Asymmetric Effects of Personal Income Tax Changes on Economic Activity: Increases, Cuts, and for Whom*

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Abstract

This paper explores whether changes in personal income tax have asymmetric effects on US economic activity. Using narrative measures of exogenous variation in personal income tax liabilities, I estimate the short-run effects of these changes based on their direction and targeted income groups. I find that the contractionary effect of tax increases is 2 times larger than the expansionary effect of tax cuts and the larger contractionary effect is mainly driven by tax increases for low- and middle-income groups. To investigate the mechanisms behind this asymmetry, I build a heterogeneous agent model with downward wage rigidities and varying unemployment risks by income groups. This model implies that labor demand shortfalls after tax increases have a greater impact on output and employment, especially by reducing employment in the bottom 90% of income groups.

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1 Introduction

Policymakers have long been interested in how economic activity responds to tax changes. Much of the macroeconomic literature has documented the effects of tax changes by assuming that those effects are symmetric: tax increases and cuts have opposite but equal impacts on the economy.[1] However, understanding the distinct implications of tax increases and cuts is critical to assessing whether taxes can be effective tools for countercyclical or redistributive fiscal policy.

In this paper, I revisit the short-run effects of personal income tax changes both empirically and theoretically, by analyzing how economic activity reacts differently to tax increases and tax cuts. My main finding is that the effects of tax changes are asymmetric across signs and heterogeneous by income group. Specifically, tax increases tend to have a greater impact on GDP and employment than the same-sized tax cuts. Also, a tax increase targeting low- and middle-income taxpayers significantly reduces their employment, but the effect of a tax cut for the same income group is mild. In contrast, both tax increases and tax cuts targeting high-income taxpayers have no discernible impacts on their employment.

Variation in income tax policy in the US provides a favorable environment for studying the asymmetric and heterogeneous effects of tax changes. The US government has implemented various tax increases and cuts since World War II. These tax reforms have had different impacts on households across income distributions, due to changes in the progressive tendency of taxation. Therefore, historical data provides more than enough variations in tax changes. However, establishing useful results from this data requires addressing three empirical challenges: (1) identifying exogenous tax changes, (2) constructing tax measures by income groups, and (3) considering non-linear relationships within econometric specifications.

First, tax policies might be enacted in reaction to the state of the economy, implying that they can be endogenous. In order to capture the clear causal effects of tax policy on the economy, this paper focuses on tax policy changes that are not driven by short-term economic conditions. To this end, I follow Romer and Romer (2010)'s narrative identification strategy. They classify US tax reforms into exogenous and endogenous ones, based on historical records such as presidential speeches, White House economic reports, and congressional reports. If the main objective of a given tax reform is for long-run economic growth or deficit reductions, the change is considered exogenous. Following their approach, I select a subset of US tax reforms that are not related to the state of the economy.

Second, tax measures need to be separately constructed for each income group. I use a large sample of individual income tax return data (for US federal taxes) from the Internal Revenue Service (IRS). Within this extensive tax reporting data, I simulate individual-level tax liabilities with

[1] See, for example, Romer and Romer (2010); Barro and Redlick (2011); Mertens and Ravn (2013); Mertens and Montiel Olea (2018); Zidar (2019).

NBER's Tax Simulator (TAXSIM), which allows me to calculate individual tax liabilities for a given year with applicable underlying tax legislation.[2] For example, in order to construct tax liability changes in 2000, I need to calculate two tax liabilities. Firstly, I compute actual tax liability in 1999. Next, I simulate a counterfactual tax liability in 2000, which is computed using the year 1999 income information and the year 2000 tax rate.[3] The tax change in 2000 is defined as the difference between the two tax liabilities. I also integrate the tax change for each taxpayer by the income group, such as the bottom 90% and the top 10% of the income distribution. Finally, I eliminate endogenous tax reforms from the time-series tax measures.

Third, estimating asymmetric effects with respect to the sign of tax changes requires considering a nonlinearity within the econometric specification. The straightforward way to estimate the asymmetric effects is to divide the shock of interest into positive and negative values and use them as regressors in the model, which is called the dichotomous specification. However, it is known from the literature that using the dichotomous specification can produce biased estimates.[4] To avoid that bias, I follow Ben Zeev (2020)'s approach that introduces quadratic terms of the shock in the local projection model from Jordà (2005). He shows that this strategy is able to yield unbiased estimates of true asymmetry. I also use Kilian and Vigfusson (2011)' method as an alternative approach to show that my empirical results are not driven by the specific functional form in the benchmark specification, but rather by the nature of the data that I consider.

Combining the exogenous tax changes by the income group and the quadratic specification, I estimate how GDP and employment are responsive to tax increases and cuts, respectively, and how the employment of each income group responds differently to tax changes. I find that tax increases have a roughly 2 times larger impact on GDP and employment relative to similarly sized tax cuts. In particular, a 1% increase in the average tax rate results in a 3.7% decrease in GDP over 2 years, while a 1% cut in the average tax rate yields a 1.7% increase in GDP. The corresponding estimates for employment are 1.6% for the tax increase and 0.5% for the tax cut. Also, I detect clear evidence that tax increases have a disproportionately larger impact on employment of the bottom 90% of each income group relative to the top 10%. A 1% increase in the average tax rate for the bottom 90% reduces their employment by 1.2% 2 years after the tax increase, while a 1% cut in the average tax rate for the same income group raises their employment by 0.4%. In contrast, tax increases and

[2] See the details in Feenberg and Coutts (1993).

[3] I use the previous year's income information to avoid two possible concerns. Measures of tax liability are a product of tax rates and taxable incomes. Taxable incomes can respond endogenously to changes in tax rates, resulting in overestimating or underestimating the actual effects of the tax rate changes. Also, tax liabilities can increase through inflation even though the tax rate does not change. Fixing income information to the prior year can address these concerns.

[4] Ben Zeev (2020) and Kilian and Vigfusson (2011) show that the dichotomous specification may cause estimated coefficients to be biased due to the misspecification problem and propose alternative methods that can address this potential bias. Using their proposed methods, Ben Zeev (2020) looks at the asymmetric effects of credit supply shocks, while Kilian and Vigfusson (2011) focus on oil price shocks.

cuts for the top 10% have no distinguishable impacts on their employment.

These empirical findings are rationalized by my proposed theoretical model. Specifically, I introduce a heterogeneous agent model featuring downward wage rigidity (DWR) and varying unemployment risks across income groups to explain the aggregate and distributional implications of tax changes.

DWR is a key mechanism to amplify the aggregate effect of tax increases. In determining whether wages fall or rise after tax increases, it matters how elastic labor and capital are to tax changes, because wages crucially depend on the equilibrium capital-to-labor ratio (K/L).[5] If capital responds more to a tax increase than the labor, then wages face downward pressure; otherwise, wages will rise. In the model, I find that the capital is more responsive to tax increases than the labor, consistent with literature (Yum, 2020). It implies that a tax increase would reduce K/L, which in turn lowers wages. Therefore, when governments raise average tax rates, wages are depressed. But wages being downwardly rigid means that wages cannot fall below the previous level and can be potentially higher than the market clearing wage. Due to the high wage level, firms reduce the demand for labor, which leads to an increase in unemployment and ultimately amplifies the contractionary effect of the tax increase. Details of the relationship between the DWR constraint and tax changes are described in Section 5.1.2.

The varying unemployment risks by income groups lead to the distributional effect of tax increases. When the DWR constraint is binding, there are labor demand shortfalls and subsequently labor rationing. In this situation, firms are less likely to hire low-productivity workers relative to high-productivity workers. Guvenen et al. (2017) provide useful estimates of how sensitive gross worker earnings are to GDP conditional on their place in the earnings distribution. When aggregate employment falls, low-income workers lose more earnings relative to high-income workers, meaning that low-income workers are much more exposed to unemployment risks than high-income workers. Consequently, a tax increase significantly lowers aggregate employment through the interaction of the DWR and also generates a distributional effect through the different unemployment risks by different income groups.

Both of these effects are driven by labor demand, and labor supply is assumed to be inelastic to tax changes in the benchmark model. However, one could think that the labor supply can also be an important margin for tax changes.[6] In order to test whether the labor supply has an important role

[5] Given a Cobb-Douglas technology, wages are determined by solving the firm's profit maximization problem:

$$w = \alpha(\frac{K}{L})^{1-\alpha}, \quad \text{where } 0 < \alpha < 1$$

[6] Keane (2011) summarizes the literature on labor supply and tax changes. Tax changes could have heterogeneous impacts on the labor supply with respect to age, gender, and income, but it is conventional wisdom that the elasticity of the labor supply is small for prime-age males.

in explaining the effect of tax changes, I include the extensive margin of labor supply decisions in the benchmark model, following Chang and Kim (2007). Model results show that introducing the labor supply does not produce significantly different output responses compared to the benchmark model. It implies that the labor supply response might be a less important margin for tax policies, whereas the large output response following the tax increase is mainly led by the labor demand adjustment.

My empirical findings are consistent with the macroeconomic literature and the more focused evidence from survey data. One strand of evidence relates to asymmetric effects across the different direction of macroeconomic policy change. Barnichon et al. (2022) show that the government spending multiplier is substantially below 1 for expansionary government spending shocks, but the multiplier is above 1 for contractionary shocks. Debortoli et al. (2020) describe how monetary easing has large effects on prices but small effects on real economic activity variables, while monetary tightening has large effects on economic activity but small effects on prices. Related to their evidence, my novel finding is that the contractionary effect of tax increases tends to be larger than the expansionary effect from the same sized tax cut. Similar to this paper, Hussain and Malik (2016) also examine whether output responses are different for tax increases and tax cuts in US data. But they find that output is strongly positive following a tax cut, whereas the output response to a tax increase is statistically insignificant, which is the opposite of my findings. To reconcile this inconsistency, I estimate output responses following their specification but include macroeconomic and policy variables as controls, given that many studies control other macroeconomic developments that might have a relationship with tax changes.[7] After including these control variables, the estimated responses in Hussain and Malik (2016) are consistent with my results.

The second strand of evidence relates to heterogeneous effects of tax changes across income distributions. Zidar (2019) finds that tax cuts benefiting low- and middle-income taxpayers generate larger growth in aggregate employment than the similarly sized tax cuts for high-income taxpayers. Mertens and Montiel Olea (2018) show that the aggregate GDP and unemployment responses to a 1% cut in the net-of-tax rate for the bottom 99% are much larger than for a narrower cut for only the top 1%. Ferraro and Fiori (2020) document that the response of the unemployment rates to tax changes varies significantly across age groups: the response for young employees is nearly twice as large as for older employees. These findings are consistent with my results in terms of the disproportionately large impact of tax changes on the lower-income groups. However, while earlier papers focus only on the heterogeneous effect of tax changes, I consider the interactions between the asymmetric and heterogeneous effects of tax policy to find the mechanism of the effects. As described above, the heterogeneous effect across the income distribution plays an important role in

[7] See, for example, Mertens and Ravn (2013); Mertens and Montiel Olea (2018); Zidar (2019); Ferraro and Fiori (2020); Demirel (2021)

explaining the asymmetric effect of tax policies.

The third strand of evidence relates to the micro evidence on asymmetric responses to income changes. Bracha and Cooper (2014) examine individuals' responses to the 2013 payroll tax increase and their 2012 tax refund, using US survey data. They find that consumption declines by 90 cents per dollar lost to the tax increase, but rises only 60 cents per additional tax refund dollar. Using UK survey data, Bunn et al. (2018) document that marginal propensities to consume (MPCs) after negative income shocks are estimated to be much larger than for positive shocks. An unexpected fall in income leads to MPCs between 0.46 and 0.68 whereas an unexpected rise in income is associated with MPCs in the range of 0.07 to 0.17. The asymmetry in how spending responds to negative and positive income shocks provides implications for tax policies. To the extent that tax policy influences households' disposable income, the asymmetry in MPCs implies that a tax increase would have a larger contractionary impact on aggregate spending than the expansionary effect from an equivalent cut in taxes.

This paper also contributes to the theoretical literature. There is growing research that explains macroeconomic questions using a heterogeneous agent model with DWR. Auclert and Rognlie (2018) explore the transmission mechanism of income inequality to output by a heterogeneous agent New Keynesian model with DWR, and suggest that higher inequality reduces output in the short-run. Jo (2019) shows that a heterogeneous agent model with various wage-setting schemes and DWR matches the shape and cyclicality of wage change distributions. Barnichon et al. (2022) consider a model with incomplete markets and DWR, and generate asymmetric and state-dependent effects of government spending multipliers. The present paper explains the asymmetric effect of tax changes by building a heterogeneous agent model with DWR and different unemployment risks across income distributions. Ferraro and Fiori (2019) also show sizable asymmetric responses of employment to tax changes, but they build a heterogeneous agent model with search frictions in the labor market and an extensive margin of employment adjustment. Their main findings are similar to this paper in that tax increases have a larger impact than tax cuts, but the main propagation mechanisms are different from this paper.

The remainder of the paper is organized as follows. Section 2 introduces how to construct tax shocks. Section 3 presents the econometric methodology. Section 4 provides empirical evidence of asymmetric and heterogeneous effects. Section 5 builds a heterogeneous agent model with DWR and different unemployment risks by income groups, and presents the quantitative results. Lastly, Section 6 concludes.

2 Data

This section describes how I construct tax measures by income groups from 1966 to 2007[8] and isolate exogenous variation in taxes for empirical analysis. I then provide a list of nontax data and their sources.

2.1 Tax data

I construct tax measures from NBER's Tax Model files, which are large samples of US Federal Individual Income Tax returns. The files include rich information about taxes and incomes. This paper focuses on changes in federal income taxes and payroll taxes.

In order to calculate tax changes, I use NBER's Tax Simulator (TAXSIM) program, which can calculate individual tax liabilities for annual tax schedules using the Tax Model files. Tax changes in year t are calculated as the difference between a counterfactual tax liability in year t and an actual tax liability in year $t-1$. The counterfactual tax liability in year t is simulated using the year $t-1$ income distribution and the year t tax rates, and the actual tax liability in $t-1$ is calculated using the year $t-1$ income distribution and the year $t-1$ tax rates. For example, consider the 2001 Economic Growth and Tax Relief Reconciliation Act. The tax change in the year 2001 is defined by comparing how much she paid in 2000 to how much she would have paid in 2000 if the 2001 tax schedule had been in place. TAXSIM considers each individual's deductions, credits, and treatment under the annual tax schedule. The resulting tax change is a substantially detailed measure of the mechanical and policy-induced change in tax liability for each tax return.[9]

After calculating tax liability changes for each taxpayer, I integrate those data by income groups and then scale by personal taxable income for the same groups.[10] Income groups are categorized into three groups: the entire population, bottom 90%, and top 10%. I define tax changes as

$$T_t^g = \frac{\text{Tax liability}_t^{counterfactual,g} - \text{Tax liability}_{t-1}^{actual,g}}{\text{Personal Taxable Income}_{t-1}^g}$$

where t indicates year and $g \in \{All, B90, T10\}$.

Among these tax changes, it is essential to select exogenous ones with respect to macroeconomic variables, in order to capture the clear causal effect of tax policy on the economy. I address

[8]The data have been issued since 1960, but 1961, 1963, and 1965 are not available. I thus start the sample in 1966.

[9]Macro tax literature uses this approach to construct varying types of tax shocks. Zidar (2019) constructs regional tax liability changes by income groups, while Mertens and Montiel Olea (2018) focus on changes in marginal tax rates rather than in tax liability. Ferraro and Fiori (2020) construct age-specific marginal tax rate shocks. My measures are similar to Zidar (2019)'s in that this paper focuses on average tax rates rather than marginal tax rates.

[10]Romer and Romer (2010)'s tax measures are scaled by GDP because their tax measures cover all type of taxes such as personal income taxes, corporate taxes, estate taxes, and so on. But since this paper focuses on personal income taxes, my measures are scaled by personal taxable incomes as in Mertens and Ravn (2013).

the identification problem by adopting Romer and Romer (2010)'s narrative approach. They classify US federal tax reforms into exogenous and endogenous ones based on historical records such as presidential speeches and congressional reports. If a tax reform is implemented by a desire to pursue deficit reduction or long-run growth rather than being a countercyclical policy designed to return growth to its normal level, it is considered exogenous. Likewise, the tax reforms taken in reaction to the state of the economy are considered endogenous. Following this classification, I pick up a subset of the federal tax reforms that are not related to the state of the economy. For endogenous years, the tax change measures are set to zero.

