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Abstract

This study estimates the effects of revenue-neutral tax structure changes on the long-run level of income per capita using panel data for 17 OECD countries over the period 1970-2004. In contrast to previous studies, we do not find a robust ranking of different types of taxes in terms of their "growth effects". In particular, we do not obtain compelling evidence favouring consumption taxes over income taxes, or favouring personal income taxes over corporate income taxes. The only robust result appears to be that shifts in tax revenue towards property taxes are associated with a higher level of income per capita in the long run.

Key Words: Tax structure, growth

JEL Classification: H2, O4.

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1 Introduction

There has been a large body of literature on the optimal structure of taxation from the perspectives of efficiency and income distribution, but there is only a small number of empirical studies on the link between tax structure and economic growth. This study investigates whether there is any revenue-neutral tax structure adjustment that could be associated with a higher level of income per capita in the long run.

This is a subject where interest is particularly relevant at the present time, as the recent global economic recession makes it appealing to reform a country's tax structure to be "growth-promoting" while maintaining fiscal stability. Some countries have recently implemented changes to their tax structures, in the direction of raising less revenue from income taxes and more revenue from consumption taxes.[1] The motivation for such "growth-promoting" tax structure reforms can be summarised by the following statement:

> "No one likes paying taxes and, with tax rates already significant in most OECD countries, further rises in rates could be highly distortive and damaging to incentives. How then should additional tax revenues be raised? In a world of growing international integration, often described as 'globalisation', raising taxes on incomes (whether from earnings or capital) could be particularly harmful to employment, investment, entrepreneurship and growth....In addition the burden of taxation could be switched more toward taxes on consumption (taxed on a destination basis) and recurrent taxes on residential property."–OECD's Current Tax Agenda (June 2010, page 16).

The above statement is closely related to the premise that taxes on income are more distortionary than taxes on consumption. The choice between the two types of taxes is one of the oldest issues in taxation policy and has led to much scholarly discussion.[2] Nonetheless, the superiority of a consumption tax over an income tax remains debatable both theoretically and empirically.

Despite growing interest in the growth effects of revenue-neutral tax structure reforms, there is only a small number of empirical studies on this topic. Early studies (Kneller et al., 1999; and Widmalm, 2001) use traditional econometric tools, such as pooled Ordinary Least Squares (OLS) and fixed-effects within-groups regressions, to estimate the effects of tax structure measures on income per capita in the long run. Implicitly, these econometric specifications restrict the slope coefficients

[1] A recent example is the Czech Republic which implemented in 2008 a major overhaul of the personal income tax, replacing the previous progressive rate schedule with a single 15% rate levied on an enlarged base. This was accompanied by significant changes to the corporate income tax and an increase in the concessionary rate of value added tax applied to many goods and services. There are similar discussions of tax structure reform in Japan and Korea. There has also been prolonged discussion on shifting the tax base from income to consumption in the United Kingdom (the *Meade Committee Report*, 1978) and the United States (*Blueprints for Basic Tax Reform*, 1977; and Gordon et al., 2004).

[2] For example, Henderson (1948), Little (1951), and Corlett and Hague (1953) on the effects of different taxes on the supply of effort; Atkinson and Stiglitz (1976), Chamley (1986), Judd (1985), and many others on the design of optimal tax structure from the perspectives of efficiency and distribution as surveyed in Auerbach (2006); Bankman and Griffith (1991), and Cunningham (1996) on the effects of different taxes on saving.

in the growth equation to be common across countries. If this restriction is invalid, the resulting estimates may be biased and the inference may be invalid.

To address this issue, Arnold et al. (2011) apply the Pooled Mean Group (PMG) estimator, first developed by Pesaran, Smith and Shin (1999), to examine the link between tax structure and growth. Their PMG estimations specify the model in a less restrictive way by relaxing the homogeneity restriction on some of the slope coefficients in the growth equation. Arnold et al. (2011) show that given the level of tax revenue as a share of GDP, raising more tax revenue from taxes on income is associated with lower income per capita in the long run. Moreover, the authors suggest a "tax and growth ranking" in terms of effects on income per capita, with recurrent taxes on immovable property at the top of this ranking, followed by consumption and other property taxes, personal income taxes, and finally corporate income taxes. These findings lend empirical support to the policy recommendations as described in the OECD's Current Tax Agenda.

This study contributes to the literature on the link between tax structure and growth by analysing data for a panel of 17 OECD countries over the period 1970-2004. In particular, we investigate the robustness of the "tax and growth ranking" suggested in Arnold et al.(2011). We find that the results are sensitive to different model specifications. In particular, we find that the PMG estimation results are not robust under less restrictive parametric assumptions. This leads us to rigorously test the validity of the parametric restrictions imposed by the PMG estimator. We show that the Hausman test (Hausman, 1978), which is often used to guide the choice of whether to impose the homogeneity restriction on certain coefficients, may have very low power in this context. Moreover we show that some of the restrictions imposed by the PMG estimator are rejected by an alternative Wald test.

The rest of the paper is structured as follows. Section 2 provides a brief review of theories and existing empirical studies. Section 3 describes the data set. Section 4 reports the benchmark PMG estimation results. In Section 5, we check the robustness of the benchmark results by using a different sample (Section 5.1), a different measure of the share of investment in GDP (Section 5.1), and different specifications of time effects (Section 5.2). In Section 6.1, we compare the PMG estimation results with results obtained using both more restrictive pooled OLS and fixed-effects within-groups estimators, and with those obtained using the less restrictive Mean Groups estimator (Pesaran and Smith, 1995). The Hausman test results are also reported. In Section 6.2, we apply a Wald test to examine the validity of the parametric restrictions imposed in the PMG estimations. In Section 6.3, we report the estimation results that are obtained by imposing common long-run coefficients only on certain variables and within certain groups of countries that are not rejected by the Wald test. Section 7 concludes.

2 Literature Review

2.1 Related theories

In the framework of the neoclassical growth model, if different taxes affect the equilibrium capital-labour ratio differently, the choice of tax structure would affect the steady-state level of income per capita. Tax structure also matters for short-run growth when the economy approaches its equilibrium. Although growth solely depends on exogenous technical progress once the economy reaches its steady state, the transition process can be as long as many decades. Therefore, even the short-run growth effects of tax structure, if any, cannot be ignored.

Nonetheless, the debate on whether different types of taxes affect factor supplies differently has not yet reached a conclusion. For example, concerning the effects of different taxes on the supply of effort, Henderson (1948) argues that a tax on consumption has the same effect as an income tax. He points out that if people work to obtain goods, their incentives to work are affected in the same way, whether the resources available to them are reduced by an income tax or a consumption tax. Any advantage of consumption taxes in their effect on incentives is due simply to the fact that a change towards consumption taxes is usually accompanied by a reduction in the degree of progressivity in the tax system.

Corlett and Hague (1953) suggest an interesting case in which a reduction in the income tax rate is compensated by a small *ad valorem* non-uniform indirect tax in a two goods economy. This combination makes sure the same tax revenue is raised from the consumer. Their central conclusion is that in general, the consumer will work harder when the higher rate of tax is levied on the good which is more complementary with leisure, and *vice versa*. Therefore, a shift from taxes on income to taxes on consumption, raising the same revenue from an individual, can either increase or reduce the supply of effort and real income.

On the other hand, proponents of consumption taxes often argue that income taxes distort investment. For example, the neoclassical investment theory pioneered by Jorgenson (1963) and Hall and Jorgenson (1967) suggests that a corporate income tax system which implies higher cost of capital would lower investment, resulting in a lower capital-labour ratio in the long run. On the contrary, lowering the tax-adjusted user cost of capital, perhaps by providing more generous investment tax credits, allowing for faster depreciation of assets, or simply reducing the statutory corporate income tax rate, can induce additional investment.

Another argument against an income tax is that it may reduce the return to saving, which is thought to be inefficient because it changes the relative prices of current and future consumption, and unfair because it discriminates between individuals with different preferences for saving. Nevertheless, the effects of income taxes on saving behaviour remains an ongoing debate and no conclusion has been reached yet.[3]

[3] Bankman and Griffith (1991), and Cunningham (1996) provide more detailed discussion on this point. Bankman

Although the link between tax structure and long-run growth is not the focus of the current study, it is worth mentioning the related literature. One source of technical progress that leads to long-run growth in the neoclassical growth models is new ideas generated by entrepreneurial activities, as emphasised in Schumpeter (1942). Cullen and Gordon (2002) show that there are several possible routes through which taxes can affect the amount of entrepreneurial risk-taking. On the other hand, in the framework of endogenous growth models, any tax policy that distorts the incentives for factor accumulation can have a permanent impact on the growth rate. Barro and Sala-I-Martin (1992) provide a comprehensive survey on the role of fiscal policy in endogenous growth models. Regarding the long-run growth effects of tax structure, Rebelo (1991) introduces a endogenous growth model which addresses the relative distortiveness of different taxes, whose conclusions lend some support to the premise that taxes on income are more distortionary than taxes on consumption.

As a summary, despite the long-standing theoretical debate on the choice between an income tax and a consumption tax, it is not clear whether different taxes would affect the level of income in the long run in different ways. As theories fail to provide clear-cut predictions, the link between tax structure and growth remains to be analysed empirically.

2.2 Early empirical studies

There is a large body of literature on the growth effects of fiscal policy, most of which focuses on macroeconomic variables such as total tax revenue as a share of GDP (Easterly and Rebelo, 1993; and Fölster and Henrekson, 2001) and total government spending as a share of GDP (Kormendi and Meguire, 1985; Grier and Tullock, 1987; and Barro, 1989, 1990, 1991). There is increasing interest in the link between tax structure and growth, but studies remain sparse. Early studies (Kneller, Bleaney and Gemmell, 1999; and Widmalm, 2001) estimate a regression function as in Equation (2.1):

$$\begin{aligned} Y_{it} &= \alpha + \beta_0' I_{it} + \beta_1' M_{it} + \beta_2' Z_{it} + \epsilon_{it} \\ i &= 1, 2, ...N, \text{ and } t = 1, 2, ...T \end{aligned} \tag{2.1}$$

where Y is the growth rate of real per capita GDP; I is a vector of important non-fiscal growth determinants suggested by theory, such as the investment-to-GDP ratio and the population growth rate; M is a vector of fiscal variables including indicators of tax structure; Z includes additional control variables such as the inflation growth rate; α is the intercept, β_0', β_1',and β_2' are vectors of coefficients, and ϵ_{it} is the error term for country i at time t. Importantly most studies include the initial level of real per capita income among the explanatory variables. In that case, if the dynamic model is stable, the long-run solution describes a steady state relationship between other explanatory variables and the level of real per capita income, rather than the growth rate.[4]

and Griffith (1991), for example, argue that the difference between an income tax and a consumption tax is only significant for riskless saving as savers could adjust their asset portifolios to offset the extra tax burden.

[4] Durlauf , Johnson and Temple (2005) provide a more detailed discussion on this point.

Both Kneller, Bleaney and Gemmell (1999) and Widmalm (2001) use five-year averages of the data to remove the effects of business cycles. Kneller, Bleaney and Gemmell (1999) argue that this allows them to separate the effects of policy variables on the transition from those on the steady state. Nevertheless, in their following study (Bleaney et al., 2001), they find that this period averaging does not appear to isolate long-run effects fully. Besides, it is generally found that the initial level of income per capita is negatively related to the current growth rate. Widmalm (2001) points out that this is an empirical regularity reflecting conditional convergence, which is consistent with both the neoclassical growth model and certain types of endogenous growth models (for example, Rebelo, 1991). Therefore, the estimated coefficients on other explanatory variables in these studies should not be interpreted as indicating long-run growth effects.

Using panel data from 22 OECD countries over the period 1970–1995, Kneller, Bleaney and Gemmell (1999) estimate the effects of different types of taxes based on Equation (2.1).[5] In their study, Y is the five-year average annual growth rate of real per capita GDP.[6] I includes the initial level of GDP per capita,[7] the investment-to-GDP ratio, and the growth rate of the labour force. M includes "distortionary" and "non-distortionary" taxes (as a ratio of total GDP), as well as other elements in the budget.[8] Their pooled OLS and fixed-effects estimation results suggest that a higher level of "distortionary" taxes (as a ratio of total GDP) reduces income per capita. Nevertheless, the benchmark results are not robust when the authors apply Instrumental Variables estimation to deal with the potential endogeneity of the tax variables.

Kneller, Bleaney and Gemmell (1999) emphasise that the estimated effects of different types of taxes may be biased if other elements in the budget, such as expenditures, are omitted. As suggested by Arnold et al. (2011), one possible solution is to focus on the growth effects of *revenue-neutral* changes in tax structure, which avoids the complication that changes in total tax revenue are reflected in changes in public spending.

Widmalm (2001) analyses the growth effects of revenue-neutral changes in tax structure based on data provided by the *OECD Tax Revenue Statistics,* which covers 23 OECD countries over the period 1965-1990. In Widmalm (2001), Y is the five-year average annual growth rate of real per capita GDP. I includes the initial level of per capita income, the investment-to-GDP ratio, and the population growth rate. Z includes variables such as the export-to-GDP ratio, the level and the variability of the inflation rate. M contains total tax revenue as a share of GDP, the share of a particular tax in total tax revenue, and a measure of progressivity.[9] Unlike Kneller, Bleaney and Gemmell (1999), different taxes are no longer grouped *a priori* into "distortionary" or "non-

[5] Their data is provided by Government Finance Statistics Yearbook, published by the IMF.

[6] The period between 1970 and 1995 is divided into five sub-periods and the authors calculate the average annual growth rate of real per capita GDP for each sub-period.

[7] Measured at the start of each five-year sub-period.

[8] The authors classify different types of taxes into "distortionary" and "non-distortionary" taxes. Distortionary taxes are defined as taxes on income and profit, payroll and manpower, property, and social security contributions. Non-distortionary taxes are defined as those imposed on domestic goods and services. Both are expressed as percentages of total GDP. Similarly, government expenditures are classified as "productive" and "non-productive" expenditures, and they are included in M. Other elements of the budget are also included so that the variables in M sum up to zero.

