Technological change and the composition of taxes and public expenditures[*]

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This version: October 2012

Abstract

The paper analyzes the determinants of four fiscal trends, observed in many developed countries over the past 40 years: a decline in the corporate tax rate and public investment offset by an increase in the labour income tax and government consumption. Within a simple neoclassical growth model with a public sector, we illustrate the interdependency between the two government problems of how to spread the tax burden and how to allocate the spending. We find that investment-specific technological changes account for one third of the change in the composition of taxes and two thirds of the change of the composition on spending.

JEL Classification: E62; H21; H54.

Keywords: Profit tax; Labor tax, Public Capital; Investment-specific technological change

"If you were successful, somebody along the line gave you some help. [...] Somebody invested in roads and bridges. If you've got a business – you didn't build that. Somebody else made that happen."
– President Barack Obama, Roanoke (VA), July 13th 2012.

1 Introduction

Over the past four decades most developed countries have experienced similar trends in several government instruments, both on the expenditure and on the taxation side. Compared to the 1960s, many governments are now allocating relatively more resources to government consumption than to public investment and shifted part of the taxation burden from corporate profits to labour income.

As shown in Figure 1, in the G7 countries government consumption has increased on average from 14 to 20 percent of GDP, while public investment has declined from 4.5 to below 3 percent of GDP. At the same time the statutory corporate tax rate has declined by 15 percentage points, while the marginal labour income tax has increased by 15 percentage points. Most of the OECD countries share at least three of these trends and the decline of the two ratios is generally robust.[1]

There are several possible explanations for these trends. For instance, the decline in the corporate tax rate has been attributed to the higher tax competition [see Devereux et al. (2002)]. The increase in government consumption has been related to the increase in openness, either because the increasing risk of international markets raise the demand for insurance from governments [Rodrik (1998)] or because openness shifts the burden of taxation abroad giving an incentive for governments to spend [Epifani and Gancia (2009)]. Also, Mehrotra and Välilä (2006) discuss the possible causes for the decline of public investment. Among the most compelling hypotheses is the decreasing need of public infrastructure and the need for fiscal stringency, particularly in Europe. These studies considered each fiscal trend in isolation. However, the proposed theories are not necessarily consistent with the remaining trends. For instance, if countries are competing for mobile capital by lowering corporate taxes, why are they decreasing public investment, an important determinant of foreign direct investment? Also, if openness has shifted the burden of taxation abroad, why

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[1]In a separate online appendix we show the variables disaggregated by country as well as for an average of 20 OECD countries. Most of the countries share the same four trends. The average within country correlation of the ratio of profit taxes over labour income tax, and the ratio of public investment over consumption is around 0.5.

Figure 1: Taxes and allocation of public spending in the G7 countries
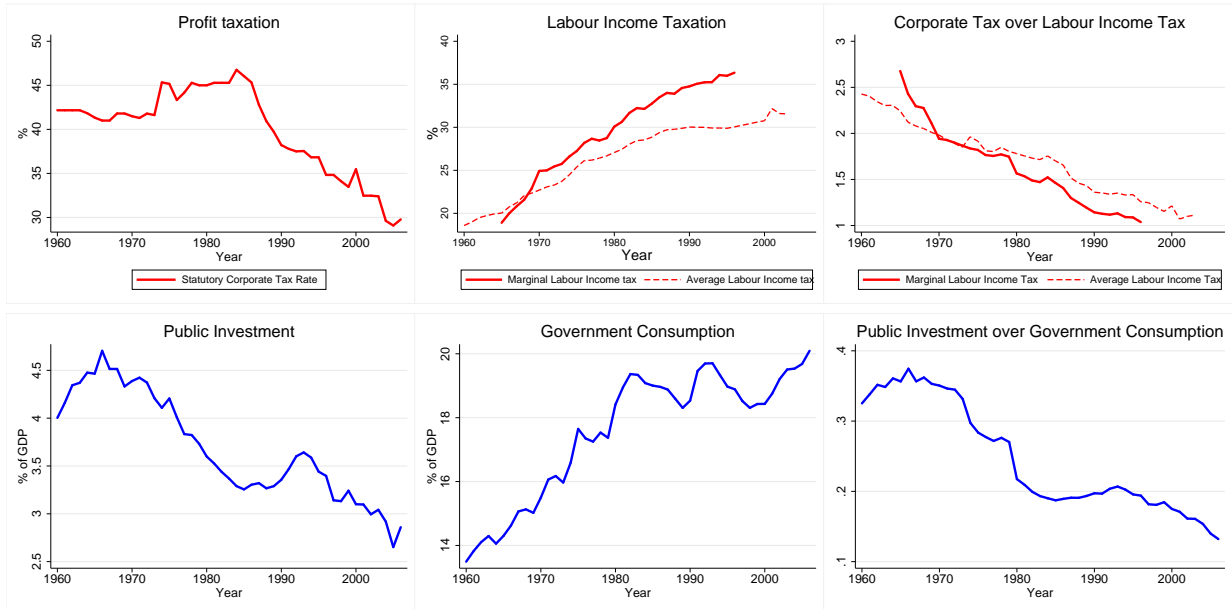
Note: The sources for the corporate tax rate is the Michigan World tax database, the marginal labour income tax is from Mendoza et al. (1994) and the average labour income tax is from the Institutions Data Set. The public investment and the government consumption series are from OECD. Series are an arithmetic mean for: Canada, France, Germany, Italy, Japan, United Kingdom and United States.

would governments increase consumption but lower investment? Understanding the reasons behind the co-movements of the four fiscal trends remains therefore an open question.

This paper proposes a positive analysis which provides useful insights in explaining these facts. Our theory is based on the idea that there is an intrinsic relation between the composition of tax revenues and the allocation of public expenditures. We develop this concept within a standard neoclassical growth model with a public sector, where a government chooses how to allocate the public expenditure between public consumption and investment in productive public capital. Public expenditures are financed by levying taxes on labour income and corporate profits. The concurrence of public capital and profit taxes introduces a link between the choice of how to allocate expenditure and how to finance it. Public capital increases the marginal productivity of private factors, partially counteracting the distortions created by the tax system. It also creates economic rents for firms, increasing their profits.

The model dynamics are driven by investment-specific technological change, in the spirit of Greenwood et al. (1997). A key feature of this study is the distinction between the rates of technological progress of private and public investment. As recognized in the literature, technological change mainly came from advancements in equipment and software, rather than in structures. Also, in the United States private non-residential investment consists mainly

of equipment and software (70 percent on average), while the government invest primarily in structures (around 65 percent).[2] It then follows that private and public investment must have experienced a different rate of technological progress. Following the procedures described in Gordon (1990), Greenwood et al. (1997) and Cummins and Violante (2002)), our calculations suggest that investment-specific technological progress was about three times faster than in the private sector than in the public sector, with an average growth rate of 2.4% and 0.8% per year, respectively.

The differences in the rates of technological progress have important implications for the behavior of our fiscal variables. As the productivity of public infrastructure declines relative to private capital, the government reduces public investment and raises government consumption. Additionally, as distortions in the private capital become more costly and the firms enjoy fewer rents, the government also reduces the profit tax and compensates by increasing the labour income tax. Quantitatively, we find that investment-specific technological changes alone account for one third of the change in the composition of taxes and two thirds of the change of the composition on spending.

The model is also used to evaluate alternative explanations, associated with "fiscal constraints", limiting the choices of one or more fiscal instruments. In our setting, any exogenous constraint in one of instruments affects the optimal choice of the other three, and can potentially explain the patterns in the data. We find, however, that while an exogenous change in only one instrument can quantitatively account for the change in the ratios of taxes and spending, it cannot explain the four trends separately. Similarly, we find that an exogenous increase in preferences for government consumption has counterfactual implications for the tax rates and public investment.