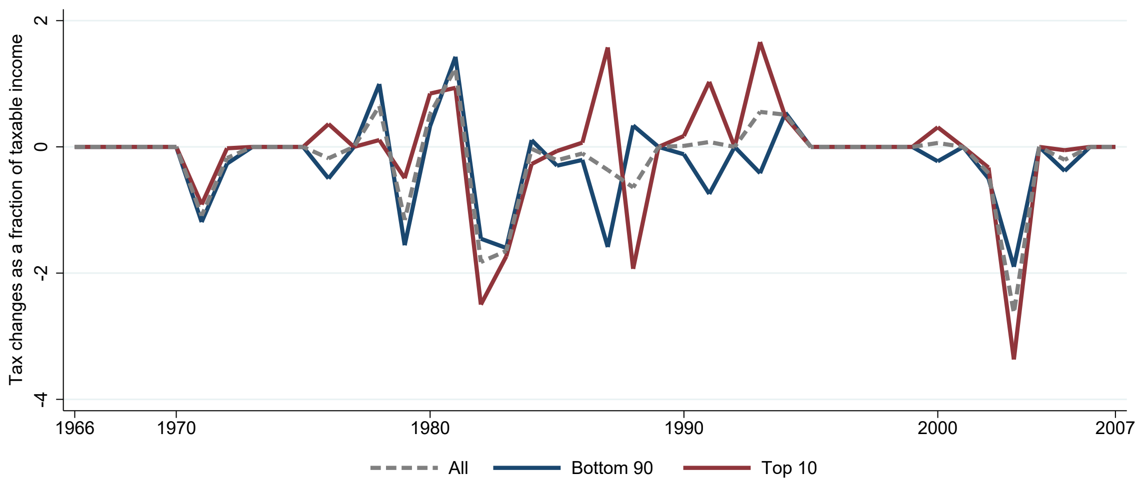
The top panel of Figure (1) displays how the selected exogenous tax changes across income groups have evolved since 1966. Prior to the 1980s, there were many cases where every tax moved in the same direction, either all tax increases or all tax cuts. However, after the mid-1980s, we see enough variations of exogenous changes that move in different directions to separately identify the tax measures by income groups.[11]

In addition, we can observe 22 exogenous tax reforms. Aggregate tax measures show 8 tax increases and 14 tax cuts during the sample period. The bottom 90% had 7 tax increases and 15 tax cuts, while the top 10% had 10 tax increases and 12 tax cuts. The Omnibus Budget Reconciliation Act of 1993, aimed at deficit reduction, is an example of exogenous tax increases. A large portion of the additional revenues came from higher marginal tax rates for high-income earners. In a speech to Congress, President Clinton said that "Over the long run, all this will bring us a higher rate of economic growth, improved productivity, and an improved economic competitive position in the world." On the other hand, the Jobs and Growth Tax Relief Reconciliation Act of 2003 is an example of exogenous tax cuts. It was intended to provide incentives for investment by lowering taxes on capital income and cutting individual tax rates. In his address describing the long-run benefits of lower taxes, President Bush emphasized that "this bill is essential to lay the groundwork for future growth and future prosperity." The long-run growth motivation for that tax reform enables us to classify it as an exogenous tax change.

As noted earlier, this paper uses NBER's TAXSIM to simulate annual tax liability and construct policy-induced changes in tax liability. This implies that the constructed tax measures are at an annual frequency. Although annual data provides fewer observations, there are advantages of using annual data (Mertens and Montiel Olea, 2018; Zidar, 2019) over using quarterly data (Romer and Romer, 2010; Mertens and Ravn, 2013). With the IRS's individual tax reporting data, we can separately identify exogenous tax changes by income groups. Since it provides the taxable income for each tax return, we can aggregate tax liabilities by income groups at our discretion. This feature allows us to investigate the heterogeneous effects of tax changes by income group and better under-

[11] In Appendix A, I decompose the tax measures into changes in federal income taxes and in payroll taxes. Figure (8) shows that most tax increases come from the change in payroll taxes, while tax cuts come from the change in federal income taxes.

Figure 1: The time series variation in tax changes across income groups



Note: The tax measures are defined as tax liability changes for each income group as a share of personal taxable income for the same income group. Each line indicates the average tax rate changes for that income group.

stand the mechanisms behind the asymmetric effects of tax changes. Also, using TAXSIM, we can address potential concerns about tax measures. Measures of tax liability use the tax rates multiplied by the taxable income. Taxable income may respond endogenously to contemporaneous changes in the tax rate, and consequently the measures may overestimate or underestimate the actual effect of the tax rate change. Also, even if the tax rate does not change, inflation may increase tax liability and distort the tax measure. I address these concerns by fixing income information to the prior year.

2.2 Nontax Data

The main variables measuring economic activity are real GDP and employment. Real GDP data come from the Bureau of Economic Analysis's (BEA) National Income and Product Accounts (NIPA) Table 1.1.3. Employment data come from the Current Population Survey (CPS). To estimate the heterogeneous effect of tax changes by income groups, I construct employment data by income groups. Based on the total income in CPS, each individual is classified into all, bottom 90%, or top 10%. Then, I aggregate the number of people employed within each income group each year.

I use control variables for aggregate macroeconomic variables and policy changes. Specifically, the consumption price index (CPI) comes from the Bureau of Labor Statistics (BLS), real government spending comes from the NIPA 1.1.3, the federal fund rate comes from the Federal Reserve Economic Data (FRED), the average corporate tax rate is federal taxes on corporate income (NIPA Table 3.2) divided by corporate profits (FRED), and personal transfer is current government transfer receipts (NIPA Table 3.7) divided by aggregate personal income.

3 Econometric Methodology

This section describes how I estimate the asymmetric responses of economic activity to tax changes. First, I introduce an econometric strategy that considers nonlinearity in the specification. Second, I display a possible concern with a conventional method of estimating the asymmetry in a regression model, and show that my benchmark specification is more suitable for this study than the conventional way.

3.1 Local Projections with the Quadratic Specification

I start by describing an econometric specification for this empirical analysis. Typically, the literature uses a linear specification, but I need to consider nonlinearity since this paper estimates whether the effects are different across the sign of tax changes. This paper employs a local projection by introducing a quadratic term of tax shocks. The local projection, proposed by Jordà (2005), allows us to assess the dynamic responses of economic activity following tax shocks. Including the second term of tax shocks also allows us to estimate the separate responses to a tax increase and a tax cut, respectively. This estimation strategy is taken from Ben Zeev (2020).

I run a series of local projection regressions combined with the quadratic term for diffterent horizons $h \in \{0, 1, ..., 4\}$:

$$y_{t+h} - y_{t-1} = \alpha_h^g T_t^g + \beta_h^g (T_t^g)^2 + \psi_h Z_t + \varepsilon_t, \tag{1}$$

where y_{t+h} is a log of the economic activity such as the real GDP and the number of people employed at horizon h; T_t^g is exogenous tax changes, where $g \in \{All, B90, T10\}$, and Z is a set of control variables consisting of 1 lag each of tax shocks, a log of government spending, federal fund rates, CPI, and a quartic trend. In order to control for other contemporaneous government fiscal policies, I include corporate tax rates and personal transfer relative to aggregate income. I also add the difference in tax liabilities between the top 10% and bottom 90% to consider tax progressivity.[12] The path of economic activity around the tax shocks is described by the sequences of coefficients $\{\alpha_h^g + \beta_h^g\}_{h=0}^{h=4}$ for tax increases and $\{\alpha_h^g - \beta_h^g\}_{h=0}^{h=4}$ for tax cuts, where $g \in \{All, B90, T10\}$, which quantifies the impacts of a tax increase and a tax cut on economic activity over different horizons. One potential probelm with the local projection approach is the serial correlation of the error terms. To deal with this concern, I adopt the Newey-West heteroskedasticity and autocorrelation-corrected (HAC) standard error from Newey and West (1987).

[12] As discussed in Jackson et al. (2019), increasing tax progressivity raises disposable income at the bottom of the income distribution, resulting in expansionary effects.

One question that may arise is how the combinations of the estimated coefficients for the shock and the quadratic term of the shock can capture the asymmetric effects. To explain this estimation strategy, we need to understand the existence of asymmetric impulse responses. Consider a data-generating process (DGP) for a time-series variable of interest y_t, as suggested by general dynamic stochastic general equilibrium (DSGE) models. It is represented by a multivariate moving average process with infinite order, as below.

$$y_t = \gamma t + \sum_{i=0}^{\infty} \alpha_i \varepsilon_{t-i} + \sum_{j=0}^{\infty}\sum_{i=0}^{\infty} \beta_{j,i}(\varepsilon_{t-i} \otimes \varepsilon_{t-j}), \tag{2}$$

where γ is the stochastic steady state growth rate of y_t, ε_t is a $k \times 1$ vector of macroeconomic shocks, α_i is the $1 \times k$ first-order MA coefficients, and β_i is the $k \times k$ second-order MA coefficients.

Assuming the shock of interest is the first element ε_t^1, the impulse response of outcome variable y_t can be computed as

$$\begin{aligned} &E\left(y_{t+h} \mid \varepsilon_t^1 > 0; \forall i > 0, \forall j, \varepsilon_{t-i}^j = 0; \forall j > 1, \varepsilon_t^j = 0\right) - E\left(y_{t+h} \mid \forall i \geq 0, \forall j, \varepsilon_{t-i}^j = 0\right) \\ &= \alpha_h^1 \varepsilon_t^1 + \beta_{h,h}^{1,1}(\varepsilon_t^1)^2, \end{aligned} \tag{3}$$

where α_h^1 is the first element of first-order coefficient vector α_h and $\beta_{h,h}^{1,1}$ is the (1,1) element of second-order coefficient matrix $\beta_{h,h}$.

Equation (3) shows that the response at horizon h to one unit of the positive shock is constructed as $\alpha_h^1 + \beta_{h,h}^{1,1}$ by putting 1 into ε_t^1, while the response at horizon h to one unit of the negative shock is constructed as $\alpha_h^1 - \beta_{h,h}^{1,1}$[13] by putting -1 in ε_t^1. The derivation of the impulse response implies that, under the theory consistent DGP, there exists asymmetry in the impulse response due to the presence of $(\varepsilon_t^1)^2$ if $\beta_{h,h}^{1,1}$ is not equal to 0.

Based on this understanding of the asymmetric impulse response, we find that including the quadratic term of shocks in the regression model would be crucial and recover true asymmetry in the shocks of interest. However, many empirical studies still use a conventional method to estimate the asymmetric effects by dividing the shock into positive and negative values and using them as the variable of interest in the regression model, an approach called dichotomous specifications. In the section 3.2, I describe a potential problem with the dichotomous specification and look at whether the similar problem may arise in my analysis as well.

[13]For the comparison purpose, I multiply the response at horizon h to one unit of the negative shock by -1. That is, $(-1) \times \{\alpha_h^1 \times (-1) + \beta_{h,h}^{1,1} \times (-1)^2\} = -(-\alpha_h^1 + \beta_{h,h}^{1,1}) = \alpha_h^1 - \beta_{h,h}^{1,1}$.

3.2 Estimation Bias from the Dichotomous Specification

The most straightforward way of estimating the asymmetric impulse response is to use the dichotomous specification via local projections. Some researchers studying the asymmetric effects of macroeconomic shocks assume that the outcome variables of interest are expressed as a moving average decomposition, in terms of positive and negative realizations of a shock, with distinguishable moving average coefficients. To this end, positive shocks are constructed by replacing negative values of the shock with zero, and negative shocks are constructed by replacing positive values of the shock with zero. However, such a dichotomous specification is known to produce an unbiased OLS estimator, as noted by Kilian and Vigfusson (2011) and Ben Zeev (2020).

Given the underlying DGP from equation (2), consider the following regression equation.

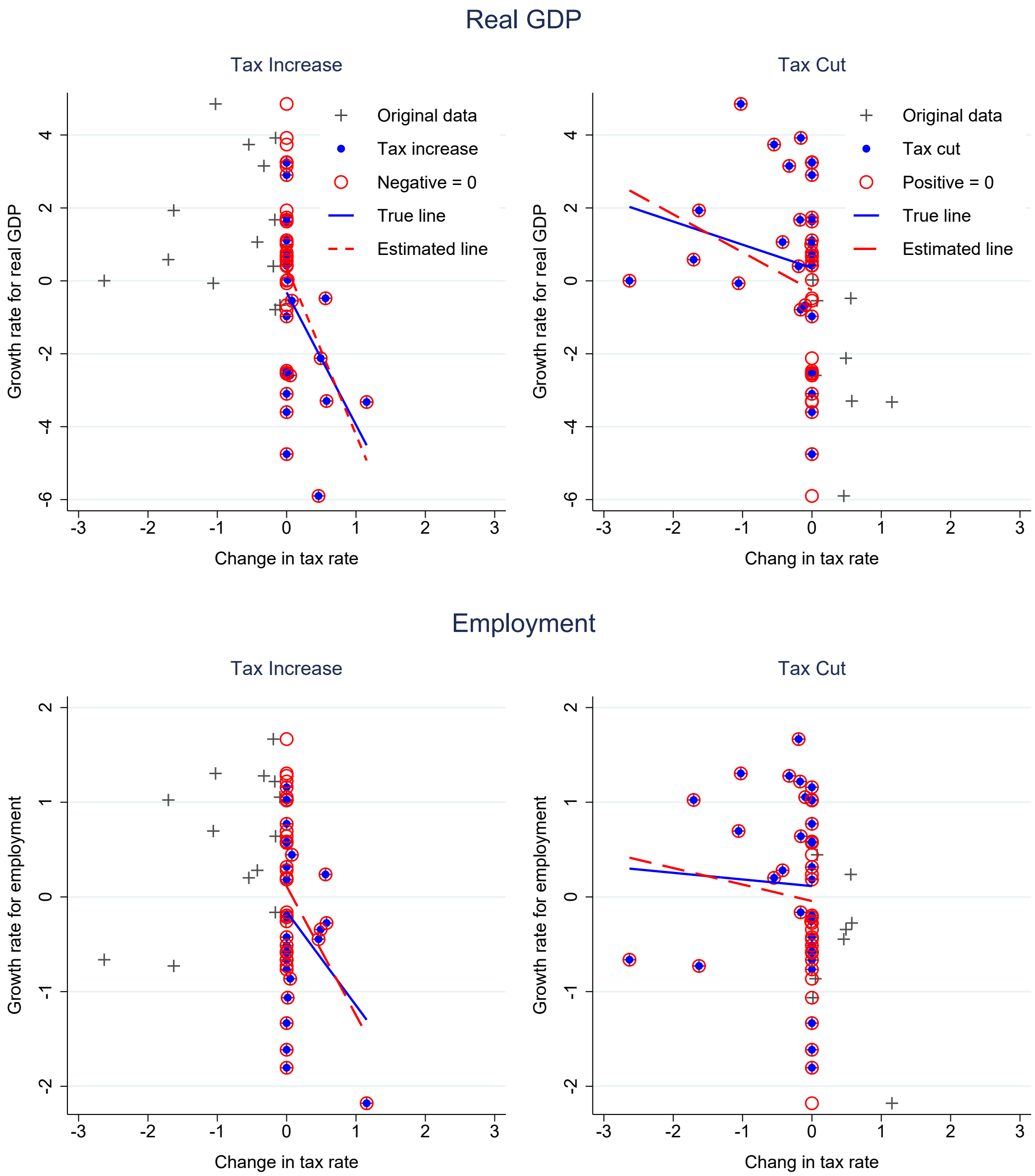
$$y_t = \gamma t + \sum_{i=0}^{\infty} b_i^{+} \varepsilon_{t-i}^{1,+} + \sum_{i=0}^{\infty} b_i^{-} \varepsilon_{t-i}^{1,-} + u_t, \tag{4}$$

where $\varepsilon_t^{1,+} = max[0, \varepsilon_t^1]$ and $\varepsilon_t^{1,-} = min[0, \varepsilon_t^1]$; b_i^+ and b_i^- are the moving average coefficients for positive and negative shocks; u_t includes all other shocks such as $\varepsilon_t^2, \varepsilon_t^2, ..., \varepsilon_t^k$. Ben Zeev (2020) reveals that there exists a sizable bias from estimating equation (4) by local projections when the true DGP is equation (2). In Appendix B.1, I introduce how to analytically solve the biased estimators from the equation (4). Appendix B.2 displays the estimation results using the dichotomous specification.

In order to examine whether my tax measures may face a similar bias problem, I decompose them by positive and negative tax shocks and illustrate the relationship between each tax shock and the cyclically adjusted 2 year growth rates for real GDP and employment, respectively. Figure (2) shows that the dichotomous specification with the censored tax measures can lead to upward bias. The plus mark denotes the original tax shock data, the blue circle includes only exogenous tax increases or tax cuts, the red hollow circle indicates the sign-based tax measures censored at zero. The blue fitted lines can be interpreted as true regression lines, while the red dashed lines represent estimated regression lines using the dichotomous specification. For both a tax increase and a tax cut, the estimated regression lines are somewhat steeper than the true regression lines, which means the censored tax measures can cause an upward bias.

