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Asymmetric Effects of Exogenous Tax Changes*

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Abstract

We study whether output responds symmetrically to tax increases and decreases in postwar US data, using the identification strategy in Romer and Romer (2010). We find evidence of important asymmetries: the output response to a tax increase is statistically insignificant, but output shows a significantly positive and permanent increase following a tax decrease. We show that this asymmetry appears to be driven by individual-income tax changes, and is transmitted to the economy through asymmetric response in aggregate consumption to tax increases and tax decreases. We also present a simple model that rationalizes our empirical findings, and illustrates how asymmetric output and consumption responses to sign-based tax changes can be generated by plausible consumption-adjustment costs.

Keywords: Tax Changes, Asymmetric Responses, Non-linear Impulse Responses

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1. Introduction

Understanding how tax changes affect aggregate economic activity is central to fiscal policy analysis. As a result, a large literature has studied how tax changes affect economic variables such as output, investment, consumption and labor supply.[1] However, it is common in this literature to assume that the effects of tax changes are symmetric, i.e., tax increases and tax decreases have essentially equal but opposite effects on aggregate economic variables. In this paper, we test and reject the hypothesis of a symmetric response of output to sign-based tax changes. We also study possible channels for this asymmetry. In particular, we find that there is an asymmetric response of consumption, and not investment, to sign-based tax changes, suggesting a possible transmission mechanism driving the asymmetric output response. Finally, we provide a way to rationalize our empirical findings, by showing how asymmetric effects of sign-based tax changes can result from asymmetric consumption-adjustment costs in an otherwise standard dynamic stochastic general equilibrium (DSGE) model.

The fundamental challenge in identifying the effect of tax changes on economic activity is that a tax policy can change in response to economic conditions, so that the explanatory variable of interest is generally endogenous. To mitigate these endogeneity concerns, we use the exogenous tax changes identified via a narrative approach by Romer and Romer (2010) (henceforth R & R). We categorize the exogenous tax changes in R & R, measured as the change in tax liabilities relative to GDP, based on their sign: *Tax increase* if the tax liabilities rise and *Tax decrease* if the tax liabilities reduce.

Empirical investigation of the hypothesis of symmetry of exogenous tax increase and decrease on macroeconomic variables is further prone to two additional challenges. First, the underlying data generating process is unknown and therefore a misspecified model may render parameter estimates inconsistent. Second, linear impulse responses (which are simply linear combinations of estimated coefficients of the model) are unable to isolate asymmetric responses that are driven by reasons other than the sign of tax changes (such as history and size of the tax changes). Therefore, one needs to depart from linear impulse responses which in our context are known to bias the dynamics of the variable of interest (Gallant et al., 1993; Koop et al., 1996). Following the methodology proposed by Kilian and Vigfusson (2011) we account for these challenges: we use a non-linear regression model that encompasses all specifications and therefore provides consistent estimates regardless of whether the true data generating process is symmetric and regardless of the precise form of asymmetry. We also

[1] See Romer and Romer (2010) for more details and references therein.

compute non-linear impulse responses which account for both the size and the history of tax changes.

In particular, we regress real output growth on contemporaneous and lagged measures of both tax increases and tax decreases, and lagged observations of output growth. For computation of impulse responses in our non-linear specification, we allow for full history and magnitude of both tax increases and decreases to affect output to correctly compute history and magnitude dependent non-linear impulse responses. These responses are computed using a three step procedure. The first step estimates and stores the coefficient and residuals from our regression. In the second step, a random consecutive series of a specified length of tax increases and decreases are drawn from the data which in combination with the information from first step is used to simulate a history dependent path of output. The last step then repeats the second step, with one change: the first observation in the randomly drawn tax change series is changed to a constant and a new path of output is simulated in this step. The magnitude of the constant accounts for the size of the change that hits the system. The difference between the two simulated series provides the impulse response of output to some constant shock size and a common history of tax changes. Repeating this process with various possible histories and sizes of the tax changes and averaging across such difference in the dynamic paths of output then accounts for all possible histories and size of the tax changes – both of which are well known to matter for the dynamics of the variable of interest especially in the asymmetric model.

Using the specification and procedure described, our baseline result establishes a significant asymmetric response of output to sign-based unanticipated tax changes. In particular, output increases significantly in response to an unanticipated tax cuts, whereas the output response to an unanticipated tax increase is insignificant. Formal tests reject symmetry. Our results therefore suggest that policy makers should be cautious in assuming that the effects of sign-based tax changes are symmetric.

To understand the transmission mechanism behind asymmetric output responses to sign-based tax changes, we augment our empirical analysis in two ways. First, following Mertens and Ravn (2013) we classify the R & R exogenous tax changes into individual-income tax changes and corporate-income tax changes. We find evidence for asymmetric effects on output only for individual-income tax changes, whereas corporate-income tax changes have symmetric effects on output. Second, we investigate how aggregate consumption, labor and investment respond to these sign-based tax changes, and find that consumption and labor have asymmetric responses whereas investment responds symmetrically. In particular, consumption does not decrease after a tax increase, whereas the labor supply does not adjust downwards in response to a tax cut. Our analysis therefore indicates that asymmetric responses in output are driven primarily by asymmetric responses in aggregate consumption and labor decisions to sign-based tax changes.

Finally, we show that our empirical results can be rationalized in a simple DSGE model where households face asymmetric consumption-adjustment costs. Such adjustment costs could be due to non-psychological factors such as pre-commitment to existing consumption plans (e.g., housing, phone contracts, insurance, education). With such adjustment costs household's ability to adjust consumption downwards is limited, and they instead adjust their labor supply in response to tax increase. As a result, aggregate output does not fall in response to a tax increase, but increases significantly after a tax cut (exhibiting the asymmetric responses to sign-based tax changes in our empirical analysis).

A number of previous studies have looked at the effects of tax changes on output without taking into account possible sign-based asymmetries. Blanchard and Perotti (2002) use a structural vector autoregression (VAR) approach and institutional information on changes in fiscal policy, and estimate a fiscal policy multiplier for output of approximately 1%.[2] Romer and Romer (2010) use narrative records to document all post-war US-legislated tax changes and divide them into endogenous and exogenous tax changes based on the motivation for each tax bill. They estimate a much larger elasticity of output (of about 3%) with respect to tax changes.[3] Mertens and Ravn (2011) use narrative tax changes and distinguish between unanticipated and anticipated changes in tax liabilities. Using a VAR approach, they estimate that an unanticipated tax cut gives rise to a significant increase in output, consumption, and investment. In particular, a 1% tax cut is associated with a 2% peak increase in output per capita. Our estimate for the effect of a tax decrease on output lies between these previous estimates, while we find no significant effects of a tax increase on output.

Our methodological approach to determine possible asymmetric effects is similar to various studies in the literature on asymmetric effects of monetary policy, such as Ravn and Sola (2004) and Cover (1992). By comparison, the literature studying asymmetric effects of tax changes is limited, and primarily concentrates on state-dependent effects of fiscal changes. For example, Auerbach and Gorodnichenko (2012) use a regime-switching model to show fiscal policy is more effective in recessions than in expansions. Fazzari et al. (2015)

[2]Blanchard and Perotti (2002) explain the small multiplier through opposite effects observed for different components of output: private consumption rises while exports and imports fall and investment crowds out because of an increase in spending.

[3]The authors suggests that a strong negative response of investment is the primary explanation for the large negative output responses to a tax change.

use input utilization as the switching variable in a regime-switching model, and find that government-spending changes have larger effects when the economy has a high degree of under-utilized resources. Hooker and Knetter (1997) utilize state-year panel data to show that a large negative change to military spending has a bigger effect on employment than the effect of a positive change to military spending. Overall, the non-linearity of variables of interest documented in this existing literature is due to state-dependence of fiscal policies. In contrast, our main focus is on the non-linearity in output responses to sign-based tax changes, and the potential channels driving this non-linearity.

Romer and Romer (2010) study whether the motivation of tax changes as "deficit-driven" or "long-run driven" has a differential effect on economic activity. Since deficit-driven tax changes consist mostly of tax increases, and long-run driven tax changes consist mostly of tax decreases, their categorization results in a tax-change series that overlaps considerably with ours. However, our categorization of tax changes based on signs, and our analysis of the transmission mechanism of asymmetric responses of output, highlight different behavioral implications of tax policy than under a categorization based on the motivation of tax changes.

More recently, Jones et al. (2015) independently explore a similar question. While they obtain broadly similar baseline results for output, our empirical approach and results are different from theirs in important ways. First, we compute non-linear impulse responses, while Jones et al. (2015) compute standard linear impulse responses. We favor the non-linear approach because Kilian and Vigfusson (2011) show that linear impulse responses do not control for the history and magnitude of shocks to a dynamic system. While the linear approach to compute impulse responses is common in the applied literature, studying the hypothesis of symmetry using such an approach can be misleading. For example, in the context of R & R's post-war US tax change data, it is crucial to account for the size of the tax-change because on average tax cuts (in R & R data) are substantially larger than the tax increase. Linear impulse responses, therefore may systematically overestimate the effect of tax cut (versus tax increase). Results based on such analysis may appear as sign-based asymmetry but in fact is size-based asymmetry. Such biases can be eliminated if we control for the magnitude of the sign-based tax changes.[4] These biases are seen most clearly when we compare our results with Jones et al.'s baseline results for the output effect of R & R tax changes without controlling for anticipatory effect, and the effect of tax changes on investment: while Jones et al.'s results suggest that these are both significantly asymmetric, our analysis based on the non-linear approach can not reject symmetry in these

[4]Similar argument is valid for the history of tax change. Failure to control for the history of tax changes can also bias the results. See Kilian and Vigfusson (2011) for more details.

cases.[5] Instead, we find significant asymmetries only for the output following unanticipated tax changes, and consistently find that investment responds symmetrically to tax changes. Our results therefore identify more robustly the sources of sign-based asymmetries, which is crucial for understanding the transmission mechanism for asymmetric tax effects.

In summary, our paper makes four main contributions. First, we use a non-linear approach to estimate the effect of sign-based tax changes and compute non-linear impulse responses. Second, we perform a wide-range of robustness exercises for our results, including explicit controls for asymmetric effects due to the magnitudes of tax changes, and provide an array of formal tests for asymmetry for all our economic variable of interest. Third, we provide a detailed analysis of potential transmission mechanisms for asymmetric output responses, identifying the response of household consumption and labor supply as the key channel through which asymmetric effects of tax changes are transmitted to aggregate output. Finally, we use the insights on the transmission mechanisms in our empirical analysis to formulate a simple DSGE model that is consistent with the empirical findings, and show how simple consumption-adjustment costs can generate asymmetric effects of tax changes.

The rest of the paper is organized as follows. Section 2 explains in detail the sources and construction of our data set. In Section 3, we describes our methodology to estimate sign-based tax effects and compute impulse responses. Sections 4 and 5 document our main results, starting with the output effect of tax changes and then analyzing transmission mechanism. Section 6 presents a simple DSGE model that can account for the type of asymmetries highlighted in our empirical results. Section 7 concludes. Figures and Tables are collected in Appendix A. Additional robustness checks and supplementary analyses are provided in an Online appendix.

2. Data

The data on tax changes are taken from Romer and Romer (2010) and cover the period 1947Q1 – 2007Q4. They study each major tax bill signed in the post-war era in the United States and classify each tax change as either exogenous or endogenous based on their analysis of government documents, presidential speeches, and congressional documents. Among the Romer and Romer (2010) tax changes, we only consider exogenous, permanent tax changes,

[5]We also provide additional robustness checks in the online appendix where we use different techniques to disentangle size versus sign-based asymmetries.

and term these as R & R tax changes. We categorize them into tax decreases (resulting from the documented exogenous, permanent tax decreases) and tax increases (resulting from the documented exogenous, permanent tax increases). We find a total of 19 tax increases and 22 tax cuts. Table A.1 and Figure 1 illustrates the magnitude, time, and sign of these tax changes. In the Appendix, we also provide a brief description of each type of a tax change in Romer and Romer (2010) data.

We also divide the R & R tax changes into anticipated and unanticipated tax changes as in Mertens and Ravn (2011). In particular, a tax change is anticipated if the signing of the tax reform and its implementation are more than 90 days apart. Figure 2 illustrates the magnitude, time, and sign of the changes in unanticipated tax series over the sample period of 1947Q1 – 2007Q4.[6] Overall, it must be noted that to deal with the endogeneity concerns the tax change data used in this paper omits all policy interventions classified as spending driven or related to the business cycles. Such omissions limit the scope of the data insofar as conducting business cycle related analyses.

As a robustness check (presented in the online appendix), we also use changes in cyclically-adjusted-tax-revenues. Cyclically-adjusted-tax-revenue has been widely used as a standard measure of tax changes in the macroeconomic literature. This measure is designed to take into account the fact that tax revenues increase and decrease with GDP. These tax revenues are therefore measured on the basis of what revenue would be if GDP were at the normal trend level. This data set covers the period 1947 Q2 - 2007 Q4. In this series, the number of total positive tax shocks is 180 and the number of total negative tax shocks is 64. However, Romer and Romer (2010), Leigh et al. (2011) and Mertens and Ravn (2012b) have pointed out potential issues with cyclically-adjusted-tax-revenues. In particular, these tax changes include many non-policy movements which are likely to be correlated with other developments affecting output.[7] As a result, the correlation between cyclically-adjusted-tax-revenue and the error term in our regression can bias the effect of tax changes on output. Therefore we only use these tax shocks for robustness and comparison purposes. The timing and the magnitude of these sign dependent tax shock measures are illustrated in Figure 3.

[6] Mertens and Ravn (2011) show that the implementation lag in R & R data is twin peaked with peaks occurring at less than 30 days or more than 151 days. Whether the recent tax changes face higher implementation lag or not is perhaps coincidental rather than systematic. As Mertens and Ravn (2011) point out that it is plausible to assume that the tax announcements are random so that they occur with the same probability on all dates. Therefore, exogenous and anticipated tax changes (unanticipated tax changes) have no systematic relation to business cycle concerns. It is also possible that certain promises during the election cycle may drive the pattern of anticipated and unanticipated tax changes but Mertens and Ravn (2011) also do not find any evidence of that. Hence it is safe to assume that tax announcements are random in our sample.

[7] For example, a stock market boom can simultaneously affect the revenue raised through taxes due to the capital gains realization and reflect other developments that will raise output in the future.

We also use a finer breakdown of the R & R tax changes into individual income and corporate income tax changes. Mertens and Ravn (2013) use the narrative account (e.g., economic reports of the president and congressional budget office) to split the R & R tax change into four categories: corporate income tax liabilities, individual income tax liabilities, employment taxes, and a residual category with other revenue-changing tax measures. Like Mertens and Ravn (2013), we discard the latter group because of the presence of considerable heterogeneity, and group together individual income tax liabilities and employment taxes and refer to these two categories of tax changes as individual income taxes. Furthermore, we also normalize these two categories – individual income and corporate income tax changes – using contemporaneous personal taxable income and corporate taxable income, respectively. Figure 4 and Figure 5, respectively, illustrate magnitude, time, and sign of our individual income and corporate income tax changes over the sample period of 1947Q1 – 2007Q4.

Data for quarterly real output, investment, consumption, government spending and total federal tax revenues are taken from the Bureau of Economics Analysis (BEA).[8] Data for the remaining macroeconomic variables (TFP, Labor hours) are from various sources. In Appendix A.1, we provide more details on each of the dataset employed in our analysis along with their sources, time span and frequency in Table 2.

3. Methodology

The existing literature studying the hypotheses of symmetry employs specific form of censored-regressor models. Censored-regressor models amount to censoring the explanatory variable whereby the positive changes in the original data set is replaced with zeros (and vice versa). However, Kilian and Vigfusson (2011) show that if, in fact, both positive and negative changes matter for the dependent variable, then a censored-regressor model that only contains a uni-directional explanatory variable (either positive change or negative change) is misspecified. Because of an in-built asymmetry in such censored-regressor models, the estimates are likely to be biased.