From an empirical viewpoint, and as a first attempt to distinguish between the possible explanations, we estimate the determinants of the tax and spending ratios, for OECD countries between 1965 and 2004. We find that both the tax and spending ratios are highly correlated with GDP per capita which suggests that technological changes has played an important role.

Our work builds on the large fiscal policy literature studying the role of public capital. This includes several works analyzing the effects of different fiscal instruments on economic growth [see e.g. Arrow and Kurz (1970), Barro (1990), Turnovsky (1997, 2000) and Baier and Glomm (2001)], and on business cycle fluctuations [see e.g. Baxter and King (1993) and

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[2]See Figure A-2 in the appendix.

Lansing (1998)]. Our paper aims instead at explaining the behavior of the fiscal instruments themselves, within a model where both taxes and expenditures are determined endogenously. Many existing studies have analyzed the choice between capital vs labor income taxation. We highlight how that choice may be intrinsically related to the allocation of expenditure across different public goods. In our model, taxing profits constitutes a way to extract the private rents generated by public capital. As a result, corporate taxes are positive also in the long-run – as opposed to the optimality of zero capital taxation in the Judd (1985) and Chamley (1986) framework.[3]

The paper continues as follows. In section 2 and 3 we describe the model, illustrate the main intuition within a simple example, and characterize the solution of the optimal policy problem. In section 4 we calibrate the model, analyze the impact of technological progress on the fiscal instruments and look at whether other sources of the observed trends are plausible. We conduct an empirical study in section 5 and section 6 concludes the paper.

2   The model

We consider a standard neoclassical growth model, augmented with productive public capital, and investment-specific technological progress. The economy is populated by a representative firm, a representative household and a government.

2.1   The economic environment

Output is produced by the representative firm using labor (n_t), private capital (K_t) and public capital (P_t). Following Arrow and Kurz (1970), we consider a constant return to scale production function $Y_t = F(K_t, P_t, n_t)$. The function $F(\cdot)$ is also assumed to be twice continuously differentiable and concave in all its arguments. Taking as given the interest rate on private capital (R_t), the wage rate (w_t), the corporate tax rate (τ_t^π), and the supply of public capital (P_t), the representative firm chooses the production factors to maximize its after-tax profits, given by

$$(1 - \tau_t^\pi) \left[F(K_t, P_t, n_t) - w_t n_t - \zeta R_t K_t \right] - (1 - \zeta) R_t K_t. \tag{1}$$

In writing equation (1), and only for the purposes of the quantitative analysis of section 4,

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[3]More generally, and as originally shown by Correia (1996) and Jones et al. (1997), when the tax system is incomplete, taxing corporate profits is an indirect way of taxing a factors of production that cannot be taxed directly. Also, Abel (2007) and Conesa and Dominguez (2006) describe environments with a non-zero optimal profit taxation, as long as dividends and capital income can be taxed at different rates.

we are assuming that a proportion $0 \leq \zeta < 1$ of the cost of capital can be deducted from the tax base. This reflects the fact that usually firms can deduct most of the depreciation costs of capital and a fraction of the financial costs of capital. The latter may reflect the firm's financing structure – assumed to be exogenous to our model – divided between bonds and equity. Typically bond interest payments can be deducted from the tax base, while dividends to shareholders cannot.[4] The parameter ζ introduces a wedge between the statutory tax rate and the effective tax rate on capital. In the limiting case of $\zeta = 0$, the profits tax rate coincides with the tax rate on capital income. At the other extreme, if all the costs of capital could be deducted from the tax base (i.e. if $\zeta = 1$), the profit taxation would be non-distortionary, and corporate taxes would always be used to their maximum extent.

In order for the firm's problem to be well-defined, we impose a limit on corporate tax rate $\tau^\pi \leq \bar{\tau}^\pi < 1$. Otherwise the firm's profits would always be negative, as can be seen in equation (1). Once this limit is imposed, and given the positive externality produced by public capital, the firm's profits are strictly positive in equilibrium, and the tax base for corporate taxation is then well-defined.[5]

As in Greenwood et al. (1997), we model investment-specific technological change assuming that the accumulation of private and public capital is given by

$$K_{t+1} = q_t^k i_t^k + K_t \left(1 - \Delta^k\right) \tag{2}$$

$$P_{t+1} = q_t^p i_t^p + P_t \left(1 - \Delta^p\right) \tag{3}$$

where Δ^k and Δ^p denote the rate of physical depreciation, and the factors q_t^k and q_t^p represent the degree of technology for producing capital goods. Throughout the analysis it is assumed that q_t^k and q_t^p grow over time at constant rates γ^k and γ^p, where possibly $\gamma^k \neq \gamma^p$.

The representative household makes her choices about investment (i_t^k), consumption (c_t), and labor (n_t), maximizing the lifetime utility

$$\sum_{t=0}^{\infty} \beta^t u\left(c_t, g_t, n_t\right), \tag{4}$$

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[4]In practice, the empirical work of Gordon and Lee (2001) shows that a decline in corporate taxes by ten percentage points (from 46% to 36%) would increase the fraction of assets financed with equity by only 3.5%.

[5]To preserve positive profits, but departing from the constant returns to scale assumption, one could include an additional factor of production in fixed supply that cannot be taxed (e.g. managerial ability), or consider other frictions like monopolistic competition and limited entry, not explicitly modeled here for simplicity.

subject to the sequence of constraints (2) and the budget constraint

$$c_t + i_t^k = w_t n_t (1 - \tau_t^n) + R_t K_t + \Upsilon_t \quad \forall t = 0, 1, 2, \ldots \tag{5}$$

The utility function $u(\cdot)$ is assumed to be separable and twice continuously differentiable in all its arguments, increasing and concave in the two types of consumption, and decreasing and concave in labor.[6] In solving her problem, the household takes as given the sequences of prices (w_t, R_t and q_t^k) as well as the labor income tax (τ_t^n), the public expenditure (g_t), and all the lump-sum transfers in terms of profits or government subsidies (Υ_t).

The government provides the public good g_t and the public investment i_t^p, raising taxes on labor income and corporate profits, subject to the balanced budget condition[7]

$$g_t + i_t^p = \tau_t^n (w_t n_t) + \tau_t^\pi (y_t - w_t n_t - \zeta R_t K_t). \tag{6}$$

Finally, the aggregate feasibility constraint is given by

$$c_t + g_t + \frac{P_{t+1} - (1 - \Delta^p)P_t}{q_t^p} + \frac{K_{t+1} - (1 - \Delta^k)K_t}{q_t^k} = F(K_t, P_t, n_t). \tag{7}$$

2.2 The competitive equilibrium

We can now define the competitive equilibrium as follows.

Definition 1 *Given a process for technology $\{q_t^k, q_t^p\}_t^\infty = 0$, and initial stock of private capital (K_0) and public capital (P_0), a competitive equilibrium is a feasible allocation $\{c_t, K_{t+1}, n_t\}_{t=0}^\infty$, a policy $\{P_{t+1}, g_t, \tau_t^\pi, \tau_t^n\}_{t=0}^\infty$ and a price system $\{R_t, w_t\}_{t=0}^\infty$ such that (i) for given prices, policies and initial capital k_0 the allocation maximizes (4) subject to the sequence of constraints (5), the capital accumulation (2) and a no-Ponzi scheme constraint; (ii) in any period t, the firm maximizes (1), given prices and public capital P_t; (iii) the government policies satisfy the budget constraint (6) and the public capital accumulation (3).*

As shown in appendix A-1.1, expressing the stocks of capital in efficiency-units, i.e. $k_t \equiv K_t/q_t^k$ and $p_t \equiv P_t/q_t^p$, defining the rates of economic depreciation $\delta^k \equiv 1 - \left(1 - \Delta^k\right)/\gamma^k$

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[6]In previous versions of this paper, we considered a specification where also public capital delivered a utility flow. Since the results are virtually identical, we prefer the current specification that simplifies the exposition of the results.