The graphical evidence from Figure (2), as well as the analytical evidence from Appendix B.1, show the benefits of introducing the quadratic term. In addition to the benchmark specification taken from Ben Zeev (2020), I use Kilian and Vigfusson (2011)'s approach as an alternative method in the robustness check, to show that my empirical results are not driven by the specific functional form of the benchmark specification.

Figure 2: The effect of censoring values of tax measures



Note: The plus mark denotes the original tax shock data. The blue circle includes only exogenous tax increases or tax cuts. The red hollow circle indicates the sign-based tax measures censored at zero. The blue fitted lines display true regression lines and the red dashed lines represent estimated regression lines using the dichotomous specification. The estimated regression lines (red dashed lines) are steeper than the true regression lines (blue lines), meaning estimating by the dichotomous specification might yield an upward bias.

4 Estimation Results

This section provides empirical evidence on the asymmetric effects of tax changes on economic activity. Section 4.1 describes the results for the asymmetric effects of tax changes on real GDP and employment. Section 4.2 provides the results for the heterogeneous effects of tax changes on employmnent and hours, by income groups. Section 4.3 discusses robustness checks.

4.1 Asymmetric Impacts on Economic Activity

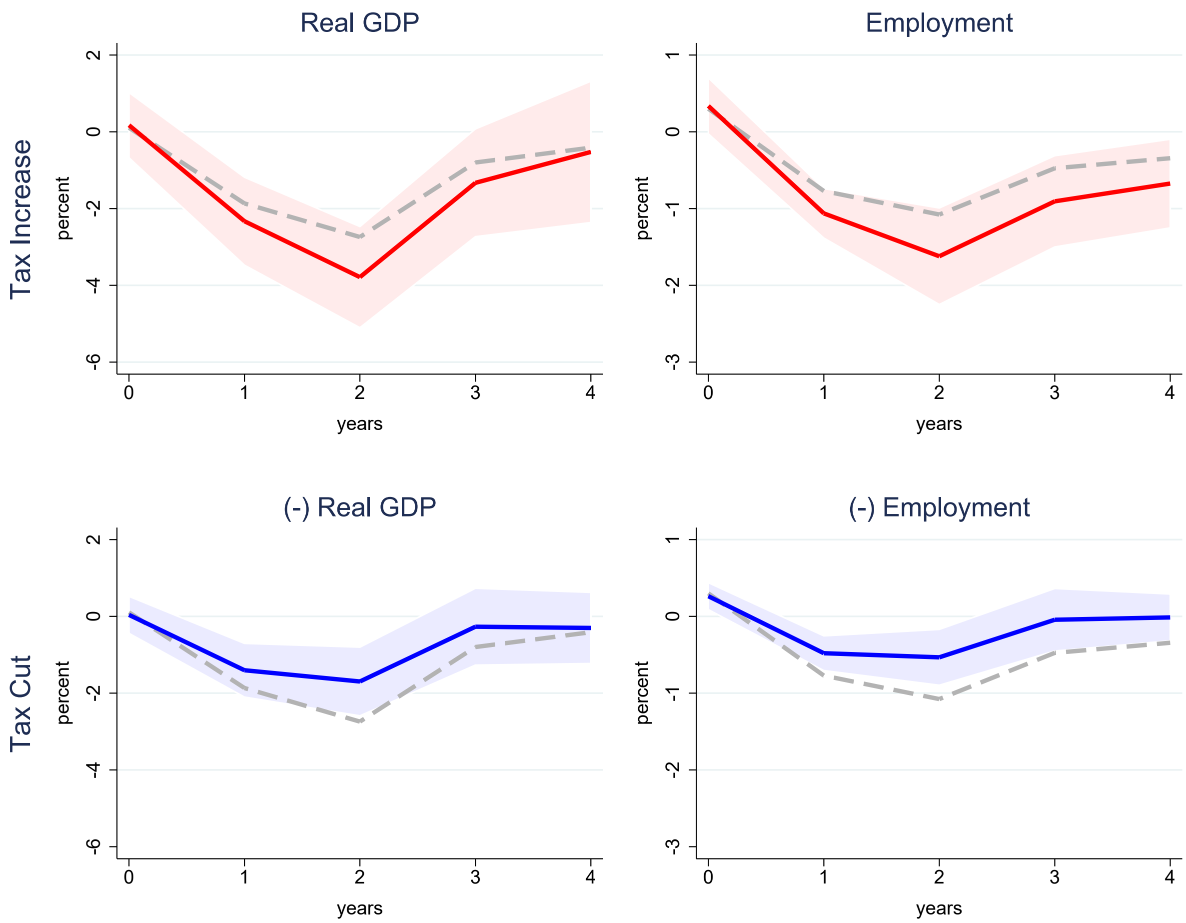
Figure (3) depicts how real GDP and employment evolve following tax increases and tax cuts, relative to the year before the tax change. The estimates for the impact of tax increases in the year h are $\widehat{\alpha}_h^{All} + \widehat{\beta}_h^{All}$ from equation (1), and those for the impact of tax cuts are $\widehat{\alpha}_h^{All} - \widehat{\beta}_h^{All}$[14]. The top panels show the impact of tax increases with a red line, and the bottom panels show the impact of tax cuts with a blue line. A gray dashed line represents the linear effect of the tax change. This figure also displays 90% confidence intervals as shaded areas.

Following a 1% increase in the average tax rate, real GDP falls on average by 2.3% in the year after the tax increase and 3.7% 2 years after the increase, relative to real GDP the year before the tax increase. Both responses remain statistically significant at the 1% level. From then onward, real GDP gradually recovers to the level before the tax increase. A cut in the average tax rate leads to a smaller impact on real GDP than an increase. Following a 1% cut in the average tax rate, real GDP rises by 1.4% in the year after the tax cut, and by up to 1.7% 2 years after the tax cut. Both responses are significant at the 1% level, and the subsequent response gradually returns to the level prior to the tax cut. The impact on employment is similar to the impact on real GDP, but it shows more persistent patterns. After a 1% increase in the average tax rate, employment tends to be 1.0% lower in the year after the increase, falls by 1.6% 2 years after the increase, and then returns to be roughly 0.9% lower 3 years and 4 years after the tax increase. These impacts are significant at the 5% level for a full 4 years after the tax increase. As in real GDP, employment is also less responsive to a tax cut than to a tax increase. After a 1% cut in the average tax rate, employment rises by 0.4% the year after the tax cut and by 0.5% 2 years after the tax cut, but returns to the initial level 3 years and 4 years after the tax cut.

In addition to the graphical evidence, Table (1) reports on a test to find statistical evidence of asymmetric impacts of tax increases and cuts. As stated in Section 3.1, the presence of the quadratic term can lead to an asymmetric relationship between economic activity and tax changes. I conduct a test for the null hypothesis of symmetry in the impulse responses from equation (1) as

[14]For a display purpose, the estimate for the impact of tax cuts is multiplied by -1.

Figure 3: Cumulative responses of real GDP and employment to tax changes



Note: This figure shows the impacts of a 1% increase and cut in the average tax rate on real GDP and employment. Specifically, the figure plots the estimates from the baseline specification of equation (1) for the impact of tax increases in year h, $\{\widehat{\alpha}_h^{All} + \widehat{\beta}_h^{All}\}_{h=0}^{h=4}$, and for the impact of tax cuts, $\{\widehat{\alpha}_h^{All} - \widehat{\beta}_h^{All}\}_{h=0}^{h=4}$. The control variables are 1 lag of each of the following variables: government spending, the federal funds rate, and inflation. The regression also includes contemporaneous corporate tax rates and government transfers, as well as 1 lag of each. Top panels show responses of tax increases with a red line, while the bottom panels show responses of tax cuts with a blue line. For display purposes, the responses of tax cuts are multiplied by -1. Standard errors are HAC standard errors from Newey and West (1987); 90 percent confidence bands are shown as shaded areas. The dashed gray lines show the linear effect of tax changes. The sample period is 1966-2007.

Table 1: Test for symmetry of impulse responses to tax changes

	Real GDP	Employment
	$H_0 : \beta_h^{All} = 0$	$H_0 : \beta_h^{All} = 0$
$h = 0$	0.06 (0.16)	0.03 (0.11)
$h = 1$	-0.46* (0.25)	-0.29** (0.11)
$h = 2$	-1.10*** (0.28)	-0.54*** (0.14)
$h = 3$	-0.53 (0.32)	-0.43** (0.17)
$h = 4$	-0.11 (0.35)	-0.33** (0.12)

This table presents statistical evidence for asymmetric impacts of tax changes on real GDP and employment. Under the null hypothesis of symmetry $H_0 : \beta_h^{All} = 0$ from equation (1), a test was conducted to see whether there is evidence against symmetry in tax changes.
* p-value < 0.1, ** p-value < 0.05, and *** p-value < 0.01.

$$H_0 : \beta_h^{All} = 0 \qquad \text{for} \quad h = 0, 1, ..., 4.$$

If the test rejects the null hypothesis, that means that the impluse responses are asymmetric, because the difference between the impulse responses to tax increases and cuts is computed as $2\beta_h^{All}$[15]. For real GDP, the results are somewhat mixed. Whereas the test fails to reject the null hypothesis of symmetry at the 3 and 4 horizon, there is evidence against symmetry at the 1 and 2 horizon. However, for employment, I find strong evidence against symmetry. The test rejects the null hypothesis of symmetry at all but the 0 horizon. At the 2 horizon, I find evidence against symmetry at the 1% significance level. The test rejects the null hypothesis at the 5% significance level at the 1, 3, and 4 horizon.

The evidence in this section shows that economic activity, represented by real GDP and employment, is substantially more responsive to tax increases than to tax cuts. Specifically, the impact of tax increases is roughly two times larger than that of tax cuts. In the next section, I shows how the responses of economic activity are different across income distributions, to show the mechanism behind the asymmetry in tax policy.

[15] $\widehat{\alpha}_h^{All} + \widehat{\beta}_h^{All} - (\widehat{\alpha}_h^{All} - \widehat{\beta}_h^{All}) = 2\beta_h^{All}$.

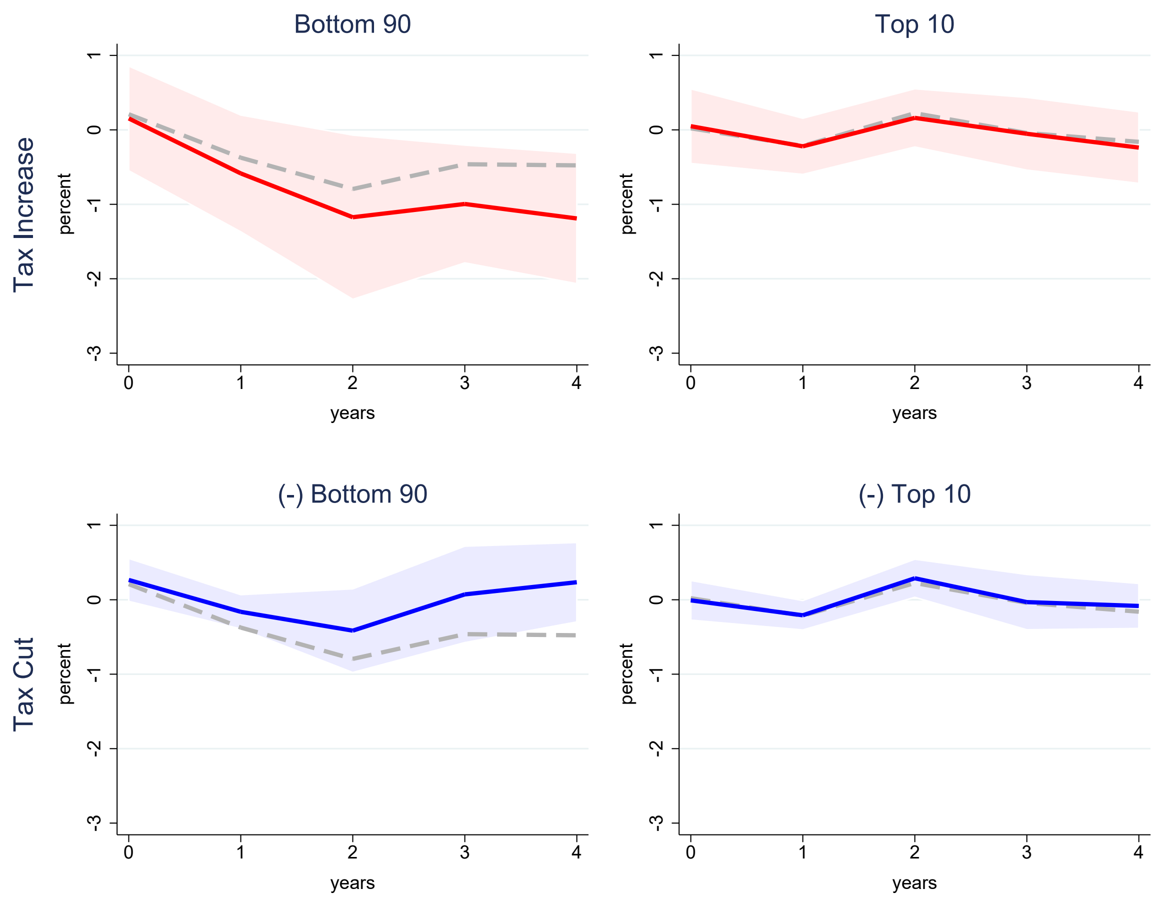
4.2 Heterogeneous Impacts on the Labor Market by Income Groups

This section further clarifies the mechanisms of the asymmetry documented above, by looking at the heterogeneous impacts of tax changes on labor market outcomes across income groups. Specifically, I assess how labor market outcomes such as employment and hours per worker respond differently to tax increases and tax cuts across income groups, by estimating equation (1) for each income group. The estimate for the impact of tax increases for each group in year h is $\widehat{\alpha}_h^g + \widehat{\beta}_h^g$ from equation (1), and that for the impact of tax cuts for each group is $\widehat{\alpha}_h^g - \widehat{\beta}_h^g$, where $g \in \{B90, T10\}$.

Figure (4) shows the estimates for the impact of tax increases and tax cuts for different income groups's respective employment levels. After a 1% increase in the average tax rate for the bottom 90%, employment for the same group falls on average by 0.6% the year after the tax increase, and by 1.2% 2 years after the tax increase. Those impacts are persistent 3 and 4 years after the tax increase and remain statistically significant at the 5% level for all horizons. However, the estimated impact of the same scaled tax cut is much smaller. Employment for the bottom 90% rises only by 0.16% the year after the tax cut, which is statistically significant at the 5% level. At the next horizon, the employment increases by 0.5%, statistically significant at the 10% level. In sharp contrast to the asymmetric impact of the tax change for the bottom 90%, its counterpart for the top 10% appears to be symmetric. Both tax increases and tax cuts for the top 10% have no detectable impact on employment for the same group. These results suggest that a substantial degress of the asymmetry shown in Figure (3) is primarily driven by tax changes for the bottom 90%. Table (2) provides further statistical evidence that the asymmetric impact is led by the bottom 90% group's response to the tax increase. The test for the bottom 90% rejects the null hypothesis of symmetry at the 3 horizon at the 10% level, and at the 4 horizon at the 1% level. However, the test for the top 10% fails to reject the null hypothesis for all horizons.

