

The stability of tax elasticities over the business cycle in European countries

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Abstract

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Keywords: Tax elasticity, Tax policy discretionary change, Business cycle, European economy, Markov-switching regimes

JEL Classification: C24, C29, E32, E62, H20, H30

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Abstract

The change of national income brings about tax revenue change. This relationship is embodied in the tax elasticity and usefully estimated both for the long-run and the short-run. In this paper we show that the short-run tax elasticity - the percent change in the tax revenue in response to a one percent change in national income - changes itself according to the business cycle. Using a novel dataset of tax policy reforms on 15 European countries from 1980 to 2013, we estimate a two state Markov-switching regression model to account for possible differences in tax elasticities during different phases of the economy. The estimated difference between elasticities during booms and recessions turns out to be always statistically significant and often even economically so. Results show a clear tendency for short-run elasticities of (i) indirect taxes, (ii) social contributions, and to a lesser extent, (iii) corporate income taxes to increase in recessions. Differences in tax elasticities for personal income taxes are somehow less pronounced. Across countries, results show a tendency for larger elasticities in recessions to prevail.

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1 Introduction

Estimating the tax elasticity, that is the tax revenue change brought about by a given change in national income, is an essential step of fiscal policy implementation. Governments use the tax elasticity to forecast revenues when preparing their budget and to estimate the cyclical component of the budget balance as a pre-requisite to assess the fiscal stance. Clearly, large forecasting errors lead to budget surprises and inaccurate assessments of the fiscal stance, possibly associated to undue fiscal policy responses. Such an outcome might be especially undesired for European Union members: in the current surveillance framework a significant deviation from the medium term budgetary objective may trigger a specific correction mechanism.

The tax elasticity is estimated using mainly two distinct approaches: The first relies on micro-data and detailed information on the national tax code, while the second is based on econometric techniques. Current practice at international institutions such as the Organization for Economic Cooperation and Development (OECD) or the European Commission (EC) relies heavily on the first approach (see Girouard and André, 2005 for a detailed illustration). The academic literature, on the other hand, has mainly followed the second approach, using econometric techniques to disentangle the *long-run tax elasticity*, that is how a tax revenue will tend to grow over time as income grows, capturing the potential growth of tax revenue, from the *short-run tax elasticity*, that is the percent change of the tax revenue in response to a one percent change in income, capturing how the tax revenue will fluctuate over the business cycle as income fluctuates. Wolswijk (2009) provides a recent example of this research.

Within the second approach, this paper questions the widely made assumption that the short-run tax elasticity remains stable over the business cycle.

The empirical analysis covers 15 European countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Spain,

Sweden, and UK. The data sample is quarterly over the period 1980-2013.

As a first contribution, we propose a regression-based model where short-run tax elasticities are allowed to shift as the economy shifts between booms and recessions, providing an estimate of tax elasticities in each state and showing that their difference across states is statistically significant. In particular, our results show a clear tendency for short-run elasticities of indirect taxes, social contributions, and, to a lesser extent, corporate income taxes to increase during recessions, while results for personal income taxes are not so clear cut. Short-run elasticities tendency to increase in recession also holds across countries, though less pronouncedly. This is so for 7 out of 15 countries, while elasticities are larger in boom for 4 countries. In the remaining 4 countries no tendency prevails.

We may call for various theoretical rationales of a time-varying tax elasticity. One motivation concerns composition effects, that is the relative change of tax bases shares of GDP (consumption, wages, asset prices) over the business cycle¹. Behavioral aspects of taxation also impinge on the variability of tax elasticities. Tax compliance, in fact, is expected to change over the business cycle as taxpayers facing economic downturns are prone to perceive a smaller risk of penalties due to tax evasion as compared to larger potential gains from avoiding bankruptcy (see Brondolo, 2009). Moreover, cyclical economic downturns can push the economic activity from the formal to the informal sector. This is consistent with evidence that tax collection efficiency appears to be lower over economic contractions and vice versa (see Sancak et al., 2010). Income inequality matters as well. As the economy slows down, the lower end of the income distribution bears the largest part of lay-offs, while the most of income tax revenues come from the higher end of the distribution for which earning and spending patterns remain relatively stable over the

¹An example is provided by Larch and Turrini (2009). They show that the increase of tax elasticities with respect to GDP at the end of the 1990s and early 2000s was mainly due to the increased share of consumption in total income in Germany and to a combination of high wage share, rising imports, and high asset prices in France.

business cycle.

We take these concerns seriously and test the stability over the business cycle of short-run elasticity of selected tax categories (personal income, corporate income, indirect, and social contributions) with respect to their bases (*tax-to-base elasticity*) along with the elasticity of the same bases with respect to GDP as a proxy for the overall level of income (*base-to-GDP elasticity*). Following the warnings of Sobel and Holcombe (1996), we also estimate the long-run elasticity and assume that it is immune from regime shifts since it reflects the long-run, potential, relationship between taxes and bases as well as between bases and GDP. We finally combine, both for the long-run and the short-run estimates, the tax-to-base and base-to-GDP elasticity in an overall estimate of *tax-to-GDP elasticity*.

As a second contribution, this paper proposes a method to deal with the omitted variables bias arising from the effect of discretionary tax policy changes on the relationship between tax revenue and income. Most studies typically tackle this bias by removing the government ex ante estimates of tax policy changes from the tax revenue thus obtaining a time series that only represent the effect of income changes.

The remainder of the paper is organized as follows. In section 2 we illustrate how our econometric methodology allows for an explicit association of estimated regimes to business cycle phases, thus overcoming most of the methodological drawbacks affecting existing attempts to estimate time-varying tax elasticities that we discuss in subsection 2.1. We then discuss how we dealt with the above mentioned omitted variables bias, using a novel approach based on the analysis of the narrative record of European Union member States' tax reforms collected by the European Commission. Section 3 presents the data description and sources, including our choice of proxy for each tax category base. We also illustrate the method we use to make the narrative record of tax reforms operational. In section 4 we discuss our results and how they relate to the existing literature on tax elasticities. Finally, section 5 draws policy implications and concludes.

2 Empirical methodology

Current empirical literature on tax elasticities typically follows a two-step procedure. In the first step, a regression model with log-level variables is estimated to obtain the long-run, potential effect of income changes on tax revenues. Given non-stationarity of the relevant time series, however, the OLS estimates would be asymptotically biased with inconsistent standard errors. To avoid coefficients' bias, the log-level regression model is usually augmented with leads and lags of the growth rate of the independent variable, thereby obtaining the Dynamic Ordinary Least Squares (DOLS) model proposed by Stock and Watson (1993).

Given its ability to accommodate higher orders of integration, and to deal with endogeneity among regressors and serial correlation issues (Koester and Priesmeier, 2012), this estimator has proved to be superior to standard OLS estimates or to Vector Error Correction Mechanism (VECM) models (Johansen, 1995), especially in small samples. Thus, we opted for a DOLS approach in conjunction with the Newey and West (1987) correction to avoid standard errors' inconsistency.

One further econometric problem arises from the effect of tax policy changes on elasticity. Figuring out how much of tax revenues changes arises automatically from changing economic conditions and how much from discretionary tax policy changes - including legislated changes in tax rates, tax base definitions, and tax administration - is the main challenge one encounters when estimating tax elasticities because it involves dealing with a huge omitted variable bias. Several studies (see Bettendorf and van Limbergen, 2013, Mourre and Princen, 2015, and Wolswijk, 2009, among others) deal with this bias collecting detailed information on national tax policy changes to quantify and remove from revenues the effect of discretionary measures using the proportional adjustment method proposed by Prest (1962).² However, as far as we know, tax reform databases for the

²A note on terminology is in order here. Most authors researching tax elasticities call tax revenue changes arising from changing economic conditions *endogenous* as opposed to revenue changes arising

countries we analyze are unavailable³. If one would try and collect this information from national sources, its reliability would be at least subject to skepticism because of cross-country differences in tax codes and tax reforms classification methods⁴. Moreover, as clearly shown by Barrios and Fagnoli (2010), comparability across countries is also limited by differences in accounting rules (accrual *versus* cash basis of accounting), or in the very definition of discretionary measure (based on a "no-policy change" *versus* current legislation assumption).

Finally, we should bear in mind that discretionary measures represent *ex ante* government estimates of the revenue effect of tax policy changes rather than *ex post* realizations, heavily relying on the accuracy of financial and macroeconomic baselines and forecasts.⁵ We thus contribute to the literature by suggesting an alternative approach to deal with this omitted variables bias that relies on qualitative information provided by a narrative record of the tax policy changes taken in European countries⁶. For each tax category and each country, we codified a series of quarterly indicator variables to record when a tax policy change took effect. This way of considering tax reforms in regression models avoids all the problems discussed above since it is unaffected by differences in accounting rules or reforms definition, as well as accuracy of measures impact forecasts, though, as obvious, it doesn't allow to account for different sizes of discretionary changes.

from discretionary tax policy changes, which they call *exogenous* (see, for example, Princen et al., 2013, p. 11). As argued by Romer and Romer, 2010, however, tax policy changes can be discretionary while being endogenous at the same time. They can be taken, in fact, in response to business cycle conditions or to finance public expenditures, so that they are systematically correlated with output - and in this sense *endogenous*. This is why we reckon the term *automatic* as opposed to discretionary tax policy changes more appropriate than *endogenous*.