In addition, most of the analysis in the applied literature computes linear impulse responses and therefore, so far the non-linearity of the impulse response function has been ignored in this literature. However, new methods such as local projection by Jordà (2005), non-linear impulse responses by Kilian and Vigfusson (2011) and Gaussian basis functions by

[8]These variables are measured using chain-type quantity index.

Barnichon and Matthes (2015) are proposed in the literature to compute possible non-linear dynamics of exogenous shocks and urge departure from computing linear-impulse responses which are independent of history and magnitude of the shock and can potentially lead to biased results, especially while studying the hypothesis of symmetry. History independence assumes that a shock hits the variable of interest, and then no subsequent shock hits the economy for the next several periods. Magnitude independence, on the other hand, restricts exploring the asymmetric responses emitting from the size of the shock. As the linear impulse responses are based on a simple linear combination of the estimates from the regression results, these responses are unable to account for differential effects stemming from the size of the shock. However, Kilian and Vigfusson (2011) proved that inferences based on linear impulse responses – that are independent of the magnitude and the history of explanatory variables – can be misleading for studying the hypotheses of symmetry.[9]

Therefore, we depart from uni-directional censored-regressors in favor of a more general, non-linear specification. In particular, we regress real output growth on contemporaneous and lagged measures of both tax increases and decreases, and lagged observations of output growth. We describe our model in detail in Section 3.1. We also allow for the full history and the magnitude of both tax increases and decreases to affect output to correctly compute history and magnitude dependent non-linear impulse responses. We describe the computation of non-linear impulse responses in detail in Section 3.2.

3.1. Framework

Our methodology combines Romer and Romer's (2010) framework with earlier works of Cover (1992) and more recently Ravn and Sola (2004) on the asymmetric effects of monetary shocks.

Let $\Delta\tau_t$ denote the change in nominal tax liabilities (normalized by nominal GDP) at time t. Define

$$\Delta\tau_t^+ = max(0, \Delta\tau_t), \qquad \Delta\tau_t^- = min(0, \Delta\tau_t) \tag{1}$$

as an increase (positive) and a decrease (negative) in the tax process, respectively. Following the literature on the asymmetric effects of monetary shocks, the first step in the estimation strategy is to estimate the exogenous changes in taxes. A simple way to perform this estimation would be to regress nominal tax revenues (divided by nominal GDP) on contemporaneous and possibly lagged values of GDP. The errors from such a regression

[9]This is exactly why our methodology and hence results differ from Jones et al. (2015) since they only compute linear impulse responses.

specification would be the exogenous component of changes in taxes that are uncorrelated with contemporaneous movements in the economy. This exogenous tax-change series can then be divided into a tax increases and a tax decrease as defined in Equation 1. In the second step, output growth is regressed on these two types of tax changes to check the presence of asymmetry without imposing any form of asymmetry.[10] Ravn and Sola (2004), Cover (1992), DeLong and Summers (1988), and many others use this methodology.

Because Romer and Romer (2010) provide us with exactly these uncorrelated (exogenous) tax changes, the first step of the estimation strategy is redundant. In particular, Romer and Romer (2010) use narrative records of major tax bills in the post-war United States to document exogenous and endogenous tax changes (see Section 2 for more detail). Following Romer and Romer (2010), we use contemporaneous and 12 lagged values of these exogenous tax increases and decreases to estimate their effect on aggregate output growth. Specifically, we estimate the following equation:

$$\Delta y_t = \alpha + \sum_{p=0}^{M} \beta_p^+ \Delta\tau_{t-p}^+ + \sum_{n=0}^{M} \beta_n^- \Delta\tau_{t-n}^- + \sum_{l=0}^{L} \beta_l \Delta y_{t-l} + \epsilon_t, \tag{2}$$

where Δy_t is the growth rate of GDP. $\Delta\tau_{t-p}^+$ and $\Delta\tau_{t-n}^-$ are, respectively, exogenous tax increase or decrease (change in tax liabilities due to exogenous, permanent tax changes as a percentage of nominal GDP). The signs $+$ and $-$ indicate an increase and a decrease in tax changes, respectively; therefore, $\sum_{p=0}^{M} \beta_p^+$ aggregates the coefficients associated with tax increase for M lags of tax changes, whereas $\sum_{n=0}^{M} \beta_n^-$ denotes the aggregate coefficient associated with tax decrease for M lags. Lastly, Δy_{t-l} is lagged values of the growth rate of GDP, and $\sum_{l=0}^{L} \beta_l$ aggregates the coefficient associated with L lags of output growth. Lagged output growth is included to control for the normal dynamics of output, the state of the economy, and a multitude of other serially correlated factors.[11]

[10] In the interest of full generality, and in particular to eschew imposing any form of asymmetry, we allow for both a tax increase and a tax decrease to affect the variable of interest, to varying extents.

[11] Note, to be consistent with Kilian and Vigfusson's (2011) methodology, we can also adapt a two-equation framework (instead of using a single-equation framework as described in Equation 2) to study our question. The two-equation framework is as follows:

$$\Delta\tau_t = \alpha_1 + \epsilon_{1t}$$

$$\Delta y_t = \alpha_2 + \sum_{p=0}^{M} \beta_p^+ \Delta\tau_{t-p}^+ + \sum_{n=0}^{M} \beta_n^- \Delta\tau_{t-n}^- + \sum_{l=0}^{L} \beta_l \Delta y_{t-l} + \epsilon_{2t}$$

This two-equation framework is exactly the same model as in Kilian and Vigfusson (2011), except that we impose exogeneity in the first equation and maintain the assumption that $\Delta\tau_t$ is serially uncorrelated. These assumptions allow us to be consistent with Romer and Romer's (2010) premise.
We redo our analysis with this alternative two-equation methodology. Qualitatively and quantitatively, we

3.2. Impulse Responses and Standard Errors

We closely follow Kilian and Vigfusson's (2011) methodology to estimate non-linear impulse responses. The interpretation of the magnitude of the impulse response function is based on Equation 2. To compute the non-linear impulse-responses, we first estimate the coefficients on the contemporaneous and the first M lags of the tax variables and the coefficients from the lagged values of output growth from Equation 2. Next, we draw various initial conditions and sequences of tax-changes. We simulate two time-paths of output (using the draws and the estimated coefficients): one that is based on these draws and the second where we replace the first value of either of the sequences of tax increase or tax decrease by a constant. We compute the difference between these two time-paths and average over the number of draws. Finally, we compute the impulse-response as the average sum of aggregate effect over different initial conditions and subsequent tax changes. Step-by-step details of the methodology and computation of impulse responses are provided in Appendix A.2.

To compute the corresponding standard-errors of the non-linear impulse responses, we follow the wild bootstrap methodology as proposed by Gonçalves and Kilian (2004). This methodology allows us to overcome the potential concerns of heteroskedasticity. Residuals which are estimated via 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. In particular, we compute the standard errors for the impulse responses from 20,000 bootstrap replications of the coefficient vector from a multivariate normal distribution with mean and variance-covariance matrix equal to the point estimates and variance-covariance matrix of the regression coefficients. See Gonçalves and Kilian (2004) for more details.

4. Results: Output

We begin by documenting the effects of an exogenous and a permanent tax increase and decrease on output in Section 4.1. Throughout the results, we report non-linear impulse responses to a 1% change in tax liabilities relative to GDP (unless stated) along with one standard error (computed by wild bootstrapped method) and 95% confidence interval. We

reach the same results. To save space, we present our key result with this alternative two-equation model in the Online appendix.

report the impulse responses for a forecast horizon of 20 quarters.

4.1. Basic Aggregate Results

Figure 6 displays the impulse responses based on Equation 2 for a sign-dependent tax changes. The non-linear impulse responses show that output responds significantly to a tax decrease and insignificantly to a tax increase, which is only suggestive that output may respond asymmetrically to these tax changes.

In particular, the estimated maximum impact of a 1% tax-liability reduction (as a percentage of GDP) is approximately 3.02% and on average the implied effect is approximately 2.5%.[12] The computed impulse response is highly significant from the 8th quarter until the end of the horizon.[13] On the other hand, the impulse responses of output corresponding to a tax increase reveal a surprisingly insignificant effect.

Although our methodology controls for the size of the tax change, we provide an empirical exercise in the online appendix that uses alternative methodologies and tax change measures to study whether our sign-based results are confounded by the varying size of tax increase versus tax decrease. In each exercise, we show that the size of the tax change does not drive the asymmetric response of output.[14]

The standard errors corresponding to the impulse responses following a tax increase and a tax decrease are comparable to the standard error bands in Romer and Romer's (2010) analysis based on deficit-driven and long-run tax changes. Our standard errors corresponding to a tax increase are quite large, which may be due to imprecise estimates. In addition, the standard error band for the output responses to a tax increases and a tax decrease overlap considerably; therefore the formal T test and F test (presented in Table 3 and Table 4, respectively) only weakly reject our null hypothesis of symmetry while Wald test of symmetry

[12]The implied effect of a tax decrease on aggregate output in our result is on average about 2.5% and is similar to the result from Romer and Romer (2010). Romer and Romer (2010) also use the single-equation specification and control for lagged GDP growth but do not allow tax increases and decreases to have a differential effect on output.

[13]The results corresponding to an alternative specification that excludes lagged GDP growth as a regressor is suppressed to conserve space; however, the documented results are robust to the exclusion of lagged output growth.

[14]To disentangle the differential effect of tax changes on output due to the size and the sign of tax change, we employ three approaches. In the first approach, we replace the large tax cuts, such as the Kennedy-Johnson tax cuts and the Reagan tax cuts with zero in our R & R tax change data, and compute the corresponding non-linear impulse responses. In the second approach, we use cyclically-adjusted-tax-revenue (CATR) changes as an alternative tax change measure and compute the non-linear impulse responses. In the third approach, we vary the size of the initial tax change with which we shock our dynamic system. This approach allows us to explore if the output response to an initial large tax change is more than a proportional to the output response to an initial small tax change.

(presented in Table 5 and Table 6) shows we cannot reject symmetry. Despite the formal test unable to reject the hypothesis of symmetry, the basic results still point out that only tax cuts have the expected positive and significant impact on output, whereas tax increases do not exhibit expected effect on output.

Furthermore, the results from tax increases may also be overstated, because, as Romer and Romer (2010) point out, the deficit-driven tax changes (which are all tax increases) are often coupled with spending cuts (which is the case for the latter part of Romer and Romer's 2010 sample). Since tax increases are potentially correlated with another force that is likely to depress output further, one would expect a bigger negative impact on output. Because our results nevertheless show a smaller output effect (which is hardly negative and is comparable to Romer and Romer's 2010 analysis of deficit-driven taxes), either this bias could be minimal or alternatively, tax increases might not behave as theory suggests. Therefore, caution must be exercised while drawing policy implications of tax increases on output. It is therefore imperative to provide a more robust analysis of the effects of sign-based tax changes. In the subsequent section, we explore in more detail whether tax increases indeed have different effect on macroeconomic variables than what the theory suggests.

4.2. Unanticipated Tax Changes

There are various types of lags in the implementation process of any macroeconomic policies especially when it come to fiscal policies which experience both legislative and implementation lags. Legislative lag is simply defined as the lag stemming from the legislative process. Even though it may be concluded from earlier discussion that some form of a change in the fiscal policy is necessary, the exact nature of the tax package to be put in place may be subject to further delays. On the other hand implementation lag is a lag in terms of actual implementation of the rule after the legislation has been passed.

If these lags are specific to a particular type of a tax change then these lags can in fact be the actual source of asymmetric effects of tax changes on output instead of the sign of tax changes. It is reasonable to assume that in the US, the legislation process is common to both tax increases and tax decreases and therefore such lags may be less of a concern for our baseline result. However, the same argument is less convincing for implementation lags. Suppose due to political economy considerations, the fiscal policies based on tax increases go into effect well after they are legislated, whereas policies based on tax reductions go into effect immediately. The difference in the timings of the implementation of the two tax changes could induce an asymmetry into the response of output to a tax increase versus a tax decrease. Therefore, the results documented in the last section could potentially be an outcome of a model misspecification rather than an empirical finding. We therefore, refine the results from the last section, by incorporating the implementation lags in the fiscal policy.

In this section, we explore how focusing our analysis only to unanticipated, permanent, and exogenous R & R tax changes modifies our responses of output. For short, we call these tax changes as unanticipated R & R tax changes.[15] This modification will allow us to remove any anticipatory effect from our analysis.

Following Mertens and Ravn (2011), in addition to lagged GDP growth as a control, we also control for the effect of anticipated tax changes on output growth.[16] Figure 7 illustrates the main result of this section and reveals that the effect of a tax cut on output is significant, whereas the effect of a tax increase on output is insignificant.

Furthermore, comparing these results with the estimation results based on R & R tax changes (illustrated in Figure 6), we find the effect of an unanticipated tax cut is highly significant for most of the horizon. Furthermore, the effect is now quantitatively almost doubled. Increase in unanticipated tax again shows insignificant effect on output.[17] Comparison of our results to the results presented in Mertens and Ravn (2011) is not straightforward because our specification and data differ from theirs. However, in an online appendix, we provide an exercise to study the effect of sign-based tax changes under Mertens and Ravn's 2011 methodology. We show that our responses to tax cuts are comparable to Mertens and Ravn's results and in addition we show that the asymmetric effects of sign-based tax changes are a feature of unanticipated tax changes but not of anticipated tax changes.

Results for the formal tests of symmetry are presented in column 2 of Table 3, Table 4, Table 5 and Table 6. Corresponding p-values of the test statistics strongly reject the null hypothesis of symmetric effects of these tax changes on output.[18] Jointly, these formal tests

[15]Section 2 provides construction of unanticipated R & R tax changes. Note that the anticipated tax changes are simply replaced by zero to construct the positive and negative unanticipated-tax-change series; therefore, compared to the R & R tax-change series (used in the preceding section), the length of the unanticipated R & R tax-change data stay unchanged.

[16]Jones et al. (2015) linear impulse responses for e.g., estimate the effect as 4% however, they do not control for the effect of anticipated tax changes while studying the effect of unanticipated tax changes on output

[17]We also redo the analysis without controlling for the anticipated tax changes, and the results (not presented in this paper) are qualitatively similar. The estimates are only marginally different.

[18]In particular, T-test statistics show that the aggregate response of output to a tax increase and a tax cut differs significantly (at 5% significance level) from each other from the 5th to the 20th horizon. The F-test statistics show that about 92% (0.4%) of the times, all the coefficients corresponding to a tax increase (cut) are jointly zero. Therefore, the F-test statistics also point toward the presence of a strong asymmetric effect of tax changes on output. Lastly, the Wald test statistics corroborates the lack of symmetry for most of the horizon, when we test if the estimated response at each horizon is symmetric and at least for the last few (17th to 20th) quarters when we test if the estimated response up to the Hth horizon is symmetric.

provide strong evidence for the asymmetric response of output to a sign-based tax changes.

4.3. Financing of Tax Changes

If a change in taxes is revenue-neutral then the reformed system would raise the same amount of revenue as the existing system leaving no need for additional policies to finance the legislated tax changes. However, when tax changes lead to non-neutral changes in revenue, financing of tax changes is important because the channel by which tax changes are financed can in itself impact the long-run output growth. Such non-neutral tax changes can be financed by some combination of changes in the future government spending or future tax changes with borrowing to bridge the timing of spending and receipts in order to ensure that the government budget constraint is met. This is especially the case for tax cuts since fiscally unsustainable policies cannot be maintained forever.

In light of this, it is possible that due to a tax increase there is also a simultaneous increase in government spending. Tax increase will push output down while increased government spending will have a positive effect on output. These opposing effects can potentially show an overall insignificant effect on output. By a similar logic, tax decreases coupled with decreased government spending could have opposing effect on output as well. More importantly, if government's choice of financing tax changes is specific to whether a tax change is an increase or a cut, output may respond asymmetrically not due to the sign of a tax change but because of the choice of financing alternatives. For example, a government may be less likely to cut government spending to finance legislated tax cuts but more willing to increase government spending after a legislated tax increase. Such asymmetric financing decisions of the government can have a positive effect on output in the short-run after a tax decrease and an insignificant impact on output after a tax decrease.