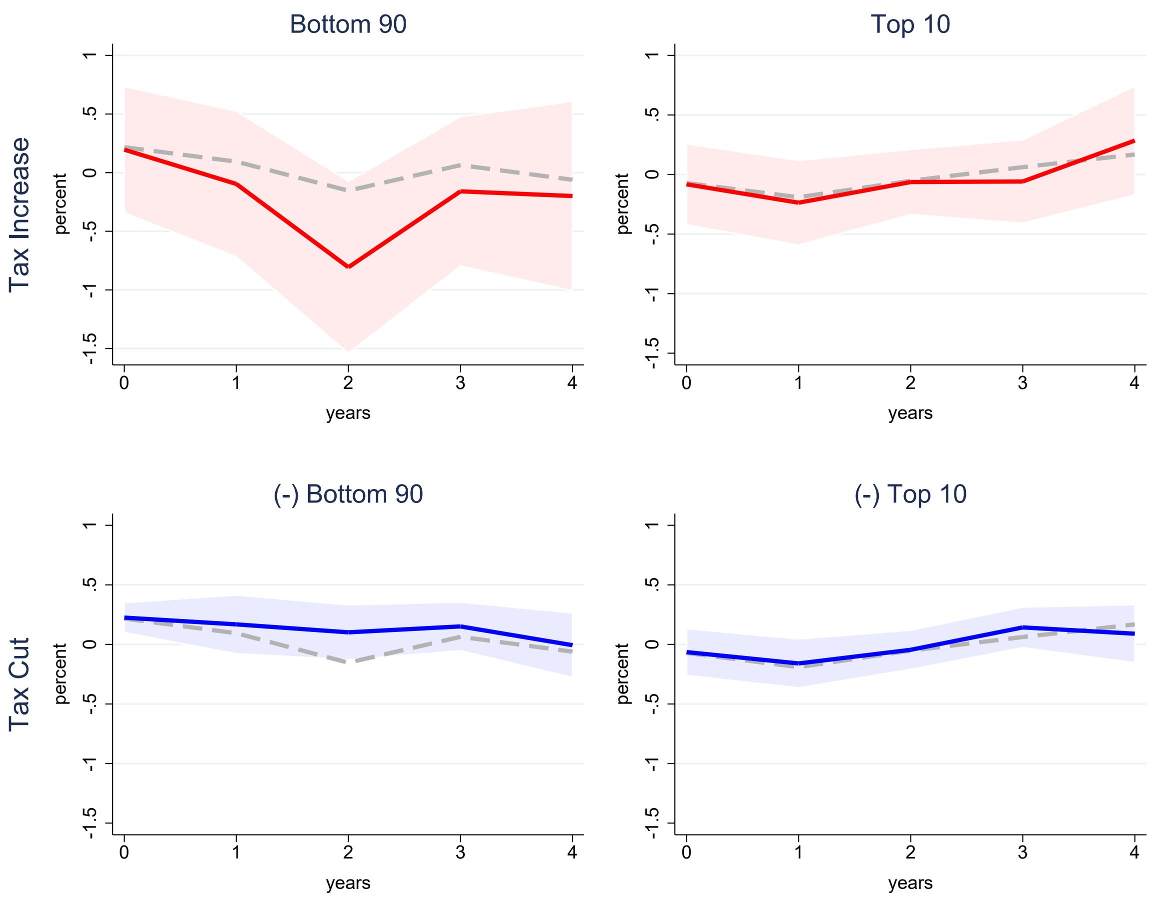
The evidence that the response of the bottom 90% leads to the asymmetric impact of tax changes is observed not only in employment (extensive margin of labor), but also in hours per worker (intensive margin of labor), though somewhat more weakly. Figure (5) shows how hours per worker react differently to tax increases and tax cuts: Hours per worker for the bottom 90% decrease 0.8% 2 years after a 1% increase of the average tax rate for the same group, which is statistically significant at the 10% level. Other estimates for tax increases are not statistically different from 0 at different horizons. Similar to the employment response, the tax increase and the tax cut for the top 10% do not appear to affect hours per worker in the same group. Table (2) shows that the evidence on hours per worker is overall similar to that on employment. The test for the bottom 90% rejects the null hypothesis of symmetry at the 2 horizon, at the 10% significance level. Given that the employment response of the bottom 90% to tax changes plays a key role in generating the asymmetric impact of tax changes, these results imply that the intensive margin may also contributes to the asymmetric impact.

Figure 4: Cumulative responses of employment to tax changes by income groups



Note: This figure shows the impacts of a 1% increase and cut in the average tax rate for different income groups on their respective employment levels. Specifically, the figure plots the estimates from the baseline specification of equation (1) for the impact of tax increases for each group in year h, $\{\widehat{\alpha}_h^g + \widehat{\beta}_h^g\}_{h=0}^{h=4}$, and for the impact of tax cuts for each group, $\{\widehat{\alpha}_h^g - \widehat{\beta}_h^g\}_{h=0}^{h=4}$, where $g \in \{B90, T10\}$. The control variables are a 1 lag of each of the following variables: government spending, the federal funds rate, and inflation. The regression also includes contemporaneous corporate tax rate and government transfers, as well as a 1 lag of each one. The top panels show responses to tax increases with a red line, while the bottom panels show responses to tax cuts with a blue line. For display purposes, the responses to tax cuts are multiplied by -1. Standard errors are HAC standard errors from Newey and West (1987); 90 percent confidence bands are shown as shaded areas. The dashed gray lines shows the linear effect of tax changes. The sample period is 1966-2007.

Figure 5: Cumulative responses of hours per worker to tax changes across income groups



Note: This figure shows the impacts of a 1% increase and cut in the average tax rate for different income groups on their respective hours per worker. Specifically, the figure plots the estimates from the baseline specification of equation (1) for the impact of tax increases for each group in year h, $\{\widehat{\alpha}_h^g + \widehat{\beta}_h^g\}_{h=0}^{h=4}$, and for the impact of tax cuts for each group, $\{\widehat{\alpha}_h^g - \widehat{\beta}_h^g\}_{h=0}^{h=4}$, where $g \in \{B90, T10\}$. The control variables are a 1 lag of each of the following variables: government spending, the federal funds rate, and inflation. The regression also includes contemporaneous corporate tax rate and government transfers, as well as a 1 lag of each one. The top panels show responses of tax increases with a red line, while the bottom panels show responses of tax cuts with a blue line. For display purposes, the responses of tax cuts are multiplied by -1. Standard errors are HAC standard errors from Newey and West (1987); 90 percent confidence bands are shown as shaded areas. The dashed gray lines shows the linear effect of tax changes. The sample period is 1966-2007.

Table 2: Test for symmetry of impulse responses to tax changes across income group

	Employment		Hours per worker	
	Bottom 90%	Top 10%	Bottom 90%	Top 10%
	$H_0 : \beta_h^{B90} = 0$	$H_0 : \beta_h^{T10} = 0$	$H_0 : \beta_h^{B90} = 0$	$H_0 : \beta_h^{T10} = 0$
$h = 0$	-0.05 (0.17)	0.02 (0.08)	-0.01 (0.17)	-0.001 (0.07)
$h = 1$	-0.21 (0.22)	0.01 (0.07)	-0.13 (0.20)	-0.03 (0.06)
$h = 2$	-0.37 (0.32)	-0.06 (0.07)	-0.45* (0.23)	-0.001 (0.06)
$h = 3$	-0.53* (0.29)	0.01 (0.06)	-0.15 (0.21)	-0.01 (0.07)
$h = 4$	-0.71*** (0.23)	-0.07 (0.11)	-0.09 (0.29)	0.09 (0.09)

This table presents statistical evidence of the asymmetric impact of tax changes on employment and hours per worker, across income groups. Under the null hypothesis of symmetry $H_0 : \beta_h^g = 0$, where $g \in \{B90, T10\}$, from equation (1), a test is conducted for whether there is evidence against symmetry in tax changes.
* p-value < 0.1, ** p-value < 0.05, and *** p-value < 0.01.

This section shows how labor market outcomes react differently to a tax increase and a tax cut across the income distribution. I find that employment and work hours among the bottom 90% are more responsive to a tax increase than among the top 10%, while the effects of a tax cut are mild for both income groups. These findings imply that the disproportionately large responses of employment and work hours for the bottom 90% income groups drive the aggregate impact on the labor market outcomes, which provides a potential mechanism for explaining the asymmetric effect of tax changes. Based on the empirical literature, there may be some concerns about the validity of these benchmark results. In the section 4.3, I describe specific threats to the validity and provide robustness checks to address the concerns.

4.3 Robustness Checks

This section discusses robustness five checks: (1) anticipated tax measures in Appendix C.1, (2) an alternative econometric methodology in Appendix C.2, (3) more segmented income groups in Appendix C.3, (4) effects on tax revenues in Appendix C.4, and (5) normalizing tax measures between the bottom 90% and top 10% in Appendix C.5.

One potential concern with my results is that tax reforms can be implemented with a delay or be applied gradually over several years. Pre-announced but not yet implemented tax increases might generate an expansionary effect on economic activity during the period prior to implementation, which could distort the actual effects of tax changes. To avoid anticipated policy variation in a similar context, Mertens and Montiel Olea (2018) exclude all tax changes resulting from reforms that were legislated at least one year before becoming effective. Following their approach, I eliminate 12 tax reforms implemented with a delay and conduct the same analysis using the remaining 10 tax reforms. In Appendix C.1, Figure (10) shows that the effects of tax changes are asymmetric even after excluding anticipated tax reforms. Each effect is somewhat smaller than the benchmark results and the confidence band is also wider due to the loss of observations.

I also conduct the same empirical analysis using a different econometric methodology. In addition to the benchmark specification, Kilian and Vigfusson (2011) suggest a way to estimate the asymmetric effects of macroeconomic shocks by mitigating the bias from the dichotomous specification. Using their proposed method, they study asymmetric effects of oil price changes on US economy. In Figure (11) of Appendix C.2, I find that the estimated effects from this alternative approach are consistent with the benchmark results, but the confidence band is wider. These results imply that my empirical findings are not driven by the specific functional form from the quadratic specification, but by the nature of the data that I consider. In Appendix C.2, I also summarize how to construct impulse response and standard errors. Given the less precisely estimates from the alternative approach, I use the local projection with the quadratic specification as the benchmark specification.

This paper classifies income distribution into the bottom 90% and top 10%. But one could argue that this classification is too broad, especially in that the bottom 90% covers individuals from the lowest income group to the middle income group. To deal with this concern, I decompose the income distribution into three groups: the bottom 50%, bottom 50-90%, and top 10%. I then estimate heterogeneous effects of tax changes on employment for each of the three income groups. In Figure (12) of Appendix C.3, I find that the disproportionately large effects on employment of the bottom 90% following a tax increase, depicted in Figure (4) and Figure (5), are driven by the response of the bottom 50-90% rather than the bottom 50%. This result can be interpreted in two ways. If we focus on labor demand, when firms face labor demand shortfalls, they are more likely to adjust the employment of middle-income workers rather than low-income or high-income workers. If we focus on labor supply, this result seems to reflect the progressive income tax policy of the United States since 1960. A large portion of US taxpayers belonging to the lowest income distribution pays little or no taxes at all. Therefore, the magnitude of the identified tax changes for the lower income group is small, resulting in the mild effect on their employment.

Policymakers are also interested in how tax changes affect tax revenues. Figure (13) in Appendix C.4 shows how tax revenue responds differently to a tax increase and a tax cut across income groups. In contrast to their impact on economic activity, tax revenue is more responsive to tax changes for the top 10% relative to the bottom 90%. My finding does not provide a direct implication for the Laffer curve, which illustrates a relationship between tax rates and the resulting levels of the government's tax revenues, suggesting theoretically revenue-maximizing income tax rates. However, it could provide suggestive evidence that tax changes for high-income taxpayers tend to be more effective, in that a tax change targeting high-income groups has a mild impact on output but leads to a substantially large response of tax revenues.

The tax measure defined in this paper tracks the change in the average tax rate for each income group, that is, the change in tax liabilities divided by income for each group. An impulse response is interpreted as a response in the outcome to a 1% change in tax rate. But, since the size of the aggregate income varies by income group, a 1% change in tax rate means different tax burdens for different income groups, implying that it could be hard to compare the size of the impulse responses to each other. In order to address this concern, I normalize my tax measures by the income of the whole group, so that responses to the normalized tax measures are comparable across income groups. As shown in Figure (14) of Appendix C.5, I find that the responses from the normalized tax measure are consistent with the responses from the benchmark measure.

5 Model

In this section, I introduce a heterogeneous agent model with DWR and varying unemployment risks across income distributions, to explain the empirical findings shown in the previous empirical studies. The model matches two empirical findings: 1) tax changes have much larger contractionary effects on the economy relative to expansionary effects, and 2) the bottom 90% income group reacts more to tax increases than the top 10%.

5.1 Environment

5.1.1 Households

Time is discrete and runs from $t = 0$ to ∞. The economy is populated by a unit mass of infiinitely-lived households who face idiosyncratic labor productivity shocks. Households vary in their idiosyncratic ability state $x \in \{x_1, x_2, ..., x_{N_x}\}$, which follows a Markov chain with transition probabilities Π. I assume that the mass of households in idiosyncratic state x is equal to $\pi(x, x')$, the probability of x in the stationary distribution of Π. Households cannot issue any assets contingent on their future idiosyncratic risks x, and they are only allowed to trade a one-period real risk-free bond to self-insure, subject to a borrowing limit $\underline{a}$ (Aiyagari, 1994). Households take the wage rate per efficiency unit of labor w and the real interest rate r, which are given by the competitive factor market. Also, households face the labor income tax τ_L and capital income tax τ_K.

A household i maximizes its utility from consumption c_{it} with a common discount factor β. The value function for a household i with idiosyncratic labor productivity x_{it} and assets a_{it} in period t, $V(a_{it}, x_{it})$, is defined as:

$$\begin{aligned} V(a_{it}, x_{it}) &= \max_{c_{it}, a_{it+1}} \{ log\, c_{it} + \beta E[V(a_{it+1}, x_{it+1}) \mid x_{it}]\} \\ s.t.\ \ & c_{it} + a_{it+1} = a_{it} + (1-\tau_{Lt}) z_{it}(x_{it}, L_t) + (1-\tau_{Kt}) r_t a_{it} \\ & a_{it+1} \geq \underline{a}, \end{aligned} \tag{5}$$

where z_{it} denotes labor income and L_t denotes a fraction of aggregate employment demanded by firms. Household labor income z_{it} is defined as the product of the real wage and the amount of labor endowment that households can supply, as in Auclert and Rognlie (2018):

$$z_{it}(x_{it}, L_t) = w_t x_{it} \gamma(x_{it}, L_t) L_t,$$

where the γ function satisfies

$$\gamma(x_{it,} 1) = 1 \quad \forall x_{it}.$$

If the economy attains full employment, then L_t is equal to 1 ($L_t = 1$). By contrast, if the economy faces labor demand shortfalls, then L_t is less than 1 ($L_t < 1$). In this situation, the economy experiences labor rationing, and households in state x_{it} are constrained to provide the fraction $\gamma(x_{it}, L_t)L_t$ of their full labor endowment. This implies that households' labor supply is affected by $\gamma(x_{it}, L_t)$ and L_t, with $\gamma(x_{it}, L_t)$ coming from the households' idiosyncratic conditions and L_t coming from the aggregate employment conditions. And I normalize the γ function:

$$E[x_{it}\gamma(x_{it}, L_t)] = 1 \quad \forall L_t \leq 1.$$

Hence, households' average labor income across the population is $E[z_{it}(x_{it}, L_t)] = w_t L_t$. Aggregate employment is a determinant of the average labor income for the whole population, while $\gamma(x_{it}, L_t)$ governs how the labor income is determined across the population given the aggregate employment conditions. We can interpret $\gamma(x_{it}, L_t)$ as indicating the incidence of unemployment. If we assume $\gamma(x_{it}, L_t) = 1$ for all households, then households' labor supply is proportionally rationed. That means that every household faces an equal unemployment risk against labor demand shortfalls. But if we assume $\gamma(x_{it}, L_t) \neq 1$ for some households, the labor supply is disproportionally rationed across households' productivity x_{it}. That means that some households face higher unemployment risks while other households face lower unemployment risks.

The γ function is calibrated to match empirical evidence. Guvenen et al. (2017) estimates how labor income growth is sensitive to output growth across the income distribution. Using their measure and the constant of Okun's law, I recalculate the elasticity of labor income to aggregate employment across the income distribution. In Section 5.3, I show details on how to calibrate the γ function.

5.1.2 Wage Rigidities

I assume that wage adjustment is constrained downwardly, as in Schmitt-Grohè and Uribe (2016)[16]. The economy-wide real wages can only fall by a limited amount each period:

$$w_t \geq \kappa w_{t-1}, \qquad 0 < \kappa \leq 1. \tag{6}$$

The aggregate employment (L_t) utilized for production can be lower than the aggregate full employment, 1, when a shock leads the DWR constraint to bind. Wages and the aggregate employment must satisfy the complementary slackness condition:

$$(L_t - 1)(w_t - \kappa w_{t-1}) = 0 \tag{7}$$

When the DWR constraint is not binding ($w_t > \kappa w_{t-1}$), the labor market clears and the economy attains full employment ($L_t = 1$). When the DWR constraint is binding ($w_t = \kappa w_{t-1}$), the economy experiences a labor demand shortfall ($L_t < 1$). In this situation, firms reduce labor demand and they are less likely to hire low-productivity workers than high-productivity workers, implying that households face different unemployment risks according to their productivity. This can be a source of heterogeneous impacts on the labor market.