³We are indeed aware of one such database at annual frequency developed by the European Commission and based on information on discretionary measures collected through questionnaires sent out to EU Member States in the context of the Output Gap Working Group (OGWG) of the Economic Policy Committee, covering a large sample of EU countries (see Barrios and Fagnoli, 2010 and Princen et al., 2013 for an analytical description). Mourre and Princen (2015) use it to analyze tax elasticities in the European Union. Unfortunately, this database is unavailable to the public.

⁴In fact, we are able to use this approach in a companion paper that focuses on Italy. See Boschi et al., 2017.

⁵Such estimates depend on a number of crucial assumptions about the fiscal multiplier, the effect of tax reforms on the bases, the informal sector, the tax compliance, and so forth.

⁶This narrative approach is much in the spirit of Ramey and Shapiro (1998).

Therefore, for each tax category we estimate the following long-run DOLS model of revenue:

$$\log T_t = \theta^{TB} + \delta^{TB} \log B_t + \sum_{j=-k}^k \phi_{1j}^{TB} \Delta \log B_{t+j} + \phi_2^{TB} D_t^T + \gamma_t^{TB} \quad (1)$$

where T_t and B_t are the tax revenue and base in year t respectively, θ^{TB} is a constant, D_t^T is the tax policy intervention dummy, γ_t^{TB} is an error term, and δ^{TB} being the long-run tax-to-base elasticity.

Next, we estimate the same regression model but with variables taken in first log-differences to gauge the short-run tax elasticity, that is the percentage change in tax revenue associated to a percent change in base. It is well known that estimates from this specification could be biased if the variables are cointegrated. To overcome this problem, we follow the common practice (e.g. Bettendorf and van Limbergen, 2013, Bouthevillain et al., 2001, Sobel and Holcombe, 1996, Wolswijk, 2009) and include lagged residuals of the long-run regression model among the regressors, thereby obtaining an error-correction model (ECM).

The main novelty of this paper consists of accounting for business cycles in the short-run regression model to capture the possible nonlinear relationship between tax revenues and income. To do so we model the underlying economy as a Markov process that switches between two states (s) the first characterized by a high growth rate of output (“boom”, b) and the second by a low growth rate of output (“recession”, r),

We thus estimate the above short-run tax-to-base elasticity model conditioning on the state of the economy $s_t = b, r$ at time t :

$$\Delta \log T_t = \alpha^{TB}(s_t) + \beta^{TB}(s_t) \Delta \log B_t + \lambda^{TB}(s_t) \gamma_{t-1}^{TB} + \phi_3^{TB}(s_t) D_t^T + \varepsilon_t^{TB} \quad (2)$$

where all coefficients, including the tax revenue short-run elasticity, β^{TB} , are conditional

on the economy state (s_t), and ε_t^{TB} is an error term.

Two short-run effects are captured in any time period: tax revenues can respond to changes in the tax base as well as to the long-run disequilibrium between revenue and base that exists at the beginning of the period.

Since we are ultimately interested in estimating the tax revenue elasticity with respect to income, we need to take into account the likely fluctuation of the relevant tax base with respect to income. Hence, we proceed in the same way as above for the tax base by first estimating:

$$\log B_t = \theta^{BY} + \delta^{BY} \log Y_t + \sum_{j=-k}^k \phi_{1j}^{BY} \Delta \log Y_{t+j} + \phi_2^{BY} D_t^T + \gamma_t^{BY} \quad (3)$$

where Y_t is the income, or GDP, level in year t and δ^{BY} is the long-run base-to-GDP elasticity.

Then we feed the lagged error term γ_{t-1}^{BY} into the regression model with log-differenced variables to obtain:

$$\Delta \log B_t = \alpha^{BY}(s_t) + \beta^{BY}(s_t) \Delta \log Y_t + \lambda^{BY}(s_t) \gamma_{t-1}^{BY} + \phi_3^{BY}(s_t) D_t^T + \varepsilon_t^{BY} \quad (4)$$

where all coefficients are conditional on the state of the economy, and β^{BY} is the short-run base-to-GDP elasticity.

The overall elasticity of the tax revenue with respect to income - the tax-to-GDP elasticity - is given by (see Perotti, 2005 and Girouard and Andr e, 2005 for a formal derivation):

$$\delta^{TY}(s_t) = \delta^{TB}(s_t) \times \delta^{BY}(s_t) \quad (5)$$

and

$$\beta^{TY}(s_t) = \beta^{TB}(s_t) \times \beta^{BY}(s_t) \quad (6)$$

We therefore obtain, for each tax category, one tax-to-GDP elasticity for each state of the economy (“boom” or “recession”).

As a comparison term, we also estimate a short-run linear elasticity for tax-to-base and base-to-GDP, and then combine them in a tax-to-GDP estimate.

2.1 Regime estimation

Only few studies, using a variety of econometric methodologies, devoted the deserved attention to time-varying tax elasticities. Bruce et al. (2006) use an ECM model to estimate long-run and short-run elasticities of personal income and sales taxes in the United States allowing for asymmetric deviation of short-run values from the long-run equilibrium. They find a relevant asymmetric behavior in most of the 50 states. Wolswijk (2009) focuses on Netherlands because of the availability of data on tax revenues net of the effect of discretionary measures. He estimates a regression model of tax revenues on their bases allowing for asymmetric effects of deviations from the long-run equilibrium. Estimates for five tax categories confirm significant differences between short-run and long-run tax-to-base elasticities, especially over economic downturns, with evidence of asymmetric behavior. Poghosyan (2011) estimates rolling regressions to quantify short-run tax elasticities of five tax categories with respect to their bases, using a panel model to compare short-run and long-run elasticities of Lithuania to that of ten new EU members. His contribution confirms the importance of allowing for cyclical differences in tax elasticities. Similar evidence is found for South Africa by Jooste and Naraidoo (2011) using a smooth transition regression model.

To estimate time-varying tax elasticities we use the methodology proposed by d’Addona

and Musumeci (2013)⁷ and model an economy an economy where output switches between two (unobservable) states: a high mean state (“boom”) and a a low mean state (“recession”). Since agents (e.g. taxpayers) cannot observe the state of the economy, they will infer the probability of being in a particular state by looking at the output growth rate realizations, which therefore acts as a state signal. We indicate the latent state of the economy by s_t and assume that it follows a hidden Markov chain with transition probabilities matrix P (see Hamilton, 1989).

Specifically, we model the output growth rate as a regime-dependent process in its mean with i.i.d. normal innovations:

$$\Delta \log Y_t = \mu(s_t) + \epsilon_t \quad (7)$$

where μ is the mean of the process conditional on the unobservable state of the economy s_t and ϵ_t is a random Gaussian shock with standard deviation σ . Through the observation of the realizations of $\Delta \log Y_t$, agents infer the underlying state of the economy by formulating the posterior probability of being in each state of the economy based on information available up to time t and on knowledge of the population parameters. Hence, the filtered posterior probability is:

$$\hat{\xi}_{t|t} = Pr\{s_t = s \mid \Omega_t\} \quad (8)$$

where s identify the state of the economy (b and r for boom and recession respectively), and Ω_t denotes the information set including all data and parameters up to time t . Agents update their beliefs according to:

$$\hat{\xi}_{t|t} = \frac{\hat{\xi}_{t|t-1} \otimes \zeta_t}{1'(\hat{\xi}_{t|t-1} \otimes \zeta_t)} \quad (9)$$

⁷See Boschi et al. (2012) for an extension to a multivariate model.

where \otimes indicates the element-by-element product, $\mathbf{1}$ denotes a vector of ones whose dimension corresponds to the number of states, and ζ_t is a vector of Gaussian density functions of output growth rates conditional on the state s_t :

$$\zeta_t = \begin{bmatrix} f(\Delta \log Y_t | s_t = b, \Omega_{t-1}) \\ f(\Delta \log Y_t | s_t = r, \Omega_{t-1}) \end{bmatrix} \quad (10)$$

with the density of $\Delta \log Y_t$ conditional on the state s_t defined as:

$$f(\Delta \log Y_t | s_t = s, \Omega_{t-1}) = \frac{1}{\sqrt{2\pi}\sigma} \exp \left\{ \frac{-(\Delta \log Y_t - \mu(s_t))^2}{2\sigma^2} \right\} \quad (11)$$

For each country, we first obtain the posterior probability, $\hat{\xi}_{t|t}$, of the economy being in each state at time t by estimating the regime-switching model using a Markov Chain Monte Carlo (MCMC) procedure that closely follows the algorithm described in section 9.1 of Kim and Nelson (1999). We then estimate the long-run regression model for each tax category. Finally, we estimate the short-run regression model by maximum likelihood using the MCMC probabilities as weights for the regression in each state of the economy. Specifically, we maximize $\ln L$ with

$$L = \prod_t^T \hat{\xi}_{t|t}^s \left\{ \frac{1}{\sqrt{\pi\sigma_s^2}} \exp \left[\left((Z_t - \hat{C}^s X_t) (Z_t - \hat{C}^s X_t)' / 2\sigma_s^2 \right) \right] \right\} \quad (12)$$

where Z_t indicates the short-run model dependent variable (tax revenue or base), \hat{C}^s indicates the vector of coefficients to be estimated, and X_t is the vector of regressors (base or GDP with leads and lags).

