiday in Iceland in 1987. Frisch elasticity of 0.37 on the intensive margin and 0.10 on the extensive margin. Population wide earnings dataset.
Stefansson (2019)	Study of one-year income tax holiday in Iceland in 1987. Intensive margin elasticity of 0.07. Findings sensitive to empirical specification.
Chetty et al. (2011)	Review of the literature. Frisch intensive margin hours elasticity of 0.54 and extensive margin elasticity of 0.28 after adjusting for frictions. However, frictions are relevant for understanding observed responses to temporary tax changes.
Saez, Slemrod and Giertz (2012)	Review of literature on elasticity of taxable income; income effects are small so estimates are Hicksian elasticities. "...there is no compelling evidence to date of real economic responses to tax rates..." (Saez, Slemrod and Giertz, 2012, p. 42) Frisch elasticity would be not much larger under plausible assumptions about MPE and wealth-to-income ratio.
Kleven and Schultz (2014)	Elasticity of taxable income of 0.05 for wage earners in Denmark; income effects small so a Hicksian elasticity.
Mertens and Montiel Olea (2018)	Short-run elasticity of taxable income of 1.2 using U.S. time-series data for 1946-2012 and narrative identification. Inconsistent with micro evidence surveyed in Saez, Slemrod and Giertz (2012).

Figure A1: Distributions of Wealth



Notes: Panel (a) shows the distribution of liquid wealth and Panel (b) shows the distribution of illiquid wealth.