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**Joint Discussion Paper Series in Economics**

by the Universities of

Aachen · Gießen · Göttingen
Kassel · Marburg · Siegen

ISSN 1867-3678

**No. 12-2021**

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MACIE PAPER SERIES

Marburg Centre for Institutional Economics

MACIE

Nr. 2021/05

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This version: 17 August 2021

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# Estimating Policy-Corrected Long-Term and Short-Term Tax Elasticities for the United States, Germany, and the United Kingdom


## Abstract

We estimate the elasticities of the most important tax categories using a new quarterly database of discretionary tax measures for the United States, Germany, and the United Kingdom over the period 1980Q1 to 2018Q2. Employing Romer and Romer's (2009) narrative approach, we construct a policy-neutral dataset based on revenue figures from governmental records. Using this quantitative information, we are able to subtract policy-induced changes, which are typically not considered in the extant literature. Furthermore, we estimate state-dependent elasticities. Our conclusions are as follows. (i) In Germany and the UK, long-term tax-to-base elasticities are generally higher than short-term elasticities, whereas results for the US are mixed. (ii) Short-term base-to-output elasticities tend to be smaller than unity, whereas long-term elasticities are close to unity. (iii) German and UK tax-to-output elasticities in the short term are lower than long-term elasticities, with mixed results for the US. (iv) For tax-to-base elasticities, we find business cycle asymmetries across countries but not within countries. (v) For base-to-output elasticities, our results suggest few asymmetries across countries and more asymmetries across tax types. (vi) Typically, the above conclusions do not hold for corporate income tax.



Keywords: Tax revenue; tax base; tax elasticity; business cycle; Germany; United Kingdom; United States.

JEL Codes: E62; H20; H30; E32.

# 1 Introduction

Fiscal policy developed as a cornerstone of Keynesian macroeconomics following the Great Depression in the early 1930s, but its popularity has fluctuated ever since. Although it was perceived as a core part of mainstream macroeconomics in the 1950s and 1960s, it was all but discredited by the occurrence of high inflation and unemployment during the 1970s. Academically, the demise of fiscal policy was fostered by the emergence of rational expectations and new classical macroeconomics. For instance, a historical account of German tax legislation reveals that the government did not make use of discretionary tax policy as a business-cycle stabilisation tool at all between 1980 and 2007 (Uhl, 2013).

However, fiscal policy made a comeback following the 2007 financial crisis and was used as a stabilisation tool in the face of the extraordinary economic slump that followed that crisis. This re-emergence of fiscal policy was accompanied by a reassessment of its impact, especially in a low-interest-rate environment. For example, the IMF (2012, p. 43) revised upwards its fiscal policy multiplier estimates, found to be ‘near 0.5 in advanced economies during the three decades leading up to 2009’, and states that ‘our results indicate that multipliers have actually been in the 0.9 to 1.7 range since the Great Recession’ (IMF, 2012). In the context of estimating fiscal policy multipliers in the form of tax policy, the estimation of tax elasticities plays a key role in forecasting budget revenues and estimating the cyclical component of the budget balance (for an illustration, see Girouard and André, 2005). Furthermore, as Mertens and Ravn (2014) show, the estimation of tax multipliers crucially depends on the appropriate elasticity choice.

In this study, we present estimations of tax elasticities for three of the five largest economies in the world: the United States, Germany, and the United Kingdom. Relying on a unique database, we provide elasticities for the most relevant tax categories at a quarterly frequency over the period 1980-2018. We apply a two-step error-correction model, which was originally proposed by Hobel and Solcombe (1996) and modified by Bruce et al. (2006) for the estimation of asymmetric tax base elasticities.

This paper differs from related studies in at least three ways. First, we use a newly constructed quarterly dataset, which allows for a comparison of tax changes across three important countries. Moreover, quarterly observations make it possible to date discretionary tax changes quite accurately and as well as estimate tax elasticities more precisely. Second, in order to calculate relevant tax elasticities, we use the proportional adjustment method proposed by Prest (1962), which allows us to isolate the revenue effect of discretionary changes in tax legislation. Dye (2004) and Wolswijk (2009) show the importance of correcting for policy changes. However, without detailed revenue effects at the quarterly level, researchers need to make use of annual data, employ impulse dummies to control for major tax reforms, or are limited to estimating tax buoyancy (e.g., van den Noord, 2000; Girouard and André, 2005). Tax buoyancy measures the *total* response of government revenues after a change in income, i.e. exogenous plus endogenous change, rather than the more interesting tax elasticity, which excludes the endogenous change. Third, we adopt a different, and arguably more intuitive, approach to measuring short-term asymmetries based on the phase of the business cycle. Instead of only contrasting recessionary and non-recessionary periods, we apply the widely used concept of potential output to differentiate between three states of the business cycle: ‘neutral’, ‘boom’ and ‘recession’. This setup avoids setting a slightly negative/positive deviation from the long-run trend equal to a large recession/boom, as the respective impact on the estimated elasticities could be very different.

Our main findings can be summarised as follows. (i) In Germany and the UK, long-term tax-to-base elasticities are generally higher than short-term elasticities, whereas results for the US are mixed. (ii) Concerning base-to-output elasticities, estimated short-term elasticities are generally smaller than unity, whereas long-term elasticities are close to unity. (iii) Tax-to-output elasticities in the short term are lower than long-term elasticities. (iv) For tax-to-base elasticities, we find business cycle asymmetries across countries but not within countries. (v) For base-to-output elasticities, our results suggest few asymmetries across countries and more asymmetries across tax types. (vi) Typically, the above conclusions do not hold for corporate income tax, which has the highest base-to-output elasticity.

The next section discusses the literature in more detail. Section 3 presents our data and Section 4 our estimation methodology. Our empirical results are presented in Section 5 and additional robustness checks in Section 6. Section 7 concludes.

## 2 Literature Review

To the best of our knowledge, there is no study that compares the tax-to-base and tax-to-output elasticities of the most relevant tax categories for the US, Germany, and the UK at (1) a quarterly frequency or (2) correcting for discretionary tax policies at the level of detail found in this paper. Using quarterly frequency makes it possible to more precisely date discretionary changes and provides more observations for estimation. Correcting for discretionary tax policies makes it possible to more accurately estimate tax-to-base elasticities. Table 1 summarises the results reported in the extant literature.

Employing annual data for 1951−1991, Sobel and Holcombe (1996) estimate LR (SR) elasticities of US personal income taxes and corporate income taxes as well as other direct and indirect tax elasticities. As suggested by Stock and Watson (1993), and similar to our approach, they apply a two-stage error correction model using dynamic OLS. However, Bruce et al. (2006) argue that Sobel and Holcombe (1996) do not employ the appropriate tax bases. Instead, Bruce et al. (2006) use annual US-state-level data from 1967 to 2000 to estimate state averages of sales and income tax revenues in the LR and the SR, using actual tax base data for each US state. Moreover, they estimate both SR and LR elasticities, and allow the former to behave asymmetrically depending on the deviation from the long-run equilibrium. In contrast to their study, we use private consumption and not, personal income as the tax base for sales taxes.

Creedy and Gemmell (2004) estimate the elasticities of income and consumption tax revenues in the UK from 1989 to 2000. They identify discretionary tax changes as an essential influence on income elasticities and report increasing annual income tax elasticities and falling consumption elasticities over their sample period. They correct for tax base deductions at every income bracket by estimating their elasticity separately using simulations, rather than directly accounting for discretionary policy changes. In a similar setup, Creedy and Gemmell (2008) simulate the elasticities of corporate income tax revenues in the UK. The authors identify the volatility of profits and tax-base deductions as important drivers of the relationship between profit growth and corporate income tax revenue and stress the necessity to control for discretionary measures when estimating corporate tax revenue elasticity.

**Table 1: Overview of Previous Studies**

| Authors | Countries | Tax Type | Short-Run Elasticity | Long-Run Elasticity |
|---|---|---|---|---|
| Sobel and Hol-combe (1996) | **US** | Personal Income | 1.16 | 1.22 |
| | | Corporate Income | 3.37 | 0.67 |
| | | Adjusted Gross Income | 0.97 | 0.95 |
| | | Retail Sales | 1.04 | 0.66 |
| | | Non-Food Retail | 1.38 | 0.70 |
| | | Motor Fuel Usage | 0.73 | 1.00 |
| | | Liquor Store Sales | –0.011(insignificant) | 0.25 |
| Creedy and Gemmell (2004) | **UK** | Personal Income | 1.20–1.40 | 1.20–1.40 |
| | | Consumption Taxes | 0.85–0.70 | 0.85–0.70 |
| Bruce et al. (2006)* | **US** | Sales Tax | 1.80 (above eq) | 0.81 |
| | | | 0.15 (below eq) | |
| | | Income Tax | 2.66 (above eq) | 1.83 |
| | | | 0.217 (below eq) | |
| Koester and Priesmeier (2012) | **Germany** | Profit-Related Taxes | 0.43 | 0.77 |
| | | Wage Taxes | 1.41 | 1.75 |
| | | VAT | 0.90 | 0.79 |
| Mourre and Princen (2019) | **Germany** | Personal Income | 0.05 (insignificant) | 1.78 (insignificant) |
| | | Corporate Income | 3.62 (insignificant) | 1.95 (insignificant) |
| | | Consumption taxes | 0.49 (insignificant) | 0.66 |
| | | SSC | 0.37 | 0.75 |
| | **UK** | Personal Income | 3.42 | 1.11 |
| | | Corporate Income | 4.72 (insignificant) | 1.62 (insignificant) |
| | | Consumption Taxes | 1.72 | 1.11 |
| | | SSC | 1.81 | 1.24 |
| Boschi and d’Addona (2019) | **Germany**: | Personal Income | 0.93 | 2.99 |
| | | Corporate Income | 0.15 (insignificant) | 1.54 |
| | | Indirect Taxes | 0.88 | –0.50 |
| | | SSC | 0.36 | 0.47 |
| | **UK**: | Personal Income | 0.53 | 1.05 |
| | | Corporate Income | 0.43 | 0.63 |
| | | Indirect Taxes | 0.70 | 0.82 |
| | | SSC | 0.74 | 1.53 |

Note: * indicates that elasticities are estimated as state averages and ‘above’ and ‘below equilibrium’ (eq) refers to relative position of the long-run relationship. ‘Insignificant’ refers to a p-value > 0.1.

Koester and Priesmeier (2012) estimate the elasticities of revenues for German wage taxes, VAT, and profit taxes. For the latter category, they combine corporation tax and capital gains tax, as well as assessed income tax. In this paper, we instead follow Mertens and Olea (2018) and differentiate between taxes on corporate and non-corporate income, including the assessed income tax revenues in the category ‘personal income’. We extend their findings by considering a longer time span, a more precise timing of tax changes, including employees’ social security contributions, and using a different definition of tax revenues. In addition, we investigate the cyclical behaviour of elasticities.

Mourre and Princen (2019) study SR and LR elasticities for EU members in a framework similar to ours. Using data from a not publicly available ECB database, they correct for discretionary tax changes. They employ pooled annual data for 2001−2013, which is likely too short a period for capturing LR dynamics. For Germany, they find significant results only for social security contributions SR and LR elasticities and consumption tax LR elasticity. No significant relationship is reported for corporate income elasticities in the UK.