We follow the above procedure to obtain the tax-to-base and base-to-GDP elasticities.

It is worth noting that in the literature reviewed above asymmetric behavior is conceived with respect to a reference term, like the long-run equilibrium, therefore not necessarily associating it to the business cycle phases. Others, like, for example, Bettendorf

and van Limbergen (2013), look at asymmetric deviations with respect to the output gap as an indicator of the business cycle, but such association is deterministic rather than stochastic. A similar deterministic analysis is implemented by Princen et al. (2013), who compare elasticities computed at each of the sample years to observe behavior over the business cycle. We emphasize that our methodology, instead, results in a close association of the two short-run elasticities with the business cycle phases and, most importantly, such association is stochastic in nature since it is obtained by weighing upon the posterior probability of the economy being in a boom or in a recession. In addition to facilitating incorporation of such elasticities in current practice of fiscal analysis at both national and international levels, this represents a significant methodological improvement with respect to the existing literature.

Furthermore, in comparison to Princen et al. (2013), our method is operationally more useful since it might be easily incorporated in surveillance and forecasting activity. In fact, we estimate one short-run elasticity that holds for all boom periods over the sample, and one for all recession periods, while Princen et al. (2013) estimate a different elasticity for every and each sample year. Princen et al. (2013) themselves acknowledge that their elasticities are difficult to interpret and highly erratic.

3 Data

Data are quarterly over the period 1980q1-2013q1, though the sample range changes across countries and tax categories depending on the minimum available length of time series for each country (see table 14). We use two sources: The Organization for Economic Cooperation and Development (OECD) quarterly sector accounts Data Warehouse and the European Central Bank (ECB) Data Warehouse. Except where indicated, data from the OECD and the ECB come originally at current prices, in millions of national currency.

Were necessary, data are seasonal adjusted using the TRAMO/SEATS programs (see Gomez and Maravall, 1996). Data are also deflated using the indicated, appropriate, deflator to render them in real terms. The Appendix reports a detailed description of data sources, definitions, and manipulation.

4 Results

A preliminary analysis of all the time series involved indicates that all variables can be reasonably considered to be driven by I(1) or I(2) stochastic trends, which justifies the use of DOLS and ECM methodologies⁸. For each country and each tax category we estimated the long-run DOLS model as well as the short-run regimes switching ECM regression, both for the tax-to-base and the base-to-GDP model⁹. We then combine the estimated values to obtain a single tax-to-GDP elasticity for each country and each tax category. The number of leads and lags in the DOLS model were chosen according to the Akaike Information Criterion (AIC) and the Schwarz information criterion (SIC). As detailed in Appendix, the tax reform dummy variables were coded so that they take value one when the reform becomes law and start exerting its effects. However, because reforms start to be discussed earlier than they take place and usually take time to be implemented, people can develop expectations on them and modify their behavior much before reforms become law. We test this hypothesis by estimating two versions of each model - one version includes the dummy variable with no leads and another version, under the hypothesis of reforms foresight, includes the dummy variable with a lead. The AIC and SIC were used to choose between the two model specifications. When the criteria results for the revenue-to-base elasticity differ from those for the base-to-GDP elasticity

⁸Unit root test results are available upon request.

⁹Long-run estimation were also performed using GLS regressions by which similar results were obtained.

model, we choose the model that gave the largest criterion improvement¹⁰.

Generally speaking, one result holds across all countries and tax categories - nonlinearity is always statistically significant, as shown by the likelihood ratio tests (LR) large statistics and small p -values,¹¹ though not always the difference between the boom and recession short-run elasticities is economically relevant.¹²

Personal income tax (PIT). The tax-to-base elasticities for PIT are reported in table 1. The long-run elasticity ranges from 0.1 percent in Portugal to almost 3 percent in Germany. The short-run, linear, elasticity is much lower than the long-run one, except for Austria, Denmark, Italy, Portugal, and Spain, and more imprecisely estimated, as shown by the large standard errors. Nonlinearity is statically significant for all countries, with a varying difference between the elasticity in booms and in recessions - it goes from more than 3.30 in Austria to 0.13 in Germany. The short-run linear elasticity always lies within the boom and the recession elasticities, except for Germany and Spain. It is unclear whether the short-run elasticity increases or not in recession - so it happens in 8 countries, while the opposite is true in the remaining 6 countries. The Markov-switching models, however, fit the data at varying degrees depending on the country - R^2 ranges from 0.04 for France to 0.61 for Austria. Koester and Priesmeier (2012) report a long-run elasticity for German PIT much smaller than our estimate (1.75 versus 2.99), while the opposite is true for short-run linear elasticity (1.41 versus 0.93). Regarding the Netherlands, Wolswijk (2009) estimates a long-run PIT elasticity similar to ours (1.57 versus 1.32) value; his short-run estimate amounts to 1.89, while ours is 1.06. Wolswijk (2009) does not find any

¹⁰These results are available upon request.

¹¹We test for regime invariance through a likelihood ratio (LR) test with statistic

$$\lambda_{LR} = 2[\ln L(\tilde{\delta}) - \ln L(\tilde{\delta}_r)] \quad (13)$$

where $\tilde{\delta}$ is the unconstrained maximum likelihood estimator and $\tilde{\delta}_r$ is the constrained estimator obtained by maximizing the likelihood function under the null hypothesis H_0 of tax elasticity regime invariance. Under H_0 , λ_{LR} has an asymptotic χ^2 distribution with degrees of freedom equal to the number of restrictions.

¹²Notice that the two-steps estimation procedure reduces the test power for nonlinearity, whose results tend thus to be conservative.

evidence of asymmetry around the trend value, while in our model the nonlinear short-run elasticity shifts from 0.40 in booms to 1.29 in recessions. Our short-run results for the Netherlands are more in line with Bettendorf and van Limbergen (2013), who also obtain a value of 1.07, while their long-run PIT elasticity is 0.89.

As for the base-to-GDP elasticities reported in table 2, the long-run elasticity is generally larger than the short-run one for almost all countries, except Norway, Spain, and UK, although the only large difference is recorded for Norway. The variability of the long-run elasticity is smaller than that of the tax-to-base elasticity and, if we abstract from Norway for which we obtain almost zero, it goes from 0.81 for Sweden to 1.8 for Portugal. Nonlinearity is statistically significant for all countries with the difference between booms and recessions elasticities varying between 0.02 for the Netherlands to more than 1 for UK, excluding Norway for which such difference is implausibly large. The short-run linear elasticity lies within the nonlinear ones for all countries. For 10 countries out of 14, the PIT base-to-GDP short-run elasticity increases in booms with respect to recessions, giving a neater message than for the tax-to-base elasticity.

Combining the tax-to-base and base-to-GDP elasticities as discussed in subsection 2.1, we obtain the PIT tax-to-GDP elasticity measure shown in table 3. The short-run elasticity is larger in booms for 7 out of 14 countries, it is larger in recessions for 6 countries, while it remains the same across business cycle phases for Greece. Changes across regimes are due to revenues for 8 out of 14 countries: Austria, Denmark, Finland, France, Germany, Greece, Ireland, and the Netherlands, while it is mostly due to bases in the remaining 6 countries (Italy, Norway, Portugal, Spain, Sweden, and UK). We can compare long-run tax-to-GDP results with the elasticity of revenues with respect to the output gap used within the European Union framework for fiscal surveillance of member states (see, for example, Mourre et al., 2013, table A.1, p. 30). We find elasticities that are smaller than the EU ones for 7 out of 14 countries, while they are larger in 4 cases. Long-run PIT elasticities for Finland (0.84) and UK (1.20) are similar to the EU

elasticities (0.91 and 1.18).

Corporate income tax (CIT). Table 4 reports the corporate tax-to-base elasticity. Most long-run elasticities, δ^{TB} , are estimated to be around 1, except for France, Greece, Spain, and UK, for which the null hypothesis of this coefficient being 1 is strongly rejected. Short-run linear elasticities, β^{TB} , are generally smaller than the long-run ones and almost all have large standard errors. The estimate for France is exceptionally large (and much larger than the long-run one) and very precisely estimated. Most other coefficients, though, are lower than one. As for the PIT case, nonlinearity in short-run elasticities is strongly supported by the likelihood-ratio tests, and in most countries - Finland, France, Germany, Italy, Spain, Sweden, and UK - the difference between booms and recessions is economically relevant. Except for Germany, the short-run linear elasticity of all countries lies between the boom and recession ones. For 5 out of 10 countries the recession elasticity is larger than the boom one, while for 4 countries the opposite is true. Greece reports both elasticities at zero. Koester and Priesmeier (2012) estimate a long-run profit taxes elasticity in Germany around half what we find (0.77 versus 1.54), while their short-run elasticity is larger than ours (0.43 versus 0.15), though within our nonlinear range. Our short-run model for Germany, however, produces so large standard errors that the elasticity estimate results unreliable.

