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: output responds insignificantly to a tax increase, but shows a significantly positive and permanent increase following a tax decrease. We also show that this asymmetry appears to be driven by individual-income tax changes, and transmitted to the economy through asymmetric response in aggregate consumption to positive and negative tax changes.

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

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1. Introduction

Understanding how tax changes affect aggregate economic activity is of central importance to the analysis of fiscal policy. Generally, the existing literature on tax policy has assumed that the effects of tax increase and decrease are symmetric. In this paper, we provide the first empirical evidence that aggregate economic output responds asymmetrically to positive and negative tax changes. We also provide evidence that this asymmetry appears to be driven by the asymmetric responses of households, as opposed to firms, and is transmitted to the economy via asymmetric responses in aggregate consumption to changes in taxes. Failure to account for such asymmetry can lead to systematic biases in the analysis of tax policy, and our results therefore suggest that policy makers trying to predict the implications of tax policy should be cautious using models that assume symmetric effects of sign-based tax changes.

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 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). We categorize the exogenous tax changes in Romer and Romer (2010), measured as the change in tax liabilities relative to GDP, based on their sign: positive if the tax liabilities increase and negative if the tax liabilities decrease. We then estimate the effect of these exogenous tax changes on output growth, and compute non-linear impulse responses following the methodology proposed by Kilian and Vigfusson (2011). In particular, we regress real output growth on contemporaneous and lagged measures of both positive and negative tax changes, and lagged observations of output growth. We also allow for the full history and the magnitude of both tax increases and decreases to affect output, in order to correctly compute history and magnitude dependent non-linear impulse responses.

Our key finding is that positive and negative tax changes have differential effects on
aggregate output. The estimated effect of a positive tax change on output is insignificant. In contrast, output increases by approximately 3.0% at its peak following a negative tax change. Qualitatively, we also find significant asymmetric responses of output when we control for the possibility of anticipatory effects of tax changes. Formal tests also reveal that the output responses to the sign-based tax changes are significantly different from each other. We also show that this result is not confounded with the potential asymmetric responses of output driven by the size rather than the sign of positive and negative tax changes.

To understand the transmission mechanism for this asymmetry, we augment our analysis in two ways. First, following Mertens and Ravn (2013) we classify the Romer and Romer (2010) 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 and investment respond to these sign-based tax changes, and find that consumption has an asymmetric response whereas investment responds symmetrically. Our analysis therefore indicates that asymmetric responses in output are driven primarily by asymmetric responses in aggregate consumption to sign-based tax changes.

Numerous 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%.

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

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1Blanchard 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.
tax changes.\textsuperscript{2} Mertens and Ravn (2011) use narrative tax changes and distinguish between surprise 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 negative tax change on output lies between these previous estimates, while we find no significant effects of positive tax changes.

Romer and Romer (2010) also 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 entirely of tax increases, and long-run driven tax changes consist primarily of tax decreases, this categorization of tax changes results in a series that considerably overlaps with our sign-based categorization of tax change series. However, relative to their analysis, we make four main contributions in this paper. First, we employ a more general non-linear methodology and compute corresponding non-linear impulse responses that are more appropriate for studying the hypothesis of symmetry (see Section 3). Second, we investigate possible transmission mechanisms for asymmetry, identifying the response of household consumption as the channel through which asymmetric responses of output are transmitted to the economy. Third, we perform a wide-range of robustness exercises for our results, including whether our results are emitting from asymmetric magnitudes of tax changes, and provide an array of formal tests for asymmetry. Finally, the categorization of tax changes based on sign, and the analysis of the transmission mechanism of asymmetric responses, highlights different behavioral implications of tax policy than a categorization based on the motivation of tax changes.

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

\textsuperscript{2}The authors suggests that strong negative response of investment are the primary explanation for the large negative output responses to a tax change.
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. (2012) use input utilization as the switching variable in the 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 the responses of output to positive and negative tax changes.

The rest of the paper is organized as follows. Section 2 describes the sources and construction of our data set. In Section 3, we describe our methodology to estimate and compute impulse responses and standard errors. In Section 4, we present and discuss our results. Section 5 concludes. Illustrations and diagnostics for the hypothesis of symmetry are provided in Appendix A.

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. The classify tax changes in response to concerns about inherited debt or changes motivated by long-term growth as exogenous with respect to contemporary movements in the economy. However, they classify tax changes that were made in response to spending incidents or to bring back
output to normal as endogenous. They then measure the exogenous tax change as a change in the nominal tax liabilities normalized by nominal GDP.

Among the Romer and Romer (2010) tax changes, we only consider exogenous, permanent tax change, and term these as R & R tax changes. We categorize them into negative tax changes (resulting from the documented exogenous, permanent tax decreases) and positive tax changes (resulting from the documented exogenous, permanent tax increases). We find a total of 19 positive tax changes and 22 negative tax changes. Figure 15 illustrates the magnitude, time, and sign of these tax changes. 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.

As a robustness check, 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 and therefore we only use these tax shocks for robustness

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3 The most obvious example of a tax change made in response to spending incidents would be a tax increase in the event of a war. Governments increase spending during war, and tax increases finance this spending. Because such a tax increase occurs in response to a contemporaneous activity in the economy, such tax changes are classified as endogenous.