In the benchmark model, the DWR constraint is binding after a tax increase. Following a tax increase, capital stock (K) responds substantially, while L is fixed because the benchmark model assumes that labor supply is inelastic. Thus, wages face downward pressure given that the wage crucially depends on the equilibrium capital-to-labor ratio (K/L). Even considering the labor supply

[16] I also nassume that real wages are constrained downwardly in a similar way to Schmitt-Grohè and Uribe (2016), which focuses on nominal wages.

in the model, the result is the same. In Section 5.5.2, I introduce the labor supply in the heterogeneous agent model following Chang and Kim (2007). This model assumes that households choose whether to work or not, which produces heterogeneous Frisch elasticity of the labor supply across income distributions: labor supply elasticity in the bottom of the income distribution is substantially large while that of the high-income group is almost zero. It implies that most employment changes after a tax increase are driven by low to middle productivity workers. Since L entails the composition of households with productivity x_i who choose to work, the change in L is dampened, and, in turn, wages face downward pressure as in the benchmark model.

5.1.3 Firms

Production is carried out by a competitive representative firm, which has a Cobb-Douglas technology. The representative firm makes decisions for labor and capital demand to maximize current profits such that:

$$\Pi_t = \max_{K_t, L_t} K_t^{\alpha} L_t^{1-\alpha} - w_t L_t - (r_t + \delta) K_t,$$

where δ is the depreciation rate for capital.

5.1.4 Government

The government collects labor income taxes and capital income taxes to balance the government budget constraint for each period:

$$G = \tau_K \int r a d\mu + \tau_L \int w L \gamma(x, L) x d\mu,$$

where μ is the measure of households with state (a, x). I assume that the tax revenues are used for wasteful government spending.

5.1.5 Tax Shock Processes

The flat-rate tax on labor and capital income follows an AR(1) process:

$$\begin{aligned} log(\tau_{Lt+1}) &= (1-\rho_L) log(\overline{\tau}_L) + \rho_L log(\tau_{Lt}) + \sigma_L \varepsilon_{Lt+1} \quad \varepsilon_{Lt+1} \sim N(0,1) \\ log(\tau_{Kt+1}) &= (1-\rho_K) log(\overline{\tau}_K) + \rho_K log(\tau_{Kt}) + \sigma_K \varepsilon_{Kt+1} \quad \varepsilon_{Kt+1} \sim N(0,1) \end{aligned}$$

where $\overline{\tau}_L$ and $\overline{\tau}_K$ is the unconditional mean of the tax rate, ρ_L and ρ_K govern the persistence of the shock, and σ_L and σ_K denote the volatility of the innovations.

5.2 Equilibrium

A stationary equilibrium consists of a value function $V(x,a)$; a set of decision rules for consumption and asset holdings, respectively $c(x,a)$ and $a'(x,a)$; aggregate inputs K and L; and the invariant distribution of households, $\psi(x)$, such that:

1. Individual households optimize: given w and r, the individual decision rules $c(x,a)$ and $a'(x,a)$, and $V(x,a)$ solve the Bellman equation.

2. The representative firm maximizes profits:

$$w = \alpha(\frac{K}{L})^{1-\alpha} \tag{8}$$

$$r = (1-\alpha)(\frac{K}{L})^{-\alpha} - \delta \tag{9}$$

3. The goods market clears:

$$\int \left\{a'(x,a) + c(x,a)\right\} d\mu + G = F(L,K) + (1-\delta)K$$

4. The capital market clears:

$$K = \int a d\mu$$

5. The government balances the budget:

$$G = \tau_K \int r a d\mu + \tau_L \int w x L \gamma(x,L) d\mu$$

5.3 Calibration

In this section, I discuss calibration for the parameters used in the model. The simulation period is quarterly, and I convert quarterly model results into annual frequencies. Table (3) summarizes each parameter value.

I assume that the gamma function takes the form of equation (10) to match empirical evidence from Guvenen et al. (2017).

$$\gamma(x_{it}, L_t) = \frac{x_{it}^{\Gamma log L_t}}{E[x_{it}^{1+\Gamma log L_t}]}, \tag{10}$$

where Γ represents the degree of disproportional employment. Guvenen et al. (2017) estimate how labor income growth is sensitive to output growth across income distributions. Using their measure and the Okun's law constant, I calculate the elasticity of labor income to aggregate employment across income distributions.[17] I choose Γ so that the labor income elasticity to aggregate employment from the model is similar to that from the empirical evidence.

Figure (6) shows the elasticity of labor income to aggregate employment across income distributions, which shows how the labor income growth changes differently by deciles following a 1% change in total employment rate. The blue bars are obtained from the model and the red bars are from the data. I find that the labor income of lower-income groups is more elastic to aggregate employment than the labor income of higher-income groups. The magnitude of the elasticity is inversely proportional to income.

Other parameters follow standards in the literature. The time discount factor (β) is set to be 0.9 so that the return to capital is 1%. The capital income share α and the depreciation rate (δ) are calibrated to be 0.33 and 0.08, respectively. For individual labor productivity shocks, I set $\rho_x = 0.939$ and $\sigma_x = 0.287$, following Chang et al. (2013).[18] Following standards in the literature, I also assume the full employment (L_{ss}) is set to be 1. The degree of DWR parameter (κ) is set to be 1, as in Auclert and Rognlie (2018) and Dupraz et al. (2019).[19] The degree of disproportional employment Γ is chosen so that the labor supply meets the labor demand from firms. According to the US Federal Individual Income Tax returns from the IRS, the average tax rate for personal income taxes was 0.34. And I estimate its persistence, which is 0.83, by assuming that the average tax rate follows the AR(1) process. I assume that both labor and capital taxes have the same average and persistence.

[17] Guvenen et al. (2017) estimate the labor income elasticity to output growth across income distributions, which is called $GDP\,Beta^g$, where g income group. I calculate the labor income elasticity to aggregate employment across income distribution using $GDP\,Beta^g$ and the Okun's law constant θ:

$$\begin{aligned}\frac{\frac{\Delta Labor\,Income_t^g}{Labor\,Income_t^g}}{\frac{\Delta L_t}{L_t}} &= \frac{\frac{\Delta Labor\,Income_t^g}{Labor\,Income_t^g}}{\frac{\Delta GDP_t}{GDP_t}} \times \frac{\frac{\Delta GDP_t}{GDP_t}}{\frac{\Delta L_t}{L_t}} \\ &= GDP\,Beta^g \times \theta\end{aligned}$$

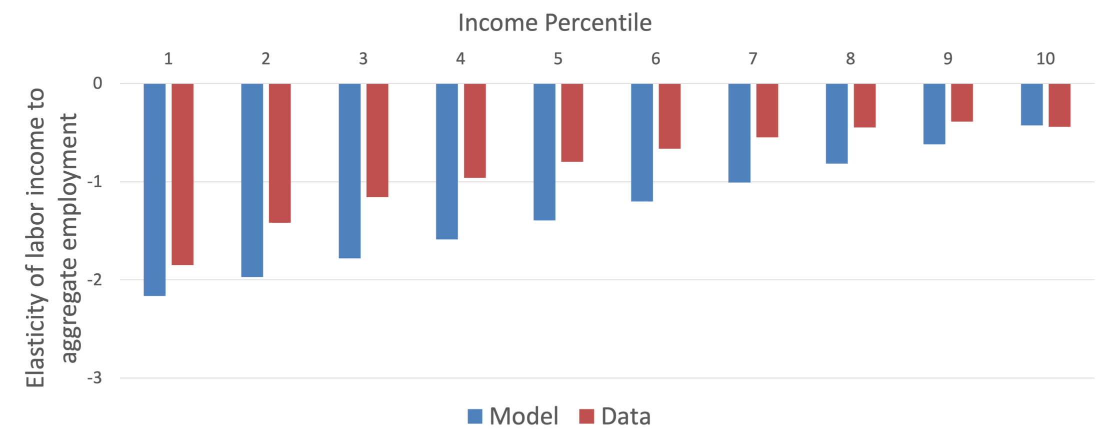
[18] I assume that $P(x,x')$ discretizes a log AR(1) process

$$log x_{it} = \rho log x_{it-1} + \sigma \varepsilon_{it}$$

with normal innovations $\varepsilon_{it} \sim N(0,1)$ and use the Tauchen (1986) method for discretization.

[19] Schmitt-Grohè and Uribe (2016) and Jo and Zubairy (2022) use $\kappa = 0.98$. Barnichon et al. (2022) uses $\kappa = 0.99$. For ease of computation, I assume that $\kappa = 1$ following Auclert and Rognlie (2018) and Dupraz et al. (2019). By making this assumption, we don't need to consider the occasional binding of DWR constraint.

Figure 6: Elasticity of labor income to aggregate employment by income groups



Note: The blue bars show the elasticity of labor income to aggregate employment across income distributions obtained from the model. The red bars show the elasticity computed based on Guvenen et al. (2017).

Table 3: Calibration of the model economy

Parameter	Description	Value
β	Discount factor	0.9
α	Capital share	0.33
δ	Depreciation rate	0.08
ρ_x	Persistence of idiosyncratic shock	0.939
σ_x	Standard deviation of idiosyncratic shock	0.287
L_{ss}	Full employment	1
$\bar{\tau}_L$, $\bar{\tau}_K$	Average tax rates	0.34
ρ_L, ρ_K	Persistence of tax rates	0.83
κ	Wage binding parameter	1
Γ	Degree of disproportional employment	-0.35

5.4 Solving the Model

I compute business cycle properties by assuming a one-time tax change (increases or cuts), starting from a steady state of a model economy, followed by a deterministic transition path. This approach delivers equilibria for heterogeneous agent models with aggregate shocks based on perfect-foresight equilibria, given unexpected shocks away from steady state. It has been widely used to study policy analysis, business cycles, and other shocks. The change in tax variables is interpreted as an unanticipated "shock," called the "MIT shock" in the recent literature, and the transition dynamics are interpreted as a response to the tax shocks. One interpretation of this approach is that the economy with the MIT shock corresponds to an economy with uncertainty regarding the same event when the probability of the event is close to zero. The details for how to compute the steady state and transition equilibrium are similarly followed by Ferriere and Navarro (2018) and summarized in Appendices D and E.

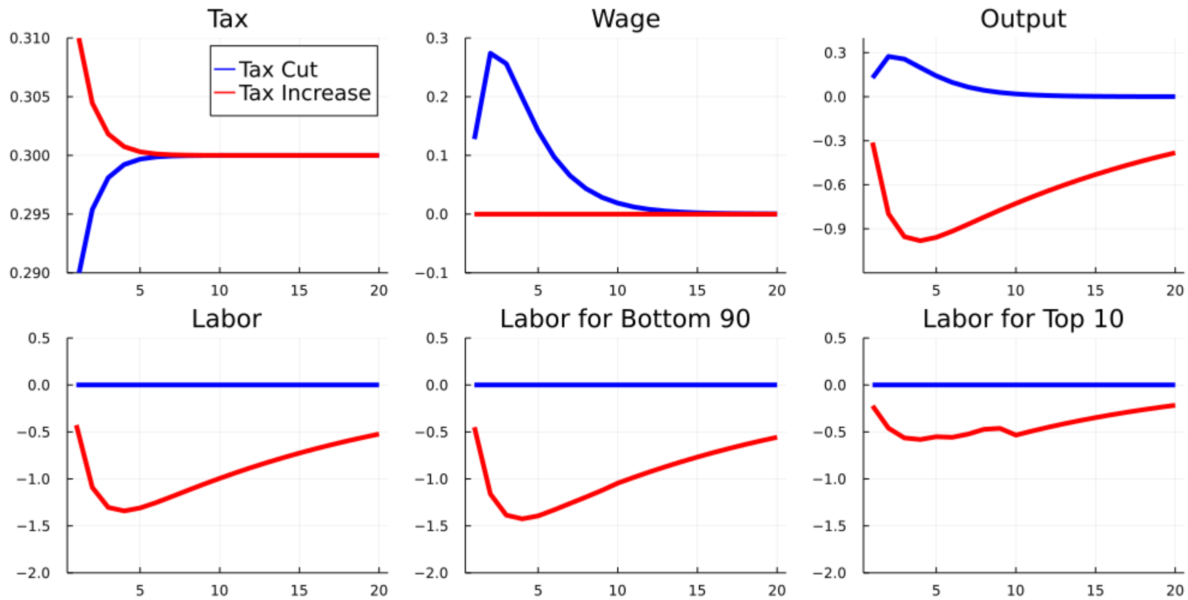
5.5 Quantitative Results

I begin by considering how the economy responds differently to both tax increases and cuts on labor and capital income. Figure (7) shows the difference of impulse responses to tax increases and tax cuts by assuming that the economy is hit by one-time, unexpected tax shocks at the time 1. Surprise tax increases for labor and capital incomes are assumed to raise the tax rate from 30% to 31% and surprised tax cuts are assumed to lead to a fall in the tax rate from 30% to 29%. The responses in Figure (7) show how output, labor, and wages are responsive to a 1% increase or a 1% cut in average tax rates.

When the government cuts taxe rates, the DWR constraint is not binding, which implies that a cut in tax rates raises wages. This is because both capital and labor rise after a tax cut, but capital is more elastic to a tax change than labor, resulting in higher wages according to equation (8). In this situation, the economy does not face labor demand shortfalls, implying that households are not exposed to unemployment risks and supply their full labor endowment. In contrast, when the government increases tax rates, the DWR constraint is binding. Wages should have fallen, but due to the DWR constraint, wages do not change. In this situation, the economy faces labor demand shortfalls and firms reduce their demand for labor. Due to the decrease in aggregate labor, output is more responsive to tax increases than tax cuts.

Figure (7) also shows the heterogeneous labor responses to tax increases across income distributions. As I described above, the DWR constraint is not binding following a cut in tax rates. This means that households do not face unemployment risks and provide a full endowment of labor. In contrast, the DWR constraint is binding after a increase in the tax rate. That implies that households face unemployment risks due to the labor demand shortfalls, which vary across income distributions. This is because firms are less likely to hire low-productivity workers than high-productivity workers. Such frim behavior is rationalized by the micro evidence from Guvenen et al. (2017) and is introduced in the model through the γ function. As a result, the response of labor for the bottom 90% is much bigger than the response for the top 10% after a tax increase.

Figure 7: Asymmetric effects of personal income tax changes on economic activity



Note: This figure shows the impacts of a 1% increase and cut in the average tax rate on output, labor, and wages. Blue lines indicate the responses to tax increases and red lines indicate the responses to tax cuts.

5.5.1 The Role of Labor Supply

Labor supply could be an important margin for the effect of tax changes on the economy. There have been many empirical findings that document a relationship between tax changes and labor supply.[20] Although the response of labor supply to tax changes tends to be heterogeneous to tax changes with respect to income, age, and gender, the conventional wisdom is that labor supply elasticities are small for prime-age males. In this paper, the model also does not consider the labor supply that is assumed to be inelastic in response to tax changes. In order to consider the effects of labor supply, I introduce a labor supply decision to the benchmark model but exclude DWR. Without the DWR assumption, I investigate how much the assumption on labor supply affects the magnitude of the effects of tax changes. Specifically, I add the extensive margin of labor decision into the benchmark model following Chang and Kim (2007). The details of the model are described in Appendix E. Figure (15) shows that the responses of output to a 1% cut in average tax rates. The results show that introducing the labor supply does not produce significantly different output responses compared to the benchmark model. It implies that the labor supply response might be a less important margin for tax policies, whereas the large output response following the tax increase is mainly led by the labor demand adjustment.

[20] See, for example, Keane (2011).

5.5.2 The Respective Impacts of Labor and Capital Income Taxes

In the empirical section, this paper studies asymmetry and heterogeneity in the effects of personal income tax changes. Personal income taxes include both labor income taxes and capital income taxes, but it is difficult to analyze each component separately. This is because I simulate tax liability changes from a large sample of the US Federal Individual Income Tax return data, using NBER's TAXIM, which does not compute separate tax liability for labor income and capital income but provides only aggregate tax liability. Therefore, I assume that the model has labor income taxes and capital income taxes, that they have the same average and persistence, and that they move together. In order to provide separate implications for labor income taxes and capital income taxes, which are not implemented in the empirical study, I do two exercises. The first is to shut down changes in capital income taxes, and the second is to shut down changes in labor income taxes. Figure (16) in the Appendix F.1 and Figure (17) in the Appendix F.2 show the impacts on wages, output, and labor in response to labor income taxes and capital income taxes, respectively. Both results are qualitatively consistent with the case of both taxes changing simultaneously, though the magnitude is somewhat smaller than the benchmark case.

6 Conclusion

This paper investigates whether the effects of tax changes are asymmetric on economic activity, depending on the direction of tax changes. I find that the short-run effects of personal income tax changes are asymmetric and heterogeneous. The contractionary effects of tax increases are three times larger than the expansionary effects of tax cutes. And the low-income and middle-income groups are more affected by tax increases than the high-income groups.