The estimates of the CIT base-to-GDP elasticities reported in table 5 are generally more precise than the tax-to-base ones, as shown by the small standard errors and by the R^2 values of the Markov-switching models. The long-run elasticities, δ^{TB} , are estimated to be equal or larger than 3 for 6 out of 11 countries, while they are larger than 2 for Austria and Finland. The elasticities of Greece and Spain are not statistically different from 1. The short-run linear elasticities are large as well, for all countries being larger than 2 (except Greece), and for 5 countries being larger than 3. Short-run nonlinearity is strongly supported by the likelihood ratio test and the difference between the two regimes' elasticities is relevant for almost all countries except Greece, Ireland, and Portugal. The

recession elasticities are larger than the boom ones in 9 out of 11 countries, while smaller for Austria. The difference is null for Greece, for which all short-run elasticities are not statistically different from zero.

Table 6 reports the overall tax-to-GDP elasticities. It shows elasticities during recessions larger than during booms in 5 out of 11 countries only, an ambiguity also revealed by the comparison of the long-run and short-run elasticities. Changes across regimes are mostly due to revenues for 4 out of 10 countries (Finland, France, Ireland, and Sweden) while they are mostly due to bases for 5 countries (Germany, Italy, Portugal, Spain, Sweden, and UK). In Greece the shift is almost null. In comparison to the estimates used within the EU fiscal surveillance framework (see Moure et al., 2013, table A.1, p. 30), our long-run tax-to-GDP elasticities are larger in 8 out of 10 countries, while they are smaller in the remaining 2 countries. The difference appears relevant in most cases, except in France and in Ireland.

Indirect tax (IND). The tax-to-base elasticities for indirect taxes are reported in table 7. Long-run elasticities range from the statistically null estimates of Belgium, France, and Germany, to the large values of Italy (2.75) and Sweden (6.36). For Austria, Greece, Spain, and weakly for Finland we could not reject the null hypothesis that the elasticity is equal to one. The short-run linear elasticity is estimated to be lower than the long-run one for 8 out of 14 countries, with larger standard errors. Nonlinearity is statistically significant for all countries, with large LR statistics and almost null p -values. The linear short-run elasticity always lies between the boom and recession ones, except for Greece, whose display highly estimates, however, renders such comparison not meaningful. The difference between booms and recessions short-run elasticities is almost always economically relevant, going from a minimum of 0.01 for Greece to 1.56 for Austria. As for the PIT case, Austria shows the largest difference between elasticities across regimes. The short-run elasticity is larger in recessions than in booms for all countries except Austria and Germany, with the largest increase from booms to recessions recorded for UK. The

Markov-switching models R^2 ranges from less than 0.10 for Italy and Sweden to more than 0.40 for Portugal and the Netherlands. Koester and Priesmeier (2012) estimate a long-run elasticity for German VAT with respect to base of 0.79, while our estimate is statistically null. By contrast, their short-run elasticity estimate of 0.90 is almost identical to our result (0.88).

For the Netherlands, Wolswijk (2009) estimates a VAT long-run elasticity of 0.90 along with two short-run values - 0.64 below the long-term level and 1.10 above the long-term level. Similarly, Bettendorf and van Limbergen (2013) estimate for the same country a long-run elasticity slightly less than one with respect to the consumption base, while the short-run value is larger but still close to one. These authors' VAT short-run elasticities range between 1.186 in good times and 0.709 in bad. Our results, instead, suggest a 1.38 long-run elasticity, while short-run elasticities are unreliably estimated. Nonlinearity is nevertheless strongly supported by the LR test.

The variability of IND base-to-GDP elasticities is lower than the tax-to-base ones (see table 8). Coefficients vary from 0.31 in Austria to 1.19 for UK. The short-run linear elasticity is lower than the long-run estimate for 12 out of 15 countries, and in between the short-run Markov-switching elasticities for all countries except Denmark. The base-to-GDP estimations are generally more precise than the tax-to-base ones, as shown by the lower standard errors. Short-run elasticities are generally nonlinear, as suggested by the large LR statistics, although the difference between booms and recessions appears lower than the tax-to-base case and in line with the PIT base-to-GDP results. The largest difference is around 0.42 for Germany. The boom elasticities are larger than the recession ones in 7 out of 15 countries. Notice, finally, that most base-to-GDP elasticities in the long-run and, especially so in the short-run, are smaller than one, showing evidence in favor of consumption smoothing. The 8 countries in which recession elasticities are smaller than boom ones, show evidence of a reducing consumption smoothing in bad times, potentially due to the consumers desire to stay afloat at a preferred consumption

level.

Tax-to-GDP elasticities are larger in booms than in recessions for 9 out of 14 countries, as shown in table 9, with the largest difference obtained for Italy, the Netherlands, and Sweden. Changes across regimes are mostly due to revenues for almost all available countries' estimates, with the exception of Germany. Our tax-to-GDP elasticities are lower than 1 - the value assumed within the EU budgetary surveillance framework (Mourre et al., 2013, table A1, p. 30) - in 8 out of 14 countries, and larger in the remaining 6 countries.

Social contributions (SC).¹³ Table 10 reports the elasticities of social contributions revenues with respect to their base. Long-run SC tax-to-base elasticities are remarkably stable across most countries, ranging from 0.80 (Finland) to 1.53 (Portugal and UK), where the majority of them display estimates close to 0.80. The exceptions are Belgium, Germany, and the Netherlands, whose values are around 0.45. The short-run linear elasticity is lower than the long-run one for 8 out of 13 countries. Nonlinearity is statistically significant, with large LR statistics and null p -values. The linear elasticity always lies between the boom and recession ones. The difference between the boom and the recession short-run elasticities is almost always economically relevant, going from a minimum of 0.01 in Portugal to almost 6 in the Netherlands. The short-run elasticity is larger in recessions than in booms for 8 out of 13 countries. The Markov-switching models R^2 ranges from less 0.17 for Germany to 0.63 for Finland

With regards to the SC base-to-GDP elasticities (see table 11) the long-run coefficients vary from 0.0 in Austria to 1.22 in Portugal. The short-run linear elasticity is lower than the long-run one for all countries except the Netherlands and Spain, and always in between the short-run Markov-switching elasticities for all countries, except Finland and Spain. The base-to-GDP estimations are generally more precise than the tax-to-base ones, as

¹³Notice that in models for Greece, Italy, and Spain, discretionary tax reforms dummy were not included because of multicollinearity due to value one occurring only once.

indicated by the lower standard errors. Short-run elasticities are generally nonlinear, as suggested by the large LR statistics. The difference between booms and recessions appears to be generally lower than the tax-to-base case. The largest difference is around 0.44 for the Netherlands. The boom elasticities are larger than the recession ones in 5 out of 13 countries.

Tax-to-GDP elasticities are larger in booms than in recessions for 8 out of 13 countries, as shown in table 12, with the largest difference obtained for Denmark, the Netherlands, and UK. Changes across regimes are mostly due to revenues for almost all countries, except for Ireland, Portugal, and UK. Our estimates of long-run tax-to-GDP elasticities are generally lower than those used by the EU Commission (Mourre et al., 2013, table A1, p. 30), the only exceptions being those of Ireland, Portugal, and UK.

Summary of short-run nonlinearity results. We summarize results on short-run tax elasticity nonlinearity - our main focus in this paper - in table 13. Results on nonlinearity may either be summarized across tax categories or countries. Across tax categories, we notice a clear tendency for short-run elasticities to increase in recessions with respect to booms. This happens to be for indirect taxes, social contribution, and, to a lesser extent, for corporate income tax, while for personal income tax the larger elasticities are evenly distributed between booms and recessions. Across countries, results are less clear cut but still show a tendency for larger elasticities in recessions to prevail. This is so for 7 out of 15 countries (Austria, Finland, France, Greece, the Netherlands, Sweden, and UK), while short-run elasticities tend to be larger in booms for 4 countries (Germany, Ireland, Norway, and Portugal). In the remaining 4 countries (Belgium, Denmark, Italy, and Spain) the number of larger elasticities in booms equals that of recessions. We need, however, to bear in mind that for some countries estimates could not be obtained for all tax categories (Austria, Belgium, Denmark, the Netherlands, Norway, and Sweden).