4 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).
and comparison purposes. The timing and the magnitude of these sign dependent tax shock measures are illustrated in Figure 3.

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, and consumption are taken from the Bureau of Economics Analysis (BEA). Data for the remaining macroeconomic variables are from various sources. The data on total factor productivity (TFP) is from Fernald (2012). 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

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5Due 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 positive tax shocks and 128 negative tax shocks. Our results persist with this variation of cyclically-adjusted-tax revenue changes but since these changes are only positive and negative 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).

6This normalization 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.

7These variables are measured using chain-type quantity index.

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

3. Methodology

The existing literature studying the hypotheses of symmetry employs specific form of censored-regressor models. Censored-regressor models amounts 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) showed 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 inbuilt asymmetry in such censored-regressor models, the estimates are likely to be biased.

In addition, so far the non-linearity of the impulse response function has been ignored in the applied literature. However, linear-impulse responses are independent of history and magnitude of the shock. History independence assumes that a shock hits the variable of interest, and then no subsequent shock hits the economy for the next several periods. This can potentially bias the results. 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. Kilian and Vigfusson (2011) proved that inferences based on impulse responses that are independent of the magnitude and the history of explanatory variables can be misleading for studying the hypotheses of symmetry.

Therefore, we depart from uni-directional censored-regressors in favor of a more general
dynamic, non-linear specification. In particular, we regress real output growth on con-
temporaneous and lagged measures of both positive and negative tax changes, 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

$$\Delta \tau_t^+ = \max(0, \Delta \tau_t), \quad \Delta \tau_t^- = \min(0, \Delta \tau_t)$$ (1)

as a positive and a negative change to the tax process, respectively. Following the litera-
ture 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 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 pos-
itive and negative changes 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 im-
posing any form of asymmetry.$^9$ Ravn and Sola (2004), Cover (1992), DeLong and Summers

$^9$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.
(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 positive and negative exogenous tax changes to estimate their effect on aggregate output growth. Specifically, we estimate the following equation:

\[ \Delta y_t = \alpha + \sum_{p=0}^{M} \beta^+_{p} \Delta \tau_{t-p}^+ + \sum_{n=0}^{M} \beta^-_{n} \Delta \tau_{t-n}^- + \sum_{l=0}^{L} \beta_{l} \Delta y_{t-l} + \epsilon_t, \]  

(2)

where $\Delta y_t$ is the growth rate of GDP. $\Delta \tau_{t-p}^+$ and $\Delta \tau_{t-n}^-$ are, respectively, positive and negative exogenous tax changes (change in tax liabilities due to exogenous, permanent tax changes as a percentage of nominal GDP). The signs + and - indicate a positive and a negative tax change, respectively; therefore, $\sum_{p=0}^{M} \beta^+_{p}$ aggregates the coefficients associated with positive tax changes for $M$ lags of tax changes, whereas $\sum_{n=0}^{M} \beta^-_{n}$ denotes the aggregate coefficient associated with negative tax changes for $M$ lags. Lastly, $\Delta y_{t-l}$ 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.\(^\text{10}\)

\(^\text{10}\)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 reach the same results. To save space, we present our key result with this alternative two-equation model in
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 sequence 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 two positive or negative sequences of tax-changes 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 Goncalves 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 Goncalves and Kilian (2004) for more details.

the online appendix, Appendix B.
4. Results

We begin by documenting the effects of negative and positive exogenous, permanent tax changes on output in Section 4.1. Throughout the results, we report impulse responses to a 1% change in tax liabilities (relative to GDP) along with one standard error (computed by wild bootstrapped method) and 95% confidence interval. We 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 negative tax change and a positive tax change. The impulse responses show that output responds significantly to a negative tax change and insignificantly to a positive tax change, which suggests 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 (t=3.04), and it occurs in the 10th quarter. The computed impulse response is highly significant from the 8th quarter until the end of the horizon.\textsuperscript{11} On the other hand, the impulse responses of output corresponding to the positive tax change reveal a surprisingly insignificant effect.

The implied effect of a negative tax change 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 negative and positive tax changes to have a differential effect on output. Relative to the VAR-based estimates of the effect of an unanticipated tax-change on output reported in Mertens and Ravn (2011), our estimates are slightly bigger. However, our initial response

\textsuperscript{11}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.
of output to a negative tax change occurs more gradually than Romer and Romer (2010) and is in line with Mertens and Ravn 2011 implied effect of an unanticipated tax-change for the first seven quarters.

The standard errors corresponding to the impulse responses following a positive tax change and a negative tax change are comparable to the standard error bands in Romer and Romer’s 2010 analysis based on deficit-driven and long-run tax changes. In particular, our standard errors corresponding to positive tax changes are quite large, which may be due to imprecise estimates. In addition, the standard error band for the output responses to a positive and a negative tax change overlap considerably; therefore the formal Wald test of symmetry (presented in the first column of Table 3 in Section A.4) shows we cannot reject symmetry at less than 10% significance level. However, overlooking the suggestive rejection of the null hypothesis of symmetry at the 15% significance level, is not as straightforward when we look at the results of students T and F tests (which are presented in the first column of Table 2 and Table 4, respectively, in Section A.4). Although the formal test results may not jointly reject hypothesis of symmetry, the basic results still point out that only negative tax changes have the expected positive and significant impact on output, whereas positive tax changes do not exhibit expected effect on output.