Mainly focusing on the period 1999‒2013, Boschi and d'Addona (2019) estimate SR and LR elasticities for Germany, the UK, and 13 other European countries employing quarterly time series data after correcting for discretionary tax policy changes. Furthermore, they allow for asymmetries related to the state of the business cycle in a Markov-switching regression. In many cases, the reported SR elasticities are significantly below unity and are particularly low during recessions. In contrast to our study, Boschi and d'Addona (2019) do not have access to quantitative values for discretionary changes but use dummies constructed from qualitative information

## 3 Data and Proportional Adjustment

In our analysis, we use personal income tax revenues, corporate income tax revenues, indirect tax revenues, and the employee share of social security contributions.[1] We employ seasonally-adjusted variables as, in most cases, the data were not available as unadjusted series. The remaining series are seasonally adjusted using the X-12 ARIMA method. We choose nominal variables, as taxes are paid on nominal wages, profits, and consumption spending. As tax bases in our benchmark models, we employ the sum of gross wages for personal income, gross profits for corporate income, private consumption for indirect taxes, and employee compensation for the SSC. We use government consumption and investment, as well as a house price index, as controls in our alternative models. The house price index data are from the Bank for International Settlements (BIS); the rest of the data are from Thomson Reuters Datastream. Hence, all our series reflect quarterly, seasonally-adjusted tax revenues in nominal local currency.

To obtain the discretionary tax policy changes, we extend the narrative accounts by Romer and Romer (2009) for the US, Cloyne (2012) for the UK, and Uhl (2013) and Gechert et al. (2016) for Germany up to the end of 2017. This unique dataset allows us to precisely identify and date the most important discretionary tax changes in three of the world's five largest economies. The narrative approach uses information about discretionary tax changes as stated in official government records.[2] These records provide estimates of revenue effects compared to the baseline scenario of *no change.* As is standard in this strand of literature, we use the full year revenue effect of each position of the respective tax bill and date the effect to either the quarter of implementation or to the next quarter when implementation occurs in the second half of a quarter. The same applies to dating phasing-out provisions. We do not consider policies that merely extend existing laws, as they do not alter tax liabilities and, hence, are different from discretionary changes. The narrative literature typically discards tax changes endogenous to GDP growth for unbiased estimation of fiscal multipliers (see, e.g., Romer and Romer, 2010; Cloyne, 2013; Mertens and Ravn, 2013; Hayo and Uhl, 2014). However, endogeneity to output growth is not our concern. Barrios and Fargnoli (2010) and Princen et al. (2013) for a sample of European countries and Conroy (2020) for Ireland discover pro-cyclical patterns of discretionary fiscal policy. Applied to the context of tax-to-output-elasticities when taking discretionary changes into account, this translates into policy-induced higher (lower) revenues in times of economic upswing (downturn). To correct for these dynamics, we include all tax changes.

Using revenue figures from official government records has the additional advantage that these estimates already consider behavioural responses and, hence, likely reflect the total impact.[3] Our narrative account covers the most

[1] Personal income (corporate income) tax is defined as tax paid by non-corporate (corporate) entities. Indirect taxes include VAT, as well as all other consumption taxes and excise duties.
[2] See the above-mentioned papers for a more detailed explanation of the data collection.
[3] See Conroy (2020, p.245) for the example of the introduction of a sugar tax.

important tax laws in the three countries.[4] Extensive analysis of the government records also allows us to differentiate between temporary and permanent policy changes. As is standard in the narrative tax literature, we treat the phasing out of temporary provisions as a discretionary change, entering the series with the opposite sign. Note that Koester and Priesmeier (2012) use only permanent policy changes. However, temporary measures, prevalent in the form of relief during the financial crisis, can substantially explain quarterly changes in revenues.

The downside of using narratively identified tax policy changes is that one is dealing with *ex ante* estimations based on whatever tax elasticities are used by the responsible tax authorities, whereas the true impact remains unknown. Furthermore, the stated revenue figures could be subject to a political bias. However, in the three sample countries, tax projections are made by fairly independent experts. For the US, for example, we mainly rely on numbers provided by the Joint Committee on Taxation (JCT), which is composed of members of both political parties and chambers. The cross-party membership makes the existence of a political bias unlikely. In Germany, representatives of six research institutes participate in the 'Working Party of Tax Revenue Forecasting'; Koester (2009) finds no evidence of a political bias. The UK's independent Office of Budgetary Responsibility (OBR) was only established in 2010 for the purpose of forecasting and controlling the long-term sustainability of the public finances. However, even for a period prior to the OBR's creation, Jonung et al. (2006) find no evidence of systematic over-optimism with respect to economic growth forecasts as used in the budgetary process. Frankel (2011) discovers a forecast bias in the fiscal balance, which increases with the forecast horizon. However, since we rely on the forecast for the next full fiscal year, any such bias should be small.

Before commencing with the actual estimations, we need to adjust the revenue series to reflect the counterfactual that today's tax system has been in place from the beginning of the sample. To that end, we use Prest's (1962) proportional adjustment method. Subtracting discretionary changes only at the time they actually occur assumes that the tax system remained unchanged over time. In contrast, we consider the cumulative effect of all tax changes by back-casting their effect to the beginning of the observation period. Thus, past tax revenues are corrected for discretionary policy changes under the assumption that the relative revenue effects are proportional over the full period. As mentioned before, temporary changes are included, too, under the assumption that their effect is proportional as well for the time period they are in place. The adjusted series then reflect revenues as if today's tax system has been in existence from the beginning of the observed period. By correcting for discretionary changes and assuming that the chosen tax bases are equal to the true tax bases, we can consistently identify the proper automatic response of the tax base (Barrios and Fargnoli, 2010).

The adjusted series is constructed as:

$$AR_{it} = R_{it} * \prod_{k=t+1}^{j} \left(\frac{R_{ik}}{R_{ik} - \Delta\tau_{ik}}\right) \ \forall \ t < j \tag{1}$$

where $i$ stands for the tax types personal income tax revenue, corporate tax revenue, indirect tax revenue, and the employee share of social security contributions. $AR_{it}$ are the adjusted revenues at time $t$, $R_{ik}$ are the unadjusted revenues, and $\Delta\tau$ are the discretionary tax changes.

[4] For the US, we consider the tax bills identified by Romer and Romer (2009) up until 2003. After 2003, we use tax bills with a full year revenue effect exceeding 0.1% of nominal GDP. The same threshold is applied in the selection of German tax laws. For the UK, we use all Budget and Pre-Budget reports, likely covering all tax changes in the period under investigation. Further information on the data is available on request.

Our back-casting horizon is limited by data availability. The quarterly revenue series go back to 1980Q1. By construction $AR_{iT} = R_{iT}$, which implies there is no discretionary change in $T$, the most recent observation. The last tax policy change recorded in our narrative dataset was implemented in 2018Q1. Therefore, we use 2018Q2 as the starting point for back-casting the adjusted revenues.

Figures 1, 3, 5, and 7 plot the adjusted revenues against actual revenues; discretionary tax changes and their cumulative effects are shown in Figures 2, 4, 6, and 8. Starting with US personal income tax, Figure 1 Panel 1, demonstrates how the Trump, Bush, and Reagan income tax cuts shift the adjusted series downwards. We also see that the temporary tax cuts legislated during the financial crisis affect the adjusted series only temporarily, while significantly explaining quarterly changes. The left panel of Figure 2 accumulates the effect of discretionary tax changes on revenues. It shows that in 1980, collected US income tax revenues would have been 50% lower if the legislation of 2018Q2 had already been in place. The cumulative effect of German personal income tax cuts, shown in the centre panel of Figure 2, is even larger, amounting to about 60% lower adjusted revenues in 1980Q1. For the UK, Figure 1 Panel 3 shows lower adjusted income tax revenues, too, but the effect is mainly driven by the Thatcher government's income tax cuts in the 1980s, whereas we observe frequent income tax increases in the 1990s and early 2000s. After 2000, income tax cuts and hikes more or less equalised each other, leading to a rather stable adjustment factor (right panel of Figure 2). The high correlation between adjusted and unadjusted revenue is in line with the findings of Barrios and Fargnoli (2010), who, however, only consider aggregated direct taxes. This finding is interesting even beyond the current context, as it suggests that at least in terms of personal income taxes, UK fiscal austerity in the aftermath of the financial crisis was tougher than in Germany.

**Figure 1: Actual and Policy-Adjusted Personal Income Tax Revenues**

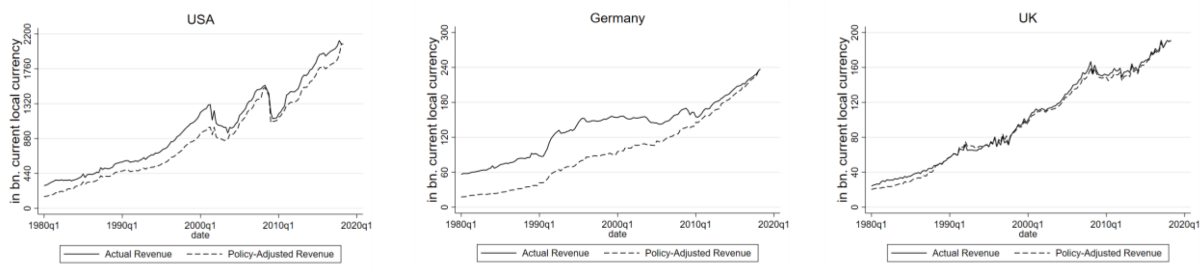
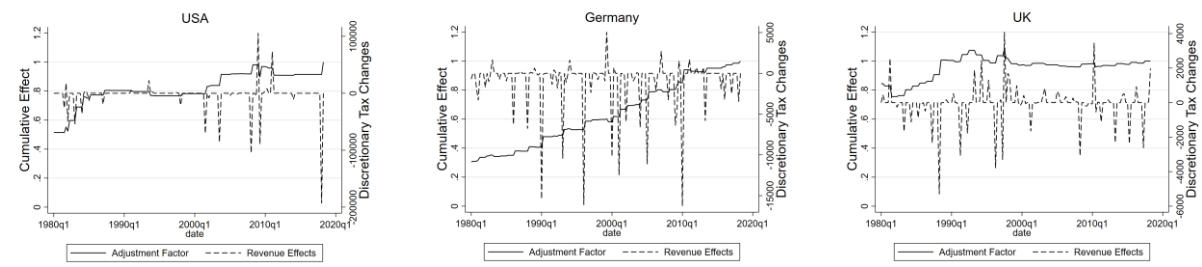



**Figure 2: Cumulative Effect of Discretionary Changes, Personal Income Tax Revenues**




Studying business tax revenues in Figure 3 suggests that they are much more volatile. Similar to personal income taxes, adjusted US business tax revenues, shown in the left panel of Figure 3, have to be adjusted downwards in light of the major tax reforms; that is, the 2017 Tax Cuts and Jobs Act, the 2002 Job Creation and Workers Assistant Act, and the 2003 Jobs and Growth Tax Relief Reconciliation Act lowered business tax liabilities. In contrast, the 1986 Tax Reform Act increased business tax liabilities (while lowering personal income tax liabilities), pushing the adjustment parameter up again, as shown in the left panel of Figure 4. The result is a volatile adjustment parameter without a clear direction over the whole observation window. In general, US business tax revenues were smaller after correcting for tax cuts, but only up to 1986. Both German (Figure 3, centre panel) and UK (Figure 3, right panel) business tax revenues and tax legislation show an erratic pattern around 2000. Taking the accumulative effect into account, German business tax revenues in 1980 would have been about 90% of the actually collected revenues. As the right panel of Figure 4 shows, business rates in the UK were cut after the financial crisis, in an effort to stimulate long-term growth and to have the lowest business rates in the G7.[5] Before this period, tax cuts and hikes roughly offset each other, with the cumulative effect leading to about 17% higher adjusted revenues in 1980.