[7]Since the government can accumulate public capital, the balanced budget condition only limits the possibility of the government to borrow from the private sector. This assumption is made for simplicity, and is largely irrelevant for the long-run implications of our analysis.

and $\delta^p \equiv 1 - (1 - \Delta^p)/\gamma^p$, and defining the production function $f(k_t, p_t, n_t) \equiv F(K_t, P_t, n_t)$, the competitive equilibrium is fully characterized by the following relations:

$$c_t + g_t + p_{t+1} - (1 - \delta^p)p_t + k_{t+1} - \left(1 - \delta^k\right) k_t = f(k_t, p_t, n_t), \tag{8}$$

$$g_t + p_{t+1} - (1 - \delta^p)p_t = \tau_t^n \left(f_{n,t} n_t\right) + \tau_t^\pi \left(f_{p,t} p_t + \frac{1 - \zeta}{1 - \zeta \tau_t^\pi} f_{k,t} k_t\right) \tag{9}$$

$$-\frac{u_{n,t}}{u_{c,t}} = f_{n,t}(1 - \tau_t^n), \tag{10}$$

$$u_{c,t} = \beta u_{c,t+1} \left[1 + \frac{1 - \tau_{t+1}^\pi}{1 - \zeta \tau_{t+1}^\pi} f_{k,t+1} - \delta^k\right], \tag{11}$$

As a result, the model is equivalent to a standard growth model, with the only differences that the capital stocks are measured in efficiency units, and δ^k and δ^p measure economic as opposed to physical depreciation. The first two equations represent the feasibility constraint and the government budget constraint, while the last two equations constitute the equilibrium conditions in the labor and capital markets, as it result from the optimality conditions of households and firms.

Some considerations are in order. First, as indicated by the Euler Equation (11), the ratio $(1 - \tau_t^\pi)/(1 - \zeta \tau_t^\pi)$ constitutes a wedge between the rate of intertemporal substitution and the marginal returns on capital, and implies an effective tax rate on private capital of $\tau^\pi(1 - \zeta)/(1 - \zeta \tau^\pi)$. Second, the government budget constraint (9) indicates that the tax base for corporate taxes is composed by two elements: the returns on private capital ($f_{k,t} k_t$) and the returns on public capital ($f_{p,t} p_t$). The presence of the latter term shows why taxing capital income is different from taxing corporate profits. Taxing corporate profits allows the government to appropriate a part of the rents associated with the provision of public capital. This indicates that the supply of public capital and the corporate profit tax rate are two interrelated choices.

3 The fiscal policy problem

3.1 A simple example with a closed-form solution

We first consider a simple example admitting an analytical solution and that illustrates the steady-state relationship between the supply of public capital and the composition of taxes. In particular, suppose the production function is Cobb-Douglas $y = k^\eta p^{\alpha - \eta} n^{1 - \alpha}$, with $0 < \eta < \alpha < 1$, the degree technology is constant ($q^k = q^p = 1 \; \forall t$), capital fully depreciates ($\delta^k = \delta^p = 1$) and that the cost of capital is not tax-deductible ($\zeta = 0$). The utility function

takes the form $u(c,n) = \log c - \frac{\phi}{2}\left[\log(n)\right]^2$, with $\phi > 1$.[8] Public consumption does not provide any utility, and is normalized to $g = 0$ without loss of generality.

In this economy, the equilibrium conditions (8) - (11) evaluated at steady-state, simplify to

$$\hat{c} \equiv c/y = 1 - \hat{p} - \hat{k} \tag{12}$$

$$\hat{p} \equiv p/y = \alpha\tau^\pi + (1 - \alpha)\tau^n \tag{13}$$

$$\hat{c}\phi\log n = (1 - \alpha)(1 - \tau^n) \tag{14}$$

$$\hat{k} \equiv k/y = \beta\eta(1 - \tau^\pi). \tag{15}$$

We can now analyze the problem of a government choosing the fiscal instruments (τ^π, τ^n, $\hat{p}$) to maximize the steady-state utility. For convenience, let's define $x \equiv \frac{1-\tau^\pi}{1-\hat{p}}$, so that the government problem becomes

$$\max_{x,\hat{p}} \ U(x,\hat{p}) \ = \ \log\hat{c}(x,\hat{p}) + \log y(x,\hat{p}) - \frac{\phi}{2}\left[\log n(x)\right]^2$$

where the welfare relevant variables are given by

$$\log y(x,\hat{p}) \ = \ \frac{\alpha - \eta}{1 - \alpha}\log\hat{p} + \frac{\eta}{1 - \alpha}\left[\log x + \log(1 - \hat{p}) + \log\beta\eta\right] + \log n(x) \tag{16}$$

$$\log\hat{c}(x,\hat{p}) \ = \ \log(1 - \beta\eta x) + \log(1 - \hat{p}) \tag{17}$$

$$\phi\log n(x) \ = \ \frac{1 - \alpha x}{1 - \beta\eta x} < 1 \tag{18}$$

where the inequality follows from the fact that $\alpha > \eta$.[9] From the definition of x and condition (18) it is easy to verify than in any equilibrium with non-confiscatory policies, i.e. $\tau^\pi < 1$ and $\tau^n < 1$, it must be that $0 < x < 1/\alpha$. We can now show three properties of the optimal policy plan (x^*, p^*).

Result 1 *The optimal policy plan is characterized by the following properties: (i) the optimal profit tax rate is a strictly increasing linear function of $\hat{p}$; (ii) the optimal supply of public capital is increasing in the public capital income share, and (iii) the tax - ratio τ^π/τ^n is increasing in $\hat{p}^*$ if and only if $x^* > 1$.*

Proof. Result (i) follows from the fact that, as implied by eqs. (16) - (18), the utility

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[8]Two conditions have to be satisfied by this specific utility function: (i) $u_n < 0$, requiring $\log n > 0$, and (ii) $u_{nn} < 0$, requiring $\log n < 1$. Equation (18) implies that in equilibrium $0 < \log n < 1$, and hence both conditions are satisfied.

[9]These equations can be obtained using (15) to replace $\hat{k}$ into eq. (12), (13) to substitute for $(1 - \tau^n)$ into eq. (14) and rearranging the production function.

function is separable in x and $\hat{p}$. Hence, the optimal value of x is independent of the level of $\hat{p}$, and the optimal profit tax is given by

$$\tau^\pi = 1 - x^*(1 - \hat{p}). \tag{19}$$

Result (ii) immediately follows from the condition $U_{\hat{p}} = 0$, implying that $\hat{p}^* = \alpha - \eta$. This indicates that the higher is the public capital income share, the higher the optimal profit tax rate and the supply of public capital. Finally, using the government budget constraint (13), the ratio between the tax rates is given by

$$\frac{\tau^\pi}{\tau^n} = \frac{1}{\tau^n} \frac{1 - x^*}{1 - \alpha x^*} + \frac{(1 - \alpha)x^*}{1 - \alpha x^*}. \tag{20}$$

Since x^* does not change with $\hat{p}$, we have

$$\frac{\partial \frac{\tau^\pi}{\tau^n}}{\partial p} = -\left(\frac{1}{\tau^n}\right)^2 \frac{\partial \tau^n}{\partial p} \frac{1 - x}{1 - \alpha x} > 0$$

$$\Leftrightarrow 1 < x < \frac{1}{\alpha},$$

which proves result (iii). ∎

The above results imply that as public capital becomes a less important factor of production – e.g. because of a reduction in $(\alpha - \eta)$ – the optimal plan prescribes a reduction in profit taxation both in absolute terms and, under easily verifiable conditions, relatively to labor income taxes. Finally, notice that equation (19) can alternatively be viewed as a simple fiscal rule. This suggests that our previous considerations would remain valid also in environments where governments do not behave optimally, but still recognize the interdependence between profit taxation and the supply of public capital, in the spirit of the quote in the introduction.[10]

3.2 Optimal fiscal policies

We now characterize the solution to the problem of a benevolent (Ramsey) planner, choosing the the best competitive equilibrium implied by the policies $\{p_{t+1}, g_t, \tau_t^n, \tau_t^\pi\}_{t=0}^\infty$. More formally, the planner's problem is to maximize eq. (4), subject to eqs. (8) - (11) and $\tau^\pi \leq \bar{\tau}^\pi$, for given initial conditions p_0 and k_0.