In the context of government spending shocks, Cloyne (2014) estimate a VAR to investigate the response of fiscal policy (tax rates and debt) to government spending shocks and show that the increase in tax rates is modest while there is a large increase in debt in response to government spending shocks. In the same context, Zubairy (2014) highlight that government spending which is financed by an increase in taxes versus an increase in government debt reveals an asymmetric size of government spending multipliers in the long-run: when taxes are increased more aggressively to the government spending shocks the multiplier is smaller than in the scenario where fiscal debt responds more aggressively than taxes. Therefore it is important to investigate whether the responses of output to sign-based tax changes as documented in our baseline result is robust to various alternative means utilized to finance tax changes.

An ideal analysis to investigate this issue in our set up would require supplementary information on how narrative tax changes were financed. However the original tax legislations do not specify the information on how tax changes were financed. Romer and Romer (2009) investigate a similar issue of whether tax cuts affect government spending or future tax changes. They conclude that tax cuts do not necessarily reduce government spending. Moreover, if anything there is an increase in the government spending (after some lags) in response to a tax cut. However, they find evidence that a tax cut does modestly increase future taxes. With these findings, they conclude that tax changes are partly financed by the increase in future taxes but more importantly by the output growth following the tax cuts.[19]

Following Romer and Romer (2009, 2010), we perform two analyses. In the first analysis, we control for the immediate and lagged changes (12 lags) in the government expenditure to control for an omitted variable bias in Equation 2 and compute non-linear impulse responses. In Figure 8 we show that the asymmetric effects are qualitatively and quantitatively very similar to the analysis that does not control for changes in government spending. This is also in line with Romer and Romer (2010). In the second analysis, we investigate whether the future government spending and tax changes are affected by tax cuts and tax increases. To do this analysis we use a simple bi-variate VAR following Romer and Romer (2009). We present our results in Figure 9. The figure plots impulse responses of government expenditure, total tax revenue, all future (exogenous and endogenous) legislated tax changes, all (exogenous and endogenous) legislated tax increases and all (exogenous and endogenous) legislated tax cuts in response to exogenous tax increases and exogenous tax decreases. Our results show that a tax increase has an insignificant effect on all of the listed variables while a tax decrease shows marginally significant increase in government expenditure; and the legislated tax changes which are primarily driven by legislated tax increases rather than further tax cuts.

Using both these analyses, we find that there is a negligible downward adjustment of government spending but an upward adjustment of future tax increases after a tax cut. As a result, partly tax cuts are paid by the output growth following the tax cuts and marginally via future increases in taxes. Tax increases on the other hand seem to have no effect on the government expenditure as well as future tax changes. Therefore, we conclude that our baseline results are robust to various financing channels of tax changes.

[19]However, Romer and Romer (2009) also urge caution while investigating the issue of how the government restores long-run budget balance. In particular, Romer and Romer (2009) state: "Since the governments long-run budgetary situation deteriorated substantially over the period we consider, to some extent this limitation is inherent: not all of the offsetting actions have yet occurred. It is possible that some of the remaining adjustment will take place on the spending side. .... But it remains the case that, over the period we consider, there is virtually no evidence of such an effect [tax cuts restraining government spending]."

5. Results: Transmission Mechanism

In this section, we explore in more detail the underline transmission mechanism of the asymmetric responses of output to sign-based tax changes. To do so, we first broadly look at if a particular type (individual income versus corporate income) sign-based tax change is responsible for asymmetric responses of output. We then look at how other major macroeconomic variables (consumption, investment and labor) behave in response to the sign-based tax changes.

5.1. Individual-Income and Corporate-Income Tax Changes

Mertens and Ravn (2013) argue, many types of taxes are available to the tax authorities for policy purposes, and these various types of tax changes may have different effects on output. Aggregating these tax changes into one composite tax change to study the effect on output may mask the real effect. In this section, we wish to explore how the use of a more disaggregated positive and negative tax measures provides additional insights about the asymmetric responses of output. Like Mertens and Ravn (2013), we only consider two broad categories of tax measures: corporate and individual income taxes. We discuss the construction of these disintegrated tax measures in the data Section 2.

A major issue with individual-income and corporate-income tax liability changes is that these two types of tax measures are highly correlated because tax reforms typically change both measures simultaneously. Such high correlation between these two types of tax measures, may violate the key exogeneity assumption in our regression equation. Therefore, like Mertens and Ravn (2013), in addition to using lagged output growth as a control, we also control for corporate-income tax changes (individual-income tax changes) when studying the effect of individual-income tax changes (corporate-income tax changes) on output. We then compute the impulse responses of output for sign-based tax changes for each type of tax measure.[20]

We illustrate the results from the analysis that employs individual-income tax changes in Figure 10. The results reveal that a cut in individual-income tax has a long-term effect on output (of approximately 2% at the peak), whereas an increase in individual-income tax has an insignificant effect on output. Although individual-income tax cuts have a small and an

[20]Like Mertens and Ravn's 2013 data, our data also has less frequency of corporate-tax changes than the individual-income tax changes. However, note that relative to the length of aggregate R & R tax changes, the length of disaggregated tax change series i.e., individual-income tax change and corporate-income tax change, are same. We only replace the latter tax changes with zero to construct the former tax change series and vice versa; therefore, we do not reduce the size of the data.

insignificant effect on output for the first 10 quarters, the effect becomes significant for the rest of the forecast horizon. However, output responses to individual-income tax increase remain insignificant throughout the horizon.

Formal tests suggest presence of the asymmetric responses of output to sign-based individual-income tax changes. The T-test statistics for the latter part of the horizon forecast (12th to 20th quarter) shows that the aggregate effects of sign-based tax changes on output differ significantly. The Wald-test statistics echo a similar idea as the p-values of the Wald-test reduce from 12th quarter onward. The F-test statistics show that the probability of all coefficients of individual-income tax cuts being jointly zero is considerably less than the probability of all coefficients of individual-income tax increases being jointly zero.

The analysis that employs sign-based corporate-income tax changes (while controlling for individual-income tax changes) shows symmetric responses for output. In particular, Figure 11 illustrates that an increase in corporate-income tax has a significantly negative effect on output from the 6th quarter until the 10th quarter. Subsequently, the estimated impact from the 10th quarter until the end of the horizon is small and insignificant. The maximum effect on output is about -1% after the 8th quarter, whereas the result from a corporate-income tax cut (also illustrated in Figure 11) shows a significantly positive effect on output for the first 10 quarters (with the peak effect of 1.3% occurring in the 8th quarter). After the 10th quarter, the effect becomes small and insignificant. The standard error bands corresponding to corporate-tax cuts and individual-income tax cuts are comparable to the standard error bands in Mertens and Ravn's 2013 analysis.[21]

Unlike sign-based individual-income tax changes, sign-based changes in corporate-income tax do not exhibit any asymmetric effects on output. Formal tests also reveal that corporate-income tax cuts and increases have opposite but symmetric effect on output. Therefore, we conclude that the asymmetric response of output observed in Section 4.1 is mainly due to the asymmetric effects of sign-based individual-income tax changes on output.

5.2. Responses of Macroeconomic Variables

So far, we have looked at the effects of tax changes on output. In this section, we seek to explore the effect of a decrease and an increase in taxes on other macroeconomic components of output, especially consumption and investment, to understand the channels of the documented asymmetric responses. Before proceeding to the main analysis, we provide a

[21]Note, Mertens and Ravn (2013) do not split the corporate-tax changes and individual-income tax changes on the basis of sign of the tax change.

component share of output for our sample in Figure 12 which shows that roughly 60% of output is consumption while 20% is investment. Rest of the output is government expenditure and trade.

We employ the following model (which mirrors our earlier specifications) to estimate the impulse responses of our variables of interest:[22]

$$X_t = A + Bt + C(L)X_{t-1} + D(L)\tau_t^+ + E(L)\tau_t^- + \epsilon_t, \tag{3}$$

This specification is in line with Mertens and Ravn (2012a) who show that this model corresponds to the dynamics of a DSGE model. τ_t^+ and τ_t^- are an exogenous tax increase and an exogenous tax cut. X_t is a vector of endogenous variables. We run this model for 2 variables at a time, where the first variables is always output and the other variable is one of our variables of interest.

$$X_t = [Y_t, Z_t]',$$

where

$$Z_t \in \{C_t, I_t, K_t, TH_t, EMP_t, AH_t, W_t, TFP_t, OPW_t\},$$

where C_t is consumption, I_t is investment, K_t is capital, TH_t is total hours worked, EMP_t is employment, AH_t is average hours per worker, W_t is real hourly wage, TFP_t is multi-factor productivity, and OPW_t is output per worker or labor productivity. The data sources for these variables are given in Table 2. All variables are in log forms. $C(L)$ is a P-order lag polynomial, and D(L) and E(L) are (R+1)-order lag polynomial. Following Mertens and Ravn (2012a), we choose $R = 12$ and $P = 1$. The results are robust to other choices of P. This model is a vector autoregression in X_t treating the tax changes as exogenous.

We compute the impulse responses as explained in section 3.2. The output response following a tax increase and a tax decrease are illustrated in Figures 13 and 14, respectively.

Because consumption and investment constitute a big portion of the output, we first discuss these results in detail and then provide a summary of results from the other macroeconomic variables. Consumption responds positively and significantly to a tax cut, with

[22] We depart from our earlier regression equation, Equation 2, and replace it with Equation 3 (which mirrors our earlier regression equation). This replacement helps us study the evolution of consumption, investment, or other macroeconomic variables of interest along with the evolution of output after a sign-based tax change. Furthermore, to capture the inter-dependencies in multiple time series, this specification is more fitting. We employ this VAR specification (which includes both tax increases and cuts as the exogenous regressor) and compute non-linear impulse responses.

the peak effect of approximately 2.5% occurring at the 10th quarter. The effect is most pronounced for the middle quarters of the forecast horizons, after which the effect becomes smaller and insignificant. Consumption response to a tax increase, on the other hand, is highly insignificant throughout the horizon forecast.

Additional analyses which splits the total consumption into durable and non-durable consumption show that a similar asymmetric effect of tax changes is observed for non-durable consumption. In contrast durable consumption shows sharp decrease in response to an increase in tax. We illustrate these results in Figure 15 and 16. The asymmetric effect of a tax increase and a tax decrease on the total consumption is primarily driven by non-durable consumption (which is approximately 50% of total consumption) relative to durable consumption (which is about 39% of total consumption). Quantitatively the effect of a tax decrease on durable consumption mimics the results presented in Mertens and Ravn (2011). Though the positive effect of a tax decrease on non-durable consumption in our analysis is roughly 2.2% at peak which is twice the effect documented in Mertens and Ravn (2011), the dynamics are not very different.

Investment shows a symmetric response to sign-based tax changes. In particular, investment falls (at the peak by approximately 11%) in response to a tax increases and increases (at the peak by approximately 11%) in response to a tax cut in the short-run before returning to its pre-change levels in the long-run. These results suggest that between consumption and investment, asymmetric output responses are channeled through asymmetric consumption responses after sign-based tax changes. Furthermore, the symmetric response of capital also lends some credence to the symmetric response of investment.

Formal tests also support the idea that relative to investment, consumption exhibits asymmetric responses to sign-based tax changes. In particular, Wald-test and F-test p-values (reported in column 2 of Table 7 and column 1 of Table 8) suggest the impulse responses of output to a tax increase and a tax cut differ significantly from each other. However, all the formal tests except the F-test for the hypothesis of symmetry of investment responses suggest investment responds symmetrically to sign-based tax changes. Jointly, the p-values for these test statistics point toward an asymmetric response of consumption and a symmetric response of investment to the sign-based tax changes.

Labor-related variables such as, total hours worked, increase in the long-run in response to both types of sign-based tax changes. Similar qualitative result is documented by Mertens and Ravn's 2011 analysis of the effect of anticipated and unanticipated tax changes on hours worked. In particular, their work shows that the hours worked increase only after some lag. Moreover, the increase is marginally significant. Qualitatively our results resonate with their results, but we also document a highly significant positive effect on hours worked in response to both tax increases and tax decreases. We therefore see a clear asymmetric effects on hours worked due to the sign-based tax changes. This increase in total hours seems to originate from a change in employment, which also increases following both types of sign-based tax change, however the increase in employment is relatively higher following a tax increase. Average hours per worker do not respond significantly to either of the tax changes. In addition, hourly wages fall significantly in the long-run following a tax increase, whereas the response in hourly wages after a tax decrease is insignificant. Labor productivity responds significantly for a few quarters when taxes decrease but otherwise responds insignificantly to both types of sign-based tax changes. Like labor productivity, TFP in general does not seem to respond significantly to our sign-based tax changes.[23]

The overall results from this section provide interesting insights about the potential channels behind the asymmetric response of output to tax changes. In summary, the main findings of this section are (i) consumption response is asymmetric whereas investment response is symmetric, (ii) durable consumption response is symmetric but non-durable consumption response is asymmetric (iii) hours worked show asymmetric responses, (iv) wages decrease significantly following a tax increase, and (v) consumption does not respond significantly to a tax increase. Jointly, these results suggest that workers resist downward change in consumption; in other words consumption is sticky downward and hence workers increase working hours to compensate decreases in wages and after-tax (disposable) income.

6. Model

So far, the literature assumes sign-based tax changes (tax increases and tax decreases) have opposite but symmetric effects on output and consumption. However, the empirical evidence presented in this paper reveals asymmetric effects of sign-based tax changes on aggregate output as well as consumption. In an otherwise standard model if households consumption is sticky downwards perhaps due to asymmetric consumption adjustment cost where reducing

[23]Whether TFP is endogenous - and can be affected by policy variables such as tax changes - is a research question in itself (see e.g., Hussain, 2015). Some studies employ firm-level data to show that tax changes affect firm-level productivity. See Gemmell et al. (2013) and Arnold and Schwellnus (2008). Heylen and Schoonackers (2011) show that personal-income taxes have a negative effect on labor productivity. An important contribution in this literature has been by Mertens and Ravn (2010), who show that tax changes have long-run effects on labor productivity. This result is very important in that it invalidates the traditional long-run restrictions used in empirical analysis of macroeconomic effects of productivity changes.

consumption (such as housing, phone contracts, insurance) is costly while increasing consumption is not, may deliver the empirical results. In the presence of such an adjustment cost, negative income shock such as a tax increase may not have a significant effect on consumption. The agents may find adjusting consumption downwards costly and may instead substitute leisure into labor to maintain prior consumption levels. On the other hand, if agents face a tax decrease, they may increase their consumption level. This asymmetric response of consumption due to consumption adjustment frictions may provide a potential channel behind asymmetric responses of aggregate consumption which translate into asymmetric responses of output in response to sign-based tax changes.

We model this potential channel using a simple DSGE model to reconcile our empirical results. In particular, we present a simple DSGE model with firms and households as the agents in an economy where agents face capital adjustment cost and consumption adjustment cost. Convex capital adjustment costs are common in DSGE models such as Baxter and Crucini (1993). Similarly, various form of psychological and non-psychological consumption adjustment have been widely used in the existing literature. In particular, the friction in consumption resulting in downward stickiness due to psychological reasons is a widely studied phenomenon. Duesenberry (1949) coined the term "ratchet" effect to explain this friction in consumption. A ratchet effect formally corresponds to a consumption function that accounts for habit formation and standard-of-living adjustments for the households. Unlike conventional frameworks in which a decrease in income is accompanied by a proportional decrease in consumption, this effect embodies a household's resistance to decrease consumption mainly due to consumption habits acquired in the past. Such representative consumer habit formation models have attracted interest in various fields of economics such as Sundaresan (1989); Christiano et al. (2005); Uhlig and Ljungqvist (2000). More recently, non-psychological reasons are also modeled for consumption adjustment and are often called consumption commitment (see for e.g., Chetty and Szeidl (2007, 2004)). The main difference between the psychological and non-psychological consumption cost is that former is an assumption about preferences while latter is a technological constraint in consumption. We use such psychological and non-psychological costs of consumption-adjustment in our model.