[9] Widmalm (2001) measures tax progressivity by estimating the elasticity of total tax revenue to GDP.

distortionary" taxes. Instead, taxes are grouped into five categories, namely, taxes on corporate income, taxes on labour and capital income for individuals, taxes on property, taxes on goods and services, and taxes on payrolls and social security contributions.[10]

Using the Extreme Bounds Analysis (Leamer, 1983), Widmalm (2001) finds that there is a robust negative correlation between the share of personal income taxes and the growth rate of GDP per capita.[11] As the investment-to-GDP ratio is included in the estimation, this result suggests that tax structure may affect growth through channels other than physical capital accumulation (for example, human capital accumulation or the supply of effort). Widmalm (2001) finds that taxes on corporate income as a share of total tax revenue have a positive but fragile correlation with income growth. The evidence is also fragile in relation to taxes on payrolls and social security contributions, taxes on property, and taxes on goods and services.

2.3 Recent empirical studies

When estimating a growth equation using traditional econometric tools such as the pooled OLS and fixed-effects estimations, it is implicitly assumed that all slope coefficients in the regression function are common across groups.[12] Countries may have similar long-run growth paths in equilibrium, but the short-run dynamics may vary. This observation could have important implications, particularly for models which explicitly distinguish between the short-run dynamics and the long-run growth path. If it is indeed invalid to impose the restriction of homogeneous coefficients on the short-run dynamics across countries, the results from the pooled OLS and fixed-effects estimations may be biased, and inference based on these specifications may be invalid.

A number of recent studies on the growth effects of tax structure (Gemmell et al., 2007; and Arnold et al., 2011[13]) apply the Pooled Mean Group (PMG) estimator, first developed by Pesaran, Smith and Shin (1999), which allows coefficients on the short-run dynamics to be heterogeneous across countries. Consider an Autoregressive-Distributed Lag (ADL) model shown below:

$$\begin{aligned} y_{it} &= \sum_{j=1}^{p} \lambda_{ij} y_{i,t-j} + \sum_{j=0}^{q} \delta'_{ij} X_{i,t-j} + \mu_i + \epsilon_{it} \\ i &= 1, 2, ...N, \text{ and } t = 1, 2, ...T \end{aligned} \tag{2.2}$$

where X_{it} $(k \times 1)$ is a vector of explanatory variables for each group i; λ_{ij} are scalars and δ'_{ij} are a vector of coefficients; μ_i represents the fixed effects and ϵ_{it} is the error term. Rearranging Equation

[10] All these tax variables are expressed as percentages of total tax revenue.

[11] The procedure of the Extreme Bounds Analysis is as follows. First, a base regression with a set of key variables (such as tax structure variables) is estimated. Then the model is re-estimated by including different additional explanatory variables in a systematic way. If the estimated coefficient of a tax structure variable remains significant over this procedure, the correlation is said to be "robust" (and "fragile", *vice versa*). OLS estimations are applied in the Extreme Bounds Analysis.

[12] i.e. all coefficients except the intercept, which is allowed to vary across countries in the fixed-effects (withing groups) estimator.

[13] Earlier versions of Arnold et al. (2011) include Arnold (2008) and Johansson et al. (2008).

(2.2), we obtain an Error Correction Model (ECM) as shown in Pesaran, Smith and Shin (1999):

$$\Delta y_{it} = \phi_i(y_{i,t-1} + \frac{\beta_i'}{\phi_i}X_{it}) + \sum_{j=1}^{p-1}\lambda_{ij}^*\Delta y_{i,t-j} + \sum_{j=0}^{q}\delta_{ij}^{*\prime}\Delta X_{i,t-j} + \mu_i + \epsilon_{it} \tag{2.3}$$

where $\phi_i = -(1-\sum_{j=1}^{p}\lambda_{ij})$, $\beta_i = \sum_{j=0}^{q}\delta_{ij}$, $\lambda_{ij}^* = -\sum_{m=j+1}^{p}\lambda_{im}$ $(j = 1, 2, ...p-1)$ and $\delta_{ij}^* = -\sum_{m=j+1}^{q}\delta_{im}$ $(j = 1, 2, ...q-1)$. One advantage of the ECM specified in Equation (2.3) is that it separates the long-run relationship between variables, as captured by the term $(y_{i,t-1} + \frac{\beta_i'}{\phi_i}X_{it})$, from the short-run adjustment or convergence dynamics. The parameter ϕ_i measures the speed of convergence towards the steady state relationship. Note that in Equation (2.3), all coefficients are i specific. The long-run homogeneity assumption restricts -$\frac{\beta_i'}{\phi_i}$ to be the same across groups. The restricted version of Equation (2.3) becomes:

$$\Delta y_{it} = \phi_i(y_{i,t-1} - \theta X_{it}) + \sum_{j=1}^{p-1}\lambda_{ij}^*\Delta y_{i,t-j} + \sum_{j=0}^{q}\delta_{ij}^{*\prime}\Delta X_{i,t-j} + \mu_i + \epsilon_{it} \tag{2.4}$$

where $\theta = \theta_i =$-$\frac{\beta_i'}{\phi_i}$. By estimating Equation (2.4) using the method of maximum likelihood, we obtain the PMG estimator.

Arnold et al. (2011) examine the effects of revenue-neutral changes in tax structure on the long-run level of income per capita, based on panel data for 21 OECD countries over the period 1970-2004 provided by the *OECD Tax Revenue Statistics*.[14] In Arnold et al. (2011), Δy_{it} is the annual growth rate of income per capita. The vector X_{it} includes the investment-to-GDP ratio, the growth rate of the working-age population, and the average years of schooling of the working-age population. To capture the effects of *revenue-neutral* changes in tax structure, total tax revenue as a share of GDP and shares of different types of taxes in total tax revenue are also included in X_{it}. Taxes are grouped into four major categories, namely, personal income taxes, corporate income taxes, consumption taxes and property taxes.[15]

The PMG estimation results in Arnold et al. (2011) are summarised in Table 1.1.[16] These results suggest that shifts in total tax revenue towards property taxes, in particular recurrent taxes on immovable property, are associated with a higher level of income per capita in the long run. The authors suggest that if there is a "tax and growth ranking" in terms of the effect of each type of tax on the long-run level of income per capita, property taxes would come top of this ranking (i.e. taxes on property tend to reduce income per capita the least), followed by consumption taxes, personal income taxes and corporate income taxes. Moreover, they find that this ranking remains robust in different model specifications with additional explanatory variables, such as the inflation rate.[17].

[14] The 21 countries are: Australia, Austria, Belgium, Canada, Denmark, France, Finland, Greece, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, the United States, and West Germany (until 1990).

[15] Different from Widmalm (2001), taxes on labour and capital income for individuals are grouped together with taxes on payrolls and social security contributions to be termed as personal income taxes.

[16] Columns 1 and 6 in Table 1.1 are Columns 3 and 4 in Table 6 in Arnold (2008). Columns 2-5 correspond to Columns 2-5 in Table 1 in Arnold et al. (2011).

[17] These results are reported in the working paper version of Arnold et al. (2011) (Table 4, Arnold 2008).

It is important to test the validity of the homogeneous long-run coefficients restriction as imposed in the PMG estimations. In practice, Hausman tests are often applied. The idea is to compare the PMG estimates with the Mean Group (MG) estimates of the long-run coefficients in the ECM. The MG estimates are obtained by estimating Equation (2.3) for each group separately and then averaging the group-specific parameter estimates (Pesaran and Smith, 1995). Under the null hypothesis that the long-run coefficients are homogeneous across countries, both the PMG and MG estimators are consistent while the PMG estimator is more efficient. Under the alternative hypothesis, only the MG estimator provides consistent estimates of the mean value of the heterogeneous long-run coefficients across groups; the PMG estimator does not. Rejection of the null hypothesis is then evidence against the validity of this homogeneity restriction.

It remains an empirical question whether the "tax and growth ranking" found in Arnold et al. (2011) is robust. Moreover, in Arnold et al. (2011), the important issue of testing the validity of the homogeneity restriction imposed on long-run coefficients is only partially addressed.[18] Furthermore, Pesaran, Smith and Shin (1999) point out that if the MG estimates are associated with large standard errors, the Hausman test is likely to have low power. A similar concern is raised in Gemmell et al. (2007).[19] This motivates us to rigorously test the validity of the homogeneity restriction imposed in the PMG estimations in this study.

2.4 Studies focusing on tax rates

It is worth noting that there are also empirical studies that compare the growth effects of different tax rates, such as Easterly and Rebelo (1993), Mendoza et al. (1997), and Lee and Gordon (2005). Although these studies do not analyse explicitly the link between revenue-neutral tax structure changes and growth outcomes, they still shed light on the current debate.

For example, Lee and Gordon (2005) estimate a growth equation which includes the top statutory corporate income tax rates, the top average personal income tax rates, average tariff rates, and the average consumption tax rates as explanatory variables. With a 70-country sample, the authors find significantly negative coefficients on statutory corporate tax rates, controlling for other determinants of economic growth as well as other tax variables.

[18] There is some discussion of the Hausman test results in the Appendix in Arnold et al. (2011). Arnold (2008) (Table 6) reports the results of the Hausman test in the basic regression model without tax variables. The null hypothesis that the long-run coefficients on the investment-to-GDP ratio, the growth rate of working population and the average years of schooling are common across groups is not rejected by the Hausman test at the 10 per cent level in this baseline specification.

[19] Gemmell et al. (2007) analyse the growth effects of tax revenue and government spending using a panel of 17 OECD countries from 1970 to 2004. We do not review this paper in detail because it is not specifically concerned with revenue-neutral tax structure changes, and it is also closely related to Kneller et al. (1999) and Bleaney et al. (2001).

2.5 Summary

In summary, growth theories predict that taxes can affect the long-run level of income per capita, for example, through channels of factor accumulation. Nevertheless, it is not clear whether different taxes would affect growth in different ways. On the other hand, empirical evidence on the relationship between tax structure and economic growth is somewhat sparse and inconclusive.

Methodologically, early empirical studies implicitly restrict all parameters except intercepts in the growth equation to be common across countries, which may be invalid if countries have different short-run dynamics as the economy approaches the steady state. Recent studies such as Arnold et al. (2011) relax this restriction by applying the PMG estimator. Nonetheless, a further step towards a better understanding of the link between tax structure and growth requires one to rigorously test the validity of the common long-run parameter restriction underlying the PMG estimations.

3 Data description

We combine data from different sources to obtain a cross-country panel dataset, which covers 17 countries over the period 1970-2004.[20] Details of data sources, variable definitions and descriptive statistics of key variables are provided in Appendix A.

Figure 1.1 illustrates the evolution of the unweighted average real GDP per capita, physical capital investment as a share of GDP, years of education and the growth rate of the working-age population over the sample period.[21] On average, there is a clear upward trend in real GDP per capita and a downward trend in the investment share. Average years of education of the working-age population experienced a steady increase from 9 years in 1970 to 12 years in 2004. There remains mild positive growth in the working-age population on average, but the magnitude remains small throughout the sample period.[22]

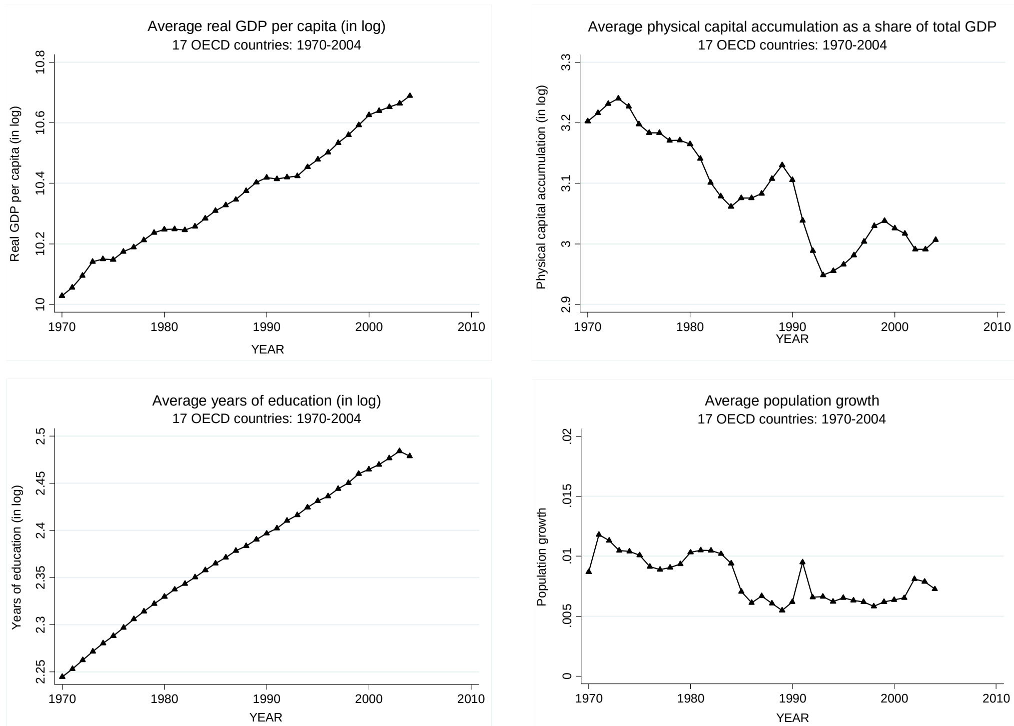
On average, tax revenue accounts for more than 30 per cent of total GDP in the sampled countries. The average total tax revenue as a share of GDP is highest in Sweden (around 47 per cent) and lowest in Japan (around 25 per cent). Tax structures are measured by the shares of major tax revenues in total tax revenue. Following Arnold et al. (2011), we distinguish between four main sources of tax revenue, namely, personal income taxes, corporate income taxes, consumption taxes

[20] The 17 OECD countries are Australia, Austria, Belgium, Canada, Denmark, France, Finland, Greece, Ireland, Japan, Netherlands, New Zealand, Norway, Sweden, Switzerland, the United Kingdom, and the United States. Compared with Arnold et al. (2011), there are four countries that are not included. These four countries are West Germany (until 1990), Italy, Spain and Portugal. The main reason for choosing a smaller panel of countries is that we include only countries with longer available time series, which is essential to conducting the Mean Group estimations and the PMG estimations allowing for cross-section dependence.