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[10]For instance, appendix A-1.3 shows that the results described above are also valid in the extreme case of a "leviathan" government, who only derives utility from the supply of public consumption.

To better understand the interactions between the tax rates and the composition of public expenditure, we can look at the first-order optimality condition with respect to the corporate tax rate, given by

$$\mu_{1,t}\left[f_{p,t}p_t + \frac{1-\zeta}{(1-\zeta\tau_t^\pi)^2}f_{k,t}k_t\right] = \lambda_{t-1}u_{c,t}f_{k,t}\frac{1-\zeta}{(1-\zeta\tau_t^\pi)^2}, \tag{21}$$

where $\mu_{1,t}$ and λ_{t-1} represent the shadow values of relaxing constraints (9) and (11), respectively.[11] The left-hand side of (21) represents the marginal benefits of increasing profit taxes due to the higher tax revenues. An increase in τ^π increases the revenues from public capital income (first term in the square brackets) and increases the tax rate applied to private capital income (as given by the ratio $\frac{1-\zeta}{(1-\zeta\tau_t^\pi)^2}$). An increase in τ^π also generates some welfare costs due to the interest rate distortions, as indicated in the right-hand side of (21). At an optimum, the planner equalizes these marginal costs and benefits. We can rewrite equation (21) as

$$\zeta\tau_t^\pi = 1 - \sqrt{\frac{f_{k,t}k_t(\lambda_{t-1}u_{c,t} - \mu_{1,t})(1-\zeta)}{\mu_{1,t}f_{p,t}P_t}}, \tag{22}$$

There are three elements that affect the choice of the tax rate. The first one is the extent to which the profit tax is tied to the tax rate on capital. If $\zeta = 1$, the firm can deduct all costs of capital from the tax base, corporate taxation becomes non-distortionary and the optimal tax rate is the upper-bound $\bar{\tau}^\pi$. In that case, the government could retrieve the maximum rents created by public capital. If $\zeta \neq 1$, the tax rate is distortionary and the government chooses it by balancing two opposite effects. On the one hand, the more distortionary the tax rate is, captured by the multiplier of the Euler equation, the lower the tax rate. On the other hand, it is increasing on the size of the rents $f_{p,t}p_t$ and on the shadow value of government revenue $\mu_{1,t}$. From these considerations it follows that the optimal level of corporate taxes is increasing on the amount of public capital supplied.

Also, the composition of public spending depends on the tax rates. This is clear when combining the first order conditions of government consumption and public capital, given by

$$\begin{aligned}
u_{g,t} = {} & \beta\mu_{2,t+1}\left[(1-\delta^p) + f_{p,t+1}\right] + \\
& \beta\mu_{3,t}(1-\tau_t^n)f_{pn,t+1} + \beta\lambda_t u_{c,t+1}\frac{1-\tau_{t+1}^\pi}{1-\zeta\tau_{t+1}^\pi}f_{pk,t+1} + \\
& \beta\mu_{1,t+1}\mathcal{R}_{P,t+1}, \tag{23}
\end{aligned}$$

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[11]For illustrative purposes only, we are assuming that the constraint $\tau^\pi \leq \bar{\tau}^\pi$ is not binding. Notice that the latter constraint might be binding in $t = 0$ but not in steady-state.

where $\mathcal{R}_{P,t+1} \equiv \left[(1 - \delta^p) + \tau^\pi_{t+1} \left(f_{pp,t+1} p_{t+1} + f_{p,t+1} \right) + \frac{\tau^\pi_{t+1}(1-\zeta)}{1-\zeta\tau^\pi_{t+1}} k_{t+1} f_{pk,t+1} + \tau^n_{t+1} f_{np,t+1} n_{t+1} \right]$ is the derivative of future government revenues with respect to public capital, while $\mu_{2,t}$ and $\mu_{3,t}$ are the shadow values of relaxing constraints (8) and (10), respectively.[12]

When choosing the allocation of spending between public investment and government consumption, the Ramsey planner equates the marginal benefit of the two types of public goods. If the government had lump sum taxes available, the marginal benefit of public investment would be the increase in future aggregate resources (first line). However, the presence of distortionary taxation gives more incentive for the government to invest. First, by increasing the productivity of private factors – and thus wages and the interest rate – it can stimulate employment and savings, counteracting the effects of distortionary taxes (second line). Second, public capital also increases future tax revenues (third line). In other words, public capital raises the marginal productivity of factors and increases the firm's rents that are taxed. Thus, higher tax rates, particularly the corporate tax rate, increase the return to public investment in terms of future tax revenues and raise the incentive for the government to invest instead of consume.

4   Technological progress and fiscal trends

We proceed next to investigate how investment-specific technological progress affect the fiscal policy choices. To that end, we calibrate the model to have some steady-state statistics within the range of the G7 countries during the '60s – the beginning of our sample evidence – and then analyze how that steady-state is affected by technological progress.

The choice of looking at the steady-state effects, as opposed to the entire transition dynamics, allows us to disentangle the effects of technological progress from the dynamics due to the re-optimization of the Ramsey plan.[13] The entire transition dynamics, but disregarding the effects of the initial re-optimizations are described in section 4.3. The transition dynamics are also explicitly taken into account in the empirical analysis of section 5.

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[12]The remaining first-order conditions are reported in appendix A-1.2.

[13]As common in the optimal taxation literature, a policy re-optimization would bring about an initial spike in profit taxation – to its upper bound – and a subsequent convergence to the steady state (after about 20 years). The implied behavior of the fiscal instrument is qualitatively consistent with what observed in the data, but the model would display an implausibly low labor tax rate in the beginning of the sample. For this reason, we abstract from considering the Ramsey re-optimization as an explanation of the observed trends. The corresponding figures are available in an online appendix.

4.1 Calibration

We specify the per-period utility function

$$u\left(c, g, n\right) = \frac{c^{1-\sigma_c}}{1-\sigma_c} - \psi^n \frac{n^{1-\sigma_n}}{1-\sigma_n} + \psi^g \frac{g^{1-\sigma_g}}{1-\sigma_g} \tag{24}$$

and a constant elasticity of substitution production function

$$f(k_t, p_t, n_t) = A_t \underbrace{\left[\theta \left(q_t^p p_t\right)^\rho + (1-\theta)(q_t^k k_t)^\rho\right]^{\frac{\alpha}{\rho}}}_{\equiv \mathcal{K}_t^\alpha} n_t^{1-\alpha}. \tag{25}$$

where A_t measures total factor productivity. This production function implies a unitary elasticity of substitution between labor and composite capital $(\mathcal{K}_t)$.[14] In turn, composite capital is obtained by combining public and private capital through a production function with a constant elasticity of substitution $\frac{1}{1-\rho}$. Also, as public expenditure enters separably in the utility function, the parameter ϕ_g could indifferently represent the preferences of a benevolent government, or those of self-interested politicians.