In our model, the household earns income by providing labor and capital to firms and both labor and capital income are taxed by the government. In such a setting, our model provides a framework for asymmetric responses of output and consumption to sign-based tax changes.

6.1. Households

The model consists of a representative household who maximizes discounted utility defined over a stream of consumption (C_t) and hours worked (H_t).

$$\max \sum_{t=0}^{\infty} \beta^t U(C_t, H_t) \tag{4}$$

where

$$U(C_t, H_t) = ln(C_t - \phi C_{t-1}) - \gamma \frac{H_t^{1+z}}{1+z}$$

Consumer's preferences are defined over a habit adjustment consumption basket with an adjustment parameter of ϕ. z is the inverse of Frisch elasticity of labor supply and γ is the relative weight of the two components of utility function.

The worker earns the market wage (W_t) by providing labor to the firms. The household owns the capital stock (K_t) and rents it to the firms in the economy at an interest rate (R_t). Household also face two kinds of adjustment costs. First is the convex adjustment costs that must be paid in order to adjust capital stocks. This adjustment cost is captured by the following functional form.

$$\Phi\left(\frac{I_t}{K_t}\right) = \frac{\Phi}{2}\left(\frac{I_t}{K_t} - \delta\right)^2 \tag{5}$$

Finally, a household faces an asymmetric consumption adjustment costs. These adjustment costs can be regarded as non-psychological costs such as consumption commitment. In particular, we choose a simple functional form for the consumption adjustment function according to Abbritti and Fahr (2013) (where modeled asymmetries are in wage adjustment). We assume that households resist downward movements in consumption whereas they allow consumption to move upwards when starting off at steady state. The particular functional form that we assume for the consumption adjustment cost function is given by

$$\Psi\left(\frac{C_t}{\bar{C}}\right) = \frac{1}{\psi^2}\left(e^{-\psi(\frac{C_t}{\bar{C}}-1)} + \psi(\frac{C_t}{\bar{C}} - 1) - 1\right) \tag{6}$$

ψ provides the parameter that captures the consumption adjustment cost. With $\psi \to 0$ corresponds to a case where there is symmetric cost for changing consumption which boils down to a standard RBC model with symmetric cost. However, $\psi > 0$ corresponds to the asymmetric adjustment of consumption: downward changes in consumption relative to steady state level of consumption are more costly than upwards adjustment of consumption.

Moreover, as ψ increases the asymmetry in the consumption adjustment cost (above and below steady state levels) increases.

The budget constraint for the household is as follows:

$$C_t + I_t + \Phi\left(\frac{I_t}{K_t}\right)K_t + \Psi\left(\frac{C_t}{\bar{C}}\right) \leq W_t H_t(1-\tau_t^H) + R_t K_t(1-\tau_t^k) + TRA_t \tag{7}$$

The left side of the budget constraint shows the expenditures of the household on consumption and investment in new capital. The right side of the equation shows the income of the household which consists of 1) labor income ($W_t H_t(1-\tau_t^H)$), which depends on the number of hours worked and is subject to labor income tax rate of τ_t^H, 2) capital income ($R_t K_t(1-\tau_t^k)$) which depends on the number of capital units invested in the firm and is subject to capital income tax rate of τ_t^k and 3) lump sum transfers from the government, TRA_t.

The law of motion of capital is given by

$$K_{t+1} = (1-\delta)K_t + I_t \tag{8}$$

where δ is the depreciation rate of capital.

There is a continuum of identical firms that produce final goods according to Cobb-Douglas technology using capital and labor.

$$Y_t = A_t K_t^{\alpha}(H_t)^{1-\alpha} \tag{9}$$

A_t is the level of aggregate productivity. We assume that each individual firm is small relative to the economy so that its decisions do not affect the level of aggregate productivity. The evolution of TFP (A_t) is as follows:

$$ln(A_t) = \phi_A ln(A_{t-1}) + \epsilon_t^A; \tag{10}$$

where $\epsilon_t^A \sim N(0, \sigma_A^2)$.

Finally, the government collects the labor and capital taxes and redistribute the taxes in a lump-sum fashion.

$$G_t = TRA_t = \tau_t^H W_t H_t + \tau_t^k R_t K_t \tag{11}$$

The government problem can be extended to include government spending (g_t) where government purchases goods from the private sector. The collected revenue is then not only redistributed as lump-sum transfers but also used for government spending. In that case, the lump-sum transfers adjust endogenously in response to variations in total tax revenue and in government spending to ensure a balanced budget. Due to Ricardian equivalence the results would be identical if we instead allowed for debt financing.[24] Though, such additional government financing decisions are important, we abstract from additional wealth effects of tax changes via government spending primarily because: our empirical analysis shows that government spending is not affected by R & R tax changes which is also inline with Romer and Romer (2009) analysis; and the estimate of the elasticity of government spending to tax changes in the DSGE model of distortionary taxation by Mertens and Ravn (2011) is quite small.

Both labor and capital income tax processes are governed by an $AR(1)$ process given by

$$\tau_t^H = (1-\rho^H)\bar{\tau^H} + \rho^H \tau_{t-1}^H + \epsilon_t^{\tau^H} \tag{12}$$

$$\tau_t^k = (1-\rho^k)\bar{\tau^k} + \rho^k \tau_{t-1}^k + \epsilon_t^{\tau^k} \tag{13}$$

6.2. Equilibrium

A competitive equilibrium consists of allocations $\{C_t, Y_t, I_t, K_{t+1}, H_t, A_t\}_{t=0}^{\infty}$, prices $\{\lambda_t,\ q_t,\ R_t,\ W_t^*\}_{t=0}^{\infty}$ (λ and q are the multipliers on the budget constraint and the capital accumulation equations respectively), and policies $\{G_t, TRA_t, \tau_t^H, \tau_t^k\}_{t=0}^{\infty}$ that solves equations 7, 8, 9, 10, 11, 12 together with the following first order conditions:

[24]Following Mertens and Ravn (2011), Equation 11 can be replaced by:

$$\begin{aligned} G_t = g_t + TRA_t &= \tau_t^H W_t H_t + \tau_t^k R_t K_t \\ g_t &= (\gamma_z)^t g_o (\xi G_t / Y_t)^{\pi_g} \end{aligned}$$

where g_t is the government spending. In the above equation if $\pi_g = 0$, then the feedback from changes in total tax revenue (due to changes in labor or capital income tax) on government spending will be zero. However, for $\pi_g \neq 0$, changes in distortionary taxes directly change the present value of current and future government spending.

$$C_t \quad : \quad \frac{1}{C_t - \phi C_{t-1}} - \beta \frac{\phi}{C_{t+1} - \phi C_t} = \lambda_t \big(1 + \frac{1 - e^{-\psi(\frac{C_t}{\bar{C}} - 1)}}{\bar{C}\psi}\big) \tag{14}$$

$$H_t \quad : \quad \lambda_t (1-\alpha) Y_t (1 - \tau_t^H) = \gamma_t H_t^{1+z} \tag{15}$$

$$K_{t+1} \quad : \quad \frac{\lambda_t}{\lambda_{t+1}} (1 + \Phi(\frac{I_t}{K_t} - \delta)) = \beta H_t (\alpha \frac{Y_{t+1}}{K_{t+1}}) - \frac{\Phi}{2} (\frac{I_{t+1}}{K_{t+1}} - \delta)^2 + (\frac{I_{t+1}}{K_{t+1}} - \delta) \Phi (\frac{I_{t+1}}{K_{t+1}})$$
$$+ \beta (1-\delta)(1 + \Phi(\frac{I_{t+1}}{K_{t+1}} - \delta)) \tag{16}$$

$$W_t \quad : \quad W_t = \frac{(1-\alpha) Y_t}{H_t} \tag{17}$$

$$R_t \quad : \quad R_t = \alpha \frac{Y_t}{K_t} \tag{18}$$

6.3. Model Estimation

The set of model parameters can be separated into two subsets Θ_1 and Θ_2. Θ_1 consists of parameters that can be easily calibrated. One time period in the model corresponds to one quarter. The discount factor β is set to 0.9926 which corresponds to a 3 percent annual real interest rate. The depreciation rate is set equal to 0.025 which implies a 10 percent annual depreciation rate. The steady state value of the income tax rate in the model is set equal to 0.13 and the corporate tax rate is set to 0.34 which are the average value of tax rates from the tax rate series calculated by Mendoza et al. (1994).

Θ_2 consists of parameters that have to be estimated.

$$\Theta_2 = [\Phi, \phi, \alpha, \phi_A, \psi]$$

Θ_2 is estimated by matching the empirical impulse responses with model-generated impulse responses. For this, we use the simulation estimation technique used by Cogley and Nason (1995). The parameters in Θ_2 are estimated as those that solve the following problem

$$\hat{\Theta}_2 = arg \min_{\Theta_2} [(\hat{\Lambda}_T^d - \Lambda_T^m(\Theta_2|\Theta_1))' \sum_d^{-1} (\hat{\Lambda}_T^d - \Lambda_T^m(\Theta_2|\Theta_1))]. \tag{19}$$

$\hat{\Lambda}_T^d$ represents a column vector of empirical responses of output, consumption and hours to a tax decrease. $\Lambda_T^m(\Theta_2|\Theta_1)$ represents the theoretical impulse responses from the model in which the set of calibrated parameters is taken as given. $\sum_{d}^{-1}$ is a weighting matrix. This is a diagonal matrix in which the estimates of variances of empirical response appear on the diagonal.

We estimate the model parameter values by imposing the same restrictions and the estimated parameter values are presented in Table 9.

6.4. Results

Figure 17 – Figure 19 illustrate the impact of one percent income tax change on output, consumption and hours in the model economy. The left panels in these figures show the response to a one percent decrease in tax liability (relative to GDP), while the right panels show the response to a one percent increase in tax liability. Additionally, in Figure 20 we show the effect of corporate tax decrease and increase on output. The model is successful in qualitatively accounting for the main features of the empirical analysis presented in this paper. In particular, the model shows:

- A tax decrease gives rise to an increase in output, consumption and hours.
- A tax increase does not reduce either of the three variables.
- Comparing responses of these variables (to the sign-based tax changes) reveal that output, consumption and hours respond asymmetrically to sign-based tax changes.
- Apart from the impulse responses of hours worked (following a positive tax shock), the theoretical responses of variables of interest lie within the confidence intervals of the empirical estimates for most of the horizon. However, qualitatively, there is still a rise in hours even after the positive tax shock.
- A standard RBC with only habit formation and no consumption adjustment cost (i.e., $\Psi\left(\frac{C_t}{\bar{C}}\right) = 0$) versus RBC model with only consumption adjustment cost and no habit formation (i.e., $\phi = 0$) show that the asymmetric responses of output, consumption and hours are driven by consumption adjustment cost only. Moreover, another difference in the impulse responses for these models is that output, consumption and hour jump by less on impact when habit persistence is greater than zero and therefore allows for the hump-shaped responses which are otherwise difficult to achieve. An RBC model with both habit formation and consumption adjustment cost results in impulse responses that better match the empirical responses.

- A corporate tax increase and tax decrease show opposite but symmetric effects on output. While the treatment of individual income taxation in RBC model is straightforward, that of capital income taxes is less so. Capital or corporate income taxes can take different forms including taxes on corporate profits (which cannot be supported in a model with perfect competition), changes in depreciation guidelines, or other complexities involved in the taxation schemes. As a result, our model is too simple to match the quantitative effects but it is successful in qualitatively showing the opposite but symmetric effects of sign-based corporate income tax changes.

In summary, the benchmark model presented in this paper, while not as rich in frictions as is usually the case in DSGE analyses, still provides a potential channel that can qualitatively deliver the asymmetric responses of the output and consumption to sign-based tax changes. In particular, resistance in adjusting consumption downwards in the presence of a tax increase is compensated by an increase in work hours by agents. This is then translated into an overall insignificant effect of a tax increase on aggregate output. However, it must be noted that our model only captures intensive margin of the labor market (i.e., total hours worked) while our empirical findings show that both intensive and extensive margins (i.e., employment) of labor market respond asymmetrically to sign-based tax shocks. Therefore, a model that includes both intensive and extensive margins may provide a richer analysis. While the model presented in this paper is simple, we believe that it serves as a useful benchmark in assessing the effects of sign-based tax shocks on important macroeconomic variables and hence highlighting important economic and behavioral explanations that may be at play in our empirical analysis.

7. Conclusion

We present empirical evidence of asymmetric response of output to sign-based (exogenous and permanent) R & R tax changes. In particular, we find unanticipated tax decrease to have a persistent and significantly positive effect on output, whereas unanticipated tax increase has no systematic effect on output.

Furthermore, we present the transmission mechanism behind the asymmetric responses of output to sign-based tax changes. First, we show that individual-income tax changes primarily drive the asymmetric responses of aggregate output. Second, we compute impulse responses of other macroeconomic variables. We find that the asymmetric responses of consumption and labor supply are the primary channels through which the asymmetric response of output is transmitted into the economy. Investment, on the other hand, shows symmetric responses to sign-based tax changes. We use the insights on the transmissions mechanisms in our empirical analysis to formulate a simple DSGE model that is consistent with the empirical findings, and show how simple consumption-adjustment costs can generate asymmetric effects of tax changes. Non-psychological effects such as consumption commitment entail limited ability of household to adjust their consumption downward and provide one potential explanation that rationalizes our empirical results.

Although our study is limited to long-run average effects of these tax changes on output growth, our empirical results have important consequences for fiscal policy. The empirical evidence of an asymmetric effect on output of sign-based tax changes speaks to the issue of the overall importance of these tax changes as a source of economic fluctuations. Our results indicate that tax cuts are important insofar as they stimulate output.[25] In particular, our results emphasize that caution must be exercised while drawing policy implications from models that assume symmetric effects of these tax changes on output responses. Since the asymmetric effect on output primarily stems from the asymmetric responses of households to the sign-based tax changes, our findings also highlight important behavioral implications of fiscal policies.

[25]Note that our results are based on unconditional responses of output to these tax changes (i.e., the impulse responses are averaged across all histories). Therefore, our results do not suggest that the economy can alternate between tax increases and tax decreases to achieve rapid growth. For such policy implications, an impulse response conditional on the current history is a more relevant statistic.

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A. Appendix

A.1. Data

This section provides further details about the dataset and the construction of variables used in the present paper:

R & R Tax Changes: The table below lists all legislations that led to various tax changes as documented in Romer and Romer (2010). Out of the documented series we use permanent and exogenous tax changes (with respect to the output). The original narrative series identify a total of 54 quarterly tax changes as exogenous. Out of these exogenous changes, 41 are permanent tax changes while the remaining are temporary. The exogenous tax changes are further classified as long-run (LR) versus deficit driven (DD) which refers to the motivation behind the tax change as identified by Romer and Romer (2010) using the executive actions and corresponding discussions in the Economic Report of the President, presidential speeches and statements, Annual Report of the Secretary of the Treasury on the State of the Finances, the Budget of the United States Government, Congressional Records, Social Security Bulletin Annual Report of the Board of Trustees of the Federal Old Age and Survivors Insurance Trust Fund. In particular, long-run tax changes are reduction in marginal tax rates in order to raise output in the long run. Since such actions are fundamentally different from the countercyclical actions - where the goal is to offset the shocks acting to reduce growth relative to normal growth such tax changes are exogenous. That is the tax changes are not driven by contemporaneous output growth. Deficit driven tax changes, on the other hand are tax increases which were legislated to deal with an inherited budget deficit. An inherited deficit reflects past economic conditions and budgetary decisions, not current conditions or spending changes and therefore are also exogenous.