[21] We use "investment" as a shorthand for physical capital investment in the rest of the paper.

[22] The average growth rate of working-age population increased from 0.62 per cent in 1990 to 0.95 per cent in 1991 (mainly due to a large increase in the working-age population in New Zealand in 1991), and it dropped to 0.66 per cent in 1992. This pattern is reflected as a spike in the figure for average population growth rates.

Figure 3.1: Real GDP per capita, physical and human capital accumulation, and population growth over time



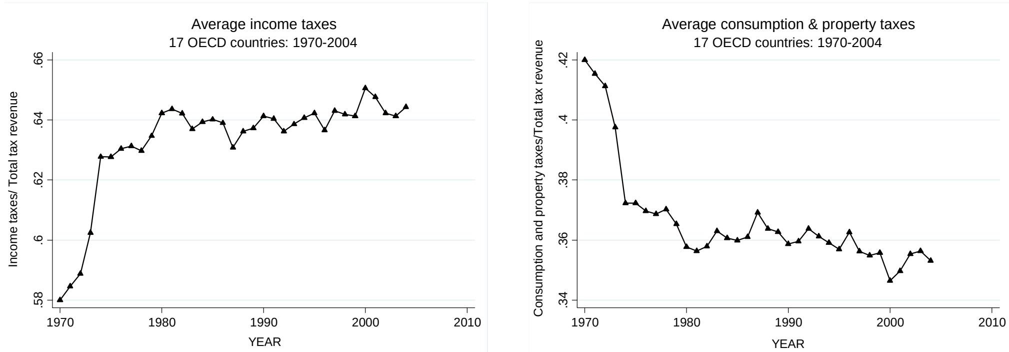
and property taxes. Details of the classification of different types of taxes are provided in Appendix A.

Figure 1.2 plots the unweighted average shares of income taxes (personal and corporate income taxes together) as well as those of consumption and property taxes in total tax revenue for the 17 countries over the period 1970-2004. It reveals that for a typical country, taxes on income account for around 58 to 65 per cent of total tax revenue between 1970 and 2004. In 2004, the share of income taxes in total tax mix exceeded 50 per cent in all 17 countries, with the lowest share in Ireland (around 54 per cent) and the highest share in Sweden (around 70 per cent). Appendix B illustrates the evolution of the composition of total tax revenue for individual countries. The dominance of income taxes over other types of taxes is observed in the majority of the 17 countries during the sample period.[23]

In Figure 1.2, we observe an initial increase in taxes on income from around 58 per cent of total tax revenue in 1970 to around 63 per cent in 1974. This is mirrored by an initial drop in the share of consumption and property taxes in total tax revenue. Figure 1.3 shows that the initial jump in the share of income taxes in total tax revenue is largely driven by the increase in personal income taxes. Appendix B shows that this pattern is observed in many countries such as Belgium, Finland,

[23] Greece and Ireland during the early 1970s were exceptions with consumption taxes accounting for a slightly larger share of total tax revenue than income taxes.

Figure 3.2: Income taxes vs. consumption and property taxes



Ireland, Japan, New Zealand and Switzerland.

Further disaggregating personal income taxes into taxes on individual income (including wages and salaries, profits and capital gains), social contributions and taxes on payrolls, we can see that following an initial jump in the early 1970s, taxes on individual income as a share of total tax revenue declined gradually over time after the early 1980s. This decline is partly offset by the growing share of social security contributions during the same period. We do not illustrate the evolution of payroll taxes that do not confer entitlement to social benefits, as their share in total tax revenue is only around 1 per cent throughout the sample period.

As shown in Figure 1.3, the average share of corporate income taxes in total tax revenue dropped slightly from early 1970s until early 1990s. This downward trend was reversed around the year 1993 when it began to increase until the year 2000. On average, corporate income taxes account for around 7 to 11 per cent of total tax revenue. Nevertheless, this average hides a considerable spread across countries as revealed in Appendix B. For example, corporate income taxes were the second most important source of tax revenue in Japan between the 1970s and the early 1990s. In the year 2004, corporate income taxes account for only 5 per cent of total tax revenue in Austria but they account for 23 per cent of total tax revenue in Norway. Apart from the spread in statutory rates of corporate income taxes, these differences can be partly explained by features including institutional factors, the degree to which firms in a country are incorporated, taxation of oil revenues and the erosion of the corporate income tax base.[24]

Figure 1.4 shows that the average share of consumption taxes (general consumption taxes plus specific consumption taxes) in total tax revenue fell from 34 to 29 per cent between 1970 and 2004, although consumption taxes remain as the second most important source for tax revenue in most countries.[25] On average, property taxes account for around 5-7 per cent of total tax revenue.[26] Nevertheless, the share of property taxes in total tax revenue is higher in some countries than in

[24] For example, as a consequence of tax avoidance, generous depreciation schemes or other instruments to postpone the taxation of earned profits (*OECD Tax Revenue Statistics* 2009).

[25] Again, Japan between the 1970s and the early 1990s is an exception.

[26] There is a spike in the graph for average property taxes as a share of total tax revenue in the year 1996 and this is largely driven by the increase in property taxes in Greece in that year.

Figure 3.3: Personal income and corporate income taxes

others, as revealed in Appendix B. For example, the average share of property taxes in total tax revenue over the period 1970-2004 exceeds 10 per cent in Canada, the United Kingdom and the United States. On the other hand, this figure is less than 3 per cent in Finland, Norway, and Sweden.

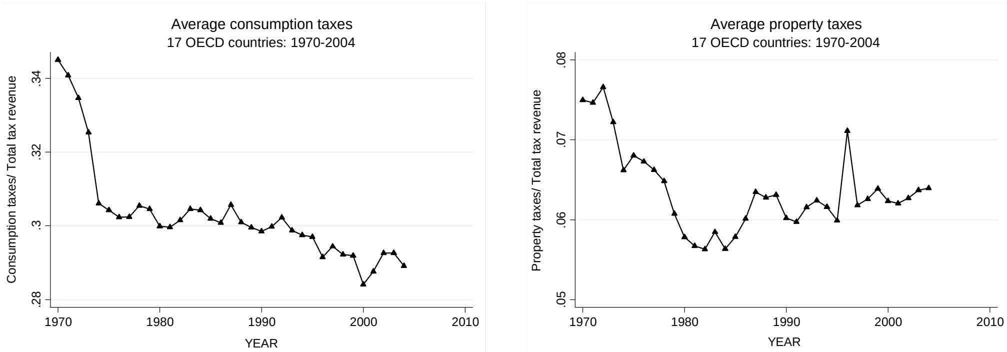
Appendix B shows that despite fluctuations in the absolute percentages of different types of taxes in total tax revenue, the relative importance of different types of taxes remains stable in most countries over the period 1970-2004, with personal income taxes as the most important source of tax revenue, followed by consumption taxes, corporate income taxes and property taxes. Furthermore, while the share of income taxes in total tax revenue becomes smaller towards the end of the sample period in some countries (for example, Netherlands and New Zealand), it increases in other countries (for example, Ireland).

4 Benchmark estimations

4.1 Model

The central question of the current study is, does there exist a revenue-neutral tax structure change that could shift the growth path upwards? To answer this question, we restrict ourselves to the

Figure 3.4: Consumption and property taxes



framework of the neoclassical growth model and focus on the long-run relationship between the *level* of output per worker and tax structure variables.[27] We consider a human capital-augmented Solow model with a standard Cobb-Douglas production function.[28] In period t, output Y is given by:

$$Y_t = K_t^{\alpha} H_t^{\beta} \left(A_t L_t\right)^{1-\alpha-\beta} \tag{4.1}$$

where K and H are physical and human capital, respectively. L is labour and A captures the level of technology. α and β are the partial elasticities of output with respect to physical and human capital. The paths of these variables are described by the following equations:

$$\begin{aligned} \dot{k} &= s^k y - (n+g+d)k \\ \dot{h} &= s^h y - (n+g+d)h \\ y &= k^{\alpha} h^{\beta} \\ \dot{A} &= gA \\ \dot{L} &= nL \end{aligned} \tag{4.2}$$

where $y = Y/AL$, $k = K/AL$ and $h = H/AL$ are quantities per effective unit of labour. s^k and s^h stand for the shares of physical and human capital investment in total output. n is the growth rate of labour, g is the rate of exogenous technological change and d is the depreciation rate of physical and human capital.

In equilibrium, $\dot{k} = 0$ and $\dot{h} = 0$. From Equation (4.2), it can be shown that:

$$\begin{aligned} k^* &= \frac{s^k y^*}{n+g+d} \\ h^* &= \frac{s^h y^*}{n+g+d} \end{aligned} \tag{4.3}$$

[27] It is not the aim of the current study to distinguish between the neoclassical and the endogenous growth models. Kocherlakota and Yi (1997) provide a good reference on how to empirically distinguish between the two models when the growth effects of taxes are concerned.

[28] The formulation of the model in this study is largely based on Arnold et al. (2007).

where k^*, h^* and y^* are the quantities in the steady state. By solving Equation (4.3), we obtain that:

$$\begin{aligned} k^* &= \left(\frac{s_k^{1-\beta} s_h^{\beta}}{n+g+d} \right)^{\frac{1}{1-\alpha-\beta}} \\ h^* &= \left(\frac{s_k^{\alpha} s_h^{1-\alpha}}{n+g+d} \right)^{\frac{1}{1-\alpha-\beta}} \end{aligned} \tag{4.4}$$

The steady state level of output per effective worker can be expressed as:

$$y^* = (k^*)^{\alpha}(h^*)^{\beta} = \left(\frac{s_k^{1-\beta} s_h^{\beta}}{n+g+d} \right)^{\frac{\alpha}{1-\alpha-\beta}} (h^*)^{\beta} \tag{4.5}$$

Taking the logarithms of the above equation, it is shown in Appendix 2 that the solution for $\ln y^*$ is:

$$\ln y^* = \frac{\alpha}{1-\alpha} \ln s_k + \frac{\beta}{1-\alpha} \ln h^* - \frac{\alpha}{1-\alpha} \ln(n+g+d) \tag{4.6}$$

Furthermore, the transitional dynamics can be expressed by the following equation (Romer, 1996):

$$\frac{d \ln y_t}{dt} = -\lambda \left(\ln y_t - \ln y^* \right) \tag{4.7}$$

where $\lambda = (1-\alpha-\beta)(g+n+d)$. Under the assumption that $\alpha + \beta < 1$, the transitional path of output can be written as:

$$\ln y_t - \ln y_{t-s} = -\varphi(\lambda) \left(\ln y_{t-s} - \ln y^* \right) \tag{4.8}$$

where s is an arbitrary lag and $\varphi(\lambda) = e^{-\lambda s} - 1$. Substituting Equation (4.6) into Equation (4.8), we obtain the following expression:

$$\begin{aligned} \ln y_t - \ln y_{t-s} &= -\varphi(\lambda) [\ln y_{t-s} - \frac{\alpha}{1-\alpha} \ln s_k - \frac{\beta}{1-\alpha} \ln h^* \\ &\quad + \frac{\alpha}{1-\alpha} \ln(n+g+d)] \end{aligned} \tag{4.9}$$

If we take $s = 1$, it can be further shown that

$$\begin{aligned} \ln \widetilde{y}_t - \ln \widetilde{y}_{t-1} &= -\varphi(\lambda) [\ln \widetilde{y}_{t-1} - \frac{\alpha}{1-\alpha} \ln s_k - \frac{\beta}{1-\alpha} \ln h^* \\ &\quad + \frac{\alpha}{1-\alpha} \ln(n+g+d)] + \widetilde{V}_t \end{aligned} \tag{4.10}$$

where $\widetilde{y} = \frac{Y}{L}$, and $\widetilde{V}_t = \varphi(\lambda) \ln A_0 + g [\varphi(\lambda) t - \varphi(\lambda) + 1]$.[29] The approximations of s_k, h^* and

[29] The calculation is shown in Appendix C.

$\ln(n+g+d)$ are explained in Appendix C.

Next, we add tax structure measures to the right-hand side of Equation (1.14). It is conventional to use the Error Correction Model (ECM) for PMG estimations. One advantage of the ECM is that it distinguishes between the long-run growth path and the short-run convergence dynamics. It is this feature that enables us to examine the link between the long-run level of income per capita and tax structure, and at the same time to impose different homogeneity restrictions on the long-run and short-run parameters. As in Arnold et al. (2011), we include first differences of all the explanatory variables to control for the short-run dynamics.[30] The benchmark regression model is then specified as in Equation (4.11):

$$\begin{aligned}\Delta \ln \widetilde{y}_{i,t} \quad = \quad & -\phi_i \left(\ln \widetilde{y}_{i,t-1} - \alpha_1 \ln s^k_{i,t} - \alpha_2 \ln h_{i,t} - \alpha_3 n_{i,t} - \sum_{j=4}^{m} \alpha_j TS_{i,t} \right) \\ & + \beta_{1,i} \Delta \ln s^k_{i,t} + \beta_{2,i} \Delta \ln h_{i,t} + \beta_{3,i} \Delta n_{i,t} + \sum_{j=4}^{m} \beta_{j,i} \Delta TS_{i,t} \\ & + \gamma'_i \times \textit{Time Effects} + \delta_i + \varepsilon_{i,t} \end{aligned} \tag{4.11}$$

where i is the subscript for each country. TS stands for a vector of indicators of tax structure, including total tax revenue (as a share of total GDP) and a combination of the tax share variables. γ_i is a vector of coefficients on the time effects. δ_i is the country-specific intercept and $\varepsilon_{i,t}$ is the error term which is assumed to follow a normal distribution. In our benchmark regressions, we follow Arnold et al. (2011) in using five-year period dummies to control for non-linear time effects.[31] In the benchmark PMG estimations, we restrict all the long-run coefficients (α_1, $\alpha_2 ... \alpha_m$) to be common across countries but allow the short-run coefficients ($\beta_{1,i}$,$\beta_{2,i}$...$\beta_{m,i}$), the coefficients on the time effects (γ_i) and the convergence rates (ϕ_i) to take different values for each country.