The model period correspond to a year, and the discount rate is accordingly set to $\beta = 0.96$, so that in steady-state the annual real interest rate is 4%. Furthermore, the curvature parameters in the utility function are fixed to $\sigma_c = 1$, $\sigma_n = 1$ (log - utility in consumption and hours) and $\sigma_g = 0.85$, which is close to the empirical estimates for the U.S. and the OECD countries [see e.g. Amano and Wirjanto (1997) and Nieh and Ho (2006)]. The eight remaining parameters ($\psi_n = 2.678$, $\psi_g = 0.362$, $\theta = 0.268$, $\rho = 0.362$, $\alpha = 0.346$, $\delta_k = 0.0767$, $\delta_p = 0.088$ and $\zeta = 0.868$) are calibrated by minimizing the sum-of-square deviations between some basic statistics implied by the model and their counterpart in the data, as summarized in Table 1.

As mentioned earlier, a crucial feature of the model is the role of public capital in the production function. The above parameters' values imply a relatively low public capital income share of about 6.1%, which lies at the lower-end of available estimates.[15] They also imply marginal distortion on private capital accumulation of about 10%. Finally, and without loss of generality, the technology parameters at the beginning of the sample are normalized to $q_0^k = q_0^p = A = 1$.

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[14] As common in the growth literature, our constant returns to scale production function is consistent with a balanced growth path in the presence of Harrod-neutral technological change, and reduces to the familiar Cobb-Douglas specification as $\rho \to 0$.

[15] For a recent survey of available estimates, together with a meta-analysis, see Bom and Ligthart (2008). Our value is also close to 5% used by Baxter and King (1993).

Table 1: Summary statistics: Data vs Model

	G7 countries	Model	
	(Average 1960-1970)	Pareto	Ramsey
Output	–	1.25	1
Hours (prop. of available time)	0.23	0.28	0.23
Private Capital (over GDP)	2.20	2.44	2.20
Public Capital (over GDP)	0.50	0.44	0.50
Private Investment (% GDP)	16.8	18.7	16.9
Public Investment (% GDP)	4.40	3.87	4.40
Gov't Consumption (% GDP)	14.6	14.7	14.6
Statutory Corporate Income Tax Rate	41.7	–	41.7
Marginal Labor Income Tax Rate	21.5	–	21.5

Note: The statistics for G7 economies refers to the simple average for the sample 1960-1970. The data sources are described in appendix A-2. Output in the Ramsey solution is normalized to one.

The measures of technological progress γ^k and γ^p are constructed decomposing private and public investment into investment in equipment and software (E&S) and structures, as available in the NIPA tables for the US. As summarized in Figure A-2, there are important differences in the quantities and in the prices of the two investment categories. First, the private sector invests primarily in E&S (about 70% of non-residential private investment), while public investment is mainly in structures (about 65%). Second, the price of structures increased on average at a rate of 1.4% per year over the sample period, while the price of E&S declined at a rate of about 2% per year. And, applying to the latter series a quality-bias adjustment factor of 2.5% per year – as suggested by Gordon (1983), and as calculated by Cummins and Violante (2002) for the period 1960-2000, the resulting constant-quality price index for E&S declined at a rate of 3.5% per year. Using the Tornquist procedure, the quality-adjusted price series and the quantity series are then combined to obtain price indexes for private and public investment, as a measure of technological advancements. The implied average growth rates are $\gamma^k = 1.0242$ and $\gamma^p = 1.008$. These growth rates, and given our initial normalization $q_0^k = q_0^p = A = 1$, imply that over a period of 35 years $q_{35}^k = (\gamma^k)^{35} = 2.31$ and $q_{35}^p = (\gamma^p)^{35} = 1.323$. In other words, our calculations suggest that the rate investment specific technological progress was about three times faster in the private sector than in the public sector. Given the production function (25), this is as if from the '60s to the 2000s capital became twice as more productive than public capital.

4.2 Explaining the co-movements of fiscal variables

The model can be used to assess the fiscal-policy implications of technological-change. Table 2 summarizes the steady-state effects of changing the technology parameters q^k, q^p from their baseline values (column 1) to the calibrated values for the 2000s (column 2), and leaving

all the remaining parameters unchanged. The movements of all the four fiscal variables, as well as those of output and private investment, are qualitatively consistent with their counterparts in the data. And, even though the model does not display a balanced growth path, hours worked remain roughly constant as output grows.

On the expenditure side there is a transfer of resources from public investment to government consumption. The investment-specific technological progress observed in the data introduces two motives to reduce public investment. First, because the effect of public capital on output is lower, and thus public investment is less profitable. Second, because public capital has less power to counteract the distortions of the tax system, as well as a dimmer impact on the stream of future tax revenues. As a result, the public to private capital ratio decline, as well as the ratio between public investment and government consumption.

Furthermore, given interdependencies between taxation and the supply of public capital illustrated above, this brings about a decline of profit taxation relatively to labor taxation. On the one hand, as public capital becomes relative less productive, the government reduces the corporate tax rate to extract a smaller fraction of the rents. For example, as the share of public capital in the production function is zero (i.e. as $q^k \to \infty$ or $q^p \to 0$), the model is equivalent to the standard model of optimal dynamic taxation. There are no rents in production, so the optimal steady-state profit tax rate is zero. One the other land, the distortions on private capital accumulation become more severe. Labor taxes are increased both for a revenue and a substitution effect, and thus the ratio between corporate and labor taxes decreases.

Table 2: Fiscal instruments and technological progress

	Baseline	Investment-Specific	Investment-Specific + TFP	TFP Only	Data G7 countries 1960-1970	Data G7 countries 1995-2005
Tax rates						
Corporate tax rate (%)	41.7	37.9 (43)	39.1 (29)	42.9 (-14)	41.7	32.9
Labor tax rate (%)	21.5	22.6 (8)	24.2 (18)	22.9 (10)	21.5	36.3
τ^π/τ^n	1.94	1.67 (26)	1.62 (31)	1.87 (9)	1.94	0.90
Government spending						
Gov't consumption$^\$$	14.6	15.4 (19)	16.6 (45)	15.7 (25)	14.6	18.9
Public investment$^\$$	4.43	3.34 (79)	3.37 (77)	4.44 (-3)	4.43	3.07
i^p/g	0.30	0.22 (61)	0.20 (70)	0.28 (13)	0.30	0.16
Non-fiscal variables						
GDP per capita	1	1.49 (33)	2.52 (100)	1.69 (45)	1	2.52
Private investment$^\$$	16.9	18.0 (93)	17.9(86)	16.8 (-8)	16.8	18.0
Hours	0.23	0.23 (1)	0.23 (2)	0.23 (1)	1	0.83

Note: In parenthesis is the percentage of the total variation in the data accounted for by the model. The statistics for G7 economies refers to the simple average for the sample 1960-1970 and 1995-2005. The data sources are described in appendix A-2. $^\$$ is in percentage of GDP. GDP per capita is normalized to 1 in the initial point.

Quantitatively, investment-specific technological progress alone accounts for one third of the change in the tax ratio and two thirds of the change in the spending ratio. It accounts for about 80% of the decline in public investment and more than 40% of the decline in the corporate tax rate. The effects on the labour tax rate and government consumption, albeit in the right direction, are quantitatively smaller, and correspond respectively to 8% and 19% of what observed in the data. However, considering also the effects of total factor productivity, namely calibrating the parameter A residually to match the observed growth rate of output (as reported in column 3), the model is able to account for about 18% of the increase in labor income taxes and 45% of the increase in government consumption. By itself, technological progress only driven by TFP would have counterfactual implications for both corporate tax rate and public investment (see column 4).