A few significant example of long-run driven tax changes include: the tax cut passed over Trumans veto in the Revenue act of 1948, the Kennedy-Johnson tax cut in the Revenue Act of 1964, the Reagan tax cut in the Economic Recovery Tax Act of 1981. Tax cuts which are exogenous but not part of our data are the tax changes which were temporary such as large parts of the 2001 and 2003 Bush tax cuts in the Economic Growth and Tax Relief Reconciliation Act of 2001 and Jobs and Growth Tax Relief Reconciliation Act of 2003, respectively. Both these tax changes reduced the marginal tax rates but in both cases the changes were intended to be temporary to spur short-run growth.

The majority of the deficit-driven actions were designed to deal with the long-run solvency of the Social Security system. The Social Security Amendments of 1977 and 1983, in particular, were major actions that raised taxes in a number of steps and did not simultaneously increase benefits. The largest deficit-driven tax increases not related to Social Security were those contained in the Tax Equity and Fiscal Responsibility Tax Act of 1982 and the Omnibus Budget Reconciliation Acts of 1990 and 1993. All of these tax increases were intended to be permanent and therefore provide appropriate examples of deficit-driven tax increases in our sample.

Tax changes which are countercyclical or motivated by spending on wars etc. are classified as endogenous. Countercyclical tax changes were most common from 1965 to 1975. The two largest countercyclical tax changes include the 1968 tax surcharge and later the 1975 tax cut. Countercyclical tax changes are non-existent in 1950s, 1980s and 1990s. Only some parts of Bush tax cuts in 2001 and all of the post-September-11th cuts contained in the Job Creation and Worker Assistance Act of 2002 were countercyclical. Spending-driven tax actions are usually tax increases, such as social security spending or Korean War, which are motivated by budgetary needs of the government however, one example where taxes were reduced due to reduction in spending was at the end of WWII. Such tax changes are regarded as endogenous since these legislations are ones taken to offset developments that would cause output growth to differ from normal, hence policy makers use taxes as a fiscal policy to adjust the output growth.

For details of each legislation for tax change, see the additional materials using the following link: http://www.aeaweb.org//articles.php?doi=10.1257/aer.100.3.763.

Anticipated and Unanticipated Tax Changes: Like Mertens and Ravn (2011), we categorize a tax change as anticipated if the signing of the tax reform and its implementation are more than 90 days apart. See Mertens and Ravn (2011) for more details. Note that our measure of the unanticipated tax changes differs from that of Mertens and Ravn (2011) in one important way. Our underlying analysis explores the long-run effects of tax changes; therefore, we are only interested in permanent tax changes. In particular, we are not considering the effects of temporary tax changes; therefore, we ignore the retroactive components of these tax changes (which by definition are for one quarter), which are mainly employed in Mertens and Ravn (2011).

Cyclically Adjusted Tax Revenue Changes (CATR): This measure is designed to take into account the fact that tax revenues increase and decrease with GDP. These tax revenues are therefore measured on the basis of what revenue would be if GDP were at the normal trend level. However, many authors have pointed out some potential endogeneity and other issues with these tax change series (See Romer and Romer (2010), Leigh et al. (2011) and Mertens and Ravn (2012b)). Due to the potential issues with this tax measure, we also redo our exercise with de-meaned cyclically-adjusted-tax-revenue changes where the de-meaned series consist of 115 tax increases and 128 tax cuts. Our results persist with this variation of cyclically-adjusted-tax revenue changes but since these changes are only an increase or a decrease with reference to the mean and therefore not easily interpretable in our context, we do not present the corresponding results in the present paper. Qualitatively, these results are similar with original cyclically-adjusted-tax-revenue changes employed in Romer and Romer (2010).

Individual & Corporate Income Tax Changes: A finer breakdown of the R & R tax changes into individual income and corporate income tax changes comes from Mertens and Ravn (2013). Like Mertens and Ravn (2013), we use a normalization that puts all the tax changes on a consistent basis as employed in Mertens and Ravn (2013). In this way, these tax changes can roughly be considered, as changes in percentage points of average tax rates.

<u>Other macroeconomic variables</u>: The data on total factor productivity (TFP) is from Fernald (2012). Fernald (2012) uses the methodology used in Basu et al. (2006) on quarterly data to estimate a TFP series from 1947Q1–2007Q4. Basu et al. (2006) construct TFP by modifying the standard Solow residuals (output growth minus revenue-share-weighted input growth) by controlling for non-technological aggregation effects in aggregate TFP, varying utilization of capital and labor, non-constant returns, and imperfect competition. Data on labor hours, employment, and labor productivity come from the Bureau of Labor Statistics (BLS). We use hours in the non-farm business sector from the labor productivity and costs database of the BLS. For total hours, we follow Mertens and Ravn (2011), who construct the series by multiplying hours per worker and civilian non-farm employment normalized by population.

Table 1: Data on Tax Shocks.

Name of Act	Date	Change in Liabilities Total	Individual	Corporate	Type	Source
Social Security Amendments of 1947	1950Q1	0.75	0.375	0.375	Exogenous, Permanent	1950 Midyear Economic Report
Revenue Act of 1948	1948Q2	-5	-5	0	Exogenous, Permanent	1948 Midyear Economic Report
Social Security Amendments of 1950	1951Q1	0.3	0.15	0.15	Endogenous, Permanent	Romer and Romer (2009)
	1954Q1	1.3	0.65	0.65	Exogenous, Permanent	1955 Economic Report
Revenue Act of 1950	1950Q4	4.7	3.2	1.5	Endogenous, Permanent	1950 Treasury Annual Report
Excess Profit Tax Act of 1950	1950Q1	3.5	0	3.5	Endogenous, Temporary	1951 Treasury Annual Report
Revenue Act of 1951	1951Q4	5.4	3.1	2.3	Endogenous, Temporary	1951 Treasury Annual Report
Expiration of Excess Profit Tax and Temporary Income Tax Increases	1954Q1	-3.7	-3.7	0	Endogenous, Permanent	1954 Treasury Annual Report
	1954Q1	-1.3	0	-1.3	Exogenous, Permanent	1954 Treasury Annual Report
Excise Tax Reduction Act of 1954	1954Q2	-1	0	0	Endogenous, Permanent	1955 Economic Report
Internal Revenue Code of 1954	1954Q3	-1.4	-0.8	-0.6	Exogenous, Permanent	1954 Treasury Annual Report
Social Security Amendments of 1954	1955Q1	0.5	0.25	0.25	Endogenous, Permanent	Romer and Romer (2009)
Federal-Aid Highway Act of 1956	1956Q3	0.6	0	0	Endogenous, Permanent	1956 Treasure Annual Report
Social Security Amendments of 1956	1957Q1	0.9	0.45	0.45	Endogenous, Permanent	Romer and Romer (2009)
Tax Rate Extension Act of 1958	1958Q3	-0.5	0	0	Exogenous, Permanent	1959 Economic Report
Social Security Amendments of 1958	1959Q1	1.1	0.55	0.55	Endogenous, Permanent	1958 Social Security October Bulletin
	1960Q1	1.9	0.95	0.95	Exogenous, Permanent	Romer and Romer (2009)
Federal-Aid Highway Act of 1959	1959Q4	0.6	0	0	Exogenous, Permanent	1959 Treasury Annual Report
Social Security Amendments of 1961	1962Q1	0.4	0.2	0.2	Endogenous, Permanent	1961 Social Security Bulletin
	1963Q1	2	1	1	Exogenous, Permanent	Romer and Romer (2009)
Changes in Depreciation Guidelines and Revenue Act of 1962	1962Q3	-1.35	0	-1.35	Exogenous, Permanent	1962 Treasury Annual Report
	1962Q4	-0.9	0	-0.9	Exogenous, Permanent	1962 Treasury Annual Report
	1963Q1	0.6	0	0.6	Exogenous, Permanent	1962 Treasury Annual Report
Revenue Act of 1964	1964Q2	-8.4	-6.7	-1.7	Exogenous, Permanent	1965 Economic Report
	1965Q1	-4.5	-3	-1.5	Exogenous, Permanent	1965 Economic Report
Excise Tax Reduction Act of 1965	1965Q3	-1.75	0	0	Exogenous, Permanent	1966 Economic Report
	1966Q1	-1.75	0	0	Exogenous, Permanent	1966 Economic Report
Social Security Amendments of 1965	1966Q1	6	3	3	Endogenous, Permanent	1966 Economic Report
	1967Q1	1.5	0.75	0.75	Endogenous, Permanent	1967 Economic Report
Tax Adjustment Act of 1966	1966Q2	0.9	0	0	Exogenous, Permanent	1966 Economic Report
Public Law 89-800 (Suspension of Investment Tax Credit)	1966Q4	1.5	0	1.5	Endogenous, Temporary	Romer and Romer (2009)
Public Law 90-26 (Restoration of Investment Tax Credit)	1967Q3	-1.6	0	-1.6	Exogenous, Permanent	Romer and Romer (2009)
Social Security Amendments of 1967	1968Q1	2	1	1	Endogenous, Permanent	1968 Economic Report
	1969Q1	3	1.5	1.5	Endogenous, Permanent	1969 Economic Report
	1971Q1	3.6	1.8	1.8	Exogenous, Permanent	1972 Budget
Revenue and Expenditure Control Act of 1968	1968Q3	8.5	5.1	3.4	Endogenous, Temporary	Romer and Romer (2009)
	1969Q1	1.7	1.7	0	Endogenous, Temporary	Romer and Romer (2009)
Tax Reform Act of 1969	1970Q1	-6.7	-6.7	0	Endogenous, Permanent	Romer and Romer (2009)
	1971Q1	-4.7	-4.7	0	Endogenous, Permanent	Romer and Romer (2009)

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Name of Act	Date	Change in Liabilities Total	Individual	Corporate	Type	Source
	1971Q1	-1	-1	0	Exogenous, Permanent	Romer and Romer (2009)
	1972Q1	-1.1	-1.1	0	Endogenous, Permanent	Romer and Romer (2009)
	1972Q1	-1	-1	0	Exogenous, Permanent	Romer and Romer (2009)
Reform of Depreciation Rules	1971Q1	-2.8	0	-2.8	Exogenous, Permanent	1972 Economic Report
1971 Changes to Social Security	1972Q1	3.1	1.55	1.55	Endogenous, Permanent	1973 Budget
Revenue Act of 1971	1972Q1	-8	-3.2	-2.7	Exogenous, Permanent	Address of President Nixon to the Congress (9/9/71)
1972 Changes to Social Security	1973Q1	10	5	5	Endogenous, Permanent	1974 Economic Report
	1978Q1	2.9	1.45	1.45	Exogenous, Permanent	Romer and Romer (2009)
1973 Changes to Social Security	1974Q1	4.2	2.1	2.1	Endogenous, Permanent	1975 Economics Report
Tax Reduction Act of 1975	1975Q2	-45.3	-12	-4.25	Endogenous, Temporary	1976 Economic Report
	1975Q3	32.5	12	4.25	Endogenous, Temporary	1976 Economic Report
Tax Reform Act of 1976	1976Q4	2.4	1.1	0.5	Exogenous, Permanent	1978 Budget
	1977Q1	-0.8	0	0	Exogenous, Permanent	1977 Economic Report
Tax Reduction and Simplification Act of 1975	1977Q3	-7	-5.4	-1.6	Exogenous, Permanent	1978 Economic Report, 1979 Budget
Social Security Amendments of 1977	1979Q1	8.8	4.4	4.4	Exogenous, Permanent	Romer and Romer (2009)
	1980Q1	1.7	0.85	0.85	Exogenous, Permanent	Romer and Romer (2009)
	1981Q1	17.2	8.6	8.6	Exogenous, Permanent	Romer and Romer (2009)
	1982Q1	1.5	0.75	0.75	Exogenous, Permanent	Romer and Romer (2009)
Revenue Act of 1978	1979Q1	-18.9	-12.6	-6.3	Exogenous, Permanent	1979 Economic Report
Crude Oil Windfall Profit Tax Act of 1980	1980Q2	8.2	0	0	Exogenous, Temporary	1982 Budget
	1981Q1	4.1	0	0	Exogenous, Temporary	1982 Budget
	1982Q1	4.1	0	0	Exogenous, Temporary	1982 Budget
Economic Recovery Tax Act of 1981	1981Q3	-8.9	-4	-4.8	Exogenous, Permanent	1983 Budget
	1982Q1	-48.8	-40	-5.5	Exogenous, Permanent	1983 Budget
	1983Q1	-57.3	-47.2	-8.9	Exogenous, Permanent	1983 Budget
	1984Q1	-36.1	-27.1	-7.9	Exogenous, Permanent	1983 Budget
Tax Equity and Fiscal Responsibility Act of 1982	1983Q1	26.4	5	7	Exogenous, Permanent	Projecting Federal Tax Revenues and the Effect of Changes in Tax Law
Social Security Amendments of 1983	1984Q1	12.1	6.05	6.05	Exogenous, Permanent	Romer and Romer (2009)
	1985Q1	8.8	4.4	4.4	Exogenous, Permanent	Romer and Romer (2009)
	1986Q1	4.2	2.1	2.1	Exogenous, Permanent	Romer and Romer (2009)
	1988Q1	15.5	7.75	7.75	Exogenous, Permanent	Romer and Romer (2009)
	1990Q1	10.3	5.15	5.15	Exogenous, Permanent	Romer and Romer (2009)
Deficit Reduction Act of 1984	1984Q3	8	6	3.3	Exogenous, Permanent	1986 Budget
Tax Reform Act of 1986	1986Q4	22.7	0	22.7	Exogenous, Permanent	1988 Budget, Projecting Federal Tax Revenues and the Effect of Changes in Tax Law
	1987Q1	-7.2	-7.2	0	Exogenous, Permanent	1988 Budget, Projecting Federal Tax Revenues and the Effect of Changes in Tax Law
	1987Q3	-20	0	-20	Exogenous, Permanent	1988 Budget, Projecting Federal Tax Revenues and the Effect of Changes in Tax Law
	1988Q1	-7.2	-7.2	0	Exogenous, Permanent	1988 Budget, Projecting Federal Tax Revenues and the Effect of Changes in Tax Law
Omnibus Budget Reconciliation Act of 1987	1988Q1	10.8	2.7	5.4	Exogenous, Permanent	Projecting Federal Tax Revenues and the Effect of Changes in Tax Law
Omnibus Budget Reconciliation Act of 1990	1991Q1	35.2	4	1	Exogenous, Permanent	Projecting Federal Tax Revenues and the Effect of Changes in Tax Law
Omnibus Budget Reconciliation Act of 1993	1993Q3	22.8	15.8	4.4	Exogenous, Permanent	Estimated Budget Effects Of The Revenue Provisions Of H.R.2264 (The Omnibus Budget Reconciliation Act Of 1993) As Agreed To By The Conferees
	1993Q4	5.3	0	0	Exogenous, Permanent	Estimated Budget Effects Of The Revenue Provisions Of H.R.2264 (The Omnibus Budget Reconciliation Act Of 1993) As Agreed To By The Conferees
	1994Q1	13.4	5.2	3.5	Exogenous, Permanent	Estimated Budget Effects Of The Revenue Provisions Of H.R.2264 (The Omnibus Budget Reconciliation Act Of 1993) As Agreed To By The Conferees
Tax Relief Act of 1997	1998Q1	-20.9	0	0	Endogenous, Permanent	An Economic Analysis of the Taxpayer Relief Act of 1997
	2000Q1	1.7	0	0	Exogenous, Permanent	Budgetary Implications of the Balanced Budget Act of 1997
	2002Q1	0.6	0	0	Exogenous, Permanent	Budgetary Implications of the Balanced Budget Act of 1997
Economic Growth and Tax Relief Reconciliation Act of 2001	2001Q3	-57	-40	-33	Endogenous, Temporary	The Budget and Economic Outlook, An Update, August 2001
	2002Q1	57	40	33	Endogenous, Temporary	The Budget and Economic Outlook, An Update, August 2001
	2002Q1	-83	-83	0	Exogenous, Permanent	The Budget and Economic Outlook, An Update, August 2001
Job Creation and Worker Assistance Act of 2002	2002Q2	-36.9		-36.9	Endogenous, Temporary	Estimated Revenue Effects Of The "Job Creation And Worker Assistance Act Of 2002"

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Table 1 – continued from previous page

Name of Act	Date	Change in Liabilities Total	Individual	Corporate	Type	Source
Jobs and Growth Tax Relief Reconciliation Act of 2003	2003Q3	-126.4	-95.2	-31.2	Exogenous, Temporary	Romer and Romer (2009)

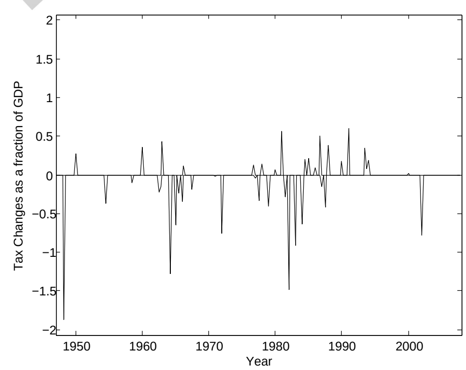
Table 2 summarizes the data sources and time period covered for each of the variables used in this paper.