4.2 Benchmark results

Table 7.2 reports the benchmark PMG estimates of the long-run coefficients ($\widehat{\alpha}_1$, $\widehat{\alpha}_2 ... \widehat{\alpha}_m$) and the estimated average speed of convergence across countries ($\widehat{\phi} = \frac{1}{17} \sum_{i=1}^{17} \widehat{\phi}_i$), based on Equation (4.11).[32] Heteroskedasticity-robust standard errors are reported. Column 7 reports the basic results when no tax variable is included in the growth equation. Columns 8-12 report the results when different combinations of tax shares are included.

The unweighted average of country-specific convergence rates is in the range between -0.2 and -0.3 in different specifications. As expected, the estimated long-run coefficients on physical and human capital are both positive and significantly different from zero, while that on the growth rate

[30] This is the same model specification as in Arnold et al. (2011). We use it here for comparability. Admittedly, richer dynamic specifications could be considered with annual data.

[31] The construction of the five-year period dummy variables is explained in Appendix A.

[32] These PMG results are computed using the xtpmg command in Stata.

of the working-age population is negative and significant. The estimated coefficient on total tax revenue (as a share of GDP) is negative in all models but it is not always significant.

In Column 8, we distinguish between personal income taxes and corporate income taxes. We find that the share of personal income taxes and that of corporate income taxes in total tax revenue are both negatively associated with the long-run level of income per capita. A standard Wald test does not reject the null hypothesis that the estimated long-run coefficients on these two types of taxes are equal.[33]

Column 9 combines consumption and property taxes together and treats income taxes (personal income taxes and corporate income taxes together) as the omitted group. The significant positive coefficient on the combined consumption and property tax share suggests that at a given level of total tax revenue (as a share of GDP), raising more of this revenue from these two types of taxes is associated with a higher level of income per capita in the long run. In Column 10, we distinguish between consumption taxes and property taxes. The estimated coefficients on the two tax share variables are both positive and significant, however, this positive association with the long-run level of income per capita is estimated to be more prominent for property taxes.[34]

It is suggested by Arnold et al. (2011) that shifts in tax revenue towards recurrent taxes on immovable property are the most "growth-friendly". This is not supported by our results in Column 11, when we further disaggregate total property taxes into recurrent taxes on immovable property and "other property taxes".[35] The estimated long-run coefficient on "other property taxes" is not only larger in magnitude but also significantly larger than that on recurrent taxes on immovable property.[36]

In Column 12, we compare personal income taxes, corporate income taxes and consumption taxes with property taxes as the omitted category. The estimated long-run coefficients on these three taxes are all negative and significant, indicating that shifts in tax revenue from these taxes to property taxes are associated with higher levels of income per capita in the steady state. Moreover, the Wald test results suggest that there is no significant difference between personal income taxes and corporate income taxes, but both have a long-run coefficient that is significantly lower than that on consumption taxes.[37]

[33] The Wald test statistic for this restriction, which has a $\chi^2(1)$ distribution under the null hypothesis of equal coefficients, is 1.03. The marginal significance level (p-value) at which the null hypothesis would be rejected is 0.31.

[34] The Wald test rejects the null hypothesis that the estimated coefficient on consumption taxes equals that on property taxes at the 1 percent level, with $\chi^2(1)= 9.70$ and a p-value of 0.002.

[35] The taxes categorised as "other property taxes" include: recurrent taxes on net wealth, taxes on estates, inheritances and gifts, taxes on financial and capital transactions, non-recurrent taxes and other recurrent taxes on property (*OECD Tax Revenue Statistics* classification).

[36] The Wald test rejects the null hypothesis of equal long-run coefficients on recurrent taxes on immovable property and "other property taxes", with a p-value of 0.000.

[37] The null hypothesis that the estimated coefficients on personal income taxes, corporate income taxes and consumption taxes are all equal is rejected by the Wald test at the 1 percent level, with $\chi^2(2) = 31.52$ and a p-value of 0.00. The null hypothesis that the estimated coefficients on personal income taxes and corporate income taxes are equal is not rejected at the 10 percent, level with $\chi^2(1) = 2.41$ and a p-value of 0.121.

4.3 Comparison with Arnold et al. (2011)

Comparing Table 1.1 and 7.2, it can be seen that the estimated long-run coefficients on the investment share are reasonably close. Differences are more prominent in the estimated long-run coefficients on human capital and on population growth. In Arnold et al. (2011), total tax revenue (as a share of GDP) has a negative and significant estimated coefficient, which remains robust throughout various model specifications. In contrast, the corresponding estimate in Table 7.2 is not always significant and is sensitive to different specifications.

More importantly, both studies find that raising more government revenue from taxes on income is associated with a lower steady-state level of income per capita. However, Arnold et al. (2011) find that corporate income taxes are less "growth friendly" than personal income taxes, which is not supported by our benchmark PMG results. We also do not find that recurrent taxes on immovable property are the most "growth friendly".

It is necessary to clarify several differences between Arnold et al. (2011) and the current study. Firstly, we use a different sample of countries. Secondly, we use total gross fixed capital formation (as a share of GDP) to measure the investment share, while Arnold et al. (2011) use non-housing fixed capital formation (as a share of GDP). Thirdly, we may construct the five-year period dummies in a different way.

The importance of these differences will be explored in the next section. In Section 5.1, we use a larger sample of countries. We also use non-housing fixed capital formation (as a share of GDP) as an alternative measure of the investment share. Section 5.2 considers three alternative specifications of the time effects. Section 5.2.1 presents the estimation results when a different set of five-year period dummies are included in the specification. Section 5.2.2 considers a more restrictive specification with country-specific linear trends. Section 5.2.3 controls for cross-section dependence, using the estimator proposed by Pesaran (2006). These variations also serve as robustness checks of our benchmark results.

5 Robustness checks

5.1 Alternative sample and proxy for the investment share

First, we examine the robustness of the benchmark regression results by using panel data for 21 OECD countries as in Arnold et al. (2011).[38] Table 7.3 summarises the results from the PMG estimations.[39] Comparing with corresponding columns in Table 7.2, we observe a similar pattern. In particular, contrary to Arnold et al. (2011) but consistent with Table 7.2, we find that there is

[38] We add four countries (West Germany until 1990, Italy, Spain and Portugal) to the original set of 17 countries.

[39] We were not able to obtain a full set of results as in Table 7.2 because the likelihood function becomes non-concave in several cases. The Newton-Raphson algorithm is used for maximisation.

no significant difference between corporate income taxes and personal income taxes (Column 16).[40]

Second, we use non-housing fixed capital formation (as a share of GDP) as an alternative proxy for the investment share.[41] Table 7.4 shows that using this different measure does not greatly affect the estimated mean convergence rate, the estimated long-run coefficient on human capital or that on the population growth rate. Now, there is some evidence that corporate income taxes are less "growth friendly" than personal income taxes in Columns 18.[42] Nonetheless, there is no evidence that recurrent taxes on immovable property are the most "growth friendly" (Column 21).

These two exercises suggest that the general pattern in our benchmark results are not very sensitive to different samples or regressors. Moreover, the discrepancies between the results in Arnold et al. (2011) and the current study cannot be fully explained by these different choices of sample and variables.

5.2 Different specifications of the time effects

In this section, we consider alternative specifications of the time effects. First, we use an alternative set of five-year period dummies to control for non-linear time effects. Second, we apply a more restrictive specification by including only a linear trend for each country instead of five-year period dummies. Finally, following Pesaran (2006), we allow for cross-section dependence.

5.2.1 5.2.1 A different set of five-year period dummies

Table 7.5 presents the PMG estimation results when an alternative set of five-year period dummies is included to control for the time effects. Previously we have included a dummy variable for each of the periods 1970-75, 1976-80, 1981-85, ... , 2001-04. Now instead we include a dummy variable for each of the periods 1970-74, 1975-79, 1980-84, ... , 2000-04. We can see that the results in Table 7.2 are quite sensitive to how the five-year period dummies are constructed.

Columns 24 and 25 show that shifts from taxes on income to those on consumption and property do not appear to affect the long-run level of income per capita. Nevertheless, when we distinguish between consumption taxes and property taxes, we find the results in these first two columns may be largely driven by consumption taxes, which do not appear to have significantly different effects from

[40] In Column 16, we cannot estimate exactly the same model as in Column 12 because the likelihood function becomes non-concave in the PMG estimation. In Column 12, property taxes are treated as the omitted group while in Column 16, we treat personal income taxes as the omitted group. The estimated coefficient on corporate income taxes is insignificantly different from zero, indicating that imposing the same coefficient on personal income taxes and corporate income taxes would be a valid restriction.

[41] We do not use non-housing fixed capital formation in our benchmark specification because more observations would be lost. For example, this data is not available for Belgium in OECD National Accounts (Belgium is included in Arnold et al. 2011, suggesting that the authors may have had access to a different data source). The likelihood function also becomes non-concave for this smaller sample in many cases when we apply different specifications of the time effects.

[42] In Column 18, the Wald test of equal coefficients on personal income taxes and corporate income taxes yields a p-value of 0.005.

income taxes in this specification.[43] We continue to find that raising a higher share of tax revenue from property taxes is associated with a significantly higher level of income per capita (Column 26), and again this is largely driven by "other property taxes" (Column 27).

We observed previously that our PMG estimation results are somewhat closer to those in Arnold et al. (2011) when we measure the investment share using non-housing fixed capital formation (as a ratio of GDP). Nevertheless, the results based on this alternative proxy for investment are also sensitive to different ways of constructing the five-year period dummies, as shown in Table 7.6. In particular, there is now no evidence that the effects of personal income taxes and corporate income taxes are different from each other (Columns 30 and 34).[44] We also find no evidence that the effects of consumption taxes are significantly different from those of income taxes.[45] On the other hand, we continue to find that shifts of tax revenue towards property taxes, and particularly towards other property taxes, are associated with a higher level of income per capita.

5.2.2 5.2.2 Linear trends

In Figure 1.1, we observe an upward trend in real GDP per capita and years of education, and a downward trend in the investment-to-GDP ratio. This observation motivates us to include $\gamma_i t$ in Equation (4.11), where t is a linear time trend and γ_i is a country-specific coefficient. Table 7.7 summarises the PMG estimation results under this model specification. In comparison with Table 7.2, some differences are observed. Firstly, the magnitude of the estimated coefficient on human capital becomes much smaller. Secondly, the estimated coefficient on total tax revenue (as a share of GDP) is now strongly negative and less sensitive to model specifications.

Consistent with the benchmark results in Table 7.2, we continue to find that shifts in tax revenue towards property taxes (Column 40), and particularly towards other property taxes (Column 39) are associated with a higher long-run level of output per capita. In contrast to the benchmark results, Columns 38-40 here suggest that consumption taxes are no "better", if not "worse", than income taxes. For example, in Column 40, the estimated coefficients on personal income taxes, corporate income taxes and consumption taxes continue to be negative. Here, the estimated coefficient on consumption taxes is not significantly different from those on the two income taxes.[46]

[43] In Column 26, the estimated long-run coefficient on consumption taxes is negative and marginally significant. In Column 28, the Wald test cannot reject the null hypothesis of equal long-run coefficients on personal inome taxes, corporate income taxes and consumption taxes (p-value equals 0.115).

[44] In Column 30, the Wald test of equal long-run coefficients on personal income taxes and corporate income taxes yields a p-value of 0.333. In Column 34, the Wald test of equal long-run coefficients on personal income taxes and corporate income taxes yields a p-value of 0.675.

[45] In Column 32, the estimated long-run coefficient on consumption taxes is insignificantly different from zero. In Column 34, the Wald test that the estimated long-run coefficients on personal income taxes, corporate income taxes and consumption taxes are equal yields a p-value of 0.661.

[46] The Wald test of equal long-run coefficients on personal income taxes, corporate income taxes and consumption taxes yields a p-value of 0.350.

5.2.3 5.2.3 Allowing for cross-section dependence

It is known that without controlling for cross-section dependence (i.e. correlation across countries in the error term for the same period), estimation based on macro-level cross-country panel data may be biased. Such bias would arise if countries tend to be affected by some common shocks, such as business cycle fluctuations. which may also be correlated with some of the included explanatory variables.

Pesaran (2006) suggests a simple procedure to allow for a form of cross-section dependence with a multiplicative factor structure. Analogously to allowing each country to have its own slope coefficients on the observed explanatory variables, this allows each country to have its own slope coefficient on an unobserved common factor. This form of cross-country dependence can be allowed for by including the time means $\frac{1}{N}\sum_{i=1}^{N}\Delta\ln y_{i,t}$ and $\frac{1}{N}\sum_{i=1}^{N}X_{i,t}$ as additional regressors in the ECM, where $\Delta\ln y_{i,t}$ is the dependent variable and $X_{i,t}$ denotes the vector of all explanatory variables. Countries are allowed to have heterogeneous responses towards the common factors. This formulation can also be regarded as a flexible way of introducing trends.

Table 7.8 summarises the PMG estimation results allowing for cross-section dependence in this way. We are only able to estimate the first four models in Table 7.2, as the likelihood function becomes non-concave in other cases. Now, the estimated average convergence rate is found to be higher, in the range between -0.344 and -0.593, while the corresponding estimate in Table 7.2 is in the range between -0.216 to -0.295. The estimated coefficient on human capital is insignificant in Column 41 and becomes significantly negative when more control variables are added. The estimated coefficient on total tax revenue (as a share of GDP) is negative and significant in these specifications.

Allowing for cross-section dependence in this way, there is some support for favouring personal income taxes over corporate income taxes (Column 42) but there is no evidence that a shift in tax revenue between taxes on income and taxes on consumption affects the level of income per capita in the long run (Column 43). Nevertheless, we continue to find a positive association between the share of property taxes in total tax revenue and the level of income per capita in the long run (Column 44). In this specification there is also a suggestion that the effects of taxes on consumption may be worse than those of taxes on income.