A heterogeneous agent model with downward wage rigidities and varying unemployment risks across income distributions rationalizes these empirical findings. The contractionary effects of tax increases are amplified through labor demand shortfalls, and the heterogeneous labor market response across income distributions leads to the distributional effects of tax changes.

The findings of this paper provide the following implication: In the post World War II sample for the US, on average, tax increases tend to be more harmful to the economy relative to the expansionary effects of tax cuts. Also, when governments design tax reforms, policymakers need to carefully take into account heterogeneous labor market responses across income distributions.

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Appendix

Appendix A. Decomposing Tax Measures into Changes in Federal Income Taxes and in Payroll Taxes

Figure 8: Decomposing tax measures into changes in federal income taxes and in payroll taxes

Note: Tax measures are decomposed into changes in federal income taxes and in payroll taxes for each income group. The orange line indicates changes in federal income taxes, the green line indicates changes in payroll taxes, and the blue dashed line shows the tax measures.

Appendix B. Understanding the Dichotomous Specification

Apppendix B.1 Analytical expressions of biased estimators[21]

The regression equation using the dichotomous specification:

$$y_{t+h} = \gamma h + \sum_{i=0}^{h-1} b_i^{+} \varepsilon_{t+h-i}^{1,+} + \sum_{i=0}^{h-1} b_i^{-} \varepsilon_{t+h-i}^{1,} + u_{t+h}, \tag{11}$$

where $\varepsilon_t^{1,+} = max[0, \varepsilon_t^1]$ and $\varepsilon_t^{1,-} = min[0, \varepsilon_t^1]$.

The underlying DGP from equation (2) can be represented in terms of ε_t^1:

$$y_{t+h} = \gamma h + \sum_{i=0}^{h-1} \alpha_i^1 \varepsilon_{t+h-i}^1 + \sum_{i=0}^{h-1} \beta_{i,i}^{1,1} (\varepsilon_{t+h-i}^1)^2 + v_{t+h}. \tag{12}$$

We can rewrite equation (12) in matrix notation as follows:

$$\begin{aligned} Y_h &= X_h B_h + U_h, \\ &= X_h A_h + \Xi_h \beta_{h,h}^{1,1} + V_h, \end{aligned} \tag{13}$$

where $X_h = [1, \varepsilon_h^{1,+}, \varepsilon_h^{1,-}]'$, $B_h = [\gamma h, b_h^{+}, b_h^{-}]$, and $A_h = [\gamma h, \alpha_h^1, \alpha_h^1]$.

Relationship between the OLS estimator $\widehat{B}_h$ and the true coefficient B_h:

$$\begin{aligned} \widehat{B}_h &= (X_h^{'} X_h)^{-1} X_h^{'} Y_h \\ &= A_h (X_h^{'} X_h)^{-1} X_h^{'} \Xi_h \beta_{h,h}^{1,1} + (X_h^{'} X_h)^{-1} X^{'} V. \end{aligned} \tag{14}$$

Taking expection of equation (14) produces

$$E[\widehat{B}_h] = A_h + \beta_{h,h}^{1,1} E[(X_h^{'} X_h)^{-1} X^{'} \Xi_h].$$

The estimation of equation (13) yields a biased estimator depending on $(X_h^{'} X_h)^{-1} X_h^{'} \Xi_h$.

Appendix B.2 Results from the Dichotomous Specification

The dichotomous specification is the most straightforward way of estimating asymmetric impulse responses to macroeconomic shocks, but, unfortunately, Section 3.2 shows that it might not yield a reliable causal effect, causing upward bias on the estimated coefficient. This section examines

[21] I refer to Ben Zeev (2020) to derive analytical expressions of biased estimators from the dichotomous specification.

whether such bias is actually observed by comparing the estimated results from the dichotomous specification to those from the benchmark specification.

To do so, I construct tax increase shocks by replacing negative values of tax measures with zero, and, similiarly, tax cut shocks are constructed by replacing positive values of tax measures with zero. Those censored tax shocks are defined as

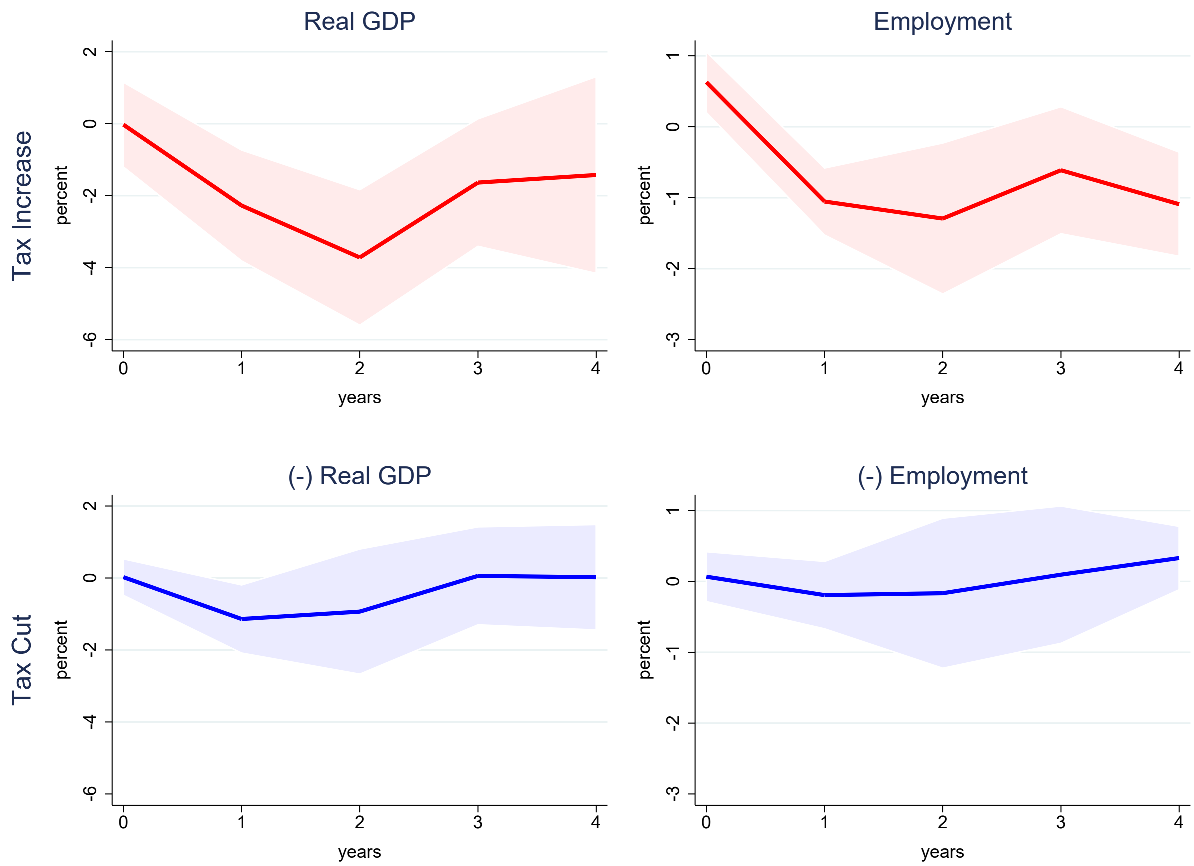
$$T_t^+ = \begin{cases} T_t & \text{if } T_t > 0, \\ 0 & \text{if } T_t \leq 0, \end{cases} \qquad T_t^- = \begin{cases} T_t & \text{if } T_t < 0, \\ 0 & \text{if } T_t \geq 0. \end{cases}$$

With the sign-based tax measures, I run a series of local projection regressions for different horizons $h \in \{0, 1, ..., 4\}$:

$$y_{t+h} - y_{t-1} = \alpha_h^+ T_t^+ + \alpha_h^- T_t^- + \psi_h Z_t + \varepsilon_t, \tag{15}$$

where y_{t+h} and Z are the same as the benchmark specification of equation (1); T_t^+ and T_t^- are tax increase shocks and tax cut shocks, respectively. The path of economic activity around the tax shocks is described by the sequences of coefficients $\{\alpha_h^+\}_{h=0}^{h=4}$ and $\{\alpha_h^-\}_{h=0}^{h=4}$.

Figure 9: The impact of tax increases and tax cuts on the economic activities with the sign-based tax measures

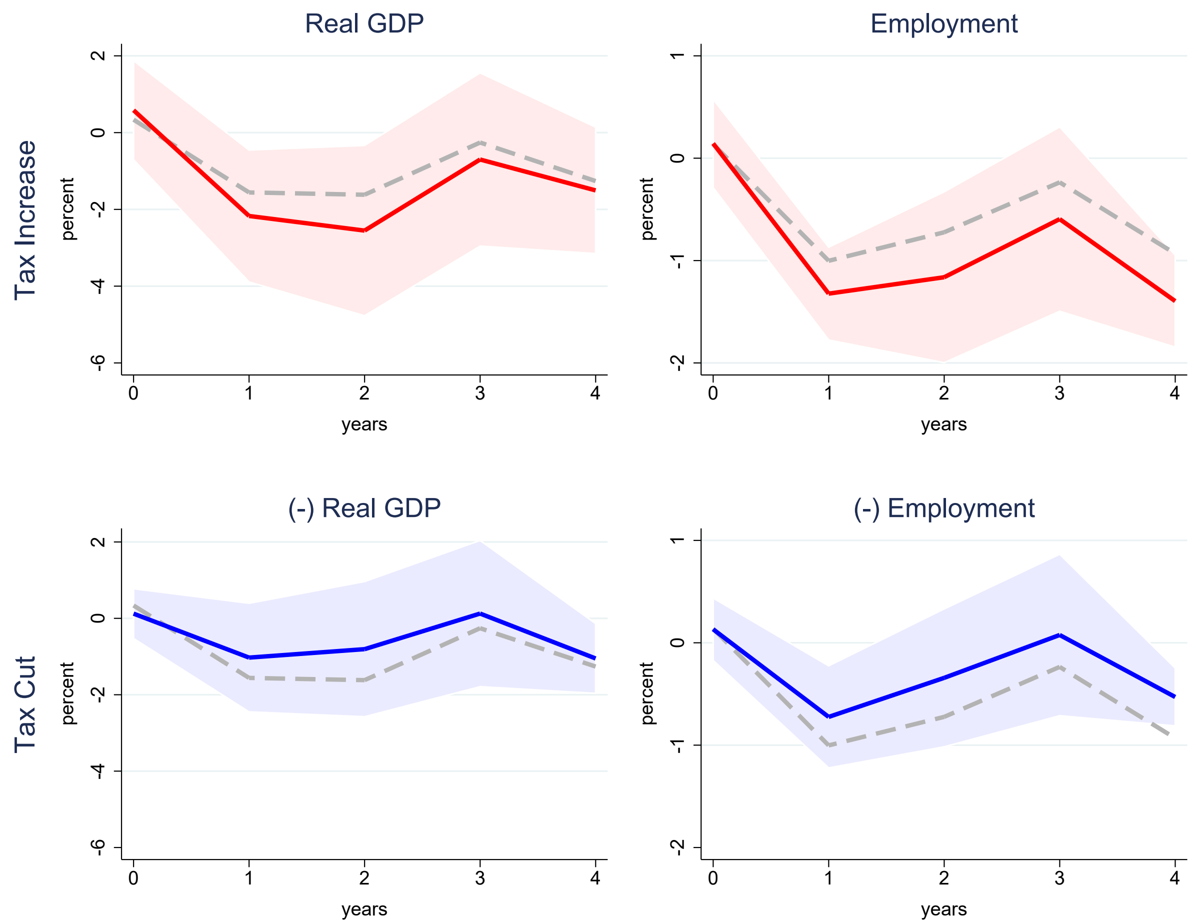


Note: Tax measures are constructed as tax liability changes as a share of taxable income. The figure plots the estimates from the equation (15) for the impact of tax increases in year h, $\{\alpha_h^+\}_{h=0}^{h=4}$, for the impact of tax cuts, $\{\alpha_h^-\}_{h=0}^{h=4}$. For comparison purposes, the responses of tax cuts are multiplied by -1. Standard errors are HAC stadard error from Newey and West (1987); 90 percent confidence bands are shown as shaded areas. The sample period is 1966-2007.

Appendix C Robustness Check for the empirical evidence

Apppendix C.1 Eliminating Anticipated Tax Reforms

Figure 10: Eliminating anticipated tax reforms



Note: This figure shows impacts of a 1% increase and cut in the average tax rate on real GDP and employment with the elimination of anticipated tax measures following Mertens and Montiel Olea (2018). Specifically, the figure plots the estimates from the baseline specification of equation (1) for the impact of tax increases in year h, $\{\widehat{\alpha}_h^{All} + \widehat{\beta}_h^{All}\}_{h=0}^{h=4}$, for the impact of tax cuts, $\{\widehat{\alpha}_h^{All} - \widehat{\beta}_h^{All}\}_{h=0}^{h=4}$. The control variables are a 1 lag of each of the following variables; government spending; the federal funds rate; and inflation. The regression also includes contemporaneous corporate tax rate and government transfers as well as a 1 lag of them. Top panels show responses of tax increases with a red line, and bottom panels show responses of tax cuts with a blue line. For a display purpose, the responses of tax cuts are multiplied by -1. Standard errors are HAC stadard error from Newey and West (1987); 90 percent confidence bands are shown as shaded areas. The dashed gray lines are the linear effect of tax changes. The sample period is 1966-2007.

Apppendix C.2 Alternative Econometric Methodology: Kilian and Vigfusson (2011)

Procedures for how to construct impulse response and standard errors:

1. Estimate the following regression equation for each type of tax changes. Collect the estimated coeffcients and the residuals ε_t:

$$\Delta y_t = \alpha + \sum_{p=0}^{M} \beta^{+} \Delta T_{t-p}^{+} + \sum_{p=0}^{M} \beta^{-} \Delta T_{t-p}^{-} + \sum_{l=0}^{L} \beta_l \Delta y_{t-l} + \varepsilon_t, \tag{16}$$

   where Δy_t growth rate of real GDP, $\Delta T_t^{+} = max(\Delta T_t, 0)$ and $\Delta T_t^{-} = min(\Delta T_t, 0)$.

2. Pick a history, Ω_{t-1}^{i}, which consists of a block of M consecutive values of ΔT_t^{+} and ΔT_t^{-}. These are actual values from the data series on these two variables. The values drawn for both changes should be for the same dates.

3. Choose a sequence of H tax increases and tax decreases from the series on these variables with replacement. Also choose a sequence of H values of the residual ε_t with replacement from the residuals collected after the initial estimation.

4. Using the history, Ω_{t-1}^{i}, and the sequence of changes, simulate H values of y_t. These values are simulated by using equation (16). Call this time path y_{t+j}^{ns}, $j = 1, 2, ..., H$.

5. Now repeat step 4 with one change. In the sequence of tax increases and tax decreases, replace the first value of either of the two tax changes by a constant value δ. If the underlying idea is to study how a tax increase affects output growth, then T_{t+1}^{+} will be set equal to δ. Values of all T_{t+1}^{+} such that $j = 2, 3, ..., H$, estimate the time path of y_t for this new sequence of tax changes and call it y_{t+j}^{s}, where $j = 1, 2, ..., H$.

6. Take the difference of the two simulated paths. Repeat steps 3 through 5 N times and collect N such series. Average the resulting series to obtain the impulse response of y_t to a tax change of size of δ conditional on history Ω_{t-1}^{i}. This impulse response of y_t can be represented as

$$IRF(h, \delta, \Omega_{t-1}^{i}) = \frac{\sum_{k=1}^{N} y_t^{s}(h, \delta, \Omega_{t-1}^{i}, k) - y_t^{ns}(h, \Omega_{t-1}^{i}, k)}{N},$$

   where $y_t^{ns}(h, \Omega_{t-1}^{i}, k)$ represents the computed value of y_t from step 4 at h-th horizon. $y_t^{s}(h, \delta, \Omega_{t-1}^{i}, k)$ represnets the estimated value of y_t from step 5 at h-th, $h = 1, 2, ..., H$ horizon after a tax change of size δ for history Ω_{t-1}^{i} selected in step 2. $k = 1, 2, ..., N$ such values are computed through steps 4 and 5.