4.3 Robustness

We have explored the robustness of our results to alternative calibrations. Table 3 reports the results under different values of the curvature parameters in the utility function, exogenously fixed in our baseline calibration.[16] The first column reports the values obtained under the baseline calibration. In the second column, the value of σ_n has been increased from 1 to 4, in order to have an aggregate Frisch elasticity of labor supply of about 0.77, in line with the recent results of Chetty et al. (2011). In the third column the curvature parameters for private and public consumption are increased to $\sigma_c = 2$ and $\sigma_g = 1$, and the fourth column considers the first two experiments jointly. In all the exercises, the remaining parameters are re-calibrated according to the procedure described in the previous sub-sections. In all these cases, the effects of investment-specific technological change are very similar to those obtained under the baseline calibration. Quantitatively, with higher σ_c and σ_g, investment specific technological progress does a better job explaining the changes in the allocation of spending, accounting for between 70 and 100 percent of the changes in government consumption and investment. On the taxation side, it improves the response of the labour tax to around 30 percent, but reduces percentage explained of the corporate tax rate to around 20.[17]

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[16]In separate exercises, we found that behavior of the fiscal instruments is monotone in changes of other preferences and technological parameters. Thus, our comparative statics exercises are largely insensitive to the particular initial values of those parameters. Specific results are available in a companion online appendix.

[17]If $\sigma_g = \sigma_c$, technological changes account for a smaller proportion of the change in public consumption and labour income tax. As the supply of g becomes relatively inelastic, the economy resemble one where public expenditure is fully exogenous. Available estimates by Amano and Wirjanto (1997) and Nieh and Ho (2006) do suggest that $\sigma_g < \sigma_c$.

Table 3: Effects on Investment-Specific Technological progress under alternative calibrations

	Baseline		Alternative	
	$\sigma_c = 1$, $\sigma_g = 0.85$	$\sigma_c = 1$, $\sigma_g = 0.85$	$\sigma_c = 2$, $\sigma_g = 1$	$\sigma_c = 2$, $\sigma_g = 1$
	$\sigma_n = 1$	$\sigma_n = 4$	$\sigma_n = 1$	$\sigma_n = 4$
Tax rates				
Corporate tax rate (%)	37.9 (43)	37.6 (48)	40.8 (11)	39.6 (25)
Labor tax rate (%)	22.6 (8)	22.8 (7)	26.6 (32)	25.9 (27)
τ^π / τ^n	1.67 (26)	1.65 (27)	1.53 (38)	1.55 (38)
Government spending				
Gov't consumption$^\$$	15.4 (19)	15.2 (18)	18.1 (85)	17.5 (72)
Public investment$^\$$	3.34 (79)	3.24 (85)	3.29 (82)	3.06 (99)
i^p / g	0.21 (64)	0.21 (64)	0.18 (87)	0.18 (92)
Non-fiscal variables				
GDP per capita	1.49 (33)	1.47 (31)	1.26 (17)	1.30 (20)
Private investment$^\$$	18.0 (93)	17.7 (101)	17.4 (88)	17.3 (110)
Hours	0.23 (2)	0.23 (0)	0.20 (79)	0.21 (59)

Note: The table report the effects of investment-specific technological change on the corresponding variables. For all the calibrations the initial values (pre-technological progress) are virtually identical to those reported in Table 1, and are omitted for brevity. In parenthesis is the percentage of the total variation in the data accounted for by the model.$^\$$ is in percentage of GDP.

Another element of robustness is to consider the entire transition dynamics rather than looking at steady-state effects. To that end, as reported Figure 2, we calculate the transition dynamic under perfect foresight of investment-specific technological progress with constant growth rates γ^k and γ^p. In doing so, we assume that the Ramsey plan was made 20 periods in advance (say in 1940), so that the effects of a policy reoptimization are vanished at the beginning of the sample data. The reported dynamics are then solely the consequence of technological progress and the results are virtually identical, both qualitatively and quantitatively, to the steady-state analysis of the previous section.

4.4 Assessing alternative explanations

An important corollary of the interdependence of fiscal instruments is that exogenous changes in one of the instruments can affect the optimal choices of all other instruments. In principle, any explanation for one trend discussed in the introduction can potentially explain the other three. Our model provides a laboratory to investigate the implications of particular exogenous movements in an instrument – say for political or economic conditions – for the allocation of spending and the division of the tax burden. We analyze the effects of constraining each of the four instruments. The results are shown in Table 4.

As the corporate tax rate decreases exogenously, the government tries to get additional revenue by raising the labour income tax. However, as total revenue falls, there is a reduction in all types of expenditures, particularly government consumption. As government

Figure 2: Ramsey plan under perfect foresight technological progress
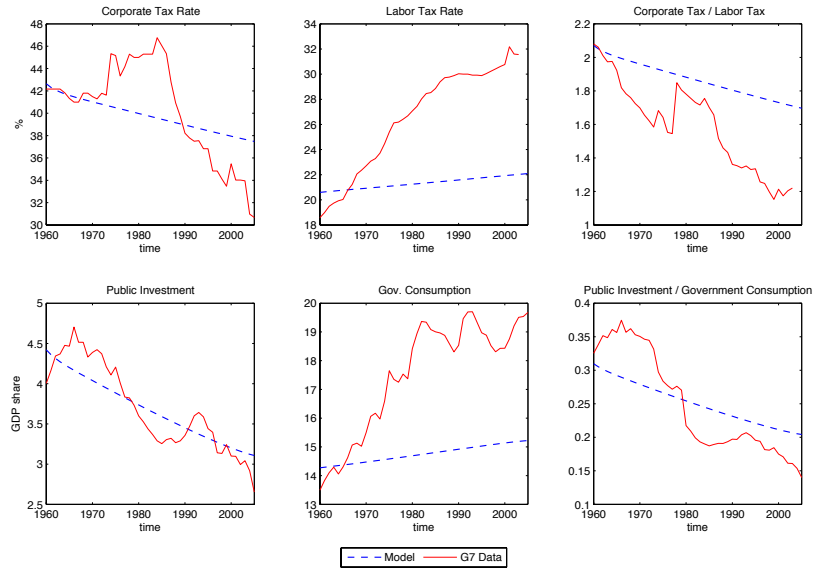
consumption increases exogenously, both taxes go up in order to raise revenue, particularly the labour income tax. On the other hand, although the government consumption drains so much revenue, there are more incentives for the government to invest because of higher taxes, such that it is optimal to increase public investment.

When one instrument changes for exogenous reasons, there is a revenue and a substitution effect. The substitution effect comes directly from the first-order conditions of the Ramsey problem, altering the ratios of spending and taxes. However, when the government exogenously increases one type of expenditure, it will require higher revenue which will push both tax rates up. Similarly, when it decreases one tax rate, it will generate lower revenue, so it forces both types of spending to go down. In most of the cases considered the revenue effects overcomes the substitution effect. Therefore, although we can explain the comovement between the two ratios with exogenous changes in only one instrument, we do not obtain the appropriate comovement between the four instruments. For an alternative explanation to be able to explain the four trends, it would be required to independently affect the incentives of two or more fiscal instruments.