5.3 Summary

In this section, we check the robustness of the benchmark regression results by using a different sample, a different proxy for the investment share and different specifications of the time effects. The benchmark estimation results are rather sensitive to these variations. The only robust result appears to be that shifts in total tax revenue towards property taxes away from other taxes are associated with a higher level of income per capita in the long run. Relative to property taxes, the shares of personal income taxes, corporate income taxes and consumption taxes in total tax revenue are all found to be negatively related to the long-run level of income per capita. However, the ranking among these three taxes is not clear. Overall, in contrast to Arnold et al. (2011), we obtain no strong evidence for favouring personal income taxes over corporate income taxes, or for favouring consumption taxes over income taxes.

Table 7.9 demonstrates that shifts in total tax revenue towards property taxes are indeed associated with a higher long-run level of income per capita in these different model specifications. Therefore, in the next section, we will focus on the role of property taxes and proceed to test the validity of the common long-run coefficients restriction imposed in the PMG estimations.

6 Testing the validity of imposing homogeneity on long-run parameters

6.1 PMG, unweighted and weighted MG estimations

Up to this point, we have only reported results from the PMG estimations, which impose homogeneity on the long-run coefficients in Equation (1.15). It is important to examine whether estimation results are sensitive to different parametric assumptions. For example, the pooled OLS and fixed-effects within-groups estimators restrict both long-run and short-run coefficients (α_1, $\alpha_2 ... \alpha_m$, ϕ, β_1, $\beta_2 ... \beta_m$ and γ) in Equation (4.11) to be homogeneous across countries. On the other hand, the Mean Group (MG) estimator allows all coefficients ($\alpha_{1,i}$, $\alpha_{2,i} ... \alpha_{m,i}$, ϕ_i, $\beta_{1,i}$, $\beta_{2,i} ... \beta_{m,i}$ and γ_i) to be country-specific. In this case we may be interested in the central tendency of the distribution of the estimated coefficients across countries, as reflected in some estimate of the mean.

The unweighted MG estimates are obtained by simply averaging the country-specific estimates of each coefficient. One potential drawback of the unweighted MG estimator is that they may be very sensitive to the presence of (possibly very imprecise) country-specific estimates with extreme values. The outlier-robust variant of the MG estimator (Bond, Leblebicioglu and Schiantarelli, 2010) addresses this issue by putting smaller weights on country-specific estimates with extreme values relative to the sample distribution. In practice, we first obtain country-specific estimates of each coefficient in separate estimations for each country. Then, we use a robust regression (Hamilton, 1991a) on a constant to calculate a weighted average for each coefficient in Equation (1.15).[47]

Table 7.10 summarises the PMG, weighted and unweighted MG, pooled OLS and fixed-effects within-groups estimates of the (mean) long-run coefficients and the (mean) speed of convergence based on Equation (4.11) when our measure of property taxes as a share of total tax revenue is included in the specification. We specify the time effect to be a linear trend in these and all subsequent estimations. The PMG and MG estimations allow for heterogeneous responses to the

[47] Following the country-by-country estimations, we regress the country-specific estimates for each variable on a constant using the STATA command "rreg", which generates the weighted average estimate by putting small weights on country-specific estimates with extreme values. Standard errors are calculated by the formula: $\widehat{\sigma} = \sqrt{\sum_i w_i \widehat{\sigma}_i^2}$, where $\widehat{\sigma}_i$ is the country-specific heteroskedasticity-robust standard error for a certain estimated coefficient, and w_i is the weight computed in the robust regression.

linear time effect, while the pooled OLS and fixed-effects within-groups estimations restrict the responses to be common across countries. It can be seen in Table 7.10 that the significant positive association between income per capita and the share of property taxes in total tax revenue is only found in the PMG estimations. Allowing all coefficients to be heterogeneous across countries, both the weighted and unweighted MG estimations yield positive mean long-run coefficients on property taxes, but with very large standard errors. When all (slope) coefficients are restricted to be common across countries, the pooled OLS (and within-groups fixed effects) regressions yield negative but insignificant long-run coefficients on property taxes.

The central question now is whether it is valid to restrict the long-run coefficients to be common across countries, as in Equation (1.15) and as imposed by the PMG estimator. Previous studies try to answer this question by comparing the PMG estimates with the unweighted MG estimates of the (mean) long-run coefficients, using the Hausman test. Under the null hypothesis that the long-run coefficients are homogeneous across countries, both the PMG and MG estimators are consistent while the PMG estimators are more efficient. Under the alternative hypothesis, however, only the MG estimator is consistent. Rejection of the null hypothesis is evidence against the validity of restricting the long-run coefficients to be the same across countries.

Table 7.11a reports the Hausman test results comparing the PMG with the unweighted MG estimates of the (mean) long-run coefficients. The Hausman test statistic for all five coefficients jointly has a $\chi^2(5)$ distribution under the null. The test statistic is 5.1, with a p-value of 0.404. Hence, the joint validity of the homogeneity restrictions imposed on these five long-run coefficients is not rejected. Considering the five restrictions individually, there is some doubt about the validity of the common long-run parameter restriction for the physical investment share (t-statistic = 1.906; p-value = 0.059). Table 7.11b compares the PMG and weighted MG estimates of each (mean) long-run coefficient individually.[48] Again there is some concern about the validity of the common long-run parameter restriction for the physical investment share (t-statistic =1.731; p-value =0.086). The restriction of common long-run coefficients is not rejected by these Hausman tests for any of the other variables.

It is worth noting that the weighted and unweighted MG estimates of the mean long-run coefficients on human capital and property taxes in Table 7.11 are very imprecise. Therefore, the Hausman test may have low power, which could incorrectly lead to the acceptance of the homogeneous long-run coefficients restriction. The low power of the Hausman test has been questioned previously by Im, Pesaran and Shin (1999) and Gemmell et al. (2007), but is not emphasised in Arnold et al. (2011). This motivates us to use an alternative method to examine the validity of the homogeneity restriction imposed on long-run parameters.

[48] We were not able to compute the joint Hausman test using the weighted MG estimator, as this would require evaluation of the full covariance matrix for this estimator, not only the stnadard errors for each coefficient.

6.2 Alternative test of the homogeneity restriction

To further examine the validity of imposing the homogeneity restriction on the long-run coefficients, we estimate a dynamic model specified as Equation (6.1):

$$\begin{aligned}\Delta \ln \widetilde{y}_{i,t} \quad = \quad & -\sum_{i=1}^{17} \phi_i \ln \widetilde{y}_{i,t-1} + \sum_{i=1}^{17} \lambda_{i,1} \ln s^k_{i,t} + \sum_{i=1}^{17} \lambda_{i,2} \ln h_{i,t} + \sum_{i=1}^{17} \lambda_{i,3} n_{i,t} \\ & + \sum_{i=1}^{17} \lambda_{i,4} (\frac{Total\ Tax}{GDP})_{it} + \sum_{i=1}^{17} \lambda_{i,5} (\frac{Property\ Tax}{Total\ Tax})_{it} \\ & + \sum_{i=1}^{17} \beta_{i,1} \Delta \ln s^k_{i,t} + \sum_{i=1}^{17} \beta_{i,2} \Delta \ln h_{i,t} + \sum_{i=1}^{17} \beta_{i,3} \Delta n_{i,t} \\ & + \sum_{i=1}^{17} \beta_{i,4} \Delta (\frac{Total\ Tax}{GDP})_{it} + \sum_{i=1}^{17} \beta_{i,5} \Delta (\frac{Property\ Tax}{Total\ Tax})_{it} \\ & + \sum_{i=1}^{17} \gamma_i t + \sum_{i=1}^{17} \delta_i + \epsilon_{it} \qquad (6.1)\end{aligned}$$

where ϕ_i is the country-specific speed of convergence and $\theta_{ij} = \frac{\lambda_{ij}}{\phi_i}$ $(i = 1, 2, ...17,\ j = 1, 2, ...5)$ are country-specific long-run coefficients on the investment-to-GDP share, human capital, the growth rate of the working-age population, total tax revenue (as a share of GDP) and property taxes (as a share of total tax revenue), respectively. γ_i is the country-specific coefficient on the linear time trend, and δ_i is the country-specific intercept. We can estimate Equation (6.1) by OLS and obtain standard errors that are robust to heteroskedasticity. Country-specific long-run coefficients and their associated standard errors are then obtained by non-linear transformation of the basic estimated coefficients.[49] Then, we can test whether the long-run coefficients θ_{ij} on a certain variable $(i = 1, 2...17)$ are the same across all countries, or across subsets of countries, using a standard Wald test.

Country-specific estimates of the long-run coefficients and the speed of convergence in Equation (6.1) are summarised in Table 7.12. The last column reports the p-values for the Wald test of equal long-run coefficients across all countries for each variable, individually. The Wald test does not reject the null hypothesis of equal long-run coefficients on the physical investment share across the 17 countries. Similarly, we cannot reject the null hypothesis of equal long-run coefficients on the working-age population growth rate and on total tax revenue (as a share of GDP), respectively.

However, the null hypothesis that the long-run coefficients on human capital investment are equal is rejected by the Wald test at the 1 per cent level, indicating that it is invalid to restrict this coefficient to be the same across all 17 countries. Note that the mean long-run coefficient on human capital investment was imprecisely estimated with a large standard error in both the weighted and the unweighted MG estimations and hence, the Hausman test of this restriction did not reject the null in either Table 7.11a or Table 7.11b. This exercise illustrates the low power of the Hausman

[49] In practice, this is achieved by the STATA command "nlcom", using the delta method.

test when the MG estimates are imprecise. Furthermore, the p-value of the Wald test of common long-run coefficients on the property tax share is only 0.231, which is lower than the p-values for the other three variables, and indicates some concern about the validity of imposing this parameter to be common across all 17 countries.

6.3 Relaxing the homogeneity restriction

Based on the findings in the previous section, it appears reasonable to impose the long-run coefficients on the investment share, the growth rate of the working-age population and total tax revenue (as a share of GDP) to be common across all countries (by imposing $\theta_{i,1} = \theta_1$, $\theta_{i,3} = \theta_3$, $\theta_{i,4} = \theta_4$ for $i = 1, ..., 17$ in Equation 6.1), while allowing the long-run coefficients on human capital investment and property taxes to be country-specific. Table 7.13 presents the estimation results based on this restricted version of Equation (6.1).

The upper panel reports country-specific long-run coefficients on human capital investment and the property tax share. The lower panel reports the common long-run coefficients on the physical investment share, the growth rate of the working-age population and total tax revenue (as a share of GDP). The last column reports the Wald test results. Again, the Wald test rejects the null hypothesis of common long-run coefficients on human capital investment at the 1 per cent level. The Wald test of common long-run coefficients on the property tax share has a p-value of 0.219.

A closer examination of the country-specific estimates for the property tax variable in Table 7.13 reveals that there is still a considerable amount of heterogeneity across countries. In fact, for only three countries do we estimate a positive and significant long-run coefficient on the share of property taxes (Finland, Ireland and the UK) while for all other countries we find insignificant estimates. Nonetheless, in terms of this coefficient, some countries appear to be more similar to each other. This observation leads us to restrict countries within certain groups to have a common long-run coefficient on the share of property taxes. We split the 17 OECD countries into three sub-groups. The first group includes Finland, Ireland and the UK. The second group includes Austria, Belgium, France, Greece, Japan, Netherlands and the US, all of which have a positive but insignificant long-run coefficient on property taxes in Table 7.13. The third group includes the remaining 7 countries which have negative but insignificant estimates. It is worth noting that the Wald tests of common long-run coefficients on property taxes within these sub-groups all yield higher p-values than that when we pool the 17 countries together.[50]

In Table 7.14, Column 55 reports the PMG estimation results when all long-run coefficients are assumed to be common across all 17 countries. Column 56 presents the results when the long-run coefficients on both human capital investment and property taxes are allowed to be country-specific. Relaxing the homogeneity restrictions on these two variables, the unweighted average estimates of the long-run coefficients on property taxes and human capital investment both become insignificant.

[50] The p-value of the Wald test statistic is 0.455 for Group 1 countries, 0.992 for Group 2 countries and 0.930 for Group 3 countries, much higher than the p-value when we pool the 17 countries together (which is 0.219).

In Column 57, we only relax the homogeneous long-run coefficient restriction on human capital investment. In this case the estimated common long-run coefficient on the property tax share again becomes positive and significant.

In Column 58, interactions between the country group dummies and the property tax variable are included in the long-run part of the PMG estimation. In this case, we restrict the long-run coefficient on property taxes to be the same across countries within a certain group, but allow this long-run coefficient to differ across groups. The results suggest that for countries in Group 1 and Group 2, a higher share of property taxes in total tax revenue is associated with a higher level of output per capita in the long run, but this association is not found for countries in Group 3.

Moreover, the Wald test rejects the null hypothesis that the estimated long-run coefficients on property taxes for all three groups of countries are equal at the 1 per cent level, but it does not reject the null hypothesis that the long-run coefficients on property taxes are equal for Group 1 and Group 2 countries.[51] Therefore, it seems reasonable to impose the homogeneity restriction on the long-run coefficient on property taxes among the countries in both Group 1 and Group 2. This restriction is imposed in Column 59. In this specification we continue to estimate a positive and significant long-run coefficient on the share of property taxes for Group 1 and Group 2 countries, while the long-run coefficient for Group 3 countries remains negative and insignificant.

7 Conclusions

Recently, there has been considerable interest in the idea of reforming a country's tax structure to be "growth-promoting" by shifting tax revenue away from taxes on income and to taxes on consumption and property. Although recent empirical studies, notably Arnold et al. (2011), suggest a ranking of different types of taxes in terms of their effects on the level of per capita income in the long run, the findings presented in this Chapter cast doubt on the robustness of this empirical result.