Table 2: Data Sources

Variables	Data Source	Time Period	Frequency
Tax changes	Romer and Romer (2010)	1947 - 2007	Quarterly
Cyclically-adjusted-tax-revenues	Romer and Romer (2010)	1947 - 2007	Quarterly
Unanticipated tax changes	Mertens and Ravn (2012a)	1947 - 2007	Quarterly
Corporate-income tax changes	Mertens and Ravn (2013)	1947 - 2007	Quarterly
Individual-income tax changes	Mertens and Ravn (2013)	1947 - 2007	Quarterly
Total hours	Mertens and Ravn (2011)	1947 - 2007	Quarterly
Total factor productivity	Fernald (2012)	1947 - 2007	Quarterly
Output	Bureau of Economics Analysis	1947 - 2007	Quarterly
Investment	Bureau of Economics Analysis	1947 - 2007	Quarterly
Consumption	Bureau of Economics Analysis	1947 - 2007	Quarterly
Govt. Spending	Bureau of Economics Analysis	1947 - 2007	Quarterly
Federal Tax Revenue	Bureau of Economics Analysis	1947 - 2007	Quarterly
Labor hours	Bureau of Labor Statistics	1947 - 2007	Quarterly
Labor productivity	Bureau of Labor Statistics	1947 - 2007	Quarterly
Employment	Bureau of Labor Statistics	1947 - 2007	Quarterly

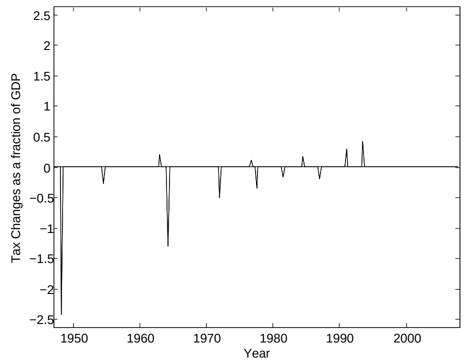
Notes: Table 2 reports the data sources, time period, and frequency of the variables used in this paper.

Figure 1: R & R Tax Changes



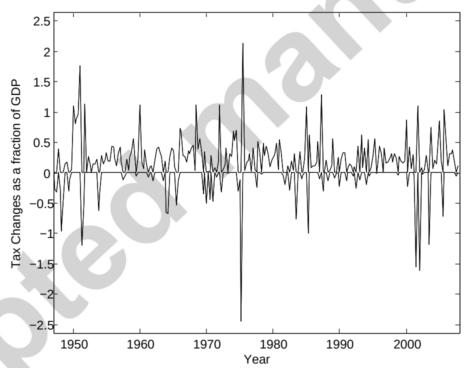
Notes: Figure 1 illustrates the frequency, magnitude and timings of a R & R tax increase and decrease. Each tax change is permanent and exogenous. Source: Romer and Romer (2010)

Figure 2: Unanticipated R & R Tax Changes



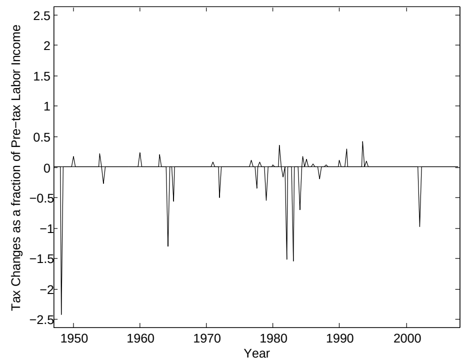
Notes: Figure 2 illustrates the frequency, magnitude, and timings of a R & R unanticipated-tax increase and decrease. Note that the tax changes are different from Mertens and Ravn (2013) because they are permanent and exogenous. For short, we call these tax changes unanticipated R & R tax changes. Source: Romer and Romer (2010) & Mertens and Ravn (2011).

Figure 3: Cyclically-Adjusted-Tax-Revenue-Changes



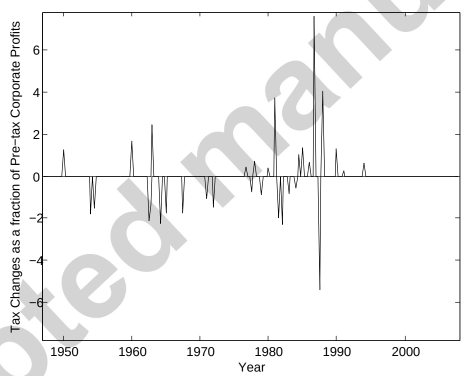
Notes: Figure 3 illustrates the frequency, magnitude, and timings of an increase and a decrease in *cyclically-adjusted-tax-revenue*. Source: Romer and Romer (2010).

Figure 4: Individual-Income R & R Tax Changes



Notes: Figure 4 illustrates the frequency, magnitude, and timings of a R & R individual-income tax increase and decrease. Note that these tax changes are different from Mertens and Ravn (2013) because they are permanent and exogenous. Source: Romer and Romer (2010) & Mertens and Ravn (2013).

Figure 5: Corporate-Income R & R Tax Changes



Notes: Figure 5 illustrates the frequency, magnitude, and timings of a R & R corporate-income tax increase and decrease. Note that these tax changes are different from Mertens and Ravn (2013) because they are permanent and exogenous. Source: Romer and Romer (2010) & Mertens and Ravn (2013).

A.2. Steps for Computation of Impulse Response and Standard Errors:

1. Estimate the following equation for a particular type of tax change. Collect the estimated coefficients for the equation and also the residuals ϵ_t:

$$\Delta y_t = \alpha + \sum_{p=0}^{M} \beta_p^+ \Delta\tau_{t-p}^+ + \sum_{n=0}^{M} \beta_n^- \Delta\tau_{t-n}^- + \sum_{l=0}^{L} \beta_l \Delta y_{t-l} + \epsilon_t, \tag{20}$$

2. Pick a history, Ω_{t-1}^i, which consists of a block of M consecutive values of $\Delta\tau_t^+$ and $\Delta\tau_t^-$.

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 decreases and tax increases from the series on these variables with replacement.[26] 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^i_{t-1}, and the sequence of changes, simulate H values of y_t. These values are simulated by using equation 20. Call this time path $y^{ns}_{t+j}, j = 1, 2, ..., H$.

5. Now repeat step 4 with one change. In the sequence of tax decreases and tax increases, replace the first value of either of the two tax changes (to the change of interest) by a constant value δ. If the underlying idea is to study how a tax increase affects output growth, then τ^+_{t+1} will be set equal to δ. Values of all τ^+_{t+j} such that $j = 2, 3, ..., H$, estimate the time path of y_t for this new sequence of tax changes and call it y^s_{t+j}, 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^i_{t-1}. This impulse response of y_t can be represented as

$$IRF(h, \delta, \Omega^i_{t-1}) = \frac{\sum_{k=1}^{N} y^s_t(h, \delta, \Omega^i_{t-1}, k) - y^{ns}_t(h, \Omega^i_{t-1}, k)}{N},$$

where $y^{ns}_t(h, \Omega^i_{t-1}, k)$ represents the computed value of y_t from step 4 at h^{th} horizon. $y^s_t(h, \delta, \Omega^i_{t-1}, k)$ represents 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^i_{t-1} selected in step 2. $k = 1, 2, ..., N$ such values are computed through steps 4 and 5.

7. Finally, average $IRF(h, \delta, \Omega^i_{t-1})$ 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 represented as

$$IRF(h, \delta) = \int IRF(h, \delta, \Omega^i) d\Omega^i.$$

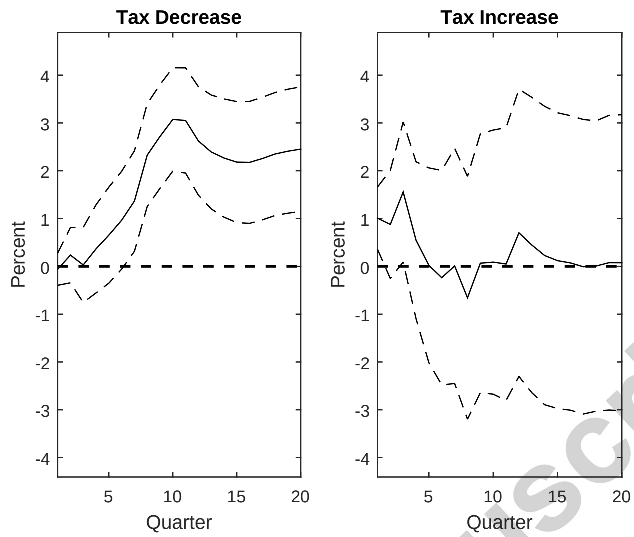
Following Kilian and Vigfusson (2011), we assign equal weights to each history and therefore, the above is simply an arithmetic average.

8. Residuals from the estimated dynamic regression models involving daily, weekly, and monthly data exhibit a strong evidence of conditional heteroskedacticity. 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, we follow the wild bootstrap methodology as proposed by Gonçalves and Kilian (2004). In particular, we use wild bootstrap M times to compute standard errors for the computed impulse responses by repeating steps 1-7 for each bootstrapped data set. We then use these standard errors to construct 95% confidence intervals.

[26] Note that when impulse responses are estimated using equation (20), the value of H cannot be bigger than M since the effect of tax changes only last for M periods.

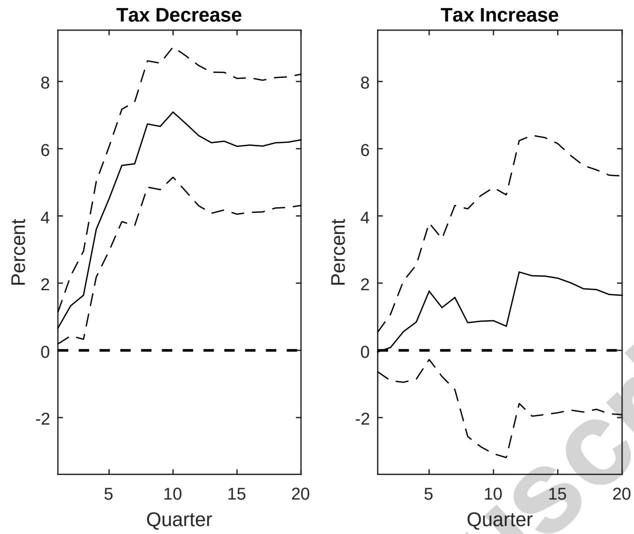
A.3. Figures

Figure 6: Impulse Responses: R & R Tax Decrease and Increase



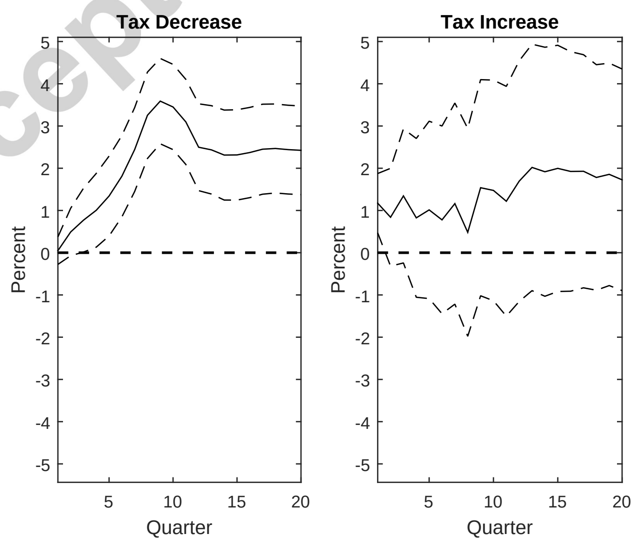
Notes: Figure 6 plots impulse responses of output to a R & R exogenous and permanent tax decrease and increase in panels 1 and 2, respectively. Each plot illustrates impulse responses based on non-linear methodology. Computation of impulse responses from non-linear methodology is based on Kilian and Vigfusson's (2011) methodology (see Section 3 and Section A.2 for more details on methodology). The non-linear impulse responses are the average of the impulse responses computed for each possible history. Impulse response for a particular history is computed by taking the difference of two simulated paths of real output growth, one in which the tax changes were randomly drawn from the empirical series, and the second in which the same tax values were used as in the first one except for one change: the first value of the particular tax series was set to a constant δ, where δ is the size of the tax change given as a shock to the dynamic system. The paths for real output growth were simulated using the coefficients estimated through a regression of real output growth on 12 lags of a tax decrease and a tax increase. One standard-deviation confidence intervals are also provided for each of the impulse responses.

Figure 7: Impulse Responses: Unanticipated R & R Tax Decrease and Increase with Anticipated Tax Change as a Control



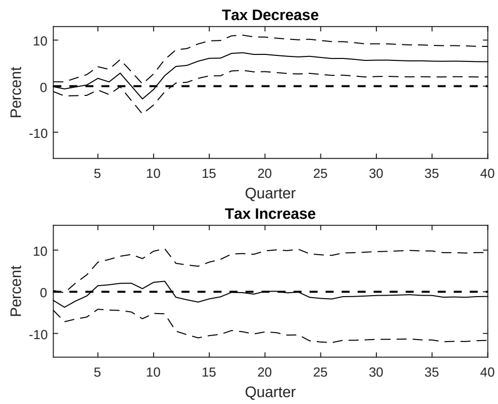
Notes: Figure 7 plots impulse responses of output to an unanticipated R & R tax decrease and increase, respectively. Unanticipated-tax changes are identified using Mertens and Ravn's (2011) methodology. Each plot illustrates impulse responses based on the non-linear methodology by Kilian and Vigfusson (2011) (See Section 3 and Section A.2 for more detail on the methodology).

Figure 8: Impulse Responses: R & R Tax Decrease and Increase with Government Spending as a Control

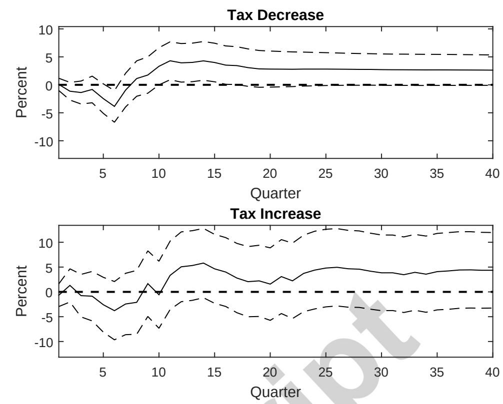


Notes: Figure 8 plots impulse responses of output to an R & R tax decrease and increase, respectively. Each plot illustrates impulse responses based on the non-linear methodology by Kilian and Vigfusson (2011) (See Section 3 and Section A.2 for more detail on the methodology).