**Figure 3: Actual and Policy-Adjusted Corporate Income Tax Revenues**

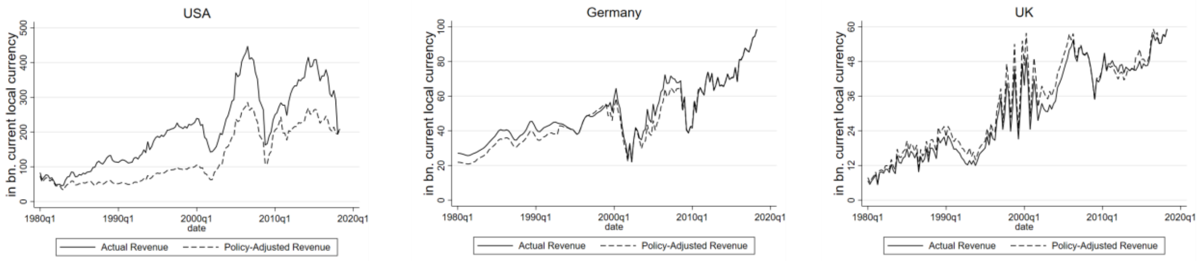



**Figure 4: Cumulative Effect of Discretionary Changes, Corporate Income Tax Revenues**

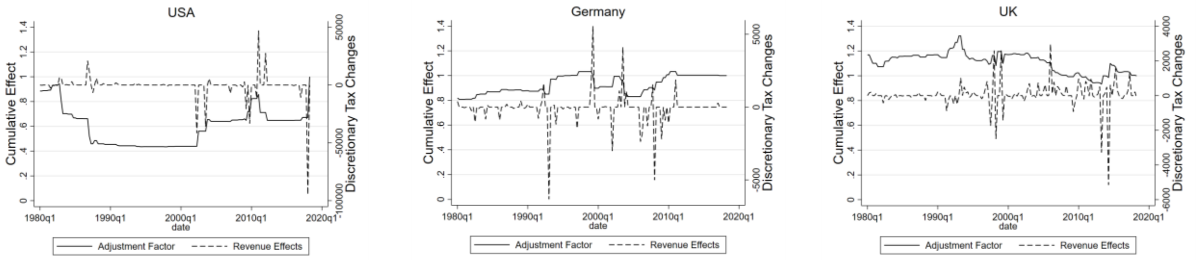



Figure 5 illustrates that the direction of the cumulative effect of indirect tax legislation is strikingly similar for all three economies, with the lowest cumulative effect in the US (left panel). This could be explained by the lack of data on sales taxes, which are levied at the state level. In our narrative account, we can cover only US excise taxes, which were altered less frequently. In both Germany (centre) and the UK (right panel), we observe mainly indirect tax increases, reflecting a shift from income taxation to consumption taxation. The cumulative effect given in Figure 6 for Germany (UK) amounts to 60% (80%) higher revenues if the current legislation had already been in place in 1980.

[5] See UK Budget (2011, p. 27) and Corporate Tax Reform: Delivering a More Competitive System (HM Treasury, November 2010).

**Figure 5: Actual and Policy-Adjusted Consumption Tax Revenues**

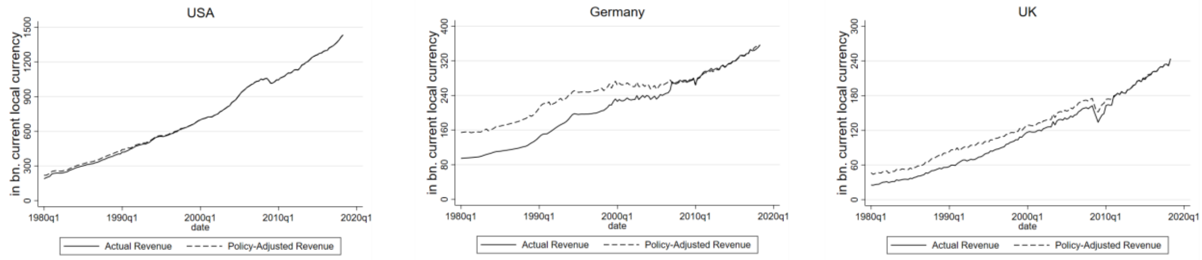



**Figure 6: Cumulative Effect of Discretionary Changes, Consumption Tax Revenues**

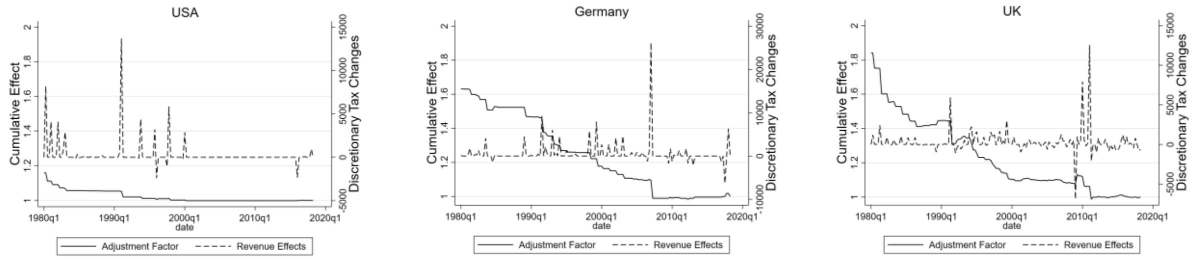



**Figure 7: Actual and Policy-Adjusted Employees SSC Revenues**

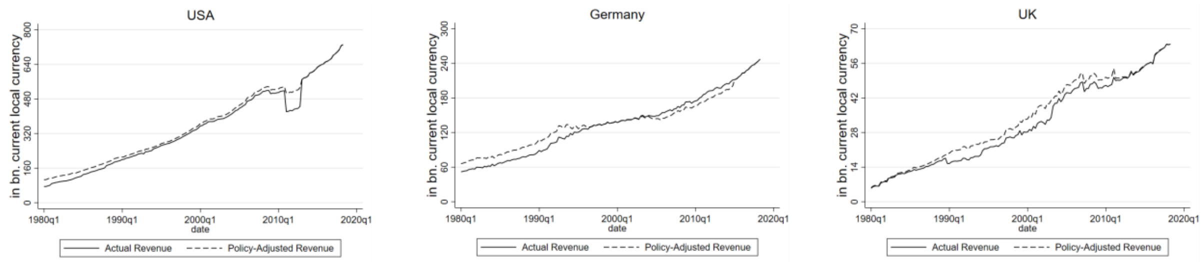
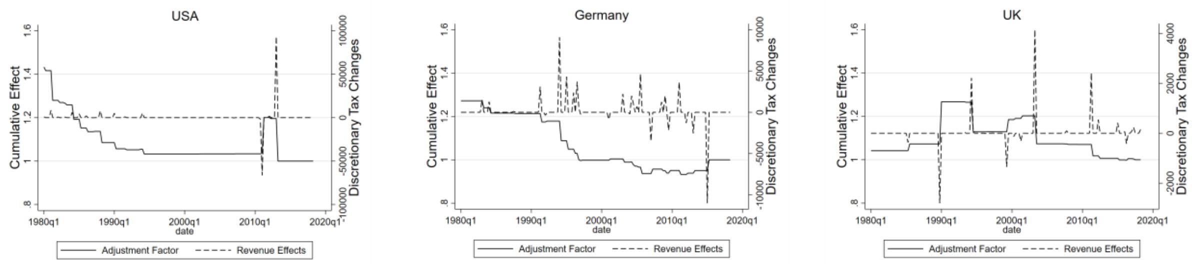



**Figure 8: Cumulative Effect of Discretionary Changes, Employees SSC Revenues**




When considering the cumulative effect of discretionary tax legislation for employees' SSCs in Figure 7, we again see an upward adjustment of revenues. As shown in the left panel of Figure 8, two notable spikes occurred in 2011Q1 and 2013Q1, which reflect the temporary payroll tax reduction to provide relief to US households in the aftermath of the financial crisis. Again, this stresses the importance of considering temporary measures to explain revenue changes in a given quarter. Legislated changes to the US Old-Age, Survivors, and Disability Insurance Program yield an accumulated effect of about 40% higher adjusted revenues in 1980Q1. When cumulating the German SSC policy changes, the effect is about the same size (roughly 30%). The effect of policy changes to the adjusted employee SSC contributions is positive in the UK too, but lower in magnitude, amounting to approximately 5% higher revenues at the beginning of our observation period. Had it not been for a large cut at the end of 1989 (right panel of Figure 8), the cumulative effect would have been about the same size as the one for Germany. From 5 October 1989, the rate of contributions below the lower earnings limit was reduced (see Cloyne, 2012), amounting to a cut equal to more than 15% of revenues at that time.

## 4 Estimation Methodology

To estimate tax base elasticities, we follow the extant literature and employ the Engle and Granger (1987) two-step regression method, which allows analysing LR and SR elasticities separately.[6]

We estimate the long-run elasticities using

$$ln(AR)_{i,c.t} = \alpha_{0,i}^{TB} + \alpha_{1,i}^{TB} ln(B)_{i,c,t} + \gamma_{i,c,t}^{TB} \quad (2)$$

where $AR_{i,c.t}$ stands for the revenue adjusted for discretionary measures of tax category *c* of country *i* at time *t*, $B_{i,c.t}$ represents the tax base of tax category *c* of country *i* at time *t*, and $\gamma_{i,c,t}$ is the error term for tax category *c* of country *i* at time *t*. The coefficient of interest $\alpha_1^{TB}$ denotes the long-run tax-to-base elasticity that measures the per cent revenue change following a 1% change in the relevant tax base.

Equation (2) may be subject to a spurious regression problem and/or small sample estimation bias, as tax revenues and bases are non-stationary (see Table A.1). Stock and Watson (1993) show that the dynamic ordinary least squares estimator (DOLS), which adds leads and lags of right-hand side variables in their first differences to Equation (2), yields consistent and asymptotically efficient coefficients. In addition, according to their Monte-Carlo study, DOLS performs well in relatively small samples, which is highly relevant for the current purpose. Moreover, potential endogeneity of the tax base is no longer problematic in this framework because tax revenues have been corrected for discretionary measures that could affect the tax bases. After estimating the relevant equations based on Equation (3), we tested whether the non-stationary variables are co-integrated. For this purpose, the obtained errors from the long-run equations were tested for stationarity using the ADF test and employing MacKinnon's (1991) critical values. We concluded that the relevant error terms are stationary for all types of revenues and, therefore, there is a co-integrating relationship between a specific revenue category and its corresponding tax base (Table A.2).

Our long-run equation takes the following form:

$$ln(AR)_{i,c.t} = \alpha_{0,i}^{TB} + \alpha_{1,i}^{TB} ln(B)_{i,c,t} + \sum_{j=-q}^{p} \emptyset_{i,j}^{TB}\, \Delta\, ln(AR)_{i,c.t+j} + \gamma_{i,c,t}^{TB} \quad (3)$$

where the lead and lag values, *q* and *p*, are determined according to the Schwarz information criterion.[7] Following Sobel and Holcombe (1996), Bruce et al. (2006), and Wolswijk (2009), we address potential inconsistencies in the estimated standard errors due to autocorrelation or heteroscedasticity by using the procedure proposed by Newey and West (1987).

[6] For instance, Bruce et al. (2006), Wolswijk (2009), Koester and Priesmeier (2012, 2017), Mourre and Princen (2015), Havranek et al. (2016), and Boschi and d'Addona (2019).

[7] In most cases, there was a consensus among various information criteria concerning the recommended lag order. In any case, our estimated elasticities are insensitive to different lag orders.