In this study, we analyse data for a panel of 17 OECD countries over the period 1970-2004. Our benchmark Pooled Mean Group estimation results principally suggest that shifts in total tax revenue towards property taxes may be associated with a higher steady-state level of income per capita. This result remains robust when we use different samples, different regressors and different specifications of the time effects. Relative to property taxes, raising more tax revenue from personal income taxes, corporate income taxes or consumption taxes are all found to be associated with a lower level of income per capita in the long run. However, we find no strong evidence for favouring personal income taxes over corporate income taxes, or for favouring consumption taxes over income taxes, as previous studies have suggested.

Furthermore, when we allow the long-run coefficients in our dynamic growth model to take different values for each country, using a Mean Group estimator, we no longer find a significant

[51] The p-value for the Wald test of this restriction is 0.882.

positive association between the share of tax revenue from property taxes and the long-run level of income per capita. This motivates us to test the validity of restricting the long-run coefficients in the growth equation to be common across countries. Using a Wald test of these restrictions, which appears to have more power that a Hausman test in this context, we find that it is invalid to impose the homogeneous long-run coefficients restriction on all the explanatory variables in the growth equation. Further investigations, imposing parameter restriction which are not rejected by the Wald test, suggest that there may be a significant positive association between the property tax share and the long-run level of income per capita, but only for a sub-group of the countries in our sample.

Our analysis suggests that it may be premature to draw concrete conclusions about the superiority of taxes on consumption over taxes on income, or about the superiority of taxes on personal income over taxes on corporate income, in terms of their effects on long-run income levels. Therefore, caution is advisable when making policy recommendations concerning "growth-promoting" revenue-neutral tax structure reforms, especially for individual countries.

Table 7.1: PMG estimation results from Arnold et al. (2011)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
LR coefficients						
Physical capital	0.204***	0.190***	0.171***	0.168***	0.111***	0.195***
	(0.04)	(0.05)	(0.05)	(0.05)	(0.45)	(0.05)
Human capital	0.99***	1.30***	1.18***	1.40***	1.57***	1.52***
	(0.11)	(0.12)	(0.13)	(0.11)	(0.11)	(0.12)
Population growth	-0.05***	-0.08***	-0.07***	-0.07***	-0.07***	-0.08***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Tax revenue/GDP		-0.24***	-0.26***	-0.22**	-0.14***	-0.25**
		(0.05)	(0.05)	(0.04)	(0.04)	(0.04)
Personal income taxes		-1.13***				-1.35***
		(0.19)				(0.34)
Corporate income taxes		-2.01***				-2.40***
		(0.32)				(0.43)
Consumption&Property taxes			0.93***			
			(0.20)			
Consumption taxes				0.74***	0.72***	0.21
				(0.18)	(0.19)	(0.34)
Property taxes				1.45***		
				(0.43)		
Immovable property taxes					2.47***	
					(0.84)	
Other property taxes					-0.34	
					(0.51)	
Mean convergence rate	-0.30***	n.a.[1]	n.a.	n.a.	n.a.	n.a.
	(0.04)					
Five-year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	699	675	696	696	678	675

[1]No estimate is reported in Arnold et al. (2011).

[2]Robust standard errors in parentheses.

[3]*** p<0.01, ** p<0.05, * p<0.1

Table 7.2: Benchmark PMG estimations (17 OECD countries)

Variables	(7)	(8)	(9)	(10)	(11)	(12)
LR coefficients						
Physical capital	0.204***	0.190***	0.171***	0.168***	0.111***	0.195***
	(0.038)	(0.039)	(0.038)	(0.039)	(0.041)	(0.037)
Human capital	2.157***	2.441***	2.453***	2.442***	2.624***	2.438***
	(0.152)	(0.121)	(0.136)	(0.131)	(0.126)	(0.120)
Population growth	-0.023**	-0.038***	-0.036***	-0.036***	-0.050***	-0.029***
	(0.010)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Tax revenue/GDP		-0.062	-0.208***	-0.112	-0.180***	-0.032
		(0.067)	(0.077)	(0.075)	(0.068)	(0.069)
Personal income taxes		-1.047***				-2.654***
		(0.184)				(0.478)
Corporate income taxes		-1.250***				-2.946***
		(0.262))				(0.494)
Consumption&Property taxes			0.786***			
			(0.192)			
Consumption taxes				0.828***	0.570***	-1.575***
				(0.211)	(0.214)	(0.455)
Property taxes				2.324***		
				(0.492)		
Immovable property taxes					1.274**	
					(0.598)	
Other property taxes					4.975***	
					(0.663)	
Mean convergence rate	-0.295***	-0.231***	-0.253***	-0.237***	-0.223***	-0.216***
	(0.040)	(0.047)	(0.040)	(0.041)	(0.040)	(0.045)
Five-year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	575	575	575	575	575	575

[1]Long-run coefficients are obtained by imposing homogeneity across countries. The mean convergence rate is the unweighted average of country-specific estimates.
[2]In this table and the subsequent tables, short-run dynamics are included, as in Equation (1.15).
[3]Robust standard errors in parentheses.
[4]*** p<0.01, ** p<0.05, * p<0.1

Table 7.3: PMG estimation (21 OECD countries)

Variables	(13)	(14)	(15)	(16)
LR coefficients				
Physical capital	0.261***	0.163***	0.137***	0.098*
	(0.031)	(0.039)	(0.045)	(0.056)
Human capital	1.522***	2.289***	2.029***	1.938***
	(0.091)	(0.135)	(0.102)	(0.108)
Population growth	-0.023***	-0.049***	-0.048***	-0.047***
	(0.006)	(0.012)	(0.011)	(0.011)
Tax revenue/GDP		-0.159**	-0.112	-0.019
		(0.091)	(0.084)	(0.093)
Corporate income taxes				0.163
				(0.255)
Consumption&Property taxes		0.964***		
		(0.204)		
Consumption taxes			1.000***	1.553***
			(0.242)	(0.300)
Property taxes			3.423***	4.519***
			(0.599)	(0.763)
Mean convergence rate	-0.276***	-0.219***	-0.206***	-0.165***
	(0.051)	(0.033)	(0.038)	(0.033)
Five-year dummies	Yes	Yes	Yes	Yes
Observations	679	679	679	679

[1] Robust standard errors in parentheses.

[2] ***p<0.01, **p<0.05, *p<0.1.

Table 7.4: PMG estimation with an alternative proxy for physical investment (17 OECD countries)

Variables	(17)	(18)	(19)	(20)	(21)	(22)
LR coefficients						
Physical capital	0.082	0.225***	0.089***	0.130***	0.000	0.221***
	(0.053)	(0.038)	(0.042)	(0.041)	(0.046)	(0.039)
Human capital	2.434***	2.633**	2.625***	2.592***	2.782***	2.607***
	(0.215)	(0.118)	(0.155)	(0.142)	(0.147)	(0.123)
Population growth	-0.022*	-0.029***	-0.044***	-0.041***	-0.050***	-0.024**
	(0.013)	(0.010)	(0.012)	(0.011)	(0.012)	(0.010)
Tax revenue/GDP		0.023	-0.108	-0.041	-0.126*	0.039
		(0.066)	(0.081)	(0.078)	(0.075)	(0.072)
PIT		-1.227***				-2.542***
		(0.188)				(0.483)
CIT		-1.774***				-3.061***
		(0.275)				(0.501)
Consumption&Property taxes			1.103***			
			(0.226)			
Consumption taxes				1.035***	0.773***	-1.275***
				(0.234)	(0.253)	(0.461)
Property taxes				2.883***		
				(0.539)		
Immovable property taxes					1.639**	
					(0.703)	
Other property taxes					5.810***	
					(0.789)	
Convergence rate	-0.257***	-0.250***	-0.267***	-0.250***	-0.227***	-0.230***
	(0.027)	(0.053)	(0.040)	(0.041)	(0.036)	(0.050)
Five-year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	533	533	533	533	533	533

[1]Robust standard errors in parentheses.

[2]*** p<0.01, ** p<0.05, * p<0.1

Table 7.5: PMG estimation with alternative five-year period dummies (17 OECD countries)

Variables	(23)	(24)	(25)	(26)	(27)	(28)
LR coefficients						
Physical capital	0.225***	0.160***	0.212***	0.197***	0.159***	0.168***
	(0.027)	(0.040)	(0.032)	(0.033)	(0.031)	(0.040)
Human capital	2.616***	2.611***	2.660***	2.562***	2.693***	2.560***
	(0.125)	(0.161)	(0.138)	(0.134)	(0.110)	(0.147)
Population growth	-0.039***	-0.059***	-0.054***	-0.052***	-0.055***	-0.057***
	(0.008)	(0.011)	(0.010)	(0.010)	(0.010)	(0.010)
Tax revenue/GDP		-0.129*	-0.116*	-0.177***	-0.262***	-0.174***
		(0.071)	(0.060)	(0.053)	(0.044)	(0.060)
Personal income taxes		-0.084				-1.056***
		(0.196)				(0.327)
Corporate income taxes		0.337				-0.883***
		(0.245)				(0.323)
Consumption&Property taxes			0.039			
			(0.184)			
Consumption taxes				-0.311*	0.087	-1.354***
				(0.177)	(0.169)	(0.328)
Property taxes				0.847***		
				(0.301)		
Immovable property taxes					-0.136	
					(0.327)	
Other property taxes					3.596***	
					(0.612)	
Mean convergence rate	-0.337***	-0.258***	-0.282***	-0.278***	-0.255***	-0.265***
	(0.047)	(0.041)	(0.042)	(0.045)	(0.051)	(0.044)
Alternative five-year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	575	575	575	575	575	575

[1] Robust standard errors in parentheses.

[2] *** p<0.01, ** p<0.05, * p<0.1

Table 7.6: PMG estimation with alternative five-year period dummies and an alternative proxy for physical investment (17 OECD countries)

Variables	(29)	(30)	(31)	(32)	(33)	(34)
LR coefficients						
Physical capital	0.170***	0.227***	-0.031	0.173***	0.113***	0.186***
	(0.035)	(0.041)	(0.056)	(0.034)	(0.032)	(0.041)
Human capital	2.925***	2.929***	3.247***	2.935***	2.750***	2.899***
	(0.169)	(0.165)	(0.272)	(0.151)	(0.119)	(0.154)
Population growth	-0.041***	-0.062***	-0.120***	-0.051***	-0.045***	-0.051***
	(0.010)	(0.013)	(0.024)	(0.012)	(0.011)	(0.012)
Tax revenue/GDP		0.052	0.292**	-0.148**	-0.249***	-0.121*
		(0.077)	(0.118)	(0.061)	(0.050)	(0.065)
Personal income taxes		-0.680***				-1.621***
		(0.231)				(0.394)
Corporate income taxes		-0.927***				-1.716***
		(0.319)				(0.401)
Consumption&Property taxes			1.080***			
			(0.311)			
Consumption taxes				0.084	0.392**	-1.470***
				(0.213)	(0.187)	(0.372)
Property taxes				1.477***		
				(0.385)		
Immovable property taxes					0.171	
					(0.373)	
Other property taxes					5.210***	
					(0.722)	
Mean convergence rate	-0.295***	-0.237***	-0.175***	-0.253***	-0.256***	-0.247***
	(0.045)	(0.047)	(0.036)	(0.043)	(0.049)	(0.049)
Alternative five-year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	533	533	533	533	533	533

[1]Robust standard errors in parentheses

[2]*** p<0.01, ** p<0.05, * p<0.1

Table 7.7: PMG estimation with linear trends (17 OECD countries)

Variables	(35)	(36)	(37)	(38)	(39)	(40)
LR coefficients						
Physical capital	0.243***	0.242***	0.245***	0.274***	0.202***	0.273***
	(0.032)	(0.030)	(0.031)	(0.022)	(0.020)	(0.022)
Human capital	-0.194	0.677**	0.863***	0.873***	0.955***	1.079***
	(0.291)	(0.307)	(0.300)	(0.249)	(0.177)	(0.268)
Population growth	-0.043***	-0.065***	-0.057***	-0.042***	-0.039***	-0.041***
	(0.012)	(0.014)	(0.013)	(0.008)	(0.008)	(0.008)
Tax revenue/GDP		-0.271***	-0.274***	-0.336***	-0.348***	-0.363***
		(0.071)	(0.067)	(0.054)	(0.024)	(0.051)
Personal income taxes		-0.804***				-1.571***
		(0.196)				(0.200)
Corporate income taxes		-0.365*				-1.714***
		(0.199)				(0.261)
Consumption&Property taxes			0.502***			
			(0.186)			
Consumption taxes				0.121	-0.525***	-1.439***
				(0.147)	(0.079)	(0.225)
Property taxes				1.676***		
				(0.220)		
Immovable property taxes					-0.123	
					(0.201)	
Other property taxes					3.308***	
					(0.218)	
Mean convergence rate	-0.217***	-0.196***	-0.203***	-0.241***	-0.257***	-0.237***
	(0.024)	(0.027)	(0.031)	(0.037)	(0.054)	(0.040)
Linear trends	Yes	Yes	Yes	Yes	Yes	Yes
Observations	575	575	575	575	575	575

[1] Robust standard errors in parentheses

[2] *** p<0.01, ** p<0.05, * p<0.1

Table 7.8: PMG estimation allowing for cross-section dependence (17 OECD countries)

Variables	(41)	(42)	(43)	(44)
LR coefficients				
Physical capital	0.176***	0.225***	0.231***	0.188***
	(0.025)	(0.009)	(0.015)	(0.015)
Human capital	-0.044	-0.360***	-0.394***	-0.278**
	(0.202)	(0.096)	(0.134)	(0.119)
Population growth	-0.035**	-0.013***	-0.022**	-0.029***
	(0.008)	(0.009)	(0.009)	(0.009)
Tax revenue/GDP		-0.241***	-0.246***	-0.327***
		(0.020)	(0.027)	(0.028)
Personal income taxes		0.095*		
		(0.051)		
Corporate income taxes		-0.214***		
		(0.091)		
Consumption & Property taxes			0.125	
			(0.083)	
Consumption taxes				-0.366***
				(0.097)
Property taxes				0.887***
				(0.195)
Mean convergence rate	-0.344***	-0.593***	-0.485***	-0.478***
	(0.054)	(0.107)	(0.081)	(0.077)
Observations	575	575	575	575

[1]Robust standard errors in parentheses.