Furthermore, the results from the positive tax change may also be overstated, because, as Romer and Romer (2010) point out, the deficit-driven tax changes (which are all positive tax changes) are often coupled with spending cuts (which is the case for the latter part of Romer and Romer’s 2010 sample). Since positive tax changes 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, positive tax changes might not behave as theory suggests. Therefore, caution must be exercised while drawing policy implications of tax increases on output. In the subsequent section, we explore in more detail whether
positive taxes behave differently than what theory suggests.

4.2. Unanticipated Tax Changes

Suppose 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 perhaps be due to political economy considerations. Such considerations could induce an asymmetry into the response of output to positive versus negative tax changes. Thus, any form of asymmetric lag, between the legislation and implementation of either a positive or a negative tax change can be a source of asymmetric effects of these tax changes on output. Therefore, the results documented in the last section could potentially be an outcome of a model misspecification.

In this section, we wish to 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. 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. Figure 7 illustrates the main result of this section and reveals that the effect of negative tax change on output is significant, whereas the effect of a positive tax change on output is insignificant.

Furthermore, comparing these results with the estimation results based on R & R tax changes (illustrated in Figure 7 and Figure 6, respectively), we find the effect is highly significant from the 3rd quarter until the 20th quarter for the estimated effect of a negative tax change. Furthermore, the effect is now quantitatively almost doubled. The maximum

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.
effect again occurs in the 10th quarter and is approximately 7% increase in output.\textsuperscript{13}

Results for the formal tests of symmetry are presented in column 2 of Table 2, Table 3, and Table 4. Corresponding p-values of the test statistics strongly reject the null hypothesis of symmetric effects of these tax changes on output. In particular, T-test statistics show that the aggregate response of output to a positive and a negative tax change differ 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 positive (negative) tax changes 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 statistic corroborates the lack of symmetry for at least the last few (17th to 20th) quarters. Jointly, these formal tests provide strong evidence for the asymmetric response of output to a positive and a negative tax change.

Comparing our estimates with the estimates from Mertens and Ravn (2011) is not straight-forward because, the tax-change series in our case differs from theirs (see Section 2). In addition, the underlined model in the current paper allows the possibility of differential effects of positive and negative tax changes on output. In particular, our results reveal a stark increase in the effect of output due to negative unanticipated R & R tax changes. The result makes economic sense because, unanticipated tax changes should, in principle, have a much bigger effect on output as no prior change in behavior is present that can dampen the effect on output.

4.3. 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\textsuperscript{15} We also redo the analysis without anticipated tax changes, and the results (not presented in this paper) are qualitatively similar. The estimates are only marginally different.
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 positive and negative tax changes for each type of tax measure.

We illustrate the results from the analysis that employs individual-income tax changes in Figure 8. The results reveal that negative individual-income tax changes have a long-term effect on output (of approximately 2% at the peak), whereas positive individual-income tax changes have an insignificant effect on output. Although the negative individual-income tax changes have a small and an insignificant effect on output for the first 10 quarters, the effect becomes significant for the rest of the forecast horizon. However, output responses to positive individual-income tax changes remain insignificant throughout the horizon.

Formal tests suggest some 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 a positive and a negative tax change 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, but the test statistics do not formally
pass the critical values. The F-test statistics show that the probability of all coefficients of
the negative individual-income tax changes being jointly zero, is considerably less than the
probability of all coefficients of the positive individual-income tax changes being jointly zero.

The analysis that employs sign-based corporate-income tax changes (while controlling for
individual-income tax changes) shows different results for output. In particular, Figure 9
illustrates that a positive corporate-income tax change 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 the negative
corporate-income tax changes (also illustrated in Figure 9) 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.

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. In addition, in our analysis, the standard error bands
corresponding to negative corporate-tax changes and negative individual-income tax changes
are comparable to the standard error bands in Mertens and Ravn’s 2013 analysis.14

Unlike positive and negative individual-income tax changes, sign-based changes in corporate-
income tax do not exhibit any asymmetric effects on output. Formal tests also reveal that
positive and negative corporate-income tax changes have symmetric effects on output. There-
fore, 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.

14Note, 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.
4.4. Size Asymmetry and Output Responses

Prior results and the estimation of impulse responses are based on a 1% change in a positive and a negative tax. However, on average, in our R & R tax changes, the negative tax changes are much larger than positive tax changes. If a tax change has to be of a certain size before eliciting a significant response of output, then the sign-based asymmetric responses of output from Section 4.1, might in fact be confounded with the size-based asymmetric effects of the tax changes on output.

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 negative tax changes, 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. Figure 10, Figure 11, and Figure 12 illustrate the results based on these three approaches, respectively.