An alternative explanation for the rise in government consumption could be the increase in the size of governments, reflecting a higher appetite for public goods of self-interested politicians and/or the underlying society.We use our model to investigate this hypothesis. In particular, we increase the value of the utility parameter ϕ_g to match the increase in government consumption from 14.6% to 18.9% of GDP. The results are similar to the exogenous changes of government consumption. It generates an increase in the labour income

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Table 4: Explaining the fiscal trends - fiscal constrains

	Baseline	Taxation		Spending		Data G7 countries	
		$\tau^\pi = 0.33$	$\tau^n = 0.36$	$g/y = 18.9\%$	$i^p/y = 3.1\%$	1960-1970	1995-2005
Tax rates							
Corporate tax rate (%)	41.7	*	-12.3 (613)	45.0 (-38)	38.9 (31)	41.7	32.9
Labor tax rate (%)	21.5	22.9 (10)	*	27.4 (40)	20.6 (-6)	21.5	36.3
τ^π/τ^n	1.90	1.44 (48)	-0.02 (-430)	1.64 (25)	1.89 (5)	1.94	0.90
Government spending							
Gov't consumption$^\$$	14.6	14.4 (-5)	17.5 (67)	*	14.7 (3)	14.6	18.9
Public investment$^\$$	4.43	4.24 (12)	5.07 (-49)	4.53 (-10)	*	4.43	3.10
i^p/g	0.31	0.29 (5)	0.29 (8)	0.24 (44)	0.21 (65)	0.30	0.16
Non-fiscal variables							
GDP per capita	1	1 (0)	0.96 (-2)	0.99 (-1)	0.98 (-1)	1	2.52
Private investment$^\$$	16.9	17.4 (46)	18.7 (154)	16.6 (-22)	17.5 (47)	16.8	18.0

Note: In parenthesis is the percentage of the total variation in the data accounted for by the model under the corresponding parameter change. In each row, asterisks denote the instruments targeted when changing the corresponding parameter(s). The statistics for G7 economies refers to the simple average for the sample 1960-1970 and 1995-2005. The data sources are described in appendix A-2. $^\$$ in percentage of GDP. GDP per capita is normalized to 1 in the initial point.

tax, but it implies an increase in both the corporate tax rate and public investment, which is inconsistent with the data. As the government needs to increase taxes to finance the higher consumption, it raises the distortions in the economy, thus increasing the incentive for building public capital.

In summary, our analysis suggests that technological changes may have played an important role in generating the four co-movements observed in the data. On the contrary, we found that exogenous changes in preferences or in the supply of public goods are inconsistent with the data, unless one considers a more complex combination of different fiscal constraints.

5   Empirical study

5.1   Methodology

The empirical part consist of the estimation of two equations of the composition of spending $\left(\frac{i_{it}^g}{g_{it}}\right)$ and the tax ratio $\left(\frac{\tau_{it}^\pi}{\tau_{it}^n}\right)$, for OECD countries. Our objective is not to find unambiguous evidence of causality, but to look whether the correlations in the data support the mechanisms of the model and the hypothesis that technological progress is an important driver of these two ratios. Therefore, we estimate both equations with panel fixed effects.

Tax structure

We include in the equation of the tax structure two main regressors, reflecting the main endogenous mechanisms of the model. The first one is the ratio of public to private capital

$\frac{p_{it}}{k_{it}}$. Given a certain level of total capital, a higher proportion of public capital, means that firms benefit of more economic rents, so governments have a bigger incentive to tax profits. The second one is the total amount of capital stock in the economy, both public and private: $\frac{k_{it}+p_{it}}{y_{it}}$. We can interpret this variable, as reflecting the dynamic transition to equilibrium.

$$\frac{\tau_{it}^\pi}{\tau_{it}^n} = \alpha_i + \rho_1 \frac{p_{it}}{k_{it}} + \rho_2 \frac{k_{it} + p_{it}}{y_{it}} + \rho_3 GDPpercapita_{it} + Controls_{it} \tag{26}$$

We then include the log of *GDP per capita* as a proxy for technological progress. We also include several types of controls. We include *Openness*, measured by the sum of imports and exports as a fraction of GDP, as a proxy for globalization. Some other controls are related to elements of the budget such as the budget deficit and the consumption tax. Others are elements of political nature like the percentage of left wing seats in the parliament and a dummy for election years. The unemployment rate is included to control for the cyclicality of some instruments. We also include a measure of education attainment and the log of population.

Allocation of spending

To understand the behaviour of expenditure side, we run regressions with the ratio of public investment to government consumption as a dependent variable. The model predicts that the composition of taxes should affect the composition of spending so we include $\frac{\tau_{it}^\pi}{\tau_{it}^n}$ in the regressions. To capture transition dynamics, we include both the total level of capital in the economy $\frac{k_{it}+p_{it}}{y_{it}}$ and the ratio of public to private capital $\frac{p_{it}}{k_{it}}$. Additionally, we include the log of GDP per capita, as well as the same controls plus the long-term interest rate.

$$\frac{i_{it}^g}{g_{it}} = \beta_i + \delta_1 \frac{\tau_{it}^\pi}{\tau_{it}^n} + \delta_2 \frac{p_{it}}{k_{it}} + \delta_3 \frac{k_{it} + p_{it}}{y_{it}} + + \delta_4 GDPpercapita_{it} + Controls_{it} \tag{27}$$

Data

We gather data for 20 OECD countries.[18] We use the top bracket statutory corporate tax rate from the Michigan World tax database and the marginal labour income tax from Mendoza et al. (1994) as our measures of profit and labour income taxes. The estimates of public and private capital are from Kamps (2006). The government consumption, as well as the series of public investment is taken from the *OECD Main Economic Indicators*.

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[18]The countries included are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom and United States.

Openness, the share of value added by the service sector over GDP, population and the budget balance are taken from the World Bank World Development Indicators. The GDP per capita is taken from the Penn World Tables. The measure of consumption tax is taken from Mendoza et al. (1994). Unemployment rate and long term interest rate are taken from the *OECD Main Economic Indicators*. Education is the average years of schooling of the population with 15 or above is from the CEP-OECD Institutions Data Set. Finally, the political variables: proportion of left wing vote and the dummy for election years are from the Comparative Parties Data Set.[19]

Before proceeding to the estimation, we checked for multicollinearity by running fixed effects univariate regressions between all the explanatory variables. The R^2 of the regressions between the log of GDP per capita and log of population is 0.66. In between all other variables, the R^2 is below 0.5.

5.2   Results

Table 5 shows the estimations of the tax structure (first four columns) and the composition of spending (last four columns). In the columns (1) and (5) we only include the main regressors and a linear time trend. Columns (2) and (6) include the log of GDP per capita and Openness. The remaining columns include the additional controls. In column (4) and (8), the regressions also include country time trends.[20]

Overall, the main correlations suggested by the model are present in the data. First, the tax structure is positively related with the composition of capital. Given a certain amount of total capital stock, a higher proportion of public capital is associated with higher profit tax relative to labour income tax. The variable is significant in all specifications with very high t-statistics. The magnitude of the coefficient of the capital ratio implies that, given the decline in the sample, this variable is associated with 10 percent of the overall decline in the tax ratio in the G7 countries. Second, in the estimations of the allocation of spending, the coefficient of the tax ratio is positive and significant. The decline of the tax ratio in the sample is associated with 30 percent decline of the ratio of spending.

The coefficient of GDP per capita is significant in both equations, with negative coefficient and large t-statistics. The increase in GDP per capita in OECD countries, is associated with a 40 percent of the decline in the tax ratio and 130 percent of the decline in the government investment-consumption ratio. *Openness*, on the other hand, is not correlated with

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[19]See the appendix A-2 for a list of the variables, sources and summary statistics.

[20]We also included time dummies instead of country specific time trends, but the results were very similar.