[2]*** p<0.01, ** p<0.05, * p<0.1.

Table 7.9: Property taxes and growth in different PMG estimations

Variables	(45)	(46)	(47)	(48)	(49)
LR coefficients					
Physical capital	0.259***	0.225***	0.180***	0.266***	0.178***
	(0.035)	(0.041)	(0.039)	(0.024)	(0.017)
Human capital	2.341***	2.005***	2.449***	0.800***	0.238
	(0.137)	(0.123)	(0.154)	(0.255)	(0.162)
Population growth	-0.017**	-0.033***	-0.022**	-0.043***	-0.020***
	(0.008)	(0.009)	(0.009)	(0.009)	(0.005)
Tax revenue/GDP	-0.369***	-0.370***	-0.325***	-0.387***	-0.232***
	(0.075)	(0.083)	(0.075)	(0.050)	(0.028)
Property taxes	1.032***	1.391***	1.675***	1.606***	0.841***
	(0.354)	(0.394)	(0.436)	(0.222)	(0.194)
Convergence rate	-0.268***	-0.228***	-0.282***	-0.238***	-0.431***
	(0.044)	(0.037)	(0.046)	(0.032)	(0.054)
Five-year dummies	Yes	Yes	Yes		
Linear trends				Yes	
Cross-section dependence					Yes
Observations	575	679	533	575	575

[1]The original sample of 17 countries is used in Columns 45, 47, 48 and 49. A sample of 21 countries is used in Column 46. We use thethe alternative specification of five-year period dummies in Column 46, and the alternative measure for physical investment share in Column 47.

[2]Robust standard errors in parentheses.

[3]*** p<0.01, ** p<0.05, * p<0.1.

Table 7.10: Property taxes and growth: PMG, MG, pooled OLS and FE estimations (17 OECD countries)

Variables	(50) PMG	(51) Unweighted MG	(52) Weighted MG	(53) OLS	(54) FE
LR coefficients					
Physical capital	0.266***	0.428***	0.356***	0.223	0.019
	(0.024)	(0.088)	(0.058)	(0.426)	(0.392)
Human capital	0.800***	1.826	0.800	-0.234	0.527
	(0.255)	(1.164)	(0.862)	(1.001	(0.682)
Population growth	-0.043***	-0.070**	-0.037	-0.324*	-0.298**
	(0.009)	(0.031)	(0.023)	(0.168)	(0.168)
Tax revenue/GDP	-0.387***	-0.228	-0.181	-0.440	-0.962
	(0.050)	(0.191)	(0.179)	(0.495)	(0.708)
Property taxes	1.606***	1.526	0.852	-2.839	-2.673
	(0.222)	(2.576)	(0.868)	(2.568)	(3.731)
Convergence rate	-0.238***	-0.322***	-0.299***	-0.014	-0.024**
	(0.032)	(0.045)	(0.043)	(0.006)	(0.010)
Linear trends	Yes	Yes	Yes	Yes	Yes
Observations	575	575	575	575	575

[1]Column 50 presents the common long-run coefficients and the mean convergence rate obtained by the PMG estimator; Columns 51 and 52 present the mean long-run coefficients and the mean convergence rate obtained by the unweighted and weighted MG estimators; Columns 53 and 54 present the common long-run coefficients and the common convergence rate obtained by the OLS and the fixed-effects within-groups regressions.

[2]Robust standard errors in parentheses.

[3]*** p<0.01, ** p<0.05, * p<0.1

Table 7.11: Hausman tests of the homogeneous long-run coefficients restriction

LR coefficients	MG	PMG	Difference	S.E[1]
a. Unweighted MG and PMG				
Physical capital	0.428	0.266	0.162	0.085
	(0.088)	(0.024)		
Human capital	1.826	0.800	1.026	1.136
	(1.164)	(0.255)		
Population growth	-0.070	-0.043	-0.027	0.030
	(0.031)	(0.009)		
Tax revenue/ GDP	-0.228	-0.387	0.158	0.184
	(0.191)	(0.050)		
Property taxes	1.526	1.606	-0.080	2.567
	(2.576)	(0.222)		
Hausman test	$\chi^2(5) = 5.1$ $Prob > \chi^2 = 0.404$			
b. Weighted MG and PMG				
Physical capital	0.356	0.266	0.090	0.052
	(0.058)	(0.024)		
Human capital	0.800	0.800	0.000	0.824
	(0.862)	(0.255)		
Population growth	-0.037	-0.043	0.007	0.021
	(0.023)	(0.009)		
Tax revenue/ GDP	-0.181	-0.387	0.206	0.172
	(0.179)	(0.050)		
Property taxes	0.852	1.606	-0.754	0.839
	(0.868)	(0.222)		

[1]S.E=$\sqrt{Var(MG) - Var(PMG)}$

[2]Robust standard errors for the MG and PMG estimates in parentheses

Table 7.12: Long-run coefficients and speed of convergence for individual countries

Variables	Australia	Austria	Belgium	Canada	Denmark	Finland	France	Greece	Ireland
Convergence rate	-0.358***	-0.152	-0.399	-0.419**	-0.442*	-0.333**	-0.094	-0.212	-0.696***
	(0.107)	(0.116)	(0.262)	(0.197)	(0.233)	(0.166)	(0.221)	(0.178)	(0.115)
Physical Capital	0.187	0.785	0.195	0.428**	0.204**	0.028	0.611	0.528***	0.286***
	(0.172)	(0.560)	(0.179)	(0.221)	(0.109)	(0.192)	(0.449)	(0.132)	(0.059)
Human Capital	-4.124***	1.867	0.376	-1.785	0.439	2.873	7.508	0.329	2.455*
	(0.951)	(4.136)	(0.666)	(2.183)	(1.513)	(1.751)	(14.639)	(2.550)	(1.290)
Population Growth	-0.011	-0.097	-0.001	-0.033	0.033	0.047	0.065	-0.037	-0.022*
	(0.023)	(0.094)	(0.040)	(0.040)	(0.041)	(0.075)	(0.215)	(0.082)	(0.012)
Tax Revenue/ GDP	0.196	-0.166	-0.106	-0.221	-0.059	-0.321	-0.472	-0.186	-0.065
	(0.285)	(1.112)	(0.246)	(0.302)	(0.169)	(0.231)	(2.115)	(0.651)	(0.142)
Property Taxes	0.836	6.012	1.435	-0.294	0.262	13.495*	20.932	0.970	1.559***
	(1.477)	(7.124)	(5.740)	(2.201)	(2.551)	(7.462)	(57.136)	(1.155)	(0.567)
	Japan	Netherlands	New Zealand	Norway	Sweden	Switzerland	UK	US	Wald test (p-value)
Convergence rate	-0.328	-0.201***	-0.301**	-0.167	-0.309	-0.756**	-0.229**	-0.086	
	(0.208)	(0.074)	(0.126)	(0.143)	(0.190)	(0.306)	(0.104)	(0.184)	
Physical Capital	0.462***	0.609**	0.303**	0.369	0.273**	0.479***	-0.044	1.572	0.603
	(0.134)	(0.269)	(0.146)	(0.260)	(0.109)	(0.159)	(0.280)	(2.912)	
Human Capital	3.812**	-2.363	-1.015	2.593	-1.17	-1.673***	4.151*	16.77	0.000
	(1.661)	(2.563)	(4.379)	(3.130)	(1.538)	(0.646)	(2.362)	(38.034)	
Population Growth	0.039	-0.136	-0.014	-0.37	-0.113	-0.021	-0.166**	-0.357	0.803
	(0.110)	(0.121)	(0.020)	(0.342)	(0.073)	(0.018)	(0.084)	(0.693)	
Tax Revenue/ GDP	-0.383	-0.024	-0.869*	-2.509	-0.131	0.155	-0.424**	1.704	0.676
	(0.463)	(0.554)	(0.453)	(2.846)	(0.217)	(0.151)	(0.176)	(2.853)	
Property Taxes	-0.219	1.095	-8.795	-28.865	-0.758	-1.29	3.581***	15.982	0.231
	(1.140)	(4.997)	(6.270)	(24.312)	(0.979)	(1.259)	(1.373)	(31.015)	

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 7.13: Relaxing the homogeneity restriction on some long-run coefficients

Country-specific coefficients

Variables	Australia	Austria	Belgium	Canada	Denmark	Finland	France	Greece	Ireland
Human capital	-4.217***	-0.639	0.728	-1.261	0.713	1.244***	3.496*	2.391	2.574***
	(0.877)	(2.525)	(0.505)	(1.838)	(1.382)	(0.467)	(2.070)	(5.408)	(0.526)
Property tax	-0.208	1.556	0.678	-0.907	-1.79	3.124**	8.554	1.287	1.352***
	(0.914)	(3.488)	(1.992)	(1.312)	(2.597)	(1.390)	(9.951)	(1.336)	(0.294)
Convergence rate	-0.324***	-0.251***	-0.331***	-0.375***	-0.264**	-0.586***	-0.138**	-0.140	-0.713***
	(0.066)	(0.067)	(0.095)	(0.093)	(0.114)	(0.133)	(0.064)	(0.096)	(0.105)

	Japan	Netherlands	New Zealand	Norway	Sweden	Switzerland	UK	US	Wald test (p-value)
Human capital	3.155***	-1.790***	-7.663**	1.081	-1.118	-0.546	2.616*	52.158	0.000
	(0.751)	(0.577)	(3.487)	(1.294)	(1.026)	(0.359)	(1.502)	(226.336)	
Property tax	0.915	0.404	-1.792	-4.873	-0.439	-0.395	1.533**	18.083	0.219
	(0.954)	(2.157)	(4.886)	(3.763)	(0.703)	(0.796)	(0.620)	(77.363)	
Convergence rate	-0.298***	-0.344***	-0.236***	-0.247**	-0.377***	-0.619***	-0.250***	-0.026	
	(0.093)	(0.053)	(0.078)	(0.118)	(0.116)	(0.148)	(0.080)	(0.081)	

Common coefficients

Physical capital	0.265***
	(0.021)
Population growth	-0.026***
	(0.006)
Tax revenue/GDP	-0.168***
	(0.046)

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 7.14: Imposing data-consistent restrictions on long-run coefficients

Variables	(55)	(56)	(57)	(58)	(59)
LR coefficients					
Physical capital	0.266***	0.265***	0.260***	0.277***	0.277***
	(0.024)	(0.021)	(0.020)	(0.018)	(0.018)
Human capital	0.800***				
	(0.255)				
Population growth	-0.043***	-0.026***	-0.033***	-0.028***	-0.028***
	(0.009)	(0.006)	(0.006)	(0.005)	(0.005)
Tax revenue/GDP	-0.387***	-0.168***	-0.159***	-0.144***	-0.145***
	(0.050)	(0.046)	(0.050)	(0.042)	(0.042)
Property taxes	1.606***		1.127***		
	(0.222)		(0.214)		
Property Taxes*Group 1				1.466***	
				(0.220)	
Property Taxes*Group 2				1.361**	
				(0.667)	
Property Taxes*Group 3				-0.472	-0.471
				(0.374)	(0.374)
Property Taxes*Group 1&2					1.457***
					(0.208)
Average country-specific coefficients					
Human capital		0.110	0.135	0.056	0.056
		(0.223)	(0.207)	(0.210)	(0.210)
Property taxes		0.184			
		(0.170)			
Convergence rate	-0.238***	-0.325***	-0.284***	-0.322***	-0.321***
	(0.032)	(0.043)	(0.036)	(0.043)	(0.043)
Linear trend	Yes	Yes	Yes	Yes	Yes
Observations	575	575	575	575	575

[1]Standard errors in parentheses.

[2]*** p<0.01, ** p<0.05, * p<0.1.

Appendix A: Definition and sources of variables

The variables used in the regressions are defined as follows:

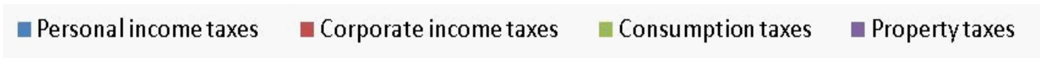
- Real GDP per capita (y): GDP at constant prices and constant PPPs (in millions US dollars) divided by the level of population aged 15-64 (in thousands). (Real GDP is provided by OECD National Accounts and the level of population aged 15-64 is provided by OECD Labour Force Statistics).
- Physical capital investment $\left(s^k\right)$: total gross fixed capital formation as a share of GDP (OECD National Account).
- Human capita investment (h): proxied by the average number of years of schooling of the population aged 25 to 64, taken from Arnold et al. (2007).
- Population growth (n): the annual growth rate of population aged 15-64 in percent (OECD Labour Force Statistics).
- Five-year period dummies: in the benchmark estimations, the period of 1970-2004 is split into 7 groups (1970-1975, 1976-1980, 1981-1985, 1986-1990, 1991-1995, 1996-2000, 2001-2004). In Section 5.2.1, the period of 1970-2004 is split into 7 groups in an alternative way (1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, 2000-2004).

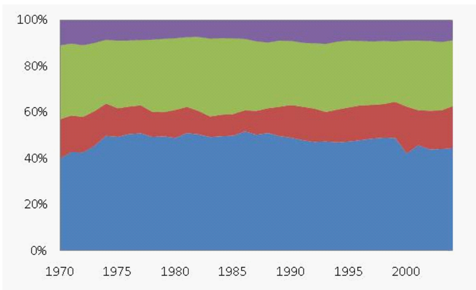
  The following variables are taken from *OECD Tax Revenue Statistics.*
- Total tax revenue/GDP: this is the total tax revenue as a percentage of GDP.
- Income taxes: this includes taxes on income, profits and capital gains (categories 1000), social security contributions (category 2000) and taxes on payroll and workforce (category 3000).
- Personal income taxes: this includes taxes on individual income, profits and capital gains (category 1100), social security contributions (category 2000) and taxes on payroll and workforce (category 3000).
- Corporate income taxes: this includes taxes on corporate income, profits and capital gains (category 1200).
- Consumption and property taxes: this is the total of consumption taxes (category 5000, 6000) and property taxes (category 4000).
- Consumption taxes: this includes taxes on goods and services (category 5000) and other consumption taxes (category 6000). Taxes on goods and services include taxes on production, sales, transfer, etc (category 5100), taxes on the permission to use goods or to perform activities (category 5200), and unallocable between category 5100 and 5200.
- Property taxes: this includes recurrent taxes on immovable property (category 4100), recurrent taxes on net wealth (category 4200), taxes on estates, inheritances and gifts (category 4300), taxes on financial and capital transactions (category 4400), non-recurrent taxes (category 4500) and other recurrent taxes on property (category 4600).