Similarly, for the short-term elasticity, we employ the following equation

$$\Delta\, ln(AR)_{i,c.t} = \beta_{0,i}^{TB} + \beta_{1,i}^{TB} \Delta ln(B)_{i,c,t} + \beta_{2,i}^{TB} \gamma_{i,c,t-1}^{TB} + \mu_{i,c,t} \qquad (4)$$

where $\beta_1^{TB}$ denotes the short-term symmetric tax-to-base elasticity. $\gamma_{i,c,t-1}^{TB}$ is the error correction term derived from Equation (2). Coefficient $\beta_2^{TB}$ represents the adjustment parameter reflecting the percentage of the previous year's deviation from the long-term tax level corrected in the current period. Put differently, it is the share of disequilibrium in per cent that is removed in every period.[8] Therefore, short-term tax revenue changes may arise from changes in the tax base and deviations from the long-term equilibrium between revenues and tax base. Thus, in this framework it is possible to account for a situation where tax revenues grow in spite of a shrinking tax base (Wolswijk, 2009).

### Asymmetric Elasticities: Business Cycle and Adjustment Speed

Equation (5) allows for the possibility that SR tax revenue growth is affected asymmetrically by three phases of the business cycle: recession (output gap < –1%), normal (–1 ≤ output gap ≤ 1%), and boom (output gap > 1%).

$$\begin{aligned}\Delta\, ln(AR)_{i,c.t} = {} & \beta_{0,i}^{TB} + \beta_{1,i}^{TB} \Delta ln(B)_{i,c,t} + \beta_{2,i}^{TB} \gamma_{i,c,t-1}^{TB} + \theta_{1,i}^{TB} DB_{i,t-1}^{+} \Delta ln(B)_{i,t} + \theta_{2,i}^{TB} DB_{i,t-1}^{+} \gamma_{i,c,t-1}^{TB} \\ & + \gamma_{1,i}^{TB} DB_{i,t-1}^{-} \Delta ln(B)_{i,t} + \gamma_{2,i}^{TB} DB_{i,t-1}^{-} \gamma_{i,c,t-1}^{TB} + v_{i,c,t}^{TB}\end{aligned} \qquad (5)$$

with: $DB_{i,t}^{+} = \begin{cases} 1, if\ gap > 0.01 \\ otherwise \end{cases}$ and $DB_{i,t}^{-} = \begin{cases} 1, if\ gap < 0.01 \\ otherwise \end{cases}$

where $DB_{i,t}$ is a dummy for country *i* at time *t* based on the sign of the output gap. $DB_{i,t}^{+}$ ($DB_{i,t}^{-}$) takes the value of 1 when the output gap is greater (less) than (minus) 1%. The coefficient for the tax base is $\beta_1^{TB}$ for normal times, ($\beta_1^{TB}$+$\theta_1^{TB}$) for booms, and ($\beta_1^{TB}$+$\gamma_1^{TB}$) for recessions. Analysing $\beta_2^{TB}$, ($\beta_2^{TB}$+$\theta_2^{TB}$), and ($\beta_2^{TB}$+$\gamma_2^{TB}$), we test whether the speed of adjustment back to the long-term equilibrium between revenues and tax base differs between normal times, booms, and recessions, respectively.

A common approach for measuring non-symmetric tax elasticities in the SR is the method proposed by Granger and Lee (1989) (see, e.g., Bruce et al., 2006; Wolswijk, 2009; Bettendorf and van Limbergen, 2013). In this case, the state of the economy is deduced from the sign of the error correction term retrieved from the long-run equation. The error correction term is translated into a dummy, taking the value 1 when revenues are above the estimated long-run relationship. However, while this is straightforward to implement, it is not really the type of asymmetry economists are normally interested in, which, as argued above, is related to the business cycle.

As described in Equation (5), we deviate from the extant literature in two ways. First, we introduce a novel corridor approach interpreting output gap fluctuations of –/+ 1% as normal and treat only fluctuations smaller/larger than that as recessions/booms. By introducing a third, neutral, state we avoid a setup that sets a slightly negative/positive deviation from the long-run trend equal to a large recession/boom. Since we have additional observations on GDP before and after our sample window, we can compute the output gap using a consistent two-sided HP filter and a standard smoothing parameter of λ = 1600. Table A3 and Figures A1–A3 show the distribution of the three different business cycle states for our sample countries. Second, following the literature on asymmetric fiscal

[8] After *t* periods, the total reduction of the disequilibrium is 1-(1+$\beta_2$)$^t$. Therefore, a higher absolute value of this adjustment parameter indicates that the relevant tax base moves faster towards its LR value.

multipliers (Auerbach and Gorodnichenko, 2013; Owyang et al., 2013; Ramey and Zubairy, 2018), we lag the indicator of the state of the economy by one quarter. This allows for a delayed adjustment of tax revenues after contractions, which might be due to a slow adjustment of employment or carried-forward losses. We believe that this approach is more useful in the context of forecasting revenues, too, as it not only provides state-dependent elasticities based on a widely used business cycle indicator but also allows for the existence of a normal business cycle position.

Comparing our business cycle indicator with the asymmetry indicator proposed by Granger and Lee (1989), we find that the correlation between the two indicators for each tax category ranges from −0.3 (German SSC) to 0.4 (US personal income tax). Furthermore, the correlation is not consistent across tax types within one country. Thus, instead of having to evaluate the revenues' position relative to their LR equilibrium before assessing the impact of the business cycle on elasticities (Dye, 2004), using the output gap allows for a consistent direct comparison across countries and tax types.

### Base-to-GDP Elasticities

After estimating LR and SR tax-to-base elasticities along with their good and bad times estimates, we apply the same estimation technique to retrieve base-to-GDP elasticities. In a final step, the product of tax-to-base elasticities and base-to-GDP elasticities will lead to the tax-to-GDP elasticities. For this purpose, the LR equation given in Equation (4) is transformed into:

$$ln(B)_{i,c.t} = \alpha_{0,i}^{BY} + \alpha_{1,i}^{BY} ln(Y)_{i,t} + \sum_{j=-q}^{p} \pi_{i,j}^{BY} \, \Delta \, ln(Y)_{i.t+j} + \epsilon_{i,c,t}^{BY} \quad (6)$$

where $Y_{i,t}$stands for the GDP of country *i* in time *t*, and the coefficient of interest $\alpha_{1,i}^{BY}$ denotes the long-run base-to-GDP elasticity that measures the per cent base changes following a 1% change in GDP. Similarly, the transformed SR equation given in Equation (5) takes the following form:

$$\Delta \, ln(B)_{i,c.t} = \beta_{0,i}^{BY} + \beta_{1,i}^{BY} \Delta ln(Y)_{i,c,t} + \beta_{2,i}^{BY} \gamma_{i,c,t-1}^{BY} + \mu_{i,c,t} \quad (7)$$

where $\beta_{1,i}^{BY}$ indicates the short-run base-to-GDP elasticity.

To estimate the asymmetric base-to-GDP elasticities, we utilise the following equation:

$$\Delta \, ln(B)_{i,c.t} = \beta_{0,i}^{BY} + \beta_{1,i}^{BY} \Delta ln(Y)_{i,c,t} + \theta_{1,i}^{BY} DB_{i,t} \Delta ln(Y)_{i,t} + \beta_{2,i}^{BY} \gamma_{i,c,t-1}^{BY} + \theta_{2,i}^{BY} DB_{i,t-1} \gamma_{i,c,t-1}^{BY} + v_{i,c,t}^{BY} \quad (8)$$

where coefficient $\beta_1^{BY}$stands for the short-run base-to-GDP elasticity during good times, whereas ($\beta_1^{BY}$+$\theta_1^{BY}$) measures the effect during bad times.

Finally, the overall tax revenue elasticity with respect to GDP—the tax-to-GDP elasticity—can be calculated for LR:

$$\alpha^{TY} = \alpha^{TB} * \alpha^{BY} \quad (9)$$

and SR:

$$\beta^{TY} = \beta^{TB} * \beta^{BY} \quad (10)$$

Equations (9) and (10) are also employed to calculate the asymmetric elasticities. The estimation of the overall tax-to-output elasticities as laid out in Equations (9) and (10) follows van den Noord (2000) and Girouard and André (2005), who do not directly estimate the relationship in a regression of tax revenues on income but in a two-step procedure. This should give us a more precise estimate of the tax-to-output elasticity, as we can take into account both the relationship between revenues and their respective tax bases and between tax bases and output. The estimate can be interpreted as *tax buoyancy*, as it measures how much revenues increase when GDP increases.[9]

## 5 Empirical Results

Table 2 reports the estimation results for the symmetric tax-to-base elasticities obtained by Equations (3) and (4) for LR and SR models. The first row shows the estimated tax-to-base elasticities for total tax revenues, for which we approximate the base by the sum of total compensation, private consumption, and corporate profits. Our results indicate that the LR estimates for the US and Germany are significantly above unity; for the UK, the LR elasticity is significantly smaller than unity. These findings indicate a progressive tax system in the US and Germany and a regressive one in the UK. The SR elasticities are significantly lower than the LR elasticities for Germany, whereas the opposite holds for the US. Adjustment speed of revenues towards the LR value is particularly fast in the UK, where catching up requires about three quarters. In Germany, this adjustment needs seven quarters and roughly twice as long as that in the US.

The second row of Table 2 shows the estimation results of the LR and SR models for personal income tax elasticities. Following the extant literature, total wages are considered as a proxy for the personal income tax base. Starting with Germany, the results indicate an overall LR tax-to-base elasticity of 2.0, which is significantly greater than 1. This demonstrates the outcome of a progressive income tax system, where the marginal tax rate is higher than the average tax rate. However, the SR tax-to-base elasticity is 0.8, which is not statistically different from unity. Thus, the estimated SR elasticity indicates a significantly lower impact of wages on revenues than does the estimated LR elasticity. For the UK, the LR personal income tax-to-base elasticity is around 1.1, which is significantly greater than 1. The SR elasticity is exactly equal to unity, which indicates a proportional tax system.

Both for Germany and the UK, the LR elasticity exceeds the SR elasticity, which could be due to collection lags. However, Koester and Priesmeier (2012) note that wage revenues are generally collected with a delay of one month and the national accounts data are adjusted accordingly. Hence, tax collection lags can only help explain this finding if a significant portion of wage tax revenue is collected with a lag of more than one month. In addition, the adjustment speed to the LR equilibrium for Germany and the UK is low. In this regard, our results for Germany are in line with the findings of Koester and Priesmeier (2012), Mourre and Princen (2019), Bouthevillain et al. (2001), and Boschi and d'Addona (2019)

In the US, the relationship between LR and SR personal income elasticities is very different: the SR tax-to-base elasticity is 2.4, which is significantly higher than the LR elasticity of 1.3. Both elasticities are significantly greater

[9] See, e.g., Tagkalakis (2017), Dudine and Jalles (2018), and Lagravinese et al. (2020).

than unity. According to Mourre and Princen (2019), such a reduction in the effectiveness of the tax system's progressivity in the LR could be due to various tax exclusions, exemptions, or deductions that narrow the tax base and benefit high-income earners. Compared to Germany, revenues have the tendency to adjust more quickly to deviations from the LR equilibrium. Our LR results are similar to the findings of van den Noord (2000) and Girouard and André (2005), who estimate the LR tax-to-base elasticity as 1.1 and 1.3, respectively.

The third row of Table 2 provides the estimation results for the social security contribution LR and SR elasticities. In our benchmark model, employees' total compensation is used as a proxy for the social security contribution base. For all countries in our sample, social security contributions vary proportionally to their tax base in the LR, that is, the tax-to-base elasticity is equal to unity. Our results stand in contrast to those of Mourre and Princen (2015) and Boschi and d'Addona (2019), as these authors report lower LR elasticities for Germany and higher elasticities for the UK. Our results are more in line with theory, possibly due to our longer time span and more precise dating and quantification of tax policy changes.