5 Policy implications and conclusion

In this paper we present estimates of long-run and short-run elasticities of tax revenues with respect to their bases and of bases with respect to GDP for the main tax categories - personal income taxes, corporate income taxes, indirect taxes, social contributions - for a large selection of European Union countries. We propose a method to estimate short-run elasticities that vary with the country's business cycle. This method consists of a Markov-switching model by which an economy's output switches between two (unobservable) states: a high mean state ("boom") and a low mean state ("recession"). Since agents (e.g. taxpayers) cannot observe the state of the economy, they will infer the probability of being in a particular state by looking at the output growth rate realizations, which therefore acts as a state signal. Through the observation of the realizations of output growth, agents infer the underlying state of the economy by formulating the posterior probability of being in each state of the economy. The short-run regression model is then estimated by maximum likelihood using the probabilities as weights for the regression in each state of the economy. As a second contribution, we propose a simple method to take account of discretionary tax measures when estimating tax elasticities. We construct a database of dummy variables that take value one when a tax reform is implemented, and zero otherwise, based on information collected and processed by the European Commission in the annual survey of taxation trends in the European Union. With regard to the main interest of this paper - the variability of short-run tax elasticities over the business cycle - our results across tax categories indicate a clear tendency for short-run elasticities to increase in recessions with respect to booms. This holds for indirect taxes, social contribution, and, to a lesser extent, for corporate income tax, while for personal income tax the larger elasticities are evenly distributed between booms and recessions. Results are confirmed across countries, with a tendency for larger elasticities in recessions to prevail. This is so for 7 out of 15 countries (Austria, Finland, France, Greece, the Netherlands, Sweden, and UK), while short-run

elasticities tend to be larger in booms for 4 countries (Germany, Ireland, Norway, and Portugal). In the remaining 4 countries (Belgium, Denmark, Italy, and Spain) the number of larger elasticities in booms equals the one in recessions. Our results have potentially important policy implications for the European Union fiscal surveillance. The current EU framework requires the estimation of a cyclically-adjusted budget balance, i.e. a budget balance based on discretionary fiscal policy measures, net of the influence of business cycle on revenues and expenditure. Computing the cyclically -adjusted budget balance relies on tax revenues elasticities with respect to the output gap and the current procedure uses long-run elasticity estimates. Our results show that tax elasticities themselves change over the business cycle, with a clear tendency to increase in recessions with respect to booms. In the same direction point results by Princen et al. (2013), whose estimation method, however, gives highly erratic elasticities. Our method, by contrast, result in only two short-run elasticities, one for boom and another for recession periods, which might therefore be easily incorporated in the cyclically-adjusted computation procedure. In more general terms, our results shed light on one important feature of the tax system. In countries and for tax categories where elasticities increase in recession, a better automatic stabilization role is exerted by the tax system since revenues tend to increase more than proportionately than output, net of discretionary fiscal policy interventions (Belinga et al., 2014).

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Table 1: Elasticity of PIT revenue with respect to its base

Country	LR elasticity	SR linear elasticity	SR MS elasticity		MS model R^2	Likelihood ratio test statistic [p-value]
	δ^{TB} (s.e.)	β^{TB} (s.e.)	Boom	Recession		
Austria	0.39** (0.23)	0.46 (0.41)	-0.03*** (0.28)	3.31* (1.68)	0.61	166 [0.00]
Belgium	-	-	-	-	-	-
Denmark	0.30*** (0.10)	0.67*** (0.15)	0.53*** (0.17)	0.80*** (0.23)	0.47	200 [0.00]
Finland	1.39*** (0.28)	0.48** (0.24)	0.40** (0.22)	0.92 (0.68)	0.47	174 [0.00]
France	2.03*** (0.52)	0.46 (0.56)	0.23 (0.47)	1.12 (0.88)	0.04	430 [0.00]
Germany	2.99*** (0.37)	0.93*** (0.22)	0.93*** (0.21)	0.80* (0.47)	0.41	223 [0.00]
Greece	0.54*** (0.18)	0.13*** (0.20)	-0.01*** (0.10)	0.40 (0.59)	0.21	128 [0.00]
Ireland	0.68*** (0.13)	0.30 (0.43)	0.53 (0.87)	0.24* (0.44)	0.29	111 [0.00]
Italy	0.31** (0.29)	0.40 (0.42)	0.45 (0.49)	0.27 (0.57)	0.19	176 [0.00]
Netherlands	1.32** (0.50)	1.06 (1.06)	0.40 (0.67)	1.29 (1.94)	0.17	72 [0.00]
Norway	1.19*** (0.32)	0.19*** (0.06)	0.09*** (0.07)	0.25*** (0.08)	0.37	151 [0.00]
Portugal	0.10*** (0.28)	0.50 (0.42)	1.02 (0.66)	0.27 (0.47)	0.39	160 [0.00]
Spain	0.76*** (0.21)	0.80 (0.58)	0.29 (0.59)	0.01 (0.89)	0.26	139 [0.00]
Sweden	1.39*** (0.29)	0.30** (0.35)	0.28** (0.29)	0.48 (1.13)	0.08	193 [0.00]
UK	1.05*** (0.08)	0.53*** (0.17)	0.77*** (0.19)	0.18** (0.31)	0.36	211 [0.00]

Notes: This table reports the long-run (LR), short-run linear (SR linear), and short-run Markov-switching (SR MS) elasticity of the PIT revenue with respect to its base, along with the Markov-switching model R^2 and the likelihood ratio (LR) test statistic described in Section 2.1. The standard errors of coefficients and the LR test p -value are also reported. The symbols *, **, and *** indicate rejection of the null hypothesis that the elasticity is zero at the 90%, 95%, and 99% confidence level, while the symbols *, **, and *** indicate rejection of the null hypothesis that the elasticity is one at the 90%, 95%, and 99% confidence level.

Table 2: Elasticity of PIT base with respect to GDP

Country	LR elasticity	SR linear elasticity	SR MS elasticity		MS model R^2	Likelihood ratio test statistic [p-value]
	δ^{TB} (s.e.)	β^{TB} (s.e.)	β^{TB} (s.e.)	β^{TB} (s.e.)		
			Boom	Recession		
Austria	1.37*** (0.12)	0.55** (0.20)	0.58*** (0.19)	0.46* (0.30)	0.24	235 [0.00]
Belgium	-	-	-	-	-	-
Denmark	0.86*** (0.08)	0.56*** (0.17)	0.73*** (0.22)	0.54** (0.24)	0.53	220 [0.00]
Finland	0.61*** (0.06)	0.32*** (0.12)	0.35** (0.15)	0.30*** (0.13)	0.48	211 [0.00]
France	0.94*** (0.06)	0.71*** (0.08)	0.59*** (0.06)	0.96*** (0.22)	0.44	696 [0.00]
Germany	1.02*** (0.23)	0.46*** (0.11)	0.49*** (0.13)	0.40*** (0.12)	0.32	234 [0.00]
Greece	1.11*** (0.10)	0.07*** (0.08)	0.12*** (0.10)	-0.03*** (0.08)	0.50	140 [0.00]
Ireland	1.51*** (0.06)	0.33*** (0.18)	0.39** (0.17)	0.18*** (0.25)	0.34	156 [0.00]
Italy	1.27*** (0.07)	0.91*** (0.16)	1.05*** (0.21)	0.84*** (0.24)	0.62	210 [0.00]
Netherlands	1.56*** (0.14)	1.00*** (0.22)	1.00*** (0.28)	0.98*** (0.26)	0.57	110 [0.00]
Norway	-0.26*** (0.29)	0.98 (0.85)	2.11*** (0.73)	-0.77 (1.57)	0.32	118 [0.00]
Portugal	1.78*** (0.32)	1.18*** (0.22)	1.93*** (0.56)	0.98*** (0.22)	0.48	200 [0.00]
Spain	1.35*** (0.05)	1.49*** (0.12)	1.13*** (0.11)	1.49*** (0.15)	0.83	231 [0.00]
Sweden	0.81*** (0.11)	0.54*** (0.10)	0.39*** (0.01)	0.70*** (0.13)	0.46	252 [0.00]
UK	1.14*** (0.06)	1.32*** (0.17)	0.88*** (0.15)	1.92*** (0.33)	0.70	232 [0.00]

Notes: This table reports the long-run (LR), short-run linear (SR linear), and short-run Markov-switching (SR MS) elasticity of the PIT base with respect to GDP, along with the Markov-switching model R^2 and the likelihood ratio (LR) test statistic described in Section 2.1. The standard errors of coefficients and the LR test p -value are also reported. The symbols *, **, and *** indicate rejection of the null hypothesis that the elasticity is zero at the 90%, 95%, and 99% confidence level, while the symbols *, **, and *** indicate rejection of the null hypothesis that the elasticity is one at the 90%, 95%, and 99% confidence level.

Table 3: Elasticity of PIT revenue with respect to GDP

Country	LR elasticity $\delta^{TB} \cdot \delta^{BY}$	SR linear elasticity $\beta^{TB} \cdot \beta^{BY}$	SR MS elasticity $\beta^{TB} \cdot \beta^{BY}$	
			Boom	Recession
Austria	0.54	0.25	-0.02	1.54
Belgium	-	-	-	-
Denmark	0.26	0.38	0.39	0.43
Finland	0.84	0.16	0.14	0.27
France	1.90	0.33	0.14	1.08
Germany	3.06	0.42	0.45	0.32
Greece	0.60	0.01	-0.00	-0.01
Ireland	1.03	0.10	0.21	0.04
Italy	0.40	0.36	0.47	0.23
Netherlands	2.05	1.06	0.40	1.26
Norway	-0.31	0.18	0.20	-0.19
Portugal	0.17	0.59	1.96	0.26
Spain	1.03	1.19	0.33	0.02
Sweden	1.13	0.16	0.11	0.34
UK	1.20	0.70	0.68	0.35

Notes: This table reports the product of the PIT tax-to-base and base-to-GDP elasticities combined in a single tax-to-GDP elasticity for the long-run (LR), short-run linear (SR), and short-run Markov-switching (SR MS).