The first approach exhibits long-run effects of the negative tax changes that are similar to the effects from original R & R negative tax changes; however the computed standard errors of the impulse responses are bigger yet significantly different from zero for almost all the quarters. The response of output to positive tax changes is again highly insignificant throughout the horizon. The differential effects of negative and positive tax changes are robust to this alternative tax-change measure which is constructed by replacing the large tax cuts by zeros. Note that the impulse responses of output to positive tax changes in Figure 10(a) and Figure 10(b) differ from each other despite the fact that the positive tax-change
series is the same for both impulse responses. This difference in the impulse responses highlights that the impulse responses in this paper are computed by controlling for the possible history of tax changes. Because the negative tax-change series used in approach one is different, the impulse responses are averaged across different histories. Comparing Figure 10(a) and Figure 10(b), we conclude that the concerns about large tax cuts in our tax measure do not drive the asymmetric responses of output to negative and positive tax changes.

The second approach uses CATR changes which, in contrast to R & R tax changes, have on average smaller size of negative CATR changes than positive CATR changes. Despite the potential issue with these tax changes, the exercise with these tax changes allow us to explore if our key result is driven because of asymmetric size of negative and positive tax changes in R & R data. Romer and Romer (2010) also use these nominal tax revenues normalized by a chain-type price index of GDP. To facilitate the comparison of these tax changes with R & R tax changes, Romer and Romer (2010) also compute the change in the real cyclically-adjusted-tax-revenues normalize by real GDP.

Figure 11 illustrates the computed response of output to a negative and a positive cyclically-adjusted-tax-revenue change. We find that the results are qualitatively similar to the results from R & R tax changes. The estimated implied effect of negative CATR changes on output is about 2.3%, whereas positive CATR changes have insignificant effect on output. This reassures that the key finding of asymmetric responses of output to sign-based tax changes is not driven by size-based asymmetry in positive and negative R & R tax changes.

In the third approach, instead of using a 1% change in tax measure, we measure the size of tax changes in terms of the standard deviation of the tax changes, such that a tax change of size 1 corresponds to one standard deviation of the positive tax change and a tax change of size -1 corresponds to one standard deviation of the negative tax change. In terms
of the non-linear methodology explained in Section 3.2 and the corresponding step-by-step explanation of the methodology in Appendix A.2, we vary the size of the initial tax change denoted by $\delta$. In particular, while simulating the time path of output for various sizes of tax changes, we replace the first value of the tax change sequence with $\delta \sigma_{\text{tax}}$, where

$$\delta \in \pm\{0.25, 1, 2, 3, 4, 5\},$$

and $\sigma_{\text{tax}}$ is the standard deviation of the R & R tax changes.\(^{15}\)

The impulse responses are illustrated in Figure 12. The impulse responses are all normalized by the size factor, which is $\delta \sigma_{\text{tax}}$. Corresponding to the normalized impulse responses, we also compute bootstrapped standard errors. Two main results are evident. First, in general, initial positive tax change of any size consistently results in an insignificant effect on output. The magnitude of output responses to an initial small positive tax change is mostly insignificant, but the effect is much bigger than the effect from initial large positive change. Second, negative tax changes in general have a significant effect on output for various sizes of initial tax changes. More importantly, the effect of various sizes of initial negative changes on output is almost proportional to the size of the initial tax change, which confirms that the asymmetric effect on output observed in the preceding sections is not an outcome of the size of negative tax changes. Interestingly, we also find that relative to large negative (initial) tax changes, small negative tax changes (i.e., tax changes of size $< 1$ standard deviation) have an almost insignificant impact on output (just as we observed for the output responses to the positive tax changes).

\(^{15}\)Note that some of the sizes of tax changes considered for this analysis are either rarely observed or have little identifying variation in the data. Therefore, estimating the effect of a particular size of a tax change on output with any precision is impossible if we take a subset of the data corresponding to the size of tax changes. However, we only replace the first value of the tax change of interest with a tax change of size $\delta \sigma_{\text{tax}}$, while the rest of the sequence of the tax changes are drawn from the original data. Variation in the size of the initial tax change then affects the time path of output. Subsequently, the difference between this time path of output and the time path of output in which the first value of tax change is not varied then provides the relative effect on the output path due to the size of the tax change. We then normalize the difference by the size of the tax change to infer whether the effect of the size of the tax change has a proportional or more than proportional effect on output.
The results from the three approaches jointly reaffirm that the size of the tax change does not drive the asymmetric response of output following a positive and a negative tax change.

4.5. Transmission Mechanism

So far, we have looked at the effects of tax changes on output. In this section, we seek to explore the effect of a negative and a positive tax change on other macroeconomic variables, especially consumption and investment, to understand the channels of the documented asymmetric responses of output.