**Table 2: Symmetric Elasticities: Tax-to-Base**

| Symmetric Elasticities Tax-to-Base | | | | | | |
|---|---|---|---|---|---|---|
| | **Long Run** | | | **Short Run** | | |
| **Tax Base** | **(I) US** | **(II) Germany** | **(III) UK** | **(IV) US** | **(V) Germany** | **(VI) UK** |
| **Total Tax Base** | 1.09*** | 1.12*** | 0.96*** | 1.62*** | 0.45*** | 0.76*** |
| *Adjustment parameter* | | | | *–0.06*** | *–0.13**** | *–0.33**** |
| *R²* | *0.99* | *0.99* | *0.99* | *0.3* | *0.18* | *0.2* |
| *No. of observations* | *149* | *149* | *147* | *149* | *149* | *147* |
| **Wages & Salaries** | 1.28*** | 2.02*** | 1.12*** | 2.41*** | 0.76*** | 1.02*** |
| *Adjustment parameter* | | | | *–0.23**** | *–0.14**** | *–0.28**** |
| *R²* | *0.99* | *0.99* | *0.99* | *0.37* | *0.25* | *0.18* |
| *No. of observations* | *147* | *149* | *149* | *147* | *149* | *149* |
| **Compensation** | 0.99*** | 1.01*** | 1.01*** | 0.55*** | 0.42*** | 1.01*** |
| *Adjustment parameter* | | | | *–0.17**** | *–0.20**** | *–0.19**** |
| *R²* | *0.99* | *0.99* | *0.99* | *0.23* | *0.2* | *0.24* |
| *No. of observations* | *151* | *145* | *149* | *151* | *145* | *149* |
| **Private Consumption** | 0.88*** | 0.64*** | 0.84*** | 0.87*** | 0.51*** | 0.52** |
| *Adjustment parameter* | | | | *–0.07*** | *–0.10*** | *–0.25**** |
| *R²* | *0.99* | *0.98* | *0.99* | *0.35* | *0.12* | *0.17* |
| *No. of observations* | *149* | *149* | *149* | *149* | *149* | *149* |
| **Corporate Profits** | 0.85*** | 1.58*** | 0.82*** | 1.18*** | 0.30* | 1.06*** |
| *Adjustment parameter* | | | | *–0.09*** | *–0.24**** | *–0.30**** |
| *R²* | *0.92* | *0.85* | *0.84* | *0.4* | *0.12* | *0.19* |
| *No. of observations* | *148* | *145* | *147* | *148* | *145* | *147* |

Notes: Underlining indicates statistically different from 1 at 5% level, *** p < 0.01, ** p < 0.05, * p < 0.1. Estimations include a constant term for all countries and a dummy for German reunification. For corporate income tax estimations, another dummy is included for Germany to reflect the comprehensive reform of profit-related taxes in 2001.

The SR elasticity might be different from unity due to statutory contribution ceilings, which are defined per individual or, in some cases, per household. Typically, under a certain threshold, wage income is exempt from social security contributions (Mourre and Princen, 2015).[10] The higher the income above the ceiling, the lower the effective contribution rate and, thus, the average effective tax rate declines (van den Noord, 2000). To sum up, social security contributions are slightly progressive in the lower part of the wage distribution, proportional in the centre, and very regressive in the upper part of the distribution. Therefore, if the portion of higher (lower) wages in the

[10] For the most up-to-date thresholds, see https://www.oecd-ilibrary.org/sites/08a1335d-en/index.html?itemId=/content/component/08a1335d-en and https://www.oecd.org/tax/tax-policy/tax-database/social-security-contributions-explanatory-annex.pdf.

overall wage bill dominates the portion of lower (higher) wages, the SR elasticity is expected to be lower (higher) than unity, and even more so when the ceiling is not adjusted for inflation. Our findings suggest that Germany and the US have an elasticity below unity and that the UK has one above unity. For Germany and the UK, our results generally correspond to those reported in the extant literature (Mourre and Princen, 2015; Boschi and d'Addona, 2019; Girouard and André, 2005). The adjustment speed does not differ across countries and implies that social security contributions need almost a year and a half to converge to their LR levels.

The fourth row of Table 2 displays the LR and SR estimation results for the consumption tax elasticities. Private consumption is considered as the consumption tax base in our model. For all countries, our results are below unity. Regarding LR elasticities, we find a particularly low value for Germany of 0.6. However, Mourre and Princen (2019) and Koester and Priesmeier (2012) estimate a LR elasticity of similar magnitude. The LR tax-to-base elasticity is 0.8 and 0.9 for the UK and the US, respectively. In each case, we also reject the hypothesis that the elasticity is statistically equal to unity. Our results are almost equal to those reported by Bruce et al. (2006) and van den Noord (2000) for the US and to those of Boschi and d'Addona (2019) for the UK. For Germany, Koester and Priesmeier (2012) argue that the elasticity is so low because an increasing portion of private consumption is not subject to VAT. Smith and Keen (2007) suggest that tax evasion and/or tax fraud could be another explanation for a consumption tax elasticity below unity.

The SR consumption tax-to-base elasticity estimates for the UK and the US are 0.5 and 0.9, respectively. However, neither elasticity is statistically different from unity. For Germany, we estimate the same SR elasticity as for the UK, but reject the hypothesis that it is equal to unity. Despite the higher difference between the SR and LR estimates, the UK adjustment speed is relatively high, indicating that the gap will be bridged within a year. We find lower adjustment speeds by a factor two to three for Germany and the US, respectively.

The last row of Table 2 sets out the estimation results for the LR and SR corporate income tax. Following the extant literature, corporate profits are taken as a proxy for the tax base. As shown in the previous section, corporate tax revenues experience a great deal of volatility over time. According to Mourre and Princen (2019) and Wolswijk (2009), the main reason for this volatility is the deviation between accounting profits and tax profits due to the special regimes and tax expenditures and the firms' practice of carrying losses backward and forward to the subsequent years.

For Germany, where we use a dummy to control for the comprehensive reform of profit-related taxes in 2001, we calculate a LR elasticity of 1.6, which is significantly larger than unity. Evidence of a progressive tax system is also provided by Girouard and André (2005) and Boschi and d'Addona (2019), who estimate the LR elasticities as 1.5. At 0.3, our estimated SR elasticity is much lower than the LR one. The adjustment speed is fast, though, taking place within one year. These results are in line with those of Boschi and d'Addona (2019) and Koester and Priesmeier (2012). Estimated as 0.8 and 0.9, the LR elasticities for the UK and US, respectively, are significantly different from unity and indicate a regressive tax system.

There are only a few studies on corporate income tax elasticities. For the UK, Mourre and Princen (2019) find no significant results for the LR or SR corporate income tax elasticities. In contrast, Boschi and d'Addona (2019) estimate a LR elasticity of 0.6 and an SR elasticity of 0.4. On the other hand, Girouard and André (2005) obtain an LR elasticity of 1.7. For the US, van den Noord (2000) and Girouard and André (2005) calculate the LR elasticities as 1.8 and 1.5, respectively. Based on theoretical grounds, Creedy and Gemmell (2008) suggest that business tax revenues are the most volatile and challenging to forecast. They argue that the volatility of revenues mainly stems from deductions and the volatility of profits itself. In the absence of discretionary changes, they predict that revenues and profits will grow at the same rate, implying a unity elasticity. However, we can reject this conjecture for all our sample countries.

### Symmetric Base-to-Output Elasticities

After estimating the tax-to-base elasticities adjusted for discretionary measures, we now turn to the base-to-output elasticities before combining the two components to obtain the tax-to-output elasticities. In this setup, it is important to clearly define LR and the SR elasticities. As the LR elasticities are obtained from log-level regressions, they show how rapidly a tax base grows compared to income. If the LR elasticity is smaller (greater) than unity, it indicates that the tax base grows more slowly (faster) than income. The SR elasticities are estimated by the change in the log of the relevant variables; they can be treated as the cyclical component of tax-base variability. Therefore, an SR elasticity smaller (greater) than unity denotes that the relevant tax base undulates less (more) than income over the business cycle (Sobel and Holcombe, 1996).

Columns (I) to (III) in Table 3 contain estimates for the LR; (IV) to (VI) those for the SR. For all countries and taxes, except corporate income tax, Table 3 shows that our estimated SR elasticities are significantly smaller than unity, suggesting that they undulate less than income over the business cycle. The reverse holds for corporate income tax, the SR elasticity of which is statistically larger than unity in all countries. This finding is consistent with the descriptive evidence presented in Figure A4 in the Appendix, which illustrates that corporate profits fluctuate more than income over the business cycle.

Starting with the long-run estimates of total tax revenues, Table 3 suggests that revenues increase almost proportionally with output. However, when testing the coefficient against unity, we find elasticities significantly greater than unity in the UK and the US but not in Germany. When disaggregating the bases, we again find base-to-output elasticities to be fairly close to unity. Overall, the point estimates range from 0.9 to 1.4, reflecting the response of German wages and salaries and US corporate profits, respectively. While the former is not statically different from zero, the latter indicates that US corporate profits grow (shrink) faster than output grows (shrinks). In contrast to wages, German corporate profits yield an elasticity above unity, whereas their UK counterpart does not. The output elasticities for wages and salaries lie below unity in all three economies, but are significant only in the US. Hence, although US corporate profits grow faster than output, US wages grow slower. For all countries, social security contributions exhibit a pattern similar to that we found for wages. Finally, private consumption is the only tax base for which we find elasticities that are statistically different from unity across all three economies. Interestingly, German private consumption grows by 0.9% when GDP grows by 1%. This finding is possibly explained by the German people's relatively high propensity to save. In contrast, private consumption in the US and the UK grows by 1.1% and 1%, respectively.

Columns (IV) to (VI) in Table 3 show that SR output elasticities of tax bases do not vary much across countries, but do vary across categories. In the SR, private consumption is the least elastic base in Germany and the US, whereas corporate profits are the most elastic tax base in all three economies. In general, the estimated elasticities are significantly different from zero and unity. The growth rates of US and German wages and salaries are roughly

60% of the GDP growth rate, whereas we estimate the elasticity of wages in the UK at only 0.45. As for the LR, due to the similarity of the two tax bases, we find that the pattern for social security contributions is very similar to that for wages. In all three economies, the change in the growth rates of corporate profits is about twice as high as that for output. In other words, when not allowing for asymmetries, which we will discuss later, profits grow faster than GDP during an upswing and drop faster during a downturn. This likely reflects corporations' ability to lower profits through deductions and special depreciation rules in times of macroeconomic contraction. Regarding the speed of adjustment, UK tax bases, on average, are the least responsive to deviations from the LR equilibrium, whereas German corporate profits catch up more quickly.