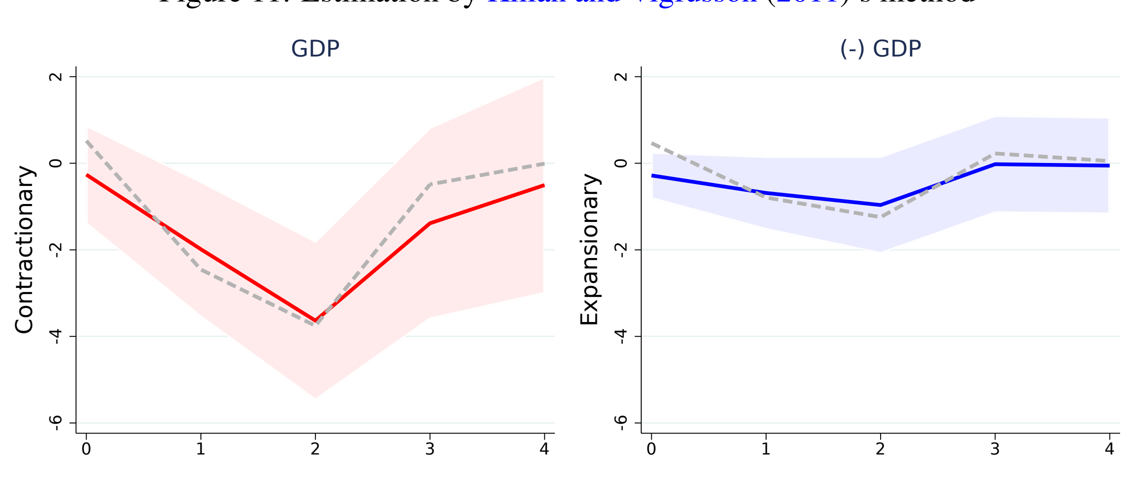
7. Finally, average $IRF(h, \delta, \Omega_{t-1}^i)$ over all histories to obtain the non-linear impulse response of y_t to a tax change of size of δ. This impulse response can be represneted as

$$IRF(h, \delta) = \int IRF(h, \delta, \Omega_{t-1}^i) d\Omega^i.$$

Following Kilian and Vigfusson (2011), we assign equal weights to each history and therefore, the above is simply an arithmeric average.

8. Residuals from the estimated dynamic regression models involving daily, weekly, and monthly data exhibit a strong evidence of conditional heteroskedasticity. Therefore, standard errors based on the standard residual-based bootstrapped method may be invalidated in the presence of such heteroskedasticity. To guard against the presence of heteroskedasticity, I follow the wild bootstrap methodology as proposed by Gonçalves and Kilian (2004). In particular, I use wild bootstrap M times to compute standard errors for the computed impulse responses by repeating steps 1–7 for each bootstrapped data set. I then use these standard errors to construct 68% confidence intervals.

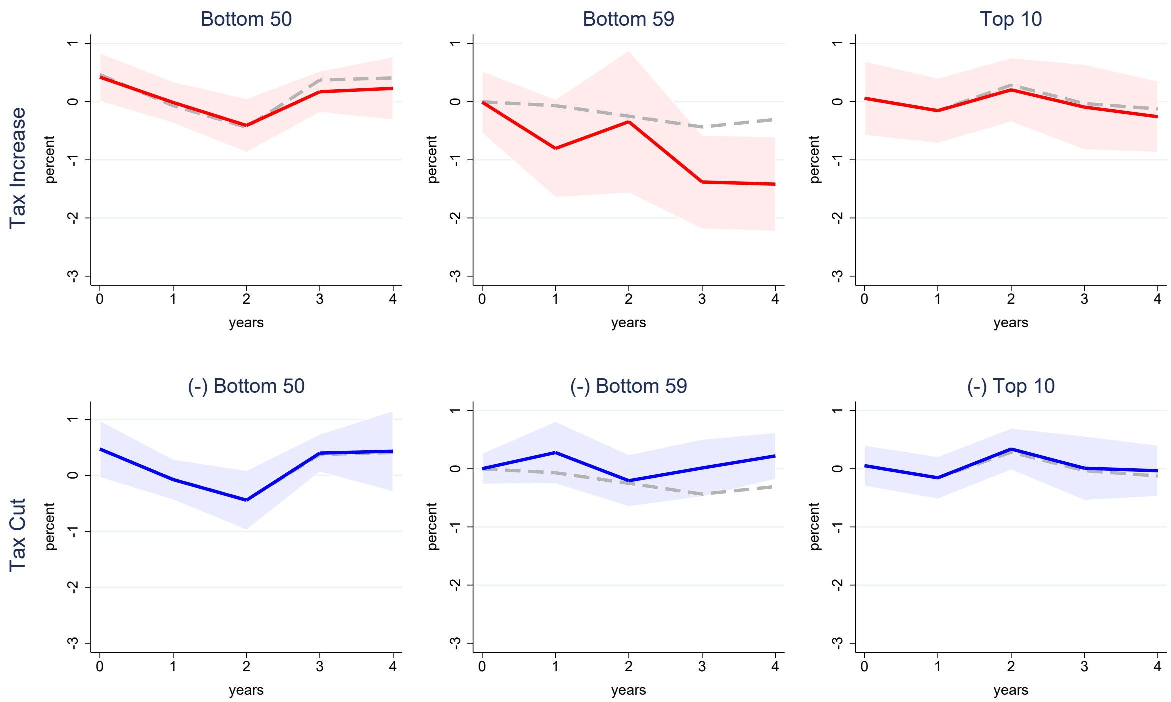
Figure 11: Estimation by Kilian and Vigfusson (2011)'s method



Note: This figure shows impacts of a 1% increase and cut in the average tax rate on real GDP and employment following Kilian and Vigfusson (2011)'s methodology. The red line denotes the response of tax increases and the blue line denotes the response of tax cuts. For a display purpose, the responses of tax cuts are multiplied by -1. 68 percent confidence bands are shown as shaded areas. The dashed gray lines are the responses from the benchmark results. The sample period is 1966-2007.

Apppendix C.3 More Segmented Income Groups

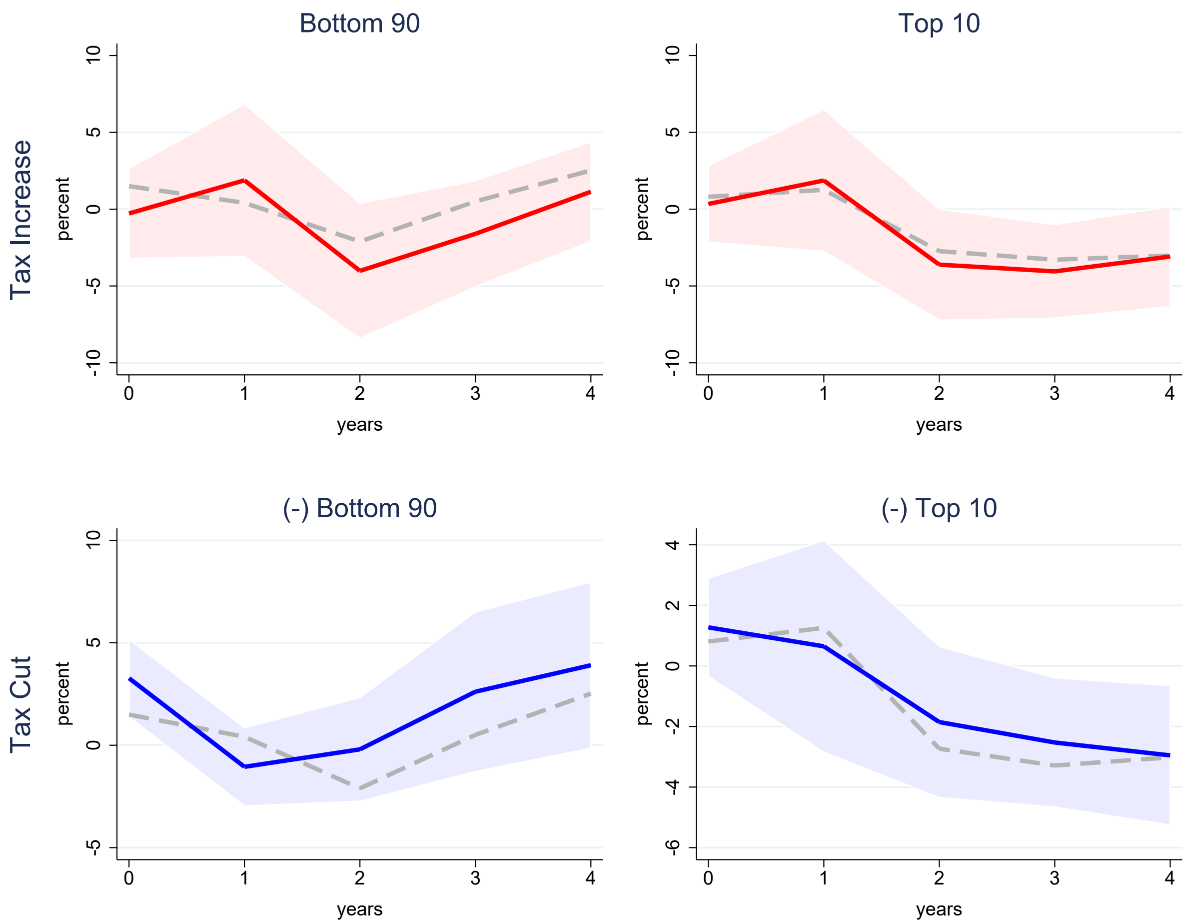
Figure 12: More Segmented Income Groups



Note: This figure shows impacts of a 1% increase and cut in the average tax rate on employment by income groups which are classified as the bottom 50%, bottom 50-90%, and top 10%. Specifically, the figure plots the estimates from the baseline specification of equation (1) for the impact of tax increases in year h, $\{\widehat{\alpha}_h^{All} + \widehat{\beta}_h^{All}\}_{h=0}^{h=4}$, for the impact of tax cuts, $\{\widehat{\alpha}_h^{All} - \widehat{\beta}_h^{All}\}_{h=0}^{h=4}$. The control variables are a 1 lag of each of the following variables; government spending; the federal funds rate; and inflation. The regression also includes contemporaneous corporate tax rate and government transfers as well as a 1 lag of them. Top panels show responses of tax increases with a red line, and bottom panels show responses of tax cuts with a blue line. For a display purpose, the responses of tax cuts are multiplied by -1. Standard errors are HAC stadard error from Newey and West (1987); 90 percent confidence bands are shown as shaded areas. The dashed gray lines are the linear effect of tax changes. The sample period is 1966-2007.

Apppendix C.4 Effects on Tax Liability

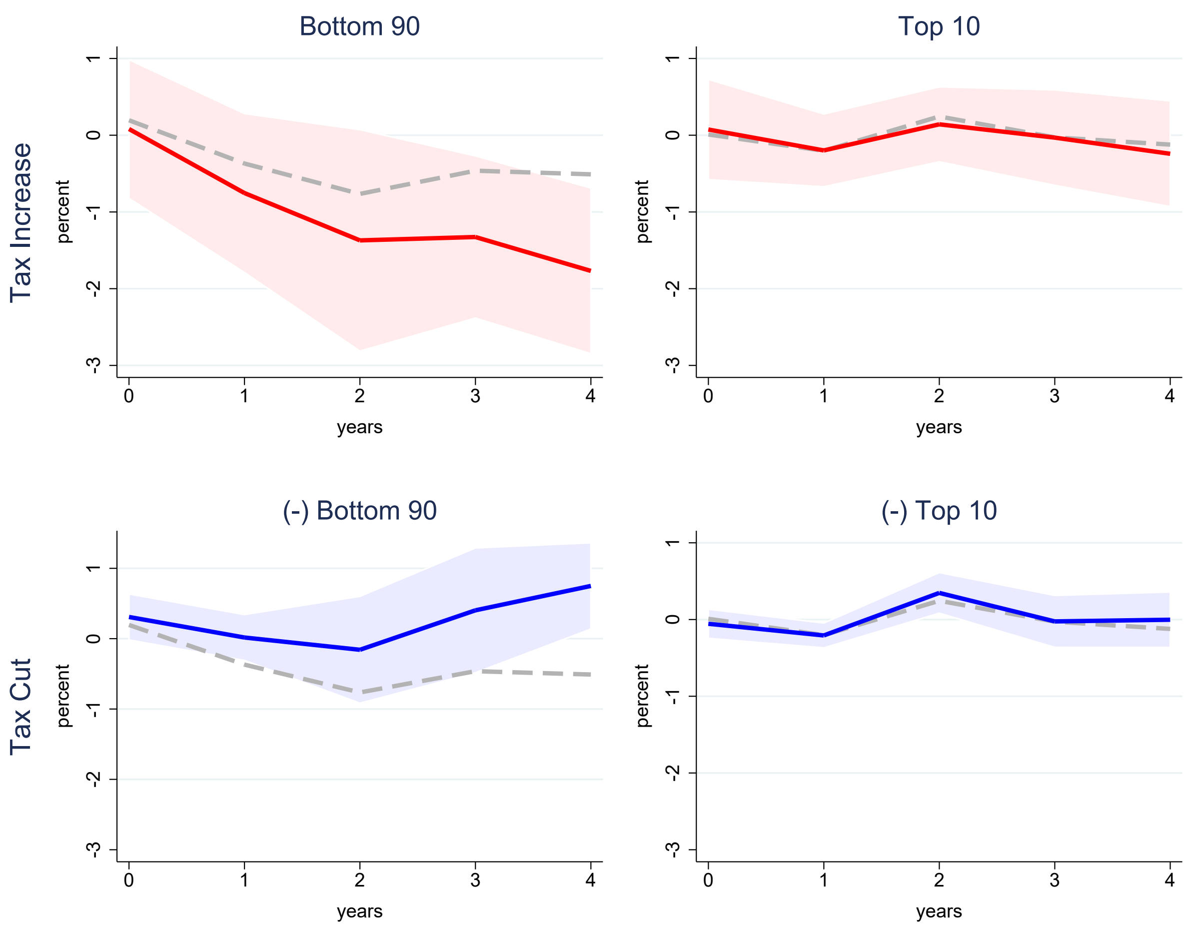
Figure 13: Effects on Tax Liability



Note: This figure shows impacts of a 1% increase and cut in the average tax rate on tax revenues. Specifically, the figure plots the estimates from the baseline specification of equation (1) for the impact of tax increases in year h, $\{\widehat{\alpha}_h^{All} + \widehat{\beta}_h^{All}\}_{h=0}^{h=4}$, for the impact of tax cuts, $\{\widehat{\alpha}_h^{All} - \widehat{\beta}_h^{All}\}_{h=0}^{h=4}$. The control variables are a 1 lag of each of the following variables; government spending; the federal funds rate; and inflation. The regression also includes contemporaneous corporate tax rate and government transfers as well as a 1 lag of them. Top panels show responses of tax increases with a red line, and bottom panels show responses of tax cuts with a blue line. For a display purpose, the responses of tax cuts are multiplied by -1. Standard errors are HAC stadard error from Newey and West (1987); 90 percent confidence bands are shown as shaded areas. The dashed gray lines are the linear effect of tax changes. The sample period is 1966-2007.

Apppendix C.5 Normalization of Tax Measures

Figure 14: Normalization of Tax Measures



Note: This figure shows impacts of a 1% increase and cut in the average tax rate on employment by income groups after normalizing tax measures. Specifically, the figure plots the estimates from the baseline specification of equation (1) for the impact of tax increases in year h, $\{\widehat{\alpha}_h^{All}+\widehat{\beta}_h^{All}\}_{h=0}^{h=4}$, for the impact of tax cuts, $\{\widehat{\alpha}_h^{All}-\widehat{\beta}_h^{All}\}_{h=0}^{h=4}$. The control variables are a 1 lag of each of the following variables; government spending; the federal funds rate; and inflation. The regression also includes contemporaneous corporate tax rate and government transfers as well as a 1 lag of them. Top panels show responses of tax increases with a red line, and bottom panels show responses of tax cuts with a blue line. For a display purpose, the responses of tax cuts are multiplied by -1. Standard errors are HAC stadard error from Newey and West (1987); 95 percent confidence bands are shown as shaded areas. The dashed gray lines are the linear effect of tax changes. The sample period is 1966-2007.

Appendix D Steady State Solution and Transition Computation

Apppendix D.1 Steady State

To solve for the steady state of the economy, I need to find wage w and interest rate r. I describe how to this.

1. Set grids for assets a and productivity levels x. Let N_a and N_x be the number of points in each grid, respectively. Compute the transition matrix of productivities $\pi(x,x')$ uisng Tauchen (1986) method.