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

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

This specification is in line with Mertens and Ravn (2012a) who show that this model corresponds to the dynamics of a DSGE model. \( \tau_t^+ \) and \( \tau_t^- \) are exogenous positive and negative tax changes. \( X_t \) 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

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

\[ ^{16}\text{We depart from our earlier regression equation, Equation 2, and replace it with Equation 3 (which mirrors our earlier regression equation). This replacement helps us study the evolution of consumption, investment, or other macroeconomic variables of interest along with the evolution of output after a positive and a negative tax change. Furthermore, to capture the inter-dependencies in multiple time series, this specification is more fitting. We employ this VAR specification (which includes both positive and negative tax changes as the exogenous regressor) and compute non-linear impulse responses.} \]
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 1. 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 positive and a negative tax change 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 negative tax changes, with 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 positive tax changes, on the other hand, is highly insignificant throughout the horizon forecast. Investment shows a symmetric response to positive and negative tax changes. In particular, investment falls (at the peak by approximately 11%) in response to positive tax changes and increases (at the peak by approximately 11%) in response to negative tax changes 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 positive and negative 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 1 of Table 5 and Table 6, respectively) suggest the impulse responses of
output to a positive and a negative tax change 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 negative and positive 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 positive and negative tax changes. This increase in total hours seems to originate from a change in employment, which also increases following both a positive and a negative tax change, however the increase in employment is more following a positive tax change. 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 positive tax changes, whereas the response in hourly wages following negative tax changes is insignificant. Labor productivity responds significantly for a few quarters following negative tax changes but otherwise responds insignificantly to both a negative and a positive tax change. Like labor productivity, TFP in general does not seem to respond significantly to a positive or a negative tax change.\footnote{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 Schwelimus (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.}

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) hours worked increase significantly following a positive tax change, (iii) wages decrease significantly following a positive tax change, and (iv) consumption does not respond significantly to a positive tax change. 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.

One way to reconcile our empirical results with the theoretical framework is to think of a simple neo-classical model with firms and households as the agents in the economy. Theory suggests, negative and positive tax changes will have opposite but symmetric effects on output. However, if a household’s consumption is sticky downward, a positive tax change will not have a significant effect on consumption. The agents will substitute leisure and investment for maintaining their prior consumption levels. On the other hand, with a negative tax change, agents will increase their consumption. This asymmetric response of consumption can then be a potential reason for the asymmetric responses of output to the sign-based tax changes.

The friction in consumption resulting into downward stickiness is a widely studied phenomenon and is referred to in the literature as the Ratchet Effect. The ratchet effect in consumption, due to Duesenberry (1949), 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 (in our case, due to positive tax changes) 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. If workers perceive the decrease in income to be permanent, or if their savings are not enough to sustain their consumption habits, they would end up supplying more labor. Thus, a combination of a standard neo-classical model and ratchet effect in consumption can deliver the results observed in this paper. The standard forces in the model would deliver the standard results in response to a negative tax change, and the ratchet effect in consumption will deliver the results that we observe in response to a positive tax change.
5. Conclusion

We present empirical evidence of an asymmetric response of output to positive and negative (exogenous and permanent) R & R tax changes. In particular, we find negative tax changes to have a persistent and significantly positive effect on output, whereas positive tax changes have no systematic effect on output. Furthermore, we find even stronger asymmetric responses of output when we use positive and negative unanticipated R & R tax changes. In addition, individual-income tax changes primarily drive the asymmetric responses of aggregate output. Lastly, the size of positive and negative tax changes does not drive our main result: an asymmetric response of output following sign-based tax changes.

We also compute impulse responses of other important macroeconomic variables. We find that the asymmetric response of consumption is the primary channel 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 suggest that a ratchet effect theory of consumption - i.e., consumption goes up when taxes increase, and consumption remains unchanged when taxes decrease - is one potential explanation for our empirical findings.

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 analysis. The empirical evidence of an asymmetric effect on output of positive and negative tax changes speaks to the issue of the overall importance of these tax changes as a source of economic fluctuations. Our results indicate that negative tax changes are important insofar as they stimulate output.\(^{18}\) 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. Moreover, we show that the asymmetric effect on output

\(^{18}\)Note that our results are based on unconditional responses of output to these tax changes (i.e., is 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.
primarily stems from the asymmetric responses of households to the sign-based tax changes. This finding suggests that household behavior induces asymmetric transmission of these tax changes for economic fluctuations. Therefore, our paper also highlights important behavioral implications of fiscal policies.

Narrative based categorizations of tax-shocks are becoming increasingly available for countries other than the US. For example, Cloyne (2013) provide a narrative categorization of tax changes in the UK, and Leigh et al. (2011) provide similar narrative tax changes for a broad selection of countries. It is therefore natural to ask how our analysis of asymmetry extends to tax data in other countries. Jones et al. (2015) make a first step in this direction, extending our analysis to study the differences in asymmetric responses of output in the United Kingdom and the United States. They argue that cross-country differences are due to differences in the nature of the tax shocks (especially VAT in the U.K.), differences in the monetary environment during the quarters in which tax shocks occurred, the overall level of public and private debt, and differences in the centralization of taxation in the UK and US.\footnote{Jones et al. (2015) do not control for the possible effect of the history of tax changes in computing impulse responses, and this may also explain part of the differences they find for UK and US data.} Similar extensions of our analysis to study differences between other countries is a natural direction for future research. Alternatively, one could extend our analysis to look for asymmetric effects of tax changes in micro level data, e.g., for individual households or firms. Our analysis of macroeconomic data suggests that there is asymmetric responses of individual household consumption to positive and negative tax changes. This could shed further light on possible ratchet effects in household consumption behavior.