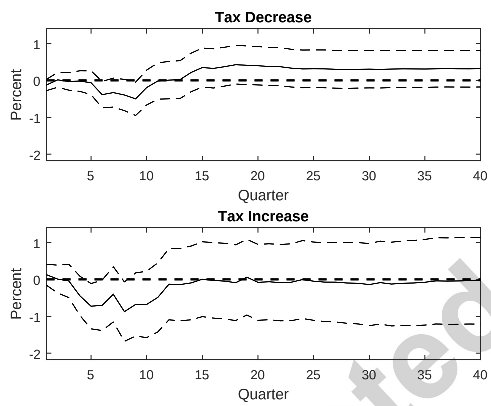
Figure 9: Impulse responses of Govt. Expenditure, Tax Revenues, Legislated Tax Changes to Sign-based Tax Changes



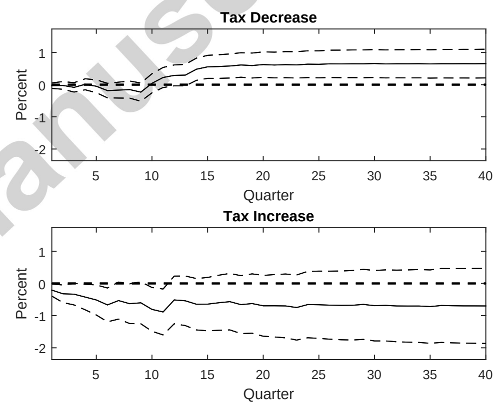
(a) Government Expenditure



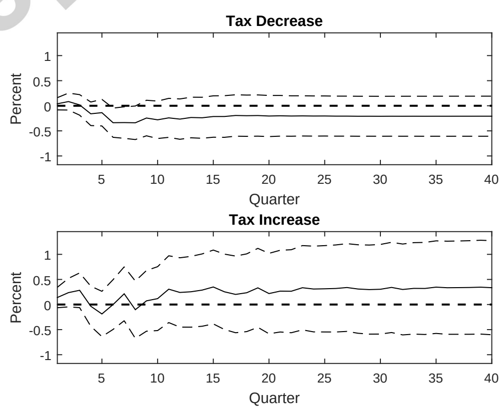
(b) Tax Revenue



(c) All Legislated Tax Changes



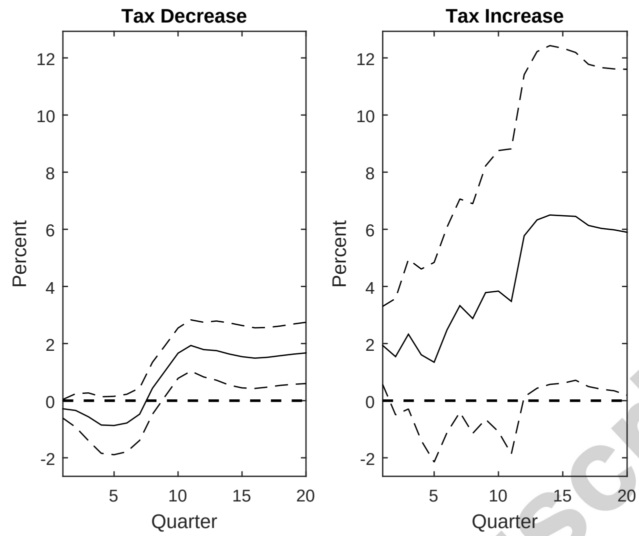
(d) All Legislated Tax Increase



(e) All Legislated Tax Decrease

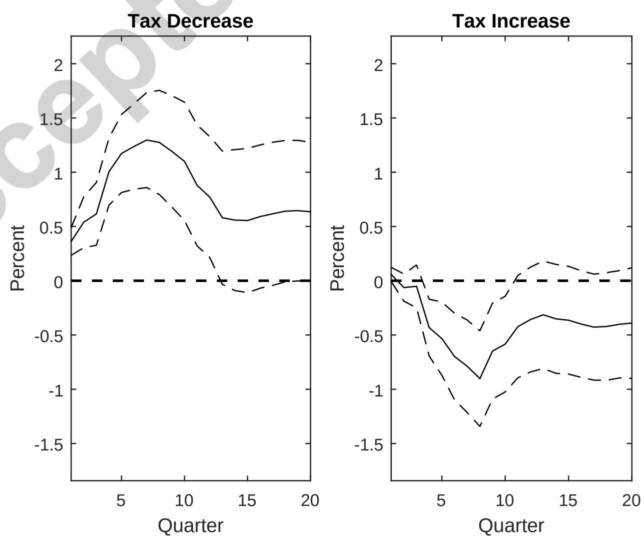
Notes: Figure 9(a) – 9(e) plot model based impulse responses of the listed variables to a tax decrease and a tax increase. Each plot illustrates impulse responses based on the non-linear methodology by Kilian and Vigfusson (2011) (See Section 3 and Section A.2 for more detail on the methodology).

Figure 10: Impulse Responses: Individual-Income Tax Decrease and Increase



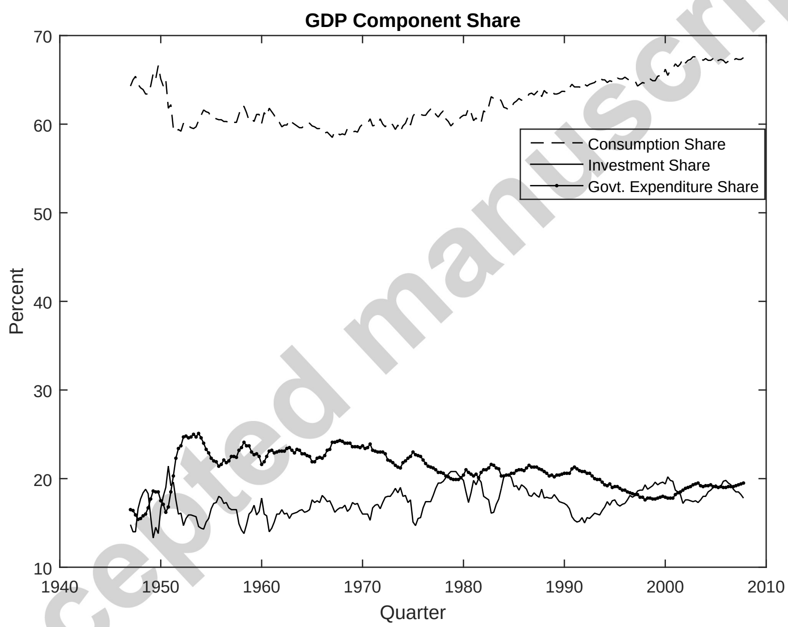
Notes: Figure 10 plots impulse responses of output to an *individual income* tax decrease and increase, respectively. Individual income tax changes are identified using Mertens and Ravn (2013)'s methodology. Each plot illustrates impulse responses based on a non-linear methodology by Kilian and Vigfusson (2011) (see Section 3 and Section A.2 for more detail on the methodology).

Figure 11: Impulse Responses: Corporate-Income Tax Decrease and Increase



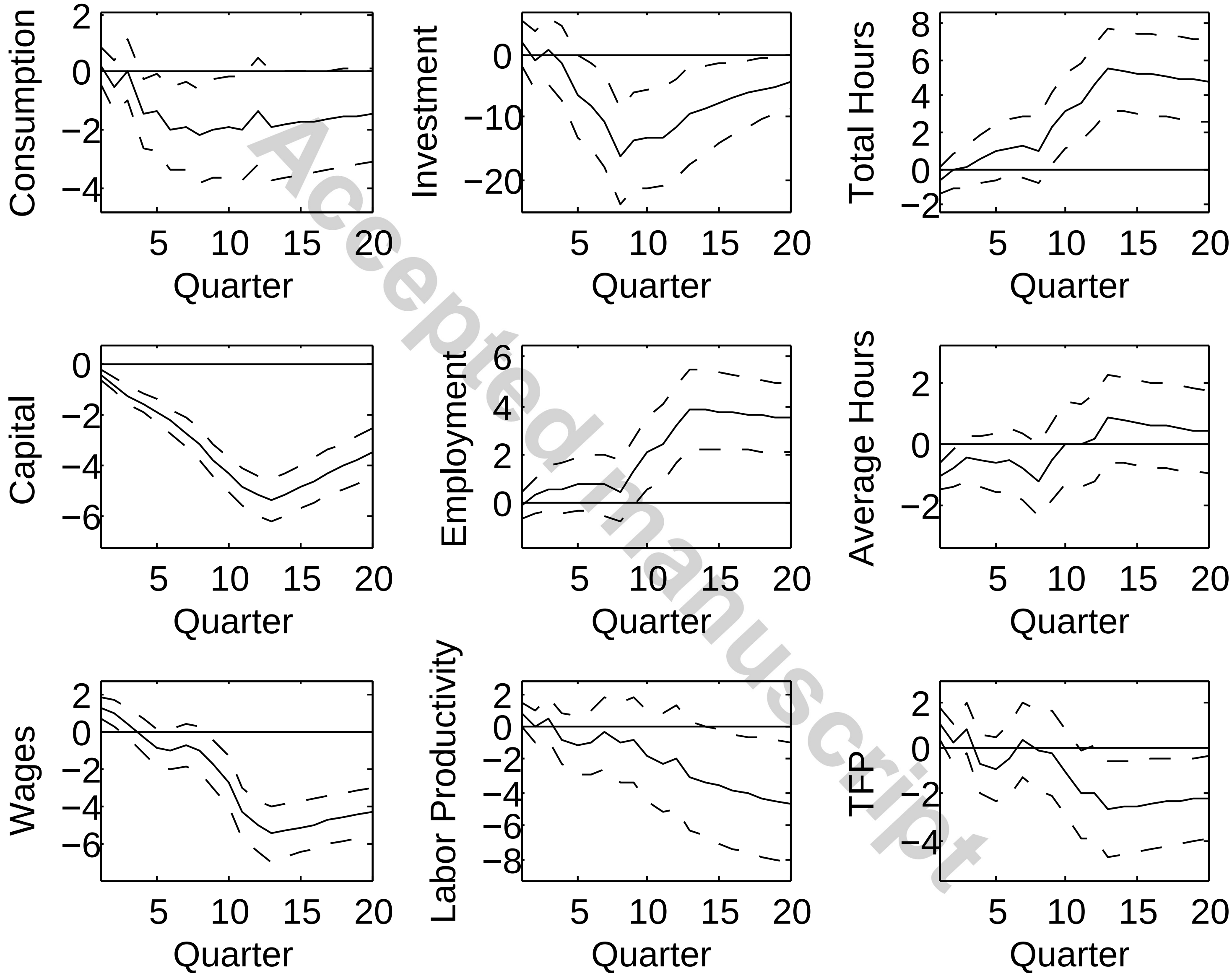
Notes: Figure 11 plots impulse responses of output to a corporate-income tax decrease and increase, respectively. Corporate-income tax changes are identified using Mertens and Ravn's (2013) methodology. Each plot illustrates impulse responses based on the non-linear methodology by Kilian and Vigfusson (2011) (see Section 3 and Section A.2 for more detail on the methodology).

Figure 12: Component of Output



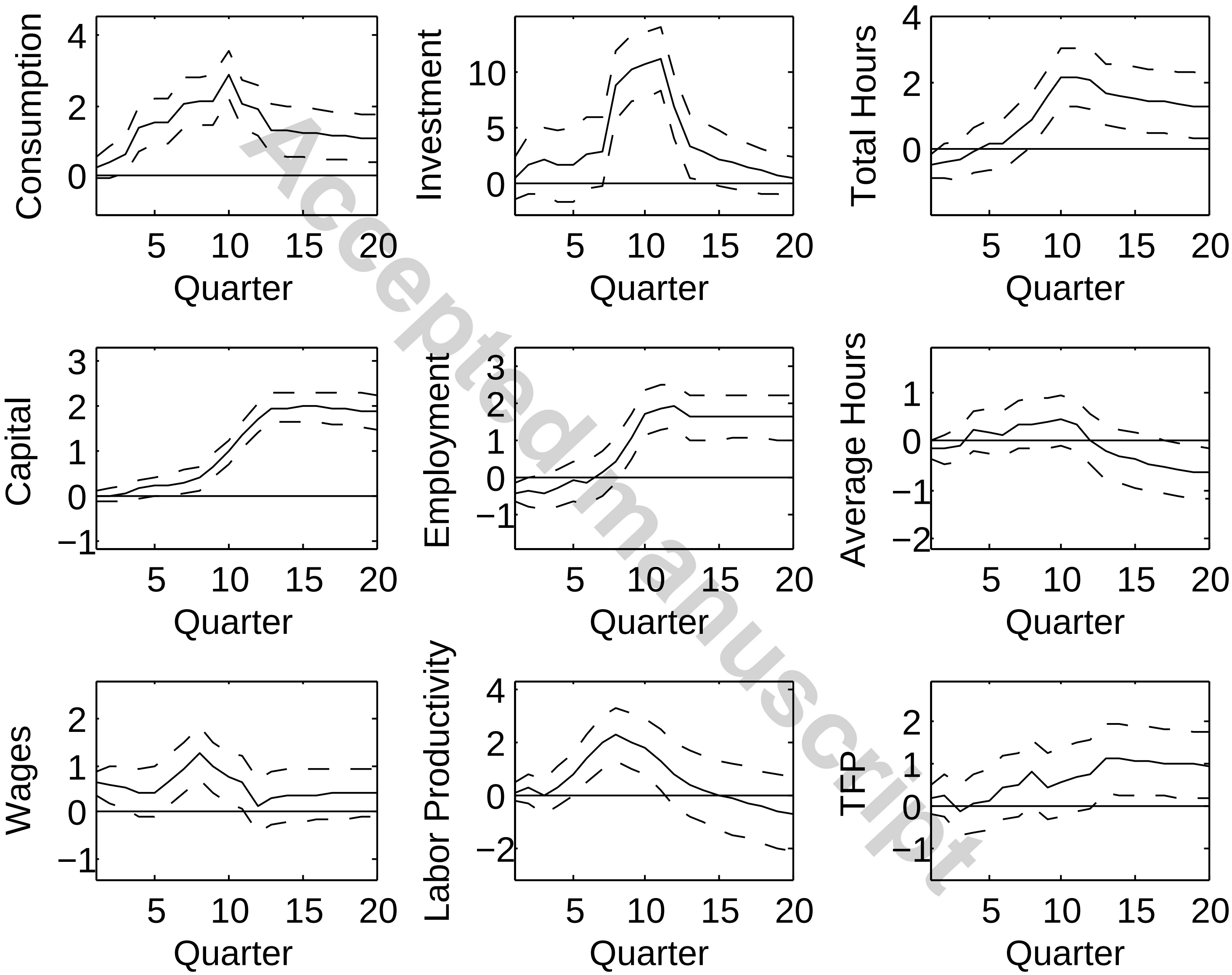
Notes: Figure 12 plots the share of consumption, investment and government expenditure as a percentage of GDP for our sample.

Figure 13: Impulse Response of Macroeconomic Variables: R & R Tax Increase



Notes: Figure 13 presents the effect of a tax increase on various macroeconomic variables. The impulse responses are from a four variable VAR with real GDP growth, the variable, the tax increase variable, and the tax decrease variable appearing in that order in the VAR. The dashed lines represent the one standard-error bands.

Figure 14: Impulse Response of Macroeconomic Variables: R & R Tax Decrease



Notes: Figure 14 presents the effect of a tax increase on various macroeconomic variables. The impulse responses are from a four variable VAR with real GDP, the variable, the tax increase variable, and the tax decrease variable appearing in that order in the VAR. The dashed lines represent the one standard-error bands.