Table 4: Elasticity of CIT revenue with respect to its base

Country	LR elasticity	SR linear elasticity	SR MS elasticity		MS model R^2	Likelihood ratio test statistic [p-value]
	δ^{TB} (s.e.)	β^{TB} (s.e.)	Boom	Recession		
Austria	-	-	-	-	-	-
Belgium	-	-	-	-	-	-
Denmark	-	-	-	-	-	-
Finland	1.18*** (0.25)	0.25 (0.45)	-0.08** (0.49)	1.05 (0.85)	0.52	82 [0.00]
France	0.46* (0.27)	3.73*** (0.60)	0.60 (0.47)	9.99*** (1.68)	0.67	208 [0.00]
Germany	1.54*** (0.42)	0.15 (0.73)	0.39 (0.82)	0.78 (1.04)	0.20	100 [0.00]
Greece	0.13* (0.07)	-0.00*** (0.10)	0.00*** (0.10)	0.00*** (0.20)	0.10	170 [0.00]
Ireland	0.86*** (0.21)	0.01*** (0.33)	0.16** (0.34)	-0.13*** (0.39)	0.17	88 [0.00]
Italy	1.26** (0.14)	-0.21** (0.51)	-0.67** (0.70)	0.12* (0.50)	0.34	114 [0.00]
Netherlands	-	-	-	-	-	-
Norway	-	-	-	-	-	-
Portugal	1.16*** (0.10)	0.21*** (0.16)	0.29 (0.51)	0.19*** (0.16)	0.23	134 [0.00]
Spain	3.21*** (0.61)	1.21 (2.25)	2.21 (2.87)	-0.06 (2.98)	0.35	28 [0.01]
Sweden	1.11*** (0.25)	-0.11*** (0.19)	0.08*** (0.17)	-1.50** (0.58)	0.50	117 [0.00]
UK	0.63*** (0.09)	0.43* (0.30)	0.19* (0.43)	0.61** (0.27)	0.39	128 [0.00]

Notes: This table reports the long-run (LR), short-run linear (SR linear), and short-run Markov-switching (SR MS) elasticity of the CIT revenue with respect to its base, along with the Markov-switching model R^2 and the likelihood ratio (LR) test statistic described in Section 2.1. The standard errors of coefficients and the LR test p -value are also reported. The symbols *, **, and *** indicate rejection of the null hypothesis that the elasticity is zero at the 90%, 95%, and 99% confidence level, while the symbols *, **, and *** indicate rejection of the null hypothesis that the elasticity is one at the 90%, 95%, and 99% confidence level.

Table 5: Elasticity of CIT base with respect to GDP

Country	LR elasticity	SR linear elasticity	SR MS elasticity		MS model R^2	Likelihood ratio test statistic [p-value]
	δ^{TB} (s.e.)	β^{TB} (s.e.)	Boom β^{TB} (s.e.)	Recession β^{TB} (s.e.)		
Austria	2.29*** (0.17)	3.52*** (0.49)	3.70*** (0.46)	3.44*** (0.53)	0.59	197 [0.00]
Belgium	-	-	-	-	-	-
Denmark	-	-	-	-	-	-
Finland	2.57*** (0.23)	3.12*** (0.46)	3.00*** (0.52)	3.34*** (0.60)	0.56	163 [0.00]
France	3.00*** (0.32)	2.55*** (0.32)	2.07*** (0.22)	4.30*** (1.24)	0.46	510 [0.00]
Germany	3.01*** (0.71)	2.19*** (0.33)	1.88*** (0.37)	2.38*** (0.34)	0.54	202 [0.00]
Greece	1.12*** (0.19)	-0.02*** (0.10)	-0.03*** (0.15)	-0.08*** (0.09)	0.23	150 [0.00]
Ireland	1.89*** (0.24)	2.00*** (0.34)	1.97*** (0.32)	2.08*** (0.50)	0.56	131 [0.00]
Italy	3.45*** (0.26)	2.90*** (0.35)	2.40*** (0.42)	3.73*** (0.68)	0.65	203 [0.00]
Netherlands	-	-	-	-	-	-
Norway	-	-	-	-	-	-
Portugal	3.44*** (1.18)	2.28** (1.00)	2.13 (1.48)	2.33** (1.14)	0.16	145 [0.00]
Spain	1.66*** (0.39)	3.02*** (0.86)	2.27*** (0.68)	5.32*** (1.22)	0.34	143 [0.00]
Sweden	3.80*** (0.49)	3.60*** (0.95)	3.37*** (0.78)	4.44*** (0.95)	0.40	148 [0.00]
UK	3.99*** (0.33)	3.61*** (0.48)	2.62*** (0.43)	3.73*** (0.86)	0.68	183 [0.00]

Notes: This table reports the long-run (LR), short-run linear (SR linear), and short-run Markov-switching (SR MS) elasticity of the CIT base with respect to GDP, along with the Markov-switching model R^2 and the likelihood ratio (LR) test statistic described in Section 2.1. The standard errors of coefficients and the LR test p -value are also reported. The symbols *, **, and *** indicate rejection of the null hypothesis that the elasticity is zero at the 90%, 95%, and 99% confidence level, while the symbols *, **, and *** indicate rejection of the null hypothesis that the elasticity is one at the 90%, 95%, and 99% confidence level.

Table 6: Elasticity of CIT revenue with respect to GDP

Country	LR elasticity $\delta^{TB} \cdot \delta^{BY}$	SR linear elasticity $\beta^{TB} \cdot \beta^{BY}$	SR MS elasticity $\beta^{TB} \cdot \beta^{BY}$	
			Boom	Recession
Austria	-	-	-	-
Belgium	-	-	-	-
Denmark	-	-	-	-
Finland	3.03	0.79	-0.23	3.51
France	1.39	9.53	1.24	43.00
Germany	4.63	0.32	0.73	1.85
Greece	0.14	0.00	0.00	0.00
Ireland	1.62	0.01	0.32	-0.27
Italy	4.36	-0.60	-1.61	0.43
Netherlands	-	-	-	-
Norway	-	-	-	-
Portugal	3.99	0.47	0.62	0.45
Spain	5.33	3.67	5.00	-0.31
Sweden	4.22	-0.39	0.27	-6.68
UK	2.50	1.56	0.50	2.26

Notes: This table reports the product of the CIT tax-to-base and base-to-GDP elasticities combined in a single tax-to-GDP elasticity for the long-run (LR), short-run linear (SR), and short-run Markov-switching (SR MS).

Table 7: Elasticity of IND revenue with respect to its base

Country	LR elasticity	SR linear elasticity	SR MS elasticity		MS model R^2	Likelihood ratio test statistic [p-value]
	δ^{TB} (s.e.)	β^{TB} (s.e.)	Boom β^{TB} (s.e.)	Recession β^{TB} (s.e.)		
Austria	0.96** (0.42)	1.47 (1.49)	1.56** (0.62)	0.00 (1.86)	0.33	319 [0.00]
Belgium	-0.13*** (0.29)	0.96** (0.43)	0.85*** (0.26)	1.37* (0.76)	0.29	258 [0.00]
Denmark	1.75*** (0.25)	0.78*** (0.16)	0.72*** (0.26)	0.80*** (0.19)	0.25	332 [0.00]
Finland	1.34*** (0.19)	0.81*** (0.24)	0.59*** (0.22)	1.60** (0.62)	0.29	311 [0.00]
France	0.31** (0.28)	0.40*** (0.22)	0.31*** (0.18)	0.82 (0.82)	0.15	372 [0.00]
Germany	-0.50*** (0.44)	0.88* (0.45)	0.89** (0.42)	0.57 (1.97)	0.18	281 [0.00]
Greece	0.97*** (0.08)	0.09*** (0.10)	0.04*** (0.07)	0.05*** (0.19)	0.16	157 [0.00]
Ireland	1.84*** (0.10)	1.07*** (0.23)	0.70** (0.34)	1.10*** (0.24)	0.38	183 [0.00]
Italy	2.75*** (0.33)	0.55 (0.47)	0.39 (0.44)	1.69 (1.77)	0.08	299 [0.00]
Netherlands	1.38*** (0.13)	0.06 (0.72)	-0.10* (0.64)	0.17 (2.15)	0.48	248 [0.00]
Norway	-	-	-	-	-	-
Portugal	1.43*** (0.21)	1.90*** (0.62)	1.63** (0.63)	2.38*** (0.85)	0.41	189 [0.00]
Spain	1.30*** (0.26)	2.18*** (0.78)	1.98*** (0.60)	3.29** (1.55)	0.33	127 [0.00]
Sweden	6.36*** (1.70)	0.55 (1.34)	0.46 (1.07)	1.27 (3.32)	0.06	184 [0.00]
UK	0.82*** (0.07)	0.70* (0.38)	0.20*** (0.27)	1.58 (1.21)	0.33	306 [0.00]

Notes: This table reports the long-run (LR), short-run linear (SR linear), and short-run Markov-switching (SR MS) elasticity of the Indirect tax revenue with respect to its base, along with the Markov-switching model R^2 and the likelihood ratio (LR) test statistic described in Section 2.1. The standard errors of coefficients and the LR test p -value are also reported. The symbols *, **, and *** indicate rejection of the null hypothesis that the elasticity is zero at the 90%, 95%, and 99% confidence level, while the symbols *, **, and *** indicate rejection of the null hypothesis that the elasticity is one at the 90%, 95%, and 99% confidence level.