**Table 3: Symmetric Elasticities: Base-to-GDP**

| Symmetric Elasticities: Base-to-GDP | | | | | | |
|---|---|---|---|---|---|---|
| | **Long Run** | | | **Short Run** | | |
| **Tax Base** | **(I) US** | **(II) Germany** | **(III) UK** | **(IV) US** | **(V) Germany** | **(VI) UK** |
| **Total Tax Base** | 1.04*** | 0.99*** | 1.03*** | 0.77*** | 0.75*** | 0.83*** |
| *Adjustment parameter* | | | | *–0.20**** | *–0.24**** | *–0.09*** |
| *R²* | *0.99* | *0.99* | *0.99* | *0.67* | *0.65* | *0.79* |
| *No. of observations* | *149* | *149* | *147* | *149* | *149* | *147* |
| **Wages & Salaries** | 0.95*** | 0.94*** | 0.98*** | 0.67*** | 0.66*** | 0.46*** |
| *Adjustment parameter* | | | | *–0.06** | *–0.10**** | *–0.08**** |
| *R²* | *0.99* | *0.99* | *0.99* | *0.32* | *0.24* | *0.27* |
| *No. of observations* | *149* | *151* | *149* | *149* | *151* | *149* |
| **Compensation** | 0.97*** | 0.95*** | 1.01*** | 0.65*** | 0.61*** | 0.45*** |
| *Adjustment parameter* | | | | *–0.06** | *–0.12**** | *–0.06**** |
| *R²* | *0.99* | *0.99* | *0.99* | *0.36* | *0.25* | *0.27* |
| *No. of observations* | *149* | *151* | *149* | *149* | *151* | *149* |
| **Private Consumption** | 1.06*** | 0.91*** | 1.04*** | 0.65*** | 0.51*** | 0.57*** |
| *Adjustment parameter* | | | | *–0.22**** | *–0.17**** | *–0.05* |
| *R²* | *0.99* | *0.99* | *0.99* | *0.57* | *0.41* | *0.44* |
| *No. of observations* | *149* | *151* | *147* | *149* | *151* | *147* |
| **Corporate Profits** | 1.39*** | 1.16*** | 1.00*** | 2.75*** | 2.02*** | 2.73*** |
| *Adjustment parameter* | | | | *–0.08*** | *–0.42**** | *–0.11**** |
| *R²* | *0.98* | *0.98* | *0.98* | *0.17* | *0.35* | *0.46* |
| *No. of observations* | *147* | *151* | *149* | *147* | *151* | *149* |

Notes: Underlining indicates statistically different from 1 at 5% level, *** p < 0.01, ** p < 0.05, * p < 0.1. Estimations include a constant term for all countries and a dummy for German reunification. For corporate income tax estimations, another dummy is included for Germany to reflect the comprehensive reform of profit-related taxes in 2001.

Comparing our results with a recent study by Boschi and d'Addona (2019), we find our LR base-to-output elasticities for German (UK) wages to be the same (slightly lower). We obtain quite different results for the elasticity of corporate profits, with our estimates only about a third in size compared to theirs. On the other hand, for German private consumption, we find a coefficient almost two times as high. In both cases, we believe our numbers to be more in line with economic theory. Comparing the SR elasticities of wages, we find them to be slightly higher (much lower) in the German (UK) case.

## Symmetric Tax-to-Output Elasticities

Theory predicts the tax-to-output elasticity (or buoyancy) to be equal to unity in the LR (Dudine and Jalles, 2018), as a value greater than unity would imply that, at some point, revenues would exceed the base. A value below unity implies that no fiscal sustainability is guaranteed (Lagravinese et al., 2020). In the SR, however, elasticity and buoyancy can differ from unity, possibly due to brackets and deductions that are not adjusted for inflation and/or because corporations can carry losses backward and forward. In line with the case of base-to-output elasticities, an LR elasticity greater (less) than unity indicates that tax revenues grow faster (slower) than income, whereas an SR elasticity greater (less) than unity denotes that the relevant tax revenue undulates more (less) than income over the business cycle.

Combining our estimated LR tax-to-base and base-to-output elasticities as laid out in Equation (9), we discover in Table 4 that US and German total tax revenues react slightly more strongly than their counterpart in the UK. The output elasticity for total revenues of 1.1 in the case of Germany lies fairly close to the 0.9 estimated by Perotti (2004), whereas our estimation of 1.1 for the US is clearly lower than the 1.9 he reports. For the UK, our estimate lies between the elasticities reported by Perotti (2004) and Cloyne (2013), namely, 0.8 and 1.6, respectively. For all three economies, we conclude that revenue collection is sustainable, as total revenues grow at the same pace as GDP.

**Table 4: Symmetric Elasticities: Tax-to-GDP**

| Symmetric Elasticities Tax-to-GDP | | | | | | |
|---|---|---|---|---|---|---|
| | | Long Run | | | Short Run | |
| **Tax Type** | (I) US | (II) Germany | (III) UK | (IV) US | (V) Germany | (VI) UK |
| Total Taxes | 1.13 | 1.08 | 0.99 | 1.25 | 0.34 | 0.63 |
| Personal Income Tax | 1.22 | 1.9 | 1.10 | 1.61 | 0.5 | 0.47 |
| Social Security Contributions | 0.96 | 0.96 | 1.02 | 0.36 | 0.26 | 0.45 |
| Consumption Tax | 0.93 | 0.58 | 0.87 | 0.57 | 0.26 | 0.30 |
| Corporate Income Tax | 1.18 | 1.83 | 0.82 | 3.25 | 0.61 | 2.89 |

Notes: Figures in tables represent the product of tax-to-base and base-to-output elasticities.

Table 4 shows that the SR tax-to-GDP elasticities for each tax type in Germany are less than unity, suggesting that revenues fluctuate less than income over the business cycle. However, estimating the LR tax-to-GDP elasticities suggests that the revenues for total taxes, personal income tax, and corporate income tax (social security contributions and consumption tax) grow faster (slower) than income. German consumption tax revenues, on the other hand, are the least responsive in the long run, with an elasticity of roughly 0.6. Such an elasticity indicates that budget financing via consumption tax is not sustainable in Germany, as revenues grow more slowly than income. Note that consumption tax yields lower-than-unity LR income elasticities in the other two economies, too.

For the UK, LR tax-to-GDP elasticities indicate for both total tax and social security contributions that revenues grow almost proportionally with income, whereas for consumption tax and corporate income tax (personal income tax), they tend to grow slower (faster). Except for corporate income tax, all SR tax-to-GDP elasticities fluctuate less than income over the business cycle.

Finally, for the US, the LR tax-to-GDP elasticities of the total tax, personal income tax, and corporate income tax (consumption tax, social security contributions) are above (below) unity. In the short run, consumption tax and social security tax (total tax, personal income tax, and corporate income tax) fluctuate less (more) than income over the business cycle. Overall, personal income tax is the most responsive in the US. This finding is driven by the sizeable tax-to-base elasticity of 2.4, whereas the base-to-GDP elasticities are relatively similar in all three economies. As mentioned previously, the personal income tax finding for the US indicates a highly progressive tax system or the failure to index tax brackets to inflation.

UK and US corporate income taxes are much more responsive in the SR than those in Germany, which is the opposite of what we find for the LR. For this tax type, Boschi and d'Addona (2019) find a qualitatively similar difference between Germany and the UK but report a much higher elasticity for Germany, as do Lagravinese et al. (2020). However, neither study adjusts revenues for discretionary changes. In general, we find lower SR tax-to-output elasticities for all three countries and tax types than do Lagravinese et al. (2020).

According to Sobel and Holcombe (1996), it is worth comparing SR and LR elasticities because the gap between these likely sheds light on the relationship between growth and variability of tax revenues. Our results demonstrate that the revenues of social security contributions and consumption tax demonstrate higher LR growth rates, albeit with a lower cyclical variability for the US. For the UK, except for corporate income tax, we find that all revenues fluctuate less than income. Finally, for Germany, the SR tax-to-output elasticities are all lower than those in the LR. Hence, the relationship between growth and variability is not necessarily the same across countries. Especially for the US and the UK, we discover that high LR revenue growth is not associated with higher SR variability.

Assuming symmetric effects, we conclude the following: (1) in the LR, aggregated tax revenues and social security contributions increase fairly proportionately with income, (2) the LR tax-to-output elasticity of personal income tax and corporate income tax is highest in Germany, (3) the LR tax-to-output elasticity of consumption tax is the lowest in Germany, (4) consumption tax grows more slowly than output in all three economies, and (5) SR tax-to-output elasticities, except for corporate income tax, are lower than LR elasticities.

### Asymmetries

During times of economic distress, governments might increase spending to stimulate output, hoping that a recovery will raise revenues and, therefore, help finance the additional spending (Dudine and Jalles, 2018). Our results suggest that this approach might work only in the US, whereas revenues grow more slowly than GDP in Germany and the UK. To further analyse this point, we estimate state-dependent elasticities, allowing for asymmetries between business cycle upswings and contractions as set out in Equation (5).

Table 5 reports the SR estimates for tax-to-base elasticities and base-to-GDP elasticities generated using an ECM, which is conditional on the state of the business cycle. For SSC, the bad times tax-to-base elasticities exceed the SR symmetric elasticities in all countries. For consumption tax, this result also holds for Germany and the UK. Independent of the state of the business cycle, German aggregated tax elasticities are the lowest across the three countries. German personal income tax elasticities are the lowest during normal times and expansions, whereas US aggregated and personal income tax elasticities are the largest during normal times. Overall, for tax-to-base elasticities, we find business cycle asymmetries across countries, but not within countries.

In contrast, when studying base-to-output elasticities, we find fewer asymmetries across countries but some across tax types. Significant business cycle asymmetries, shaded in Table 5, are detected for German and UK personal income tax and social security contributions. Elasticities are significantly lower during recessions than during booms. The reverse is found for German corporate income taxes, suggesting that during booms, profits do not move in line with GDP. Thus, business cycle asymmetries differ across countries, types of taxes, and elasticities.

There are some common patterns, though. For corporate income taxes in all countries, the good times tax-to-base elasticities are higher than bad times tax-to-base elasticities. Considering base-to-GDP elasticities, social security contributions and personal income tax elasticities are higher in booms than in recessions in all three economies. In terms of statistical significance, most of the boom and recession elasticities in Table 5 are neither statistically different from each other nor across countries.