Figure 15: Impulse Response of Non-Durable Consumption: R & R Tax Increase and Decrease

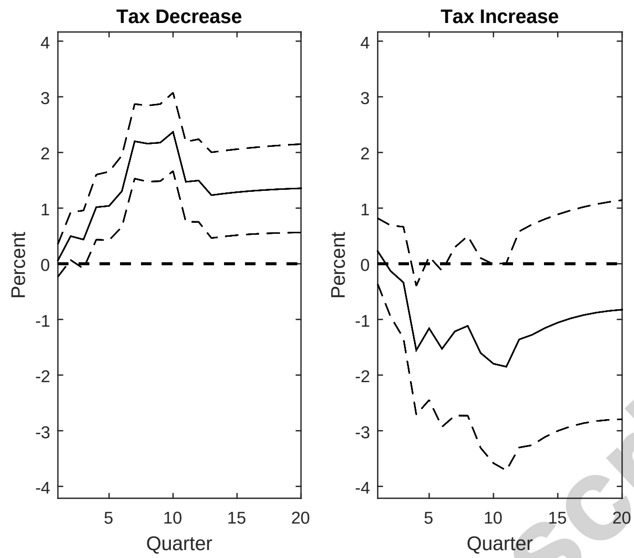


Figure 15 plots impulse responses of non-durable consumption to a R & R tax decrease and decrease tax change, respectively. Each plot illustrates impulse responses based on the non-linear methodology by Kilian and Vigfusson (2011) (see Section 3 and Section A.2 for more detail on the methodology).

Figure 16: Impulse Response of Durable Consumption: R & R Tax Increase and Decrease

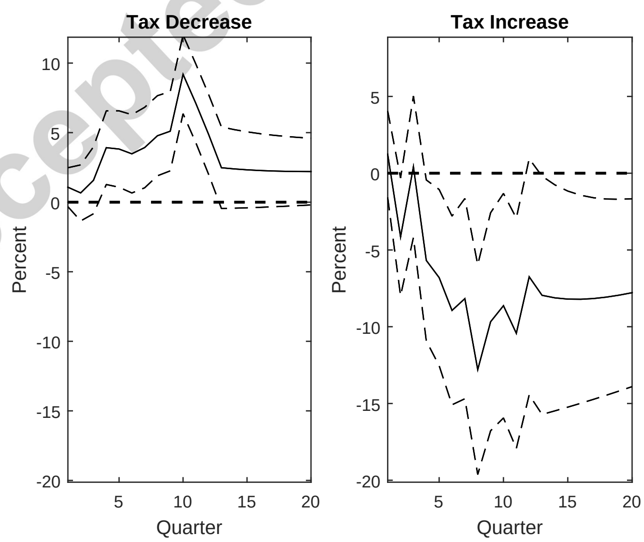
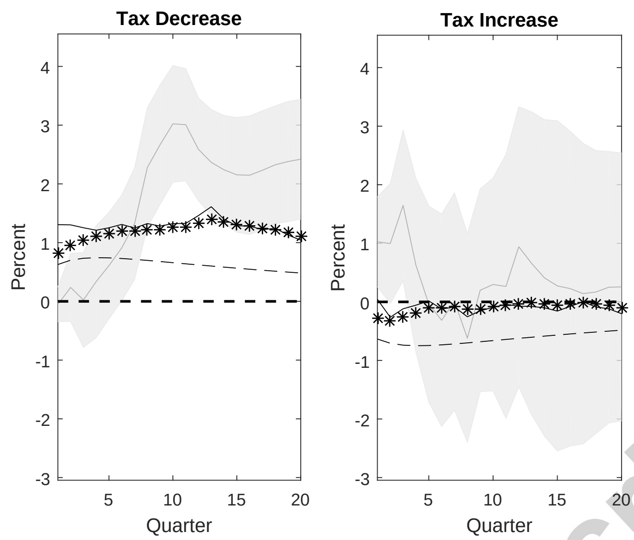


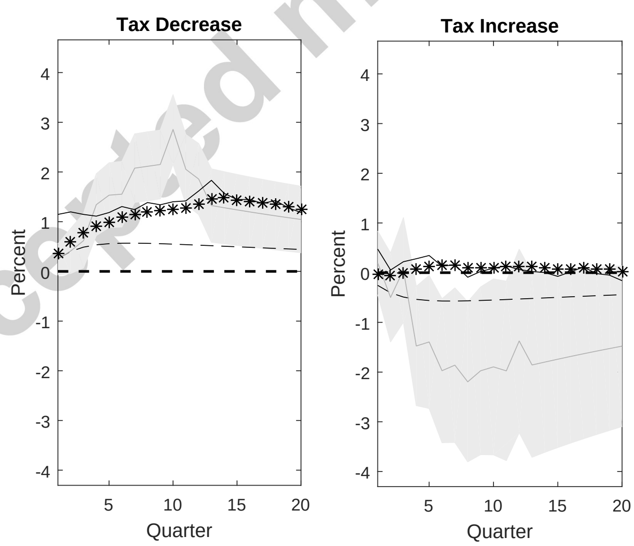
Figure 16 plots impulse responses of durable consumption to a R & R tax decrease and decrease tax change, respectively. Each plot illustrates impulse responses based on the non-linear methodology by Kilian and Vigfusson (2011) (see Section 3 and Section A.2 for more detail on the methodology).

Figure 17: Model: Impulse Responses of Output to a Tax Decrease and Increase



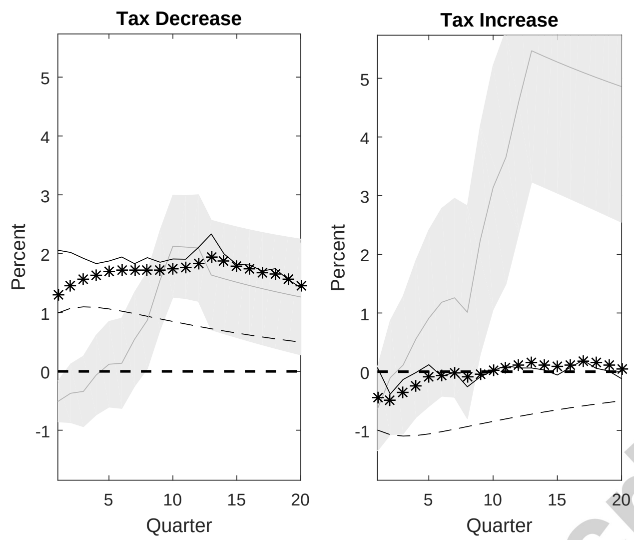
Notes: −− line for standard RBC model with Habit formation, – for standard RBC model with consumption adjustment cost and ∗∗ for standard RBC model augmented with Habit formation and consumption adjustment cost, gray for empirical impulse responses of output with error bands.

Figure 18: Model: Impulse Responses of Consumption to a Tax Decrease and Increase



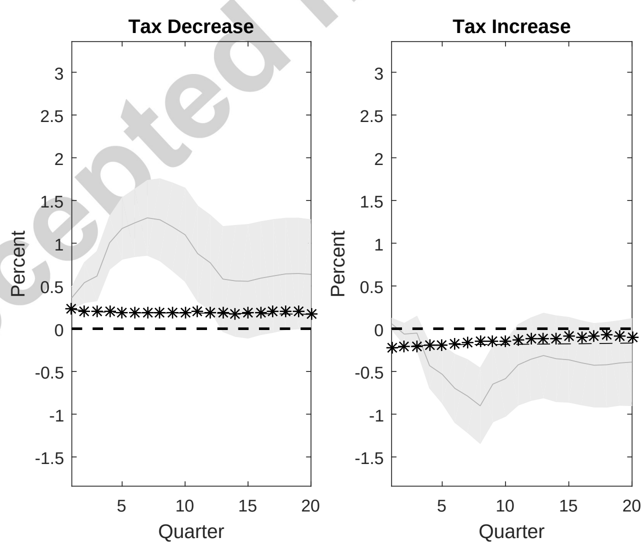
Notes: −− line for standard RBC model with Habit formation, – for standard RBC model with consumption adjustment cost and ∗∗ for standard RBC model augmented with Habit formation and consumption adjustment cost, gray for empirical impulse responses of consumption with error bands.

Figure 19: Model: Impulse Responses of Hours to a Tax Decrease and Increase



Notes: −− line for standard RBC model with Habit formation, − for standard RBC model with consumption adjustment cost and ∗∗ for standard RBC model augmented with Habit formation and consumption adjustment cost, gray for empirical impulse responses of hours with error bands.

Figure 20: Model: Impulse Responses of Output to a Corporate Income Tax Decrease and Increase



Notes: − for standard RBC model with consumption adjustment cost and ∗∗ for standard RBC model augmented with Habit formation and consumption adjustment cost, gray for empirical impulse responses of output with error bands.

A.4. Diagnostic Tests Results

Table 3: p - values of the T test of $H_0 : IRF\,(h, \delta) = -IRF\,(h, -\delta)\,\forall h = 0, 1, 2, \cdots, H.$ for output

T Test	R & R	Unanticipated	Personal Income	Corporate Income
H	P value	P value	P value	P value
1	0.116004	0.24386	0.044121	0.003822
2	0.201308	0.169953	0.234931	0.037556
3	0.187613	0.155026	0.212841	0.058323
4	0.33454	0.03875	0.386509	0.099675
5	0.388138	0.018853	0.43493	0.108629
6	0.38623	0.018261	0.298962	0.175367
7	0.300245	0.017913	0.203001	0.205913
8	0.269046	0.018892	0.175323	0.288063
9	0.159837	0.019391	0.094421	0.208076
10	0.138584	0.012644	0.075816	0.229472
11	0.150387	0.019108	0.082991	0.262422
12	0.143379	0.010544	0.026881	0.287034
13	0.184656	0.014403	0.019729	0.362287
14	0.217984	0.014448	0.018368	0.395085
15	0.235997	0.014699	0.018206	0.404378
16	0.238777	0.013906	0.017046	0.404119
17	0.235518	0.014179	0.018303	0.405772
18	0.222732	0.012537	0.017539	0.390173
19	0.210442	0.011849	0.017233	0.377106
20	0.206994	0.010568	0.01777	0.376602

Table 4: p - values of the F test of $H_0 : \sum_{n=0}^{M} \beta_n^- = 0$ (or) $H_0 : \sum_{p=0}^{M} \beta_p^+ = 0$ for output

F Test	R & R	Unanticipated	Personal Income	Corporate Income
$\sum_{n=0}^{M} \beta_n^- = 0$	0.285245	0.0046	0.4257	0.2406
$\sum_{p=0}^{M} \beta_p^+ = 0$	0.80261	0.9296	0.7688	0.235

Table 5: p - values of the Wald test of (1) $H_0 : IRF\,(h,\delta) = -IRF\,(h,-\delta)\,\forall h = 1,2,\cdots,H.$ for output

Wald Test	R & R	Unanticipated	Personal Income	Corporate Income
1	0.246216	0.434883	0.085872	0.002258
2	0.402386	0.223322	0.461809	0.051357
3	0.37137	0.26254	0.412756	0.066197
4	0.663089	0.056453	0.767176	0.092713
5	0.770194	0.01761	0.866162	0.077057
6	0.766985	0.025525	0.59064	0.156856
7	0.58561	0.030151	0.404877	0.210854
8	0.525393	0.03657	0.351019	0.385454
9	0.309055	0.045078	0.190489	0.211936
10	0.268073	0.031078	0.150615	0.271088
11	0.297314	0.050633	0.166328	0.338126
12	0.283718	0.028584	0.051173	0.393657
13	0.369971	0.033699	0.037755	0.581355
14	0.438674	0.031549	0.034625	0.676829
15	0.476898	0.029623	0.034836	0.704092
16	0.482895	0.027413	0.032406	0.700025
17	0.476176	0.028034	0.035721	0.703722
18	0.449391	0.023992	0.034291	0.655619
19	0.423221	0.021927	0.033963	0.618185
20	0.414172	0.019528	0.034724	0.618971

Table 6: p - values of the Wald test (2) of $H_0 : IRF\,(1\ to\ h,\delta) = -IRF\,(1\ to\ h,-\delta)\,\forall h = 1,2,\cdots,H.$ for output

Wald Test	R & R	Unanticipated	Personal Income	Corporate Income
H	P value	P value	P value	P value
1	1	1	0.999999	0.986396
2	1	1	0.999981	0.978798
3	1	1	0.99992	0.952844
4	1	0.986405	0.999633	0.92322
5	1	0.872332	0.999633	0.921289
6	0.999999	0.865944	0.991265	0.918575
7	0.999993	0.863957	0.988734	0.917671
8	0.999993	0.858335	0.986951	0.882251
9	0.999914	0.858089	0.961903	0.795155
10	0.999909	0.812543	0.958022	0.711059
11	0.999881	0.738458	0.955901	0.710673
12	0.999839	0.664282	0.606839	0.689347
13	0.999815	0.654001	0.598702	0.599467
14	0.999813	0.61553	0.552789	0.594536
15	0.999812	0.566727	0.55154	0.59431
16	0.99981	0.529592	0.522277	0.59383
17	0.999799	0.144144	0.479698	0.58942
18	0.999796	0.076079	0.479334	0.582738
19	0.999796	0.075054	0.446482	0.578314
20	0.999795	0.073125	0.409437	0.575352

Table 7: p - values of the Wald test (1): $H_0 : IRF(h, \delta) = -IRF(h, -\delta) \forall h = 1, 2, \cdots, H$. for consumption and investment; Wald test (2): $H_0 : IRF(1 \; to \; h, \delta) = -IRF(1toh, -\delta) \forall h = 1, 2, \cdots, H$.; and T test.

	Consumption	Consumption	Consumption	Investment	Investment	Investment
Horizon	Wald (1)	Wald (2)	T	Wald (1)	Wald (2)	T
1	0.4595	1	1	0.5715	0.2520	0.2851
2	0.9308	1	1	0.8744	0.5335	0.4339
3	0.6029	0.9999	1	0.6766	0.2999	0.3269
4	0.9172	0.9989	1	0.95639	0.5409	0.4764
5	0.9227	0.9979	1	0.5292	0.4609	0.7391
6	0.7883	0.9964	1	0.4850	0.6088	0.7701
7	0.9053	0.9896	0.9999	0.30789	0.4501	0.8300
8	0.9662	0.9572	0.9999	0.32639	0.5180	0.8205
9	0.9306	0.9572	0.9995	0.6818	0.4629	0.6542
10	0.6399	0.8738	0.8109	0.9994	0.3139	0.6220
11	0.9718	0.7094	0.9994	0.7475	0.4854	0.5921
12	0.8276	0.5374	0.9953	0.5575	0.4130	0.7121
13	0.8090	0.2108	0.9948	0.4873	0.5947	0.7462
14	0.8118	0.1978	0.9947	0.4713	0.5933	0.7526
15	0.8151	0.1580	0.9929	0.4582	0.5917	0.7575
16	0.8186	0.1576	0.9908	0.4479	0.5900	0.7610
17	0.8223	0.1345	0.9874	0.4403	0.5883	0.7632
18	0.8260	0.1316	0.9850	0.4350	0.5865	0.7642
19	0.8298	0.1657	0.9859	0.4319	0.5848	0.7642
20	0.8335	0.8193	0.9816	0.4309	0.5831	0.7633

Notes: Wald (1) (Wald (2)) tests the hypothesis of symmetry for estimated responses at the Hth horizon (up to the Hth horizon) to a tax decrease and a tax increase.

Table 8: p - values of the F test of $\sum_{n=0}^{M} \beta_n^- = 0$ and $\sum_{p=0}^{M} \beta_p^+ = 0$ for consumption and investment

F Test	Consumption	Investment
$\sum_{n=0}^{M} \beta_n^- = 0$	0.0019	0.00609
$\sum_{p=0}^{M} \beta_p^+ = 0$	0.5651	0.8605

Table 9: Parameter Estimates

Parameter	Estimate	Parameter	Estimate
β	0.9926	α	0.3640
δ	0.0250	ψ	1439
$\bar{\tau}^H$	0.1300	Ψ	10.2504
$\bar{\tau}^k$	0.3400	ϕ_A	0.8222
z	0.0061	ϕ	0.6465
ρ_k	0.9500	ρ	0.9521
γ	0.8710		

Notes: Table 9 reports the estimated parameters under Equation 19.