6. Acknowledgments

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Economic Conference (2014), Canadian Economic Association (2014), and RES International Monetary Fund (2014) for useful comments. We would like to extend special thanks to Chetan Dave, John Leahy, Karel Mertens and David Romer for extremely helpful comments and Lutz Kilian and Robert J. Vigfusson for providing code and data for replication purposes.
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A. Appendix

A.1. Data

Table 1: Data Sources

<table>
<thead>
<tr>
<th>Variables</th>
<th>Data Source</th>
<th>Time Period</th>
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<td>1947 - 2007</td>
<td>Quarterly</td>
</tr>
<tr>
<td>Corporate-income tax changes</td>
<td>Mertens and Ravn (2013)</td>
<td>1947 - 2007</td>
<td>Quarterly</td>
</tr>
<tr>
<td>Total hours</td>
<td>Mertens and Ravn (2011)</td>
<td>1947 - 2007</td>
<td>Quarterly</td>
</tr>
<tr>
<td>Output</td>
<td>Bureau of Economics Analysis</td>
<td>1947 - 2007</td>
<td>Quarterly</td>
</tr>
<tr>
<td>Investment</td>
<td>Bureau of Economics Analysis</td>
<td>1947 - 2007</td>
<td>Quarterly</td>
</tr>
<tr>
<td>Consumption</td>
<td>Bureau of Economics Analysis</td>
<td>1947 - 2007</td>
<td>Quarterly</td>
</tr>
</tbody>
</table>

Notes: Table 1 reports the data sources, time period, and frequency of the variables used in this paper.

Figure 1: R & R Tax Changes

Notes: Figure 15 illustrates the frequency, magnitude and timings of a positive and a negative R & R tax change. 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 positive and a negative R & R unanticipated-tax change. 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 a positive and a negative cyclically-adjusted-tax-revenue change. Source: Romer and Romer (2010).
Notes: Figure 4 illustrates the frequency, magnitude, and timings of a positive and a negative R & R individual-income tax changes. 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).

Notes: Figure 5 illustrates the frequency, magnitude, and timings of a positive and a negative R & R corporate-income tax changes. 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 $\epsilon_t$:

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

(4)

2. Pick a history, $\Omega_{t-1}^i$, 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 $H$ negative and positive changes from the series on these variables with replacement. Also choose a sequence of $H$ values of the residual $\epsilon_t$ with replacement from the residuals collected after the initial estimation.

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

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

6. Take the difference of the two simulated paths. Repeat steps 3 through 5 $N$ times and collect $N$ such series. Average the resulting series to obtain the impulse response of $y_t$ to a tax change of size of $\delta$ conditional on history $\Omega_{t-1}^i$. This impulse response of $y_t$]

\footnote{Note that when impulse responses are estimated using equation (4), the value of $H$ cannot be bigger than $M$ since the effect of tax changes only last for $M$ periods.}

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can be represented as

\[ IRF(h, \delta, \Omega^i_{t-1}) = \frac{\sum_{k=1}^{N} y_t^i(h, \delta, \Omega^i_{t-1}, k) - y_{ts}^i(h, \Omega^i_{t-1}, k)}{N}, \]

where \( y_{ts}^i(h, \Omega^i_{t-1}, k) \) represents the computed value of \( y_t \) from step 4 at \( h^{th} \) horizon. \( y_t^i(h, \delta, \Omega^i_{t-1}, k) \) represents the estimated value of \( y_t \) from step 5 at \( h^{th}, h = 1, 2, ..., H \) horizon after a tax change of size \( \delta \) for history \( \Omega^i_{t-1} \) 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 \( \delta \). This impulse response can be represented as

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

8. Residuals from the estimated dynamic regression models involving daily, weekly, and monthly data exhibit a strong evidence of conditional heteroskedasticity. Therefore, standard errors based on the standard residual-based bootstrapped method may be invalidated in the presence of such heteroskedasticity. To guard against the presence of heteroskedasticity, we follow the wild bootstrap methodology as proposed by Goncalves 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.
A.3. Figures

Figure 6: Impulse Responses: Negative and Positive R & R Tax Changes

Notes: Figure 6 plots impulse responses of output to a negative and a positive R & R exogenous and permanent tax change 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 $\delta$, where $\delta$ 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 negative and a positive tax change. One standard-deviation confidence intervals are also provided for each of the impulse responses.
Figure 7: Impulse Responses: Negative and Positive Unanticipated R & R Tax Changes with Anticipated Tax Change as a Control

Notes: Figure 7 plots impulse responses of output to a negative and a positive unanticipated R & R tax change, 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: Negative and Positive Individual-Income Tax changes

Notes: Figure 8 plots impulse responses of output to a negative and a positive individual income tax change, 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 9: Impulse Responses: Negative and Positive Corporate-Income Tax Changes

Notes: Figure 9 plots impulse responses of output to a negative and a positive corporate-income tax change, 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 10: Impulse responses: Various Sizes of Positive and Negative Tax changes

(a) Impulse Responses - Excluding large negative tax changes: Negative and positive R & R tax changes

(b) Impulse Responses: Negative and positive R & R tax changes

Notes: Figure 12 plots impulse responses of output to a negative and a positive R & R tax change. Figure 10(a) illustrates the impulse responses of output to a tax-change series which excludes four large negative tax changes namely, the Truman tax change, the Kennedy-Johnson tax change, the Reagan tax change, and the Nixon tax change. Figure 10(b) illustrates the impulse responses of output to an original R & R tax-change series (that contains all exogenous, permanent tax changes). Each plot illustrates impulse responses based on the methodology by Kilian and Vigfusson (2011) (see Section 3 and Section A.2 for more detail on the methodology).
Figure 11: Impulse Responses: Cyclically-Adjusted Negative and Positive Tax changes