**Table 5: Asymmetric Elasticities: Tax-to-Base and Base-to-GDP**

| | | Asymmetric Elasticities Tax-to-Base | | | Asymmetric Elasticities Base-to-GDP | | |
|---|---|---|---|---|---|---|---|
| Tax Type | | (I) US | (II) Germany | (III) UK | (IV) US | (V) Germany | (VI) UK |
| Total Taxes | Bad Times | 1.37*** | 0.28* | 0.51* | 0.83*** | 0.79*** | 0.90*** |
| | Adjustment parameter | –0.07 | –0.16** | –0.45*** | –0.17 | –0.48*** | –0.12* |
| | Normal Times | 1.79*** | 0.46*** | 0.54* | 0.78*** | 0.74*** | 0.79*** |
| | Adjustment parameter | –0.06 | –0.14** | –0.29*** | –0.11 | –0.37*** | –0.09* |
| | Good Times | 1.62*** | 0.63*** | 1.25*** | 0.67*** | 0.76*** | 0.88*** |
| | Adjustment parameter | –0.18* | –0.05 | –0.64*** | –0.49*** | –0.09 | –0.03 |
| | $R^2$ | 0.31 | 0.19 | 0.23 | 0.7 | 0.67 | 0.8 |
| | No. of observations | 149 | 149 | 147 | 149 | 149 | 147 |
| Personal Income Tax | Bad Times | 2.70*** | 0.44 | 0.97* | 0.63*** | 0.31* | 0.31*** |
| | Adjustment parameter | –0.39*** | –0.08 | –0.16* | –0.17* | –0.02 | –0.05 |
| | Normal Times | 2.52*** | 1.23*** | 0.65 | 0.70*** | 0.57*** | 0.33*** |
| | Adjustment parameter | –0.32*** | –0.19*** | –0.40*** | –0.08* | –0.01 | –0.07** |
| | Good Times | 2.34*** | 0.64*** | 2.07*** | 0.65*** | 1.29*** | 0.73*** |
| | Adjustment parameter | –0.04 | –0.02 | –0.55** | 0.04 | –0.17*** | –0.19** |
| | $R^2$ | 0.41 | 0.3 | 0.24 | 0.34 | 0.36 | 0.36 |
| | No. of observations | 147 | 149 | 149 | 149 | 151 | 149 |
| Social Security Contributions | Bad Times | 0.67*** | 0.66** | 1.45*** | 0.64*** | 0.30* | 0.30*** |
| | Adjustment parameter | –0.14 | –0.25** | –0.23*** | –0.08 | 0.00 | 0.01 |
| | Normal Times | 0.48*** | 0.90*** | 1.19*** | 0.66*** | 0.52*** | 0.33*** |
| | Adjustment parameter | –0.16*** | –0.16** | –0.18*** | –0.09** | –0.04 | –0.06*** |
| | Good Times | 0.53*** | 0.32*** | 0.70*** | 0.67*** | 1.15*** | 0.68*** |
| | Adjustment parameter | –0.28*** | –0.25** | –0.17 | 0.03 | –0.17*** | –0.10*** |
| | $R^2$ | 0.25 | 0.25 | 0.26 | 0.37 | 0.35 | 0.35 |
| | No. of observations | 151 | 145 | 149 | 149 | 151 | 151 |
| Consumption Taxes | Bad Times | 0.79*** | 0.64*** | 0.46* | 0.74*** | 0.61*** | 0.61*** |
| | Adjustment parameter | –0.08* | –0.16* | –0.33*** | –0.28*** | –0.22*** | 0.06 |
| | Normal Times | 0.74*** | 0.54** | 0.50** | 0.60*** | 0.35*** | 0.48*** |
| | Adjustment parameter | –0.08** | –0.10* | –0.23*** | –0.18*** | –0.06 | –0.05 |
| | Good Times | 0.73*** | 0.41** | 0.76** | 0.55*** | 0.73*** | 0.69*** |
| | Adjustment parameter | –0.10** | –0.18** | –0.38*** | –0.54*** | –0.26*** | 0.08 |
| | $R^2$ | 0.36 | 0.14 | 0.18 | 0.59 | 0.5 | 0.46 |
| | No. of observations | 147 | 149 | 149 | 149 | 151 | 147 |
| Corporate Income Tax | Bad Times | 0.81*** | 0.31 | 1.39** | 3.15*** | 3.11*** | 2.94*** |
| | Adjustment parameter | –0.21*** | –0.27* | –0.23* | –0.32*** | –0.68*** | –0.14* |
| | Normal Times | 1.13*** | 0.08 | 0.83** | 3.22*** | 2.41*** | 2.87*** |
| | Adjustment parameter | -0.06 | –0.25*** | –0.37*** | –0.10* | –0.29*** | –0.07 |
| | Good Times | 1.46*** | 0.57** | 1.73 | 1.70*** | -0.04 | 2.29*** |
| | Adjustment parameter | –0.04 | 0.06 | -0.76 | –0.02 | –0.48*** | –0.12 |
| | $R^2$ | 0.43 | 0.13 | 0.21 | 0.24 | 0.44 | 0.48 |
| | No. of observations | 147 | 145 | 147 | 149 | 151 | 149 |

Notes: *** p < 0.01, ** p < 0.05, * p < 0.1. Estimations include a constant term for all countries and a dummy for German reunification. For corporate income tax estimations, another dummy is included for Germany to reflect the comprehensive reform of profit-related taxes in 2001. Underlining indicates statistically different from 1, bold indicates statistically different from the UK, italic indicates statistically different from the US, bold and italic indicate statistically different from both countries, and shaded stands for statistically different from good times at a 5% significance level.

## 6 Robustness Section

This section presents two robustness checks. First, we employ an OLS model rather than a DOLS to estimate tax-to-base and base-to-output elasticities. Second, we provide estimates of consumption tax and social security contribution tax-to-base elasticities employing alternative bases and a small extension for US personal income tax.

Table A4 in the Appendix reports the Engle and Granger (1987) LR estimates of the tax-to-base and base-to-GDP elasticities. The error correction term obtained from this alternative setup is employed in the SR analysis. The change in our coefficients is minimal, except for the SR elasticities for total taxes, social security contributions, consumption tax, and UK corporate income tax, which are higher than our benchmark estimations by 0.2, 0.1, 0.2, and 0.2, respectively. None of these differences is statistically significant at the 5% level. Similarly, the changes in the base-to-output elasticities are very close to the ones obtained with DOLS. The only exception is the SR corporate income tax profit estimates, but the differences are again not statistically significant at the 5% level.

Given the deductibility of mortgage interest payments, we extend our model by adding house price changes as a control variable (Wolswijk, 2009).[11] We find that the relevant coefficient is zero and none of the estimated SR and LR elasticities change. Consumption tax is taken not only from private consumption but also from government consumption and government investment (Bettendorf and van Limbergen, 2013; Koester and Priesmeier, 2012; Mourre and Princen, 2015). We include these variables as controls (see bottom part of Table A5), but they do not affect our results.[12]

For employee social security contributions, we use total compensation as a tax base, which comprises gross wages as well as employers' contributions to social security. One can argue, however, that employers' and employees' shares are derived from gross wages. In other words, although employers officially pay a share, this is really a wage component. Consequently, as a robustness check, we use gross wages as the base for social security contributions. The middle section of Table A5 provides the alternative estimation results for LR and SR social security contribution elasticities and shows that our results are robust to this change.

## 7 Conclusion

Investigating the United States, Germany, and the United Kingdom over the period 1980−2018, we present estimates of LR and SR elasticities of tax revenues with respect to their bases and of bases with respect to GDP. The following tax categories are considered: total taxes, personal income tax, social security contributions, consumption tax, and corporate income taxes. We employ a new quarterly database of discretionary tax measures for three major economies. In addition, we examine the speed of adjustment of tax revenue towards equilibrium using an error correction model. Differentiating between three phases of the business cycle—recessions, normal times, and booms—allows us to study potential asymmetries in elasticities.

Our conclusions are as follows. (i) In Germany and the UK, long-term tax-to-base elasticities are generally higher than short-term elasticities, whereas results for the US are mixed. (ii) Short-term elasticities for base-to-output elasticities tend to be smaller than unity, whereas long-term elasticities are close to unity. (iii) German and UK tax-to-output elasticities in the short term are lower than long-term elasticities, with mixed results for the US. (iv) For tax-to-base elasticities, we find business cycle asymmetries across countries, but not within countries. (v) For

[11] Mortgage interest relief was abolished in 2000 in the UK and in 2006 in Germany. However, since it was available for more than 50% of our sample, we conduct this exercise in the two countries, too.
[12] Note that the elasticities obtained from this alternative specification are not directly comparable to our benchmark results. As emphasised in Bettendorf and van Limbergen (2013), considering an equal change in all demand components, the total elasticity in the LR, for instance, for the UK, will be calculated as 0.65 + 0.20 = 0.85, which is very close to the LR elasticity (0.84) of our benchmark model.

base-to-output elasticities, our results suggest few asymmetries across countries, but more asymmetries across tax types. (vi) Typically, the above conclusions do not hold for corporate income tax.

The elasticities obtained in this study can be utilised in government revenue forecasts and computing cyclically adjusted budget balances. Our findings suggest how tax elasticities change over the course of the business cycle. Moreover, the sizeable differences between the estimated SR and LR base-to-output elasticities have potentially important implications for the trade-off between growth and variability of tax bases. In this regard, we find that long-run revenue growth does not necessarily come at the cost of high volatility. Finally, the estimated elasticities can be useful as an input when studying the dynamic impact of fiscal policy instruments on macroeconomic indicators, for instance, in the context of structural vector autoregressions or dynamic stochastic general equilibrium models.

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## Appendix

**Figure A1: USA: Recession Periods, Discretionary Measures, and Quarterly Change of Total Tax Revenues, in billion**

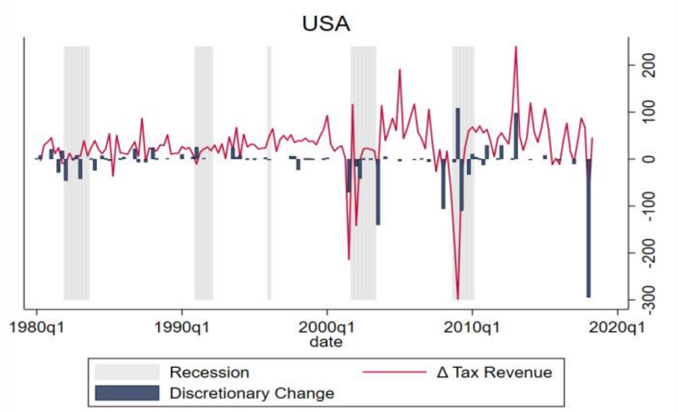



**Figure A2: Germany: Recession Periods, Discretionary Measures, and Quarterly Change of Total Tax Revenues, in billion**

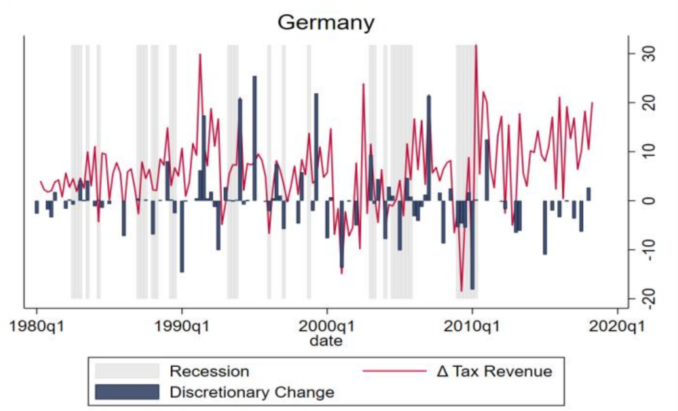



**Figure A3: UK: Recession Periods, Discretionary Measures, and Quarterly Change of Total Tax Revenues, in billion**

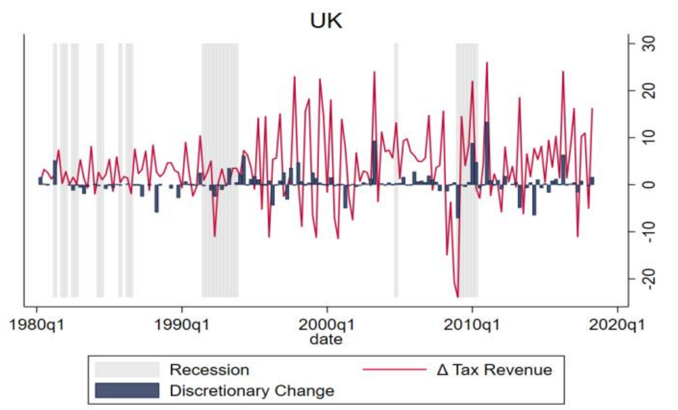


**Table A1: Augmented Dickey–Fuller Test Results**

| | United States<br>Estimation Period: 1980Q1–2018Q2 | | | | Germany<br>Estimation Period: 1980Q1–2018Q2 | | | | United Kingdom<br>Estimation Period: 1980Q1–2018Q2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Level** | **Lags** | **First Difference** | **Lags** | **Level** | **Lags** | **First Difference** | **Lags** | **Level** | **Lags** | **First Difference** | **Lags** |
| **Total Tax** | –0.82 | 2 | –6.30*** | 1 | 2.14 | 1 | –13.33*** | 0 | –1.96 | 3 | –8.47*** | 2 |
| **Total Base** | –1.1 | 2 | –5.30*** | 2 | –0.31 | 2 | –2.97** | 4 | –1.64 | 1 | –4.59*** | 2 |
| **Personal Income Tax** | –1.61 | 1 | –11.13*** | 0 | 1.63 | 1 | –3.33*** | 3 | –2.31 | 2 | –10.62*** | 1 |
| **Total Wages** | –1.64 | 3 | –4.34*** | 2 | –0.68 | 2 | –6.63*** | 1 | –2.34 | 2 | –5.29*** | 2 |
| **Indirect Taxes** | –0.8 | 2 | –5.86*** | 1 | –0.68 | 2 | –11.33*** | 1 | –1.48 | 2 | –14.22*** | 0 |
| **Private Consumption** | –0.53 | 2 | –4.93*** | 1 | –1.09 | 1 | –14.12*** | 0 | –1.04 | 2 | –4.25*** | 3 |
| **Corporate Income Tax** | –2.52 | 1 | –11.01*** | 0 | –2.1 | 2 | –8.33*** | 1 | –2.51 | 3 | –11.03*** | 2 |
| **Company Profits** | –2.19 | 1 | –13.44*** | 0 | –1.12 | 3 | –6.28*** | 4 | –2.19 | 3 | –9.31*** | 2 |
| **Social Security Taxes** | –0.65 | 1 | –7.17*** | 1 | 1.39 | 1 | –3.14** | 3 | –1.83 | 2 | –10.13*** | 1 |
| **Compensation** | –1.6 | 3 | –4.21*** | 2 | –0.88 | 2 | –6.12*** | 1 | –1.98 | 1 | –10.60*** | 0 |
| **House Price** | –2.33 | 4 | –3.33*** | 4 | –0.93 | 4 | –2.57* | 3 | –1.89 | 2 | –4.31*** | 4 |