Table 8: Elasticity of IND base with respect to GDP

Country	LR elasticity	SR linear elasticity	SR MS elasticity		MS model R^2	Likelihood ratio test statistic [p-value]
	δ^{TB} (s.e.)	β^{TB} (s.e.)	Boom	Recession		
Austria	0.31*** (0.04)	0.08*** (0.02)	0.11*** (0.02)	0.06*** (0.04)	0.24	508 [0.00]
Belgium	0.37*** (0.10)	0.59*** (0.08)	0.47*** (0.05)	0.69*** (0.13)	0.52	359 [0.00]
Denmark	0.32*** (0.16)	0.47*** (0.11)	0.58*** (0.12)	0.52*** (0.16)	0.27	336 [0.00]
Finland	0.50*** (0.07)	0.44*** (0.08)	0.46*** (0.08)	0.34*** (0.12)	0.39	397 [0.00]
France	0.69*** (0.08)	0.58*** (0.10)	0.70*** (0.08)	0.36*** (0.18)	0.39	447 [0.00]
Germany	0.50** (0.21)	0.29*** (0.10)	0.44*** (0.10)	0.02*** (0.15)	0.28	401 [0.00]
Greece	0.83*** (0.05)	-0.11*** (0.10)	-0.22*** (0.14)	-0.06*** (0.13)	0.32	148 [0.00]
Ireland	0.99*** (0.07)	0.31*** (0.11)	0.22*** (0.13)	0.34*** (0.14)	0.24	189 [0.00]
Italy	0.79*** (0.08)	0.50*** (0.09)	0.62*** (0.10)	0.31*** (0.13)	0.35	433 [0.00]
Netherlands	1.41*** (0.08)	0.52*** (0.11)	0.43*** (0.10)	0.58*** (0.15)	0.25	416 [0.00]
Norway	-0.04*** (0.15)	0.26*** (0.09)	0.20*** (0.11)	0.28*** (0.13)	0.08	563 [0.00]
Portugal	1.05*** (0.08)	0.85*** (0.09)	0.64*** (0.09)	0.94*** (0.14)	0.61	319 [0.00]
Spain	1.15*** (0.02)	1.04*** (0.14)	1.02*** (0.14)	0.86*** (0.21)	0.70	181 [0.00]
Sweden	0.56*** (0.05)	0.39*** (0.08)	0.41*** (0.07)	0.38*** (0.13)	0.32	380 [0.00]
UK	1.19*** (0.05)	0.72*** (0.09)	0.56*** (0.08)	0.74*** (0.14)	0.47	443 [0.00]

Notes: This table reports the long-run (LR), short-run linear (SR linear), and short-run Markov-switching (SR MS) elasticity of the Indirect tax base with respect to GDP, along with the Markov-switching model R^2 and the likelihood ratio (LR) test statistic described in Section 2.1. The standard errors of coefficients and the LR test p -value are also reported. The symbols *, **, and *** indicate rejection of the null hypothesis that the elasticity is zero at the 90%, 95%, and 99% confidence level, while the symbols *, **, and *** indicate rejection of the null hypothesis that the elasticity is one at the 90%, 95%, and 99% confidence level.

Table 9: Elasticity of IND revenue with respect to GDP

Country	LR elasticity $\delta^{TB} \cdot \delta^{BY}$	SR linear elasticity $\beta^{TB} \cdot \beta^{BY}$	SR MS elasticity $\beta^{TB} \cdot \beta^{BY}$	
			Boom	Recession
Austria	0.30	0.12	0.16	0.00
Belgium	-0.05	0.56	0.40	0.94
Denmark	0.56	0.37	0.42	0.42
Finland	0.67	0.35	0.27	0.55
France	0.21	0.23	0.22	0.29
Germany	-0.25	0.25	0.39	0.01
Greece	0.80	-0.01	-0.01	-0.00
Ireland	1.83	0.33	0.16	0.38
Italy	2.17	0.27	0.24	0.52
Netherlands	1.94	0.03	-0.04	0.10
Norway	-	-	-	-
Portugal	1.51	1.61	1.04	2.23
Spain	1.50	2.28	2.01	2.84
Sweden	3.54	0.21	0.19	0.48
UK	0.98	0.50	0.11	1.18

Notes: This table reports the product of the Indirect tax-to-base and base-to-GDP elasticities combined in a single tax-to-GDP elasticity for the long-run (LR), short-run linear (SR), and short-run Markov-switching (SR MS).

Table 10: Elasticity of SC revenue with respect to its base

Country	LR elasticity	SR linear elasticity	SR MS elasticity		MS model R^2	Likelihood ratio test statistic [p-value]
	δ^{TB} (s.e.)	β^{TB} (s.e.)	β^{TB} (s.e.)	β^{TB} (s.e.)		
			Boom	Recession		
Austria	0.81*** (0.17)	0.59* (0.32)	0.51** (0.22)	0.91* (0.52)	0.37	226 [0.00]
Belgium	0.43** (0.20)	0.72*** (0.25)	0.83*** (0.20)	0.24* (0.44)	0.27	242 [0.00]
Denmark	-0.81*** (0.21)	1.45*** (0.47)	2.81*** (0.95)	1.15*** (0.49)	0.38	165 [0.00]
Finland	0.80*** (0.22)	0.81*** (0.12)	0.64*** (0.09)	1.10*** (0.18)	0.63	253 [0.00]
France	0.95*** (0.10)	0.41** (0.27)	0.11*** (0.20)	0.83** (0.39)	0.35	224 [0.00]
Germany	0.47*** (0.13)	0.36*** (0.16)	0.41** (0.16)	0.13*** (0.30)	0.17	245 [0.00]
Greece	0.82*** (0.20)	1.08** (0.39)	1.28*** (0.39)	0.81** (0.39)	0.49	121 [0.00]
Ireland	1.22*** (0.15)	0.91*** (0.31)	0.93* (0.50)	0.88*** (0.32)	0.39	149 [0.00]
Italy	0.88*** (0.19)	0.34*** (0.21)	0.24*** (0.20)	1.14* (0.67)	0.30	195 [0.00]
Netherlands	0.43 (0.70)	-1.88** (1.24)	-0.67 (1.10)	-7.66** (3.22)	0.40	143 [0.00]
Norway	-	-	-	-	-	-
Portugal	1.53*** (0.16)	0.65*** (0.14)	0.63** (0.30)	0.65*** (0.15)	0.44	213 [0.00]
Spain	0.82*** (0.11)	0.81*** (0.16)	0.63*** (0.13)	0.95*** (0.34)	0.57	169 [0.00]
Sweden	-	-	-	-	-	-
UK	1.53*** (0.16)	0.74** (0.27)	0.66** (0.28)	0.87** (0.33)	0.25	202 [0.00]

Notes: This table reports the long-run (LR), short-run linear (SR linear), and short-run Markov-switching (SR MS) elasticity of the Social contributions revenue with respect to its base, along with the Markov-switching model R^2 and the likelihood ratio (LR) test statistic described in Section 2.1. The standard errors of coefficients and the LR test p -value are also reported. The symbols *, **, and *** indicate rejection of the null hypothesis that the elasticity is zero at the 90%, 95%, and 99% confidence level, while the symbols *, **, and *** indicate rejection of the null hypothesis that the elasticity is one at the 90%, 95%, and 99% confidence level.

Table 11: Elasticity of SC base with respect to GDP

Country	LR elasticity	SR linear elasticity	SR MS elasticity		MS model R^2	Likelihood ratio test statistic [p-value]
	δ^{TB} (s.e.)	β^{TB} (s.e.)	Boom β^{TB} (s.e.)	Recession β^{TB} (s.e.)		
Austria	0.30*** (0.09)	0.27*** (0.06)	0.29*** (0.06)	0.20*** (0.12)	0.30	304 [0.00]
Belgium	0.30*** (0.09)	0.02*** (0.10)	-0.16*** (0.06)	0.20*** (0.29)	0.26	269 [0.00]
Denmark	0.70*** (0.13)	0.13*** (0.13)	0.18*** (0.14)	0.00*** (0.18)	0.31	235 [0.00]
Finland	0.56*** (0.07)	0.49*** (0.07)	0.48*** (0.07)	0.41*** (0.10)	0.62	267 [0.00]
France	0.72*** (0.09)	0.53*** (0.06)	0.48*** (0.06)	0.58*** (0.07)	0.64	312 [0.00]
Germany	0.42 (0.40)	0.40*** (0.08)	0.44*** (0.08)	0.35*** (0.07)	0.38	270 [0.00]
Greece	0.88*** (0.14)	0.03*** (0.05)	-0.02*** (0.04)	0.06*** (0.11)	0.28	144 [0.00]
Ireland	1.14*** (0.08)	0.07*** (0.16)	0.09*** (0.15)	-0.03*** (0.21)	0.24	188 [0.00]
Italy	0.88*** (0.09)	0.40*** (0.15)	0.36*** (0.22)	0.42*** (0.14)	0.29	210 [0.00]
Netherlands	0.47*** (0.09)	0.47*** (0.12)	0.72*** (0.13)	0.28*** (0.15)	0.41	262 [0.00]
Norway	-	-	-	-	-	-
Portugal	1.22*** (0.18)	0.57*** (0.20)	0.80** (0.32)	0.48** (0.22)	0.34	228 [0.00]
Spain	0.65*** (0.06)	0.81*** (0.13)	0.79*** (0.13)	0.70*** (0.18)	0.55	189 [0.00]
Sweden	-	-	-	-	-	-
UK	0.82*** (0.06)	0.60*** (0.15)	0.42*** (0.15)	0.82*** (0.22)	0.48	248 [0.00]

Notes: This table reports the long-run (LR), short-run linear (SR linear), and short-run Markov-switching (SR MS) elasticity of the Social contributions base with respect to GDP, along with the Markov-switching model R^2 and the likelihood ratio (LR) test statistic described in Section 2.1. The standard errors of coefficients and the LR test p -value are also reported. The symbols *, **, and *** indicate rejection of the null hypothesis that the elasticity is zero at the 90%, 95%, and 99% confidence level, while the symbols *, **, and *** indicate rejection of the null hypothesis that the elasticity is one at the 90%, 95%, and 99% confidence level.