Notes: Figure 11 plots impulse responses of output to a negative and a positive cyclically adjusted tax change, respectively. Each plot illustrates impulse responses based on non-linear methodology by Kilian and Vigfusson (2011) (see Section 3 and Appendix A.2 for more detail on the methodology).
Figure 12: Impulse Responses: Various Sizes of Positive and Negative Tax changes

(a) Non-linear impulse response of output: For various sizes of $R$ & $R$ negative tax changes

(b) Non-linear impulse response of output: For various sizes of $R$ & $R$ positive tax changes

Notes: Figure 12(a) and Figure 12(b) plot impulse responses of output to a negative and a positive $R$ & $R$ tax change of size $0.25 \times STD$, $1 \times STD$, $2 \times STD$, $3 \times STD$, $4 \times STD$ and $5 \times STD$, respectively. Each plot illustrates impulse responses based on the methodology by Kilian and Vigfusson (2011) (see Section 3 and Section A.2 for more detail on the 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 GDP growth (output), 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 $\delta$, where $\delta$ was the size of the change given to the tax series. The paths for real GDP growth (output) were simulated using the coefficients estimated through a regression of real GDP growth on 12 lags of a negative and a positive tax change. One standard-deviation confidence intervals are also provided for each of the impulse responses.
Notes: Figure 13 presents the effect of positive tax changes on various macroeconomic variables. The impulse responses are from a four variable VAR with real GDP growth, the variable, the positive tax change variable, and the negative tax change variable appearing in that order in the VAR. The dashed lines represent the one standard-error bands.
Figure 14: Impulse Response of Macroeconomic Variables: Total Negative R & R Tax Measures

Notes: Figure 14 presents the effect of positive tax changes on various macroeconomic variables. The impulse responses are from a four variable VAR with real GDP, the variable, the positive tax change variable, and the negative tax change variable appearing in that order in the VAR. The dashed lines represent the one standard-error bands.
A.4. Diagnostic Tests Results

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

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<th>Corporate Income P value</th>
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<td>17</td>
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<td>0.017233</td>
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<tr>
<td>19</td>
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<td>0.01777</td>
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</table>
Table 3: $p$ - values of the Wald test of $H_0: IRF(h, \delta) = -IRF(h, -\delta) \forall h = 0, 1, 2, \cdots, H.$ for output

<table>
<thead>
<tr>
<th>Wald Test</th>
<th>R &amp; R</th>
<th>Unanticipated</th>
<th>Personal Income</th>
<th>Corporate Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
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</tr>
<tr>
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<td>1</td>
<td>1</td>
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<td>0.999992</td>
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</tr>
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<td>0.92322</td>
</tr>
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<tr>
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<tr>
<td>12</td>
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<td>0.599467</td>
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<tr>
<td>13</td>
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<td>0.552789</td>
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</tr>
<tr>
<td>14</td>
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</tr>
<tr>
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<td>0.99981</td>
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</tr>
<tr>
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<tr>
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<tr>
<td>19</td>
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<td>0.575352</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>F Test</th>
<th>R &amp; R</th>
<th>Unanticipated</th>
<th>Personal Income</th>
<th>Corporate Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sum_{n=0}^{M} \beta_n^- = 0$</td>
<td>0.285245</td>
<td>0.0046</td>
<td>0.4257</td>
<td>0.2406</td>
</tr>
<tr>
<td>$\sum_{p=0}^{M} \beta_p^+ = 0$</td>
<td>0.80261</td>
<td>0.9296</td>
<td>0.7688</td>
<td>0.235</td>
</tr>
</tbody>
</table>
Table 5: p-values of the Wald test and T test of $H_0: \text{IRF}(h, \delta) = -\text{IRF}(h, -\delta) \forall h = 0, 1, 2, \cdots, H.$ for consumption and investment

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Consumption Wald P-value</th>
<th>Investment Wald P-value</th>
<th>Consumption T P-value</th>
<th>Investment T P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.252032</td>
<td>0.285122</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0.533491</td>
<td>0.433992</td>
</tr>
<tr>
<td>3</td>
<td>0.999999</td>
<td>1</td>
<td>0.299912</td>
<td>0.326921</td>
</tr>
<tr>
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<td>0.998857</td>
<td>1</td>
<td>0.540868</td>
<td>0.476455</td>
</tr>
<tr>
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<td>0.460991</td>
<td>0.739186</td>
</tr>
<tr>
<td>6</td>
<td>0.996426</td>
<td>1</td>
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<td>0.77016</td>
</tr>
<tr>
<td>7</td>
<td>0.989634</td>
<td>0.999933</td>
<td>0.450177</td>
<td>0.830087</td>
</tr>
<tr>
<td>8</td>
<td>0.957227</td>
<td>0.999918</td>
<td>0.518004</td>
<td>0.820598</td>
</tr>
<tr>
<td>9</td>
<td>0.957219</td>
<td>0.999473</td>
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<td>0.654238</td>
</tr>
<tr>
<td>10</td>
<td>0.87378</td>
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</tr>
<tr>
<td>11</td>
<td>0.709404</td>
<td>0.999402</td>
<td>0.48547</td>
<td>0.592191</td>
</tr>
<tr>
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<td>0.537461</td>
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<tr>
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<tr>
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<td>0.764268</td>
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<tr>
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<td>0.819322</td>
<td>0.981564</td>
<td>0.583163</td>
<td>0.763368</td>
</tr>
</tbody>
</table>