Notes: *, **, *** indicate significance at 10%, 5%, and 1% level, respectively. The lags are obtained according to the Schwarz information criterion. For level estimations, the ADF regressions involve an intercept and a trend term, whereas for difference estimations, only a constant term is included.

**Table A2*: Augmented Dickey–Fuller Test Results for Residuals from Long-Term DOLS Equations***

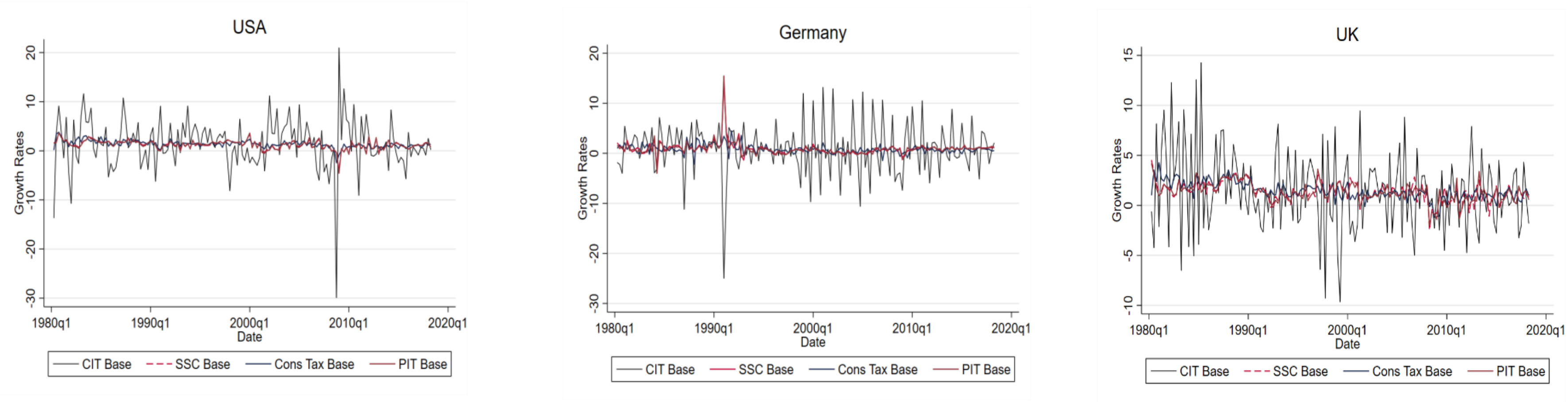
| | **United States**<br>**Level** | **Germany**<br>**Level** | **United Kingdom**<br>**Level** |
|---|---|---|---|
| **Total Tax** | –2.33*** | –4.25*** | –5.29*** |
| **Personal Income Tax** | –4.84*** | –3.81*** | –4.95*** |
| **Indirect Taxes** | –2.32** | –3.09*** | –4.96*** |
| **Corporate Income Tax** | –4.15*** | –4.08*** | –5.09*** |
| **Social Security Taxes** | –3.70*** | –4.46*** | –5.55*** |

Notes: *, **, *** indicate significance at 10%, 5%, and 1% level, respectively. The ADF regressions include no deterministic terms.

**Table A3: Summary of Good, Bad, and Normal Times Dummies**

| | US | Germany | UK |
|---|---|---|---|
| **Number of good times** | 33 | 33 | 24 |
| **Number of bad times** | 26 | 33 | 27 |
| **Number of normal times** | 95 | 88 | 103 |

**Figure A4: Log Growth Rates of Variables**



## Table A4: Symmetric Elasticities Estimations with OLS

| | Tax-to-Base | | | | | | Base-to-GDP | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Long Run | | | Short Run | | | Long Run | | | Short Run | | |
| Tax Type | (I) US | (II) Germany | (III) UK | (IV) US | (V) Germany | (VI) UK | (VII) US | (VIII) Germany | (IX) UK | (X) US | (XI) Germany | (XII) UK |
| **Total Tax Base** | 1.10*** | 1.10*** | 0.94*** | 1.60*** | 0.53*** | 0.92*** | 1.04*** | 0.99*** | 1.03*** | 0.83*** | 0.76*** | 0.83*** |
| *Adjustment parameter* | | | | *-0.06** | *-0.05* | *-0.34**** | | | | *-0.16**** | *-0.23**** | *-0.12**** |
| *$R^2$* | *0.99* | *0.99* | *0.99* | *0.31* | *0.13* | *0.23* | *0.99* | *0.99* | *0.99* | *0.69* | *0.65* | *0.81* |
| *No of observations* | *153* | *153* | *153* | *152* | *152* | *152* | *153* | *153* | *153* | *152* | *152* | *152* |
| **Wages & Salaries** | 1.27*** | 2.01*** | 1.12*** | 2.32*** | 0.80*** | 1.03*** | 0.95*** | 0.95*** | 0.98*** | 0.68*** | 0.64*** | 0.46*** |
| *Adjustment parameter* | | | | *-0.17**** | *-0.14**** | *-0.28**** | | | | *-0.07** | *-0.10**** | *-0.08**** |
| *$R^2$* | *0.99* | *0.99* | *0.99* | *0.35* | *0.26* | *0.19* | *0.99* | *0.99* | *0.99* | *0.35* | *0.24* | *0.29* |
| *No of observations* | *153* | *153* | *153* | *152* | *152* | *152* | *153* | *153* | *153* | *152* | *152* | *152* |
| **Compensation** | 0.99*** | 0.98*** | 1.01*** | 0.58*** | 0.51*** | 1.13*** | 0.97*** | 0.95*** | 1.01*** | 0.66*** | 0.58*** | 0.47*** |
| *Adjustment parameter* | | | | *-0.17**** | *-0.09**** | *-0.14**** | | | | *-0.07*** | *-0.13**** | *-0.06**** |
| *$R^2$* | *0.99* | *0.99* | *0.99* | *0.23* | *0.16* | *0.2* | *0.99* | *0.99* | *0.99* | *0.4* | *0.25* | *0.28* |
| *No of observations* | *153* | *153* | *153* | *152* | *152* | *152* | *153* | *153* | *153* | *152* | *152* | *152* |
| **Private Consumption** | 0.88*** | 0.60*** | 0.81*** | 0.88*** | 0.58*** | 0.73*** | 1.06*** | 0.92*** | 1.04*** | 0.72*** | 0.47*** | 0.61*** |
| *Adjustment parameter* | | | | *-0.07*** | *-0.08*** | *-0.17**** | | | | *-0.18**** | *-0.18**** | *-0.07*** |
| *$R^2$* | *0.99* | *0.98* | *0.99* | *0.38* | *0.11* | *0.12* | *0.99* | *0.99* | *0.99* | *0.58* | *0.44* | *0.47* |
| *No of observations* | *153* | *153* | *153* | *152* | *152* | *152* | *153* | *153* | *153* | *152* | *152* | *152* |
| **Corporate Profits** | 0.84*** | 1.52*** | 0.83*** | 1.14*** | 0.32* | 0.91*** | 1.30*** | 1.16*** | 1.01*** | 2.67*** | 2.52*** | 2.55*** |
| *Adjustment parameter* | | | | *-0.06** | *-0.15**** | *-0.31**** | | | | *-0.08*** | *-0.42**** | *-0.10**** |
| *$R^2$* | *0.92* | *0.85* | *0.84* | *0.4* | *0.12* | *0.19* | *0.98* | *0.98* | *0.98* | *0.17* | *0.36* | *0.42* |
| *No of observations* | *153* | *153* | *153* | *152* | *152* | *152* | *153* | *153* | *153* | *152* | *152* | *152* |

Notes: Underlined indicates statistically different from 1 at 5% level, *** p<0.01, ** p<0.05, * p<0.1. Estimations include a constant term for all countries and a dummy for German reunification. For corporate income tax estimations, another dummy is included for Germany to reflect the comprehensive reform of profit-related taxes in 2001.

**Table A5: Estimations with OLS Model**

| Tax Type | (I) US | (II) Germany | (III) UK | (IV) US | (V) Germany | (VI) UK |
|---|---|---|---|---|---|---|
| **Symmetric Elasticities Tax-to-Base** | | | | | | |
| | | **Long Run** | | | **Short Run** | |
| **Wages & Salaries** | 1.27*** | 2.05*** | 1.12*** | 2.41*** | 0.81*** | 1.11*** |
| **Housing Price** | 0.00 | –0.01 | 0.00* | 0.00 | –0.00* | 0.00 |
| *Adjustment parameter* | | | | *–0.25**** | *–0.13**** | *–0.25**** |
| *$R^2$* | *0.99* | 0.99 | *0.99* | *0.38* | *0.26* | *0.16* |
| *No. of observations* | *147* | 151 | *149* | *147* | *151* | *149* |
| **Wages & Salaries** | 1.01*** | 1.00*** | 1.04*** | 0.50*** | 0.37*** | 0.86*** |
| *Adjustment parameter* | | | | *–0.17**** | *–0.23**** | *–0.21**** |
| *$R^2$* | *0.99* | *0.99* | *0.99* | *0.24* | *0.19* | *0.22* |
| *No. of observations* | *151* | *145* | *149* | *151* | *145* | *149* |
| **Private Consumption** | 0.77*** | 0.28** | 0.65*** | 0.81*** | 0.57*** | 0.55** |
| **Gov't Consumption & Investment** | 0.13* | 0.32** | 0.20*** | 0.10 | –0.08 | –0.14 |
| *Adjustment parameter* | | | | *–0.08*** | *–0.10*** | *–0.33**** |
| *$R^2$* | *0.99* | *0.98* | *0.99* | *0.36* | *0.12* | *0.21* |
| *No. of observations* | *149* | *151* | *149* | *149* | *151* | *149* |

Notes: Underlining indicates statistically different from 1 at the 5% level, *** p < 0.01, ** p < 0.05, * p < 0.1. Estimations include a constant term for all countries and a dummy for German reunification. For corporate income tax estimations, another dummy is included for Germany to reflect the comprehensive reform of profit-related taxes in 2001.