2. Guess K/L. With (8) and (9), compute w and r.

3. Solve for household policies by value function iteration. For a given guess, solve for the following Bellam equation.[22]

$$\begin{aligned}\widehat{V}(a_{it},x_{it}) = \max_{c_{it},a_{it+1}} &\{log\, c_{it} + \beta E[V(a_{it+1},x_{it+1}) \mid x_{it}]\} \\ s.t. c_{it} + a_{it+1} &= a_{it} + (1-\tau_{Lt}) z_{it}(x_{it}, L_t) + (1-\tau_{Kt}) r_t a_{it} \\ a_{it+1} &\geq \underline{a},\end{aligned}$$

   iterate until $||\widehat{V} - V|| < \varepsilon^V$. I use $\varepsilon^V = 1e-10$.

4. Compute the stationary measure implied by the optimal policies of step 3. For a given guess $\mu(a,x,)$, compute implies measure $\widehat{\mu}(a,x)$ as

$$\widehat{\mu}(a_{i'},x_{j'}) = \sum_{i=1}^{N_a}\sum_{j=1}^{N_x} \mathbb{L}\{a_{i'} = a'(a_i,x_j,)\}\pi_x(x_{j'},x_j)\mu(a_i,x_j),$$

   where $\mathbb{L}$ computes a linear interpolation: $\mathbb{L}(a_i,a') = \mathbb{I}(a' \in (a_{i-1},a_i])\frac{a'-a_{i-1}}{a_i-a_{i-1}}$. Iterate until $||\widehat{\mu} - \mu|| < \varepsilon^{\mu}$. I use $\varepsilon^{\mu} = 1e-10$.

5. Compute $\widehat{K/L}$ and compare with the guess K/L. Iterate until $||\widehat{K/L} - K/L|| < \varepsilon^{KL}$. I use $\varepsilon^{KL} = 1e-8$.

Apppendix D.2 Transition

I solve for the transition using a shooting algorithm. I assume that the economy returns to its steady state T periods after tax shocks. During the transition, I know the path $\{\tau_{Lt}, \tau_{Kt}\}_{t=1}^{T}$. And I also

[22] I put more grids for smaller values of a. And I use the value function iteration with a cubic interpolation and the Golden Section Search for optimazation.

know that the value function at $t = T$ is equal to its steady state value $V_T(a,x,) = V(a,x)$ and that the measure at time $t = 1$ is equal to the steady state value $\mu_1(a,x) = \mu(a,x)$. Given a guess for the capital-to-labor ratio $\{K_t/L_t\}_{t=1}^T$, compute $\{w_t,r_t\}_{t=1}^T$ such that $(w_T,r_T) = (w,r)$. I solve the household problem backwards and iterate on the suquence $\{w_t,r_t\}_{t=1}^T$ to clear markets. Then, using the policy functions from the backward induction, the economy can be simulated forward. Modify and iterate until convergence. To be specific, the details are as follows:

1. For computing the transition, import the value functions and decision rules for both the initial state and the terminal state from the steady state calculation above.[23] Also import the invariant distribution μ at both the initial state and the terminal state.

2. Guess the time series of K_t/L_t for $t = 1,2,...,T$, where $t = 1$ is the period when the unexpected change in τ_L and τ_K happend and $t = T$ is sufficiently far in future so that I can assume that by the time T the economy is sufficiently close to the steady state. From the guess for K_t/L_t, compute w_t and r_t using (8) and (9). Assume that at $t = T+1$, the economy is in the steady state. From there, with backward induction, the value functions and the policy functions for $t = 1,...,T$ can be solved. That is, given the value function $V_{t+1}(a,x)$ in period $t+1$, solve for period t's value as

$$V(a_{it},x_{it}) = \max_{c_{it},a_{it+1}} \{log\, c_{it} + \beta E[V(a_{it+1},x_{it+1}) \mid x_{it}]\}$$
$$s.t. c_{it} + a_{it+1} = a_{it} + (1-\tau_{Lt})z_{it}(x_{it},L_t) + (1-\tau_{Kt})r_t a_{it}$$
$$a_{it+1} \geq \underline{a},$$

   As terminal condition, use $V_T(a,x) = V(a,x)$.

3. Compute the time $t+1$ measure using the household's policies of step2. Given $\mu_t(a,x)$, compute $t+1$ measure as

$$\mu(a_{i'},x_{j'}) = \sum_{i=1}^{N_a}\sum_{j=1}^{N_x} \mathbb{L}\{a_{i'} = a'(a_i,x_j,)\}\pi_x(x_{j'},x_j)\mu(a_i,x_j).$$

   Use $\mu_1(a,x) = \mu(a,x)$ as initial condition.

4. Using the policy function and measure, Compute $\{\widehat{K_t/L_t}\}_{t=1}^T$ and compare with the guess $\{K_t/L_t\}_{t=1}^T$. Iterate until $||\widehat{K/L} - K/L|| < \varepsilon^{KL}$.

In the case of DWR, solving for the transition is a little different because the wage is fixed at the steady state level by the assumption from (6): $w_t = w$ for $t = 1,2,...,T$. Guess the time series of

[23] In this paper, the initial state is the same as the terminal state because tax shocks are transitory

K_t for $t = 1, 2, ..., T$ instead of K_t/L_t. Then, L_t is determined by w_t and K_t based on the equation (8): $L_t = K_t(\frac{\alpha}{w_t})^{\frac{1}{1-\alpha}}$ for $t = 1, 2, ..., T$. The remaining procedure is the same as the above. Compute $\{\widehat{K}_t\}_{t=1}^T$ and compare with the guess $\{K_t\}_{t=1}^T$. Iterate until $||\widehat{K} - K|| < \varepsilon^K$. I use $\varepsilon^K = 1e-8$.

Appendix E A Heterogeneous Agent Model with Labor Supply

To examine a role of labor supply, I introduce a heterogeneous agent model by incorporating labor supply decision. I consider a population of infiitely-lived households who decide how much to consume c and save for the next period a'. Households face idiosyncratic labor productivity shocks. The labor productivity $x \in \{x_1, x_2, ..., x_{N_x}\}$ follows a Markov chain with transition probabilities $\{\pi_{ij}\}_{i,j=1}^{N_x}$, where $\pi_{i,j} \equiv Pr(x'_j \mid x_i)$. Households cannot issuse any assets contingent on their future idiosyncratic risks x, and they are only allowed to trade a one-period real risk-free bond to self-insure, subject to a borrowing constraint $a' \geq 0$ (Huggett, 1993; Aiyagari, 1994). Labor supply is endogenous at the extensive margin: households can either work h or zero (Chang and Kim, 2007). Households take the wage rate per efficiency unit of labor w and the real interest rate r, which are given by the competitive factor market. Households also take as given the labor income tax τ_L and capital tax τ_K.

The value function for an employed household, $V^E(a, x_i)$, is defined as:

$$
\begin{aligned}
V^E(a,x_i) \quad &= \quad \max_{c,a'} \left\{ log\, c - Bh + \beta \sum_{j=1}^{N_x} \pi_{ij} V(a', x'_j) \right\} \\
s.t. \quad & \quad c + a' = a + (1-\tau_L) w x_i h + (1-\tau_K) r a \\
& \quad a' \geq 0 \\
& \quad h \in \{\overline{h}, 0\}.
\end{aligned}
$$

The value function for a non-employed household, $V^N(a, x_i)$, is defined as:

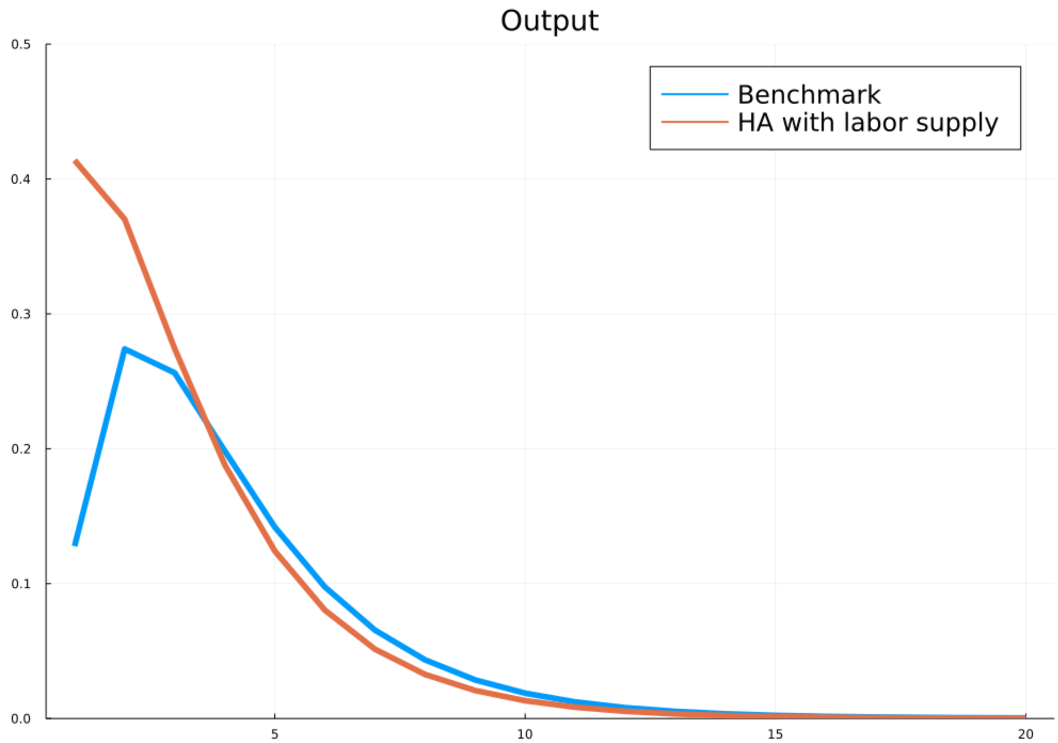
$$
\begin{aligned}
V^N(a,x_i) \quad &= \quad \max_{c,a'} \left\{ log\, c + \beta \sum_{j=1}^{N_x} \pi_{ij} V(a', x'_j) \right\} \\
s.t. \quad & \quad c + a' = a + (1-\tau_K) r a \\
& \quad a' \geq 0.
\end{aligned}
$$

Then, the employment decision problem of households is given by:

$$
V(a,x_i) \quad = \quad \max_{H \in \{0,h\}} \left\{ V^E(a,x_i), V^N(a,x_i) \right\}.
$$

Other features of the model is the same as the benchmark model.

Figure 15: A heterogeneous agent model with labor supply

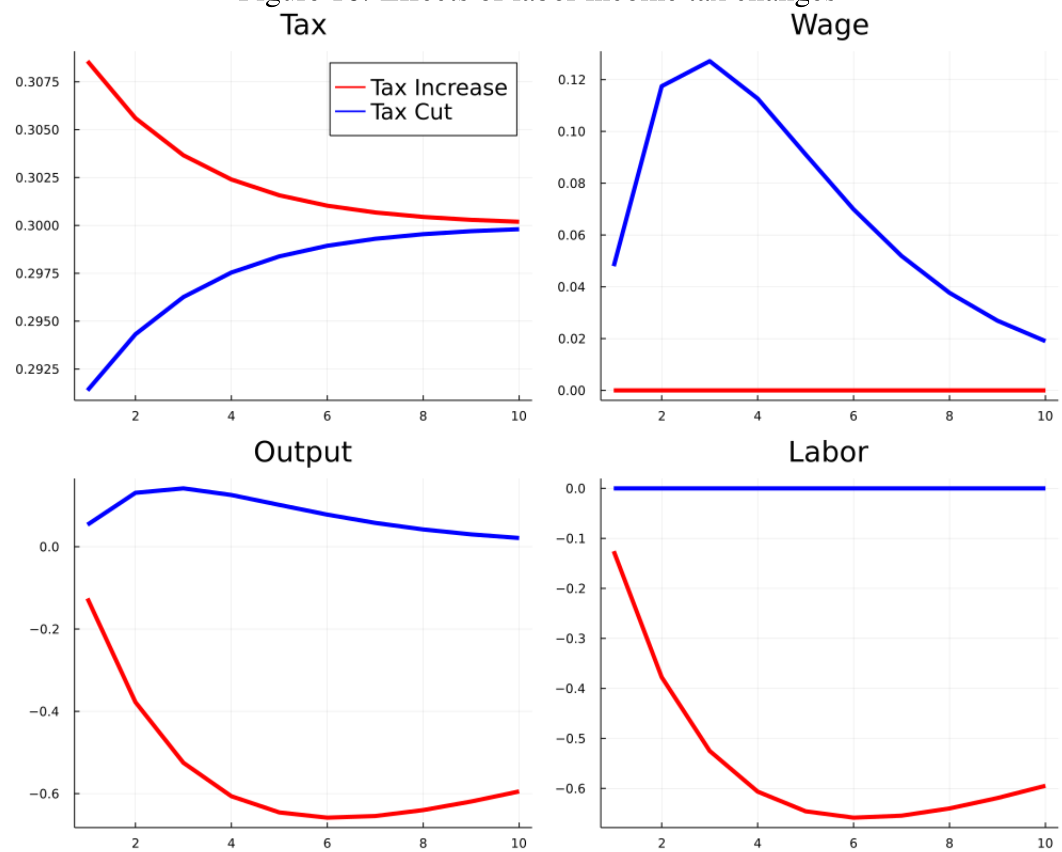


Note: This figure shows responses of output to a 1% cut in average tax rates. The blue line shows the result from the benchmark model, and the orange line shows the result from the heterogeneous agent modle with labor supply.

Appendix F Decomposing Effects of Labor and Capital Income Tax

Appendix F.1 Effects of Labor Income Tax Changes

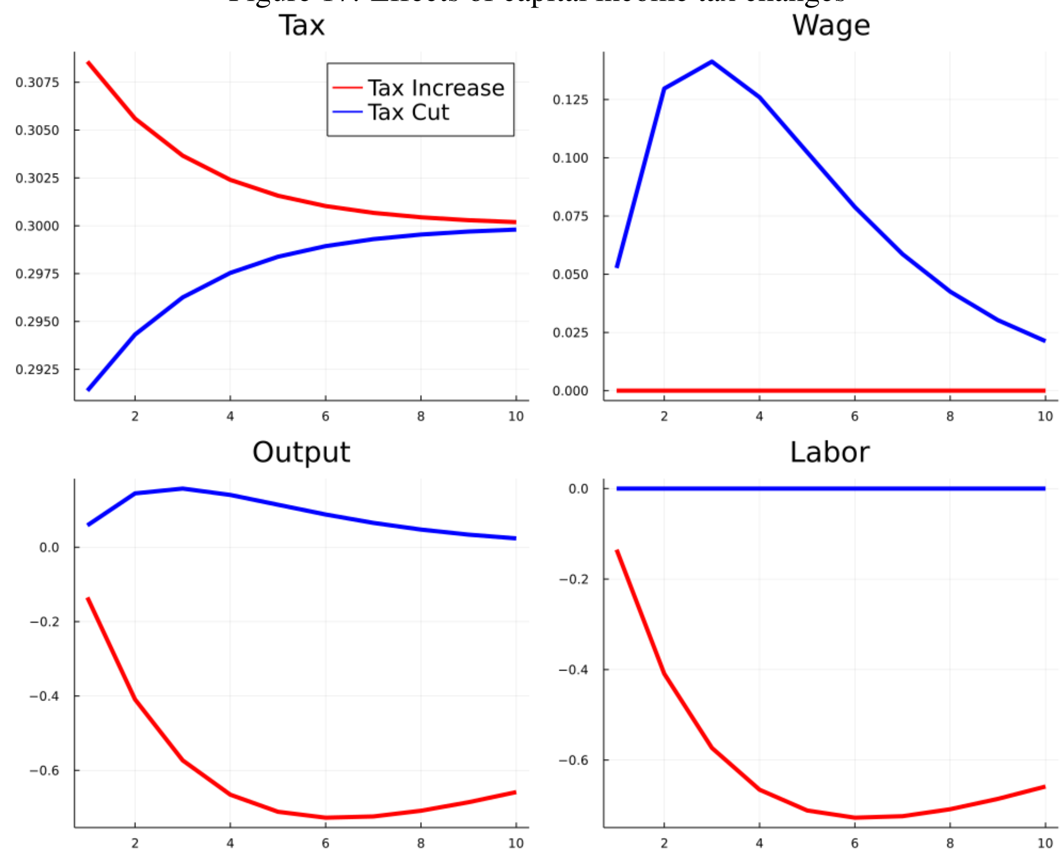
Figure 16: Effects of labor income tax changes



Note: This figure shows impacts of a 1% increase and cut in the average labor income tax rate on output, labor, and wage. Blue lines indicate the responses to tax increases and red lines the responses to tax cuts.

Appendix F.2 Effects of Capital Income Tax Changes

Figure 17: Effects of capital income tax changes



Note: This figure shows impacts of a 1% increase and cut in the average capital income tax rate on output, labor, and wage. Blue lines indicate the responses to tax increases and red lines the responses to tax cuts.