Table 6: 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

<table>
<thead>
<tr>
<th>F Test</th>
<th>Consumption</th>
<th>Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sum_{n=0}^{M} \beta_{n}^{-} = 0$</td>
<td>0.0019</td>
<td>0.00609</td>
</tr>
<tr>
<td>$\sum_{p=0}^{M} \beta_{p}^{+} = 0$</td>
<td>0.5651</td>
<td>0.8605</td>
</tr>
</tbody>
</table>
B. Robustness: Online Appendix

This section provides a robustness check for our key result of asymmetric output responses to exogenous positive and negative tax changes, by using an alternative methodology that utilizes a two-equation specification to exactly match the framework provided by Kilian and Vigfusson (2011). In the text, instead of two-equation model, we use a single-equation model because single-equation specification generalizes the regression approach pioneered by Romer and Romer (2010) and facilitates comparison across the two studies. The main purpose of this exercise is to show that the two methodologies are quantitatively and qualitatively exactly the same.

B.0.1. Steps for Computation of Impulse Response and Standard Errors:

1. Estimate the following equations. Collect the estimated coefficients for the equation and the residuals:

\[ \Delta \tau_t = \alpha_1 + \epsilon_{1t} \]  
\[ \Delta y_t = \alpha_2 + \sum_{p=0}^{M} \beta_{p}^+ \Delta \tau_{t-p}^- + \sum_{n=0}^{M} \beta_{n}^- \Delta \tau_{t-n}^- + \sum_{l=0}^{L} \beta_{l} \Delta y_{t-l} + \epsilon_{2t}, \]  

Note that a tax change is denoted with \( \Delta \tau_t \), which is the series provided by Romer and Romer’s 2010 narrative data.

2. Estimate \( \Delta \tau_t \) using \( \epsilon_{1t} \) via Equation 5 and then define the following:

\[ \Delta \tau_t^+ = \max(0, \Delta \tau_t), \quad \Delta \tau_t^- = \min(0, \Delta \tau_t). \]  

Note that the estimated values of \( \Delta \tau_t \) series match \( \Delta \tau_t \) provided by the data. Therefore, under this two-equation model and the single-equation model (provided in Section 3), the positive and negative tax changes are also exactly the same.

3. Pick a history, \( \Omega_{t-1} \), which consists of a block of \( M \) consecutive values of all model
variables. These are actual values from the data series. The values drawn for all the variables should be for the same dates.

4. Choose a sequence of $H$ values of the residual $\epsilon_{1t}$ and $\epsilon_{2t}$ with replacement from the residuals collected after the initial estimation.

5. Using the history, $\Omega_{t-1}^i$, and $\epsilon_{1t}$, simulate $H$ values of $y_t$. These values are simulated by using equation 6. Call this time path $y_{t+1}^{ns}, j = 1, 2, ..., H$. Note that $\epsilon_{1t} = \Delta \tau_t - \Delta \bar{\tau}_t$; therefore, it is a linear transformation of $\Delta \tau_t$.

6. Repeat step 4 with one change. In the $\epsilon_{1t}$ sequence, replace the first value with a constant value $\delta$ and estimate the time path of $y_t$ for this new sequence of tax changes and call it $y_{t+1}^s$, where $j = 1, 2, ..., H$.

7. 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 (i.e., $\epsilon_{1t}$) of size $\delta$ conditional on history $\Omega_{t-1}^i$. This impulse response of $y_t$ can be represented as

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

where $y_{t+1}^{ns}(h, \Omega_{t-1}^i, k)$ represents the computed value of $y_t$ from step 4 at $h^{th}$ horizon.

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

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

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

9. Residuals from the estimated dynamic regression models involving daily, weekly, and
monthly data exhibit a strong evidence of conditional heteroskedasticity. Therefore, standard errors based on the standard residual-based bootstrapped method may be invalidated in the presence of such heteroskedasticity. To guard against the presence of heteroskedasticity, we follow the wild bootstrap methodology as proposed by Goncalves 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.

Below, we present the impulse responses using a single-equation model and two-equation model to show that the two approaches provide the same results.

Figure 15: Non-Linear Impulse Response of Output: Single-Equation and Two-Equation Model

Notes: Figure 15 plots impulse responses of output to a negative and a positive R & R tax change for single-equation model (gray plot) and two-equation model (black plot). Each plot illustrate impulse responses based on the general methodology by Kilian and Vigfusson (2011) (see Section A.2 and Section B.0.1 for more detail on the methodology based on single-equation and two-equation model, respectively). 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 $\delta$, where $\delta$ 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 negative and a positive tax change. One standard-deviation confidence intervals are also provided for each of the impulse responses.