Table 12: Elasticity of SC revenue with respect to GDP

Country	LR elasticity $\delta^{TB} \cdot \delta^{BY}$	SR linear elasticity $\beta^{TB} \cdot \beta^{BY}$	SR MS elasticity $\beta^{TB} \cdot \beta^{BY}$	
			Boom	Recession
Austria	0.24	0.16	0.15	0.18
Belgium	0.13	0.01	-0.13	0.05
Denmark	-0.57	0.18	0.50	0.00
Finland	0.45	0.40	0.31	0.45
France	0.68	0.22	0.05	0.48
Germany	0.20	0.14	0.18	0.05
Greece	0.73	0.03	-0.02	0.05
Ireland	1.39	0.06	0.09	-0.03
Italy	0.77	0.14	0.09	0.48
Netherlands	0.20	-0.89	-0.48	-2.18
Norway	-	-	-	-
Portugal	1.86	0.37	0.50	0.31
Spain	0.53	0.66	0.50	0.67
Sweden	-	-	-	-
UK	1.26	0.44	0.28	0.71

Notes: This table reports the product of the Social contributions tax-to-base and base-to-GDP elasticities combined in a single tax-to-GDP elasticity for the long-run (LR), short-run linear (SR), and short-run Markov-switching (SR MS).

Table 13: Summary of short-run Markov-switching results

Country	Larger in boom				Larger in recession			
	PIT	CIT	Ind	SC	PIT	CIT	Ind	SC
Austria		-	✓		✓	-		✓
Belgium	-	-		✓	-	-	✓	
Denmark		-	=	✓	✓	-	=	
Finland					✓	✓	✓	✓
France					✓	✓	✓	✓
Germany	✓		✓	✓		✓		
Greece		=	✓		✓	=		✓
Ireland	✓	✓		✓			✓	
Italy	✓	✓					✓	✓
Netherlands		-			✓	-	✓	✓
Norway	✓	-	-	-		-	-	-
Portugal	✓	✓		✓			✓	
Spain	✓	✓					✓	✓
Sweden				-	✓	✓	✓	-
UK	✓					✓	✓	✓

Notes: This table reports a summary of short-run tax-to-GDP results. For each country and each tax category, the symbol "✓" indicates whether short-run tax elasticity is larger in boom or recession. The symbol "=" indicates that elasticity does not change across business cycle regimes, while the symbol "-" indicates that overall tax-to-GDP estimates could not be obtained.

Table 14: Data sample coverage for regression models

Country	PIT	CIT	Indirect	SC
Austria	99q1-13q1 (57)	99q1-13q1 (57)	91q1-13q1 (89)	99q1-13q1 (57)
Belgium	-	-	95q2-13q1 (72)	99q1-13q1 (57)
Denmark	99q1-13q1 (57)	99q1-13q1 (57)	91q2-13q1 (88)	99q1-13q1 (57)
Finland	99q1-13q1 (57)	99q1-13q1 (57)	91q1-13q1 (89)	99q1-13q1 (57)
France	80q1-13q1 (133)	80q1-13q1 (133)	91q1-12q4 (88)	99q1-13q1 (57)
Germany	99q1-12q4 (56)	99q1-12q4 (56)	91q2-12q4 (87)	99q1-13q1 (57)
Greece	00q1-13q1 (53)	00q1-13q1 (53)	00q1-13q1 (53)	00q1-11q1 (45)
Ireland	02q1-13q1 (45)	02q1-13q1 (45)	00q2-13q1 (52)	00q2-13q1 (52)
Italy	99q1-13q1 (57)	99q1-13q1 (57)	91q1-13q1 (89)	99q1-12q4 (56)
Netherlands	05q1-13q1 (33)	05q1-13q1 (33)	91q1-13q1 (89)	99q1-13q1 (57)
Norway	02q1-13q1 (45)	-	80q1-13q1 (133)	-
Portugal	99q1-13q1 (57)	99q1-13q1 (57)	96q1-13q1 (69)	99q1-13q1 (57)
Spain	01q2-13q1 (48)	01q2-12q4 (47)	01q2-13q1 (48)	01q2-11q2 (41)
Sweden	99q1-13q1 (57)	99q1-13q1 (57)	93q2-13q1 (80)	-
UK	99q1-13q1 (57)	99q1-13q1 (57)	90q1-13q1 (93)	99q1-13q1 (57)

Notes: This table reports the maximum data sample range for each country and each tax category. The number of observations is in brackets.

Appendix A

Data sources and manipulation

Personal income tax (PIT) revenue: The PIT revenue data consist of the general government receipts from current taxes on income, wealth, etc. levied on households and non-profit institutions serving households sector. We express revenues in real terms using the GDP deflator, national base/reference year, seasonal adjusted. Both revenue and GDP deflator data are from the OECD database. PIT revenue data for Belgium are unavailable, while those for Greece are used in nominal terms due to the national deflator unavailability.

Personal income tax base: The PIT base is obtained as the sum of gross operating surplus and mixed income, compensation of employees, property income and gross entrepreneurial income of the households and non-profit institutions serving households sector. We use the GDP deflator to obtain deflated data. Data are taken from the OECD database. As for revenue, the PIT base data for Belgium are unavailable, while those for Greece are in nominal terms.

Corporate income tax (CIT) revenue: The CIT revenue data consist of the general government receipts from current taxes on income, wealth, etc. levied on corporations (both non-financial and financial), deflated using the GDP deflator. Both series are from the OECD database.

Corporate income tax base: the CIT base is given by the sum of the gross operating surplus and mixed income, property income, and gross entrepreneurial income, deflated using the GDP deflator. Both series are from the OECD database.

Indirect tax (IND) revenue: General government indirect tax receipts, from the ECB database. Seasonal adjustment is obtained using TRAMO/SEATS. We obtain deflated revenue data using the private final consumption expenditure deflator in the na-

tional base/reference year, seasonal adjusted, taken from the OECD database. Indirect taxes of Belgium and Greece are in nominal terms due to the national deflator unavailability. Norway's data on indirect tax revenues are unavailable.

Indirect tax base: Chained volume estimates of private final consumption expenditure, in millions of national currency, national reference year, seasonal adjusted, taken from the OECD database. Exceptions are Belgium, for which chained volumes data are unavailable and we must resort to current prices data, and Greece, for which we use current prices data to match nominal data on revenue. Data for Greece, moreover, are not seasonal adjusted at source, so that we use TRAMO/SEATS to adjust them.

Social contributions (SC): General government social contributions, from the ECB database. Seasonal adjustment is obtained using TRAMO/SEATS. The series are expressed in real terms using the GDP deflator. Social contributions of Greece are in nominal terms due to the national deflator unavailability. Norway's data on social contributions are unavailable.

Social contributions base: Gross wages and salaries, seasonal adjusted and adjusted by working days, at current prices in millions of national currency from the OECD database. Data are expressed in real terms using the GDP deflator, except for Greece due to the national deflator unavailability. Norway's and Sweden's data on gross wages and salaries are unavailable.

GDP level: Chained volume estimates of gross domestic product in millions of national currency, national reference year, seasonal adjusted at source, OECD database. Exceptions are data for Greece, seasonal unadjusted at source.

GDP growth rate: Real GDP growth rate compared to previous quarter, seasonal adjusted, from the OECD database. For Greece, we computed the GDP growth rate from the chained volume estimate level seasonal adjusted using TRAMO/SEATS.

Tax policy changes dummies For each country and each tax category we codified a quarterly dummy variable that takes value 1 in quarters when a tax policy change took

effect and zero otherwise. To overcome concerns about the comparability of tax reforms classification methods, we relied on information collected and processed by the European Commission in the annual survey of taxation trends in the European Union.¹⁴ Being the survey conducted by the European Union country policy analysts, we can be sufficiently confident that uniform criteria and methodology for reforms classification and dating are followed. One further advantage of this source is that we avoided getting stacked in minor changing details of national tax systems because the European Commission only reports major reforms. As for time alignment, we entered the value 1 only in quarters for which the European Commission's report clearly indicates the month when the reform was implemented and took effect. When the reform was adopted within the annual budget law, the dummy takes value 1 in the first quarter of the year following the budget approval. If only the year is reported, we entered a value of 1 for each and every quarter of that year.

¹⁴See all report issues available at http://ec.europa.eu/taxation_customs/taxation/gen_info/economic_analysis/tax_structures/article_5171_en.htm

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