Descriptive statistics of key variables

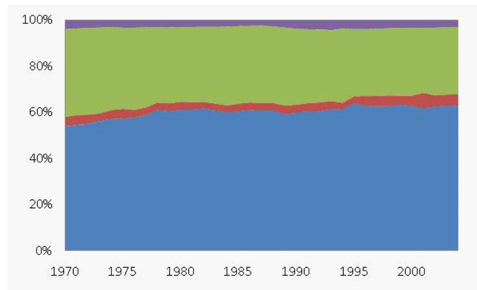
Variables	Mean	S.D	Min	Max
$\ln y$	10.358	0.249	9.563	10.978
$\ln s^k$	3.089	0.174	2.714	3.591
$\ln h$	2.374	0.123	2.001	2.595
n	0.811	0.648	-0.888	4.729
Tax revenue/GDP	0.355	0.078	0.181	0.522
Personal income taxes/Tax revenue	0.548	0.078	0.265	0.726
Corporate income taxes/Tax revenue	0.081	0.046	0.006	0.281
Consumption taxes/Tax revenue	0.303	0.076	0.128	0.524
Property taxes /Tax revenue	0.064	0.036	0.008	0.214

Appendix B: Proportions of major tax revenues in total tax mix

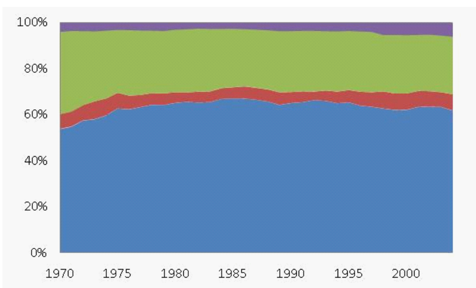




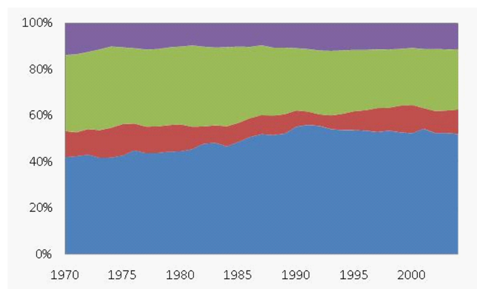
Australia



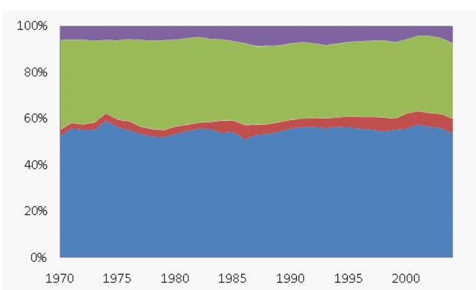
Austria



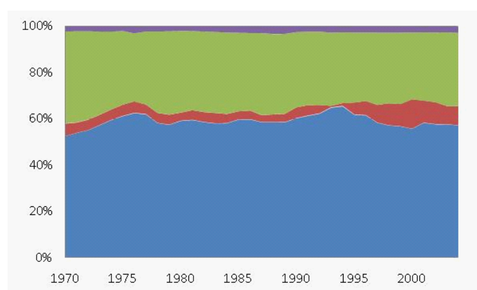
Belgium



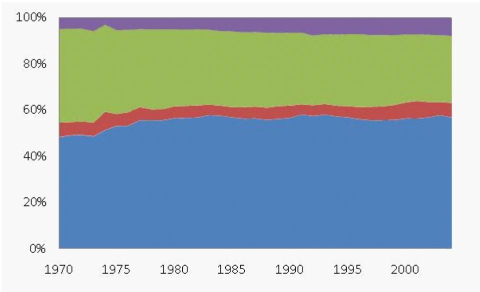
Canada



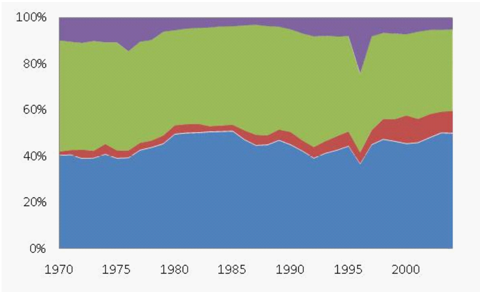
Denmark



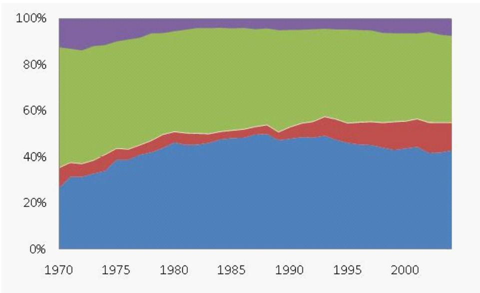
Finland



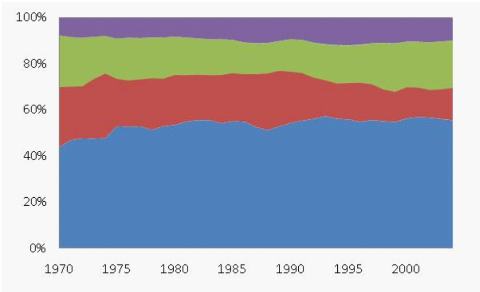
France



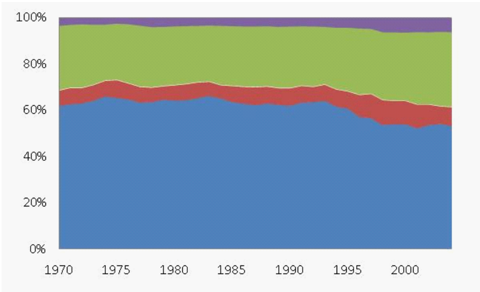
Greece



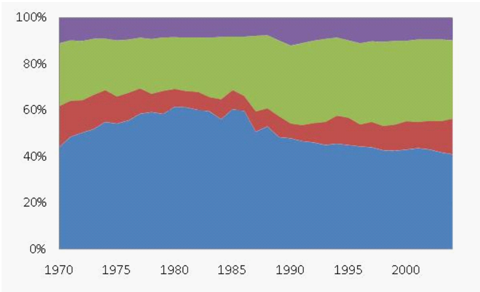
Ireland



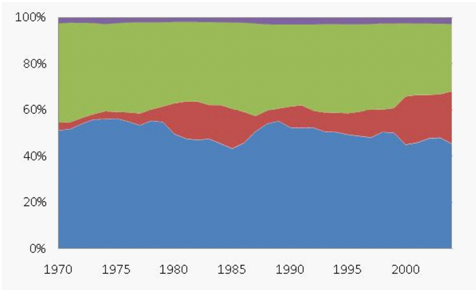
Japan



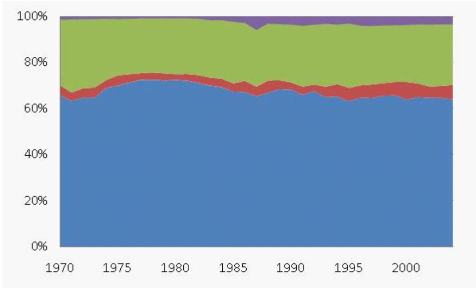
Netherlands



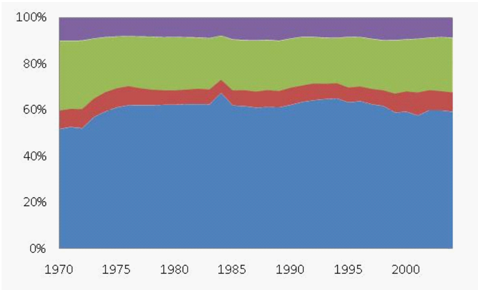
New Zealand



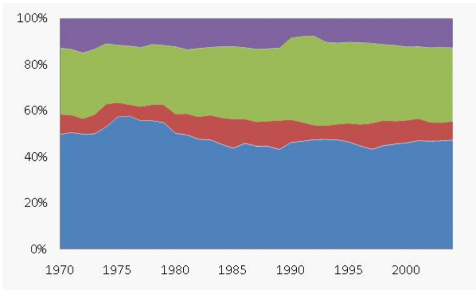
Norway



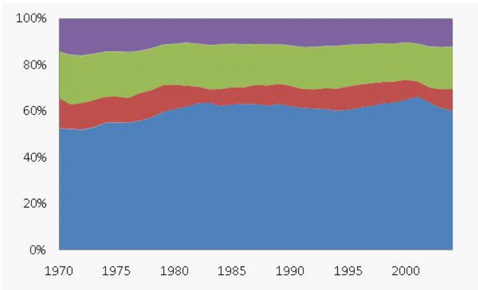
Sweden



Switzerland



United Kingdom



United States

Appendix C: Calculation of Equation (1.10) and Equation (1.14)

1. This shows how we obtain Equation (4.6).

From Equation (4.5), we have:

$$y^* = (k^*)^\alpha (h^*)^\beta = \left(\frac{s_k^{1-\beta} s_h^\beta}{n+g+d}\right)^{\frac{\alpha}{1-\alpha-\beta}} (h^*)^\beta$$

Taking logarithms, we obtain the following:

$$\begin{aligned}
\ln y^* &= \alpha \ln k^* + \beta \ln h^* \\
&= \frac{\alpha}{1-\alpha-\beta} \ln \frac{s_k^{1-\beta} s_h^\beta}{n+g+d} + \beta \ln h^* \\
&= \frac{\alpha(1-\beta)}{1-\alpha-\beta} \ln s_k + \frac{\alpha\beta}{1-\alpha-\beta} \ln s_h - \frac{\alpha}{1-\alpha-\beta} \ln (n+g+d) + \beta \ln h^* \\
&= \frac{\alpha(1-\beta)}{1-\alpha-\beta} \ln s_k + \frac{\alpha\beta}{1-\alpha-\beta} \ln \frac{(n+g+d)\, h^*}{y^*} - \frac{\alpha}{1-\alpha-\beta} \ln (n+g+d) \\
& \quad + \beta \ln h^* \\
&= \frac{\alpha(1-\beta)}{1-\alpha-\beta} \ln s_k + \left(\frac{\alpha\beta}{1-\alpha-\beta} + \beta\right) \ln h^* + \left(\frac{\alpha\beta}{1-\alpha-\beta} - \frac{\alpha}{1-\alpha-\beta}\right) \times \\
& \quad \ln (n+g+d) - \frac{\alpha\beta}{1-\alpha-\beta} \ln y^*
\end{aligned}$$

where the fourth line follows from the fact that in the steady state, according to Equation (4.3), $s_h = \frac{(n+g+d)h^*}{y^*}$. Rearranging the above equation, we obtain that:

$$\ln y^* = \frac{\alpha}{1-\alpha} \ln s_k + \frac{\beta}{1-\alpha} \ln h^* - \frac{\alpha}{1-\alpha} \ln(n+g+d)$$

2. This shows how we obtain Equation (1.14).

From Equation (4.9), we have the following expression:

$$\ln y_t - \ln y_{t-s} = -\varphi(\lambda) \left[\ln y_{t-s} - \frac{\alpha}{1-\alpha} \ln s_k - \frac{\beta}{1-\alpha} \ln h^* + \frac{\alpha}{1-\alpha} \ln(n+g+d)\right]$$

where $y = \frac{Y}{AL}$. Taking $s = 1$, then it is equivalent to express Equation (4.9) in the following way:

$$\ln \frac{Y_t}{A_t L_t} - \ln \frac{Y_{t-1}}{A_{t-1} L_{t-1}} = -\varphi(\lambda) \left[\ln \frac{Y_{t-1}}{A_{t-1} L_{t-1}} - \overbrace{\frac{\alpha}{1-\alpha} \ln s_k - \frac{\beta}{1-\alpha} \ln h^* + \frac{\alpha}{1-\alpha} \ln(n+g+d)}^{F}\right]$$

$$\rightarrow \ln \frac{Y_t}{L_t} - \ln \frac{Y_{t-1}}{L_{t-1}} = -\varphi(\lambda) \left[\ln \frac{Y_{t-1}}{L_{t-1}} - F\right] + \ln A_t - \ln A_{t-1} + \varphi(\lambda) \ln A_{t-1}$$

$$\rightarrow \ln \widetilde{y}_t - \ln \widetilde{y}_{t-1} = -\varphi(\lambda)\left[\ln \widetilde{y}_{t-1} - F\right] + \varphi(\lambda)\ln A_0 + g\left[\varphi(\lambda)t - \varphi(\lambda) + 1\right]$$

3. We follow Arnold et al. (2007) to approximate $\ln s_k$ using $\ln s_{k,t} + \Gamma\Delta \ln s_{k,t}$, as the share of human capital investment in GDP in the steady state (s_k) is not observable. Γ is a function of parameters of the model that need not be specified and the term $\Gamma\Delta \ln s_{k,t}$ is included in the short-run dynamics in Equation 1.15. Similarly, we approximate $\ln h^*$ using $\ln h_t + \Psi\Delta \ln h_t$, where Ψ is a function of parameters and the term $\Psi\Delta \ln h_t$ is included in the short-run dynamics in Equation 1.15. Following Arnold et al. (2007), we approximate $\ln(n + g + d)$ using n_t, as both g and d are not directly observable.

References

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