Table 5: Determinants of the tax structure and allocation of spending

	Profit-labour tax ratio				Public investment-consumption ratio			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Public-Private capital ratio	4.144***	4.164***	2.232***	2.367***	-0.382***	-0.372***	-0.250*	-0.370**
	(9.01)	(8.59)	(4.45)	(4.58)	(-2.57)	(-2.72)	(-1.66)	(-2.41)
Total capital	0.176***	0.197***	0.339***	0.323***	-0.232***	-0.242***	-0.276***	-0.276***
	(2.90)	(3.19)	(6.05)	(4.72)	(-12.89)	(-14.99)	(-15.99)	(-13.11)
Tax ratio					0.048***	0.038***	0.043***	0.057***
					(3.19)	(2.80)	(2.70)	(3.39)
Trend	-0.033***	-0.023***	0.012**		-0.002***	0.007***	0.005***	
	(-20.21)	(5.10)	(2.29)		(-2.76)	(5.52)	(3.10)	
Openness		-0.002	-0.002	-0.002		0.002***	0.002**	0.001
		(-1.03)	(-1.02)	(-0.61)		(3.10)	(2.28)	(1.34)
GDPpc		-0.464***	-0.793***	-0.685***		-0.418***	-0.426***	-0.503***
		(-2.64)	(-5.05)	(-3.85)		(-9.15)	(-8.29)	(-8.90)
Pop			-3.449***	-3.197***			0.030	-0.189
			(-10.06)	(-7.67)			(0.24)	(-1.39)
Left			0.006***	0.006***			-0.001*	-0.001
			(3.63)	(3.25)			(-1.82)	(-1.41)
Election			0.008	0.011			0.002	0.001
			(0.40)	(0.53)			(0.34)	(0.14)
Balance			-0.001	-0.001			-0.009***	-0.009***
			(-0.26)	(-0.26)			(-6.56)	(-5.98)
Consumption Tax			-0.013**	-0.016**			0.005**	0.004*
			(-2.09)	(-2.24)			(2.51)	(1.85)
Unemployment			-0.031***	-0.035***			-0.004*	-0.003
			(-4.65)	(-4.89)			(-1.77)	(-1.55)
Education			-0.007	-0.004			0.016**	0.011
			(-0.28)	(-0.13)			(2.30)	(1.32)
Interest							-0.001	0.001
							(-0.47)	(0.56)
Observations	396	331	312	312	396	390	365	365
Countries	(18)	(18)	(18)	(18)	(18)	(18)	(18)	(18)
Country time trends	No	No	No	Yes	No	No	No	Yes
R^2	0.67	0.67	0.74	0.77	0.52	0.63	0.70	0.74

Note: the sample is from 1965 to 1996. The countries included are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, United Kingdom and United States. The regressions are estimated with panel fixed effects. T-statistics reported in brackets. ***,**,* means significance at 1%, 5%, 10%, respectively.

the tax structure. This result is in contrast with several papers that find that openness and tax competition are key determinants of the corporate profit taxes. This discrepancy, might be driven by the fact that our sample does not include the last 15 years, where the tax competition has become more intense. What we can say from our regressions is that, until 1996, openness does not seem to be related with the structure of the tax system. Curiously, *Openness*, is associated with a higher level of public investment rather than a higher level of government consumption. This might suggest that the dimension of international competition until the 90s was actually a phenomenon that forced the governments to increase

investment rather than lowering taxes. All in all, the decline of public investment relative to consumption seems to be mainly driven by technological changes.

In the tax equation, the total level of capital in the economy affects positively the tax ratio. We interpret this result as suggesting that the transition to steady-state does not affect the tax structure. If it did, we would expect a negative sign. As it has been pointed out, the theoretical results on the transition dynamics of optimal tax depends on the crucial assumption that the governments can credibly commit to the future path of taxes, which is time inconsistent. On the contrary, the transition dynamics seem relevant for the evolution of the spending ratio. The total level of capital is associated with a lower weight of public investment. Furthermore, this effect is much stronger if we start with a lower proportion of public capital relative to private capital, as it was suggested by the model.

When we do not include any of the controls, the coefficient of the time trend is significant and negative for both ratios. But when we include all the controls is no longer significant or negative. Among the remaining variables, population, political orientation, the level of consumption tax and unemployment are significant in the tax equation and the budget balance and consumption tax are significant in the spending equation. The resulting R^2 is in between 0.53 and 0.74 depending on the specification considered.

6   Conclusion

We argued that considering the joint determination of government expenditures and fiscal revenues may help explaining some basic fiscal trends observed in many countries over the past 40 years. According to our model, investment-specific technological progress alone, and as opposed to exogenous fiscal constraints, can account for a significant proportion of the changes in the fiscal instruments. Our empirical analysis, as a first attempt to investigate these relations, supports the main mechanisms of the model and confirms a strong correlation of the profit-labour tax ratio and the government investment-consumption ratio with GDP per capita.

Distinguishing between the driving forces of the fiscal trends is of primary importance. Concerns for public capital depreciation and proposals for increasing public investment are recurring themes in political debates. Our results suggest that a lower investment in public infrastructure is not necessarily inefficient, and is instead desirable in response to technological progress that is affecting the production structure. Instead, public expenditure should be allocated to other categories, e.g. education or R&D, more relevant in the new economy.

Additional explanations for the observed fiscal trends are certainly possible. Fiscal constraints can have a profound impact on public finance beyond their direct effect. For instance, openness and globalization have been indicated in the literature as sources of the increase in government consumption and the decline in corporate taxes. Our analysis suggest that those changes may in turn be associated with lower public investment and higher labor income taxes. Also, while an increase in the size of governments does not seem consistent with the evolution of the tax rates, the role of more complex political economy factors cannot be excluded. One assumption in our paper is that fiscal policies result from optimal decisions, and do not consider political shocks. Our results highlight the importance of considering the allocation of expenditures and composition of taxes within a single framework, and we hope they will constitute a useful benchmark for future studies in the fiscal policy and political economy literature.

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Appendix

A-1 Main Derivations of the Model

A-1.1 A convenient re-formulation of the model

The purpose of this section is to show how the model of section 2 can be conveniently re-formulated as to resemble a standard neoclassical growth model with public capital. For convenience, we first define a measure of capital in terms of efficiency units $k_t \equiv K_t/q_t^k$ and $p_t \equiv P_t/q_t^p$. Thus, using the capital accumulation equation (2) the household budget constraint (5) can be written as

$$c_t + k_{t+1} = w_t n_t (1 - \tau_t^n) + \left(1 + r_t - \delta^k\right) k_t + \Upsilon_t$$

where $r_t \equiv q_{t-1} R_t$ and $\left(1 - \delta^k\right) \equiv \left(1 - \Delta^k\right) q_{t-1}^k / q_t^k = \left(1 - \Delta^k\right) / \gamma^k$. Similarly, and using eq. (3), the feasibility constraint (7) and the government budget constraint (6) become

$$(1 - \tau_t^\pi) \left[f(k_t, p_t, n_t) - w_t n_t - \zeta r_t k_t \right] - (1 - \zeta) r_t k_t.$$

$$g_t + p_{t+1} - (1 - \delta^p) p_t = \tau_t^n \left(f_{n,t} n_t \right) + \tau_t^\pi \left(f_{p,t} p_t + \frac{1 - \zeta}{1 - \zeta \tau_t^\pi} f_{k,t} k_t \right)$$

with $(1 - \delta^p) \equiv\equiv \left(1 - \Delta^k\right) / \gamma^p$ and $f(k_t, p_t, n_t) \equiv F(q_t^k k_t, q_t^p p_t, n_t)$, corresponding to eqs. (8) and (9) in the main text.

Finally, solving the household's and firm's problem, and after imposing the condition $\tau^\pi < 1$, we obtain the standard optimality conditions

$$-\frac{u_{n,t}}{u_{c,t}} = f_{n,t}(1 - \tau_t^n)$$

$$u_{c,t} = \beta u_{c,t+1} \left[1 + \frac{1 - \tau_t^\pi}{1 - \zeta \tau_t^\pi} f_{k,t+1} - \delta^k \right],$$

corresponding to eqs. (10) and (11) in the text.

A-1.2 Optimality conditions of the Ramsey problem

Given initial conditions p_0 and k_0, the Ramsey planner maximizes eq. (4), subject to (8)-(11) and the upper-bound on profit taxation $\tau_\pi < 1$. After taking derivative to the corresponding

Lagrangean formulation, the resulting optimality conditions are:

$$\tau_t^\pi: \quad \mu_{1,t}\left[f_{p,t}p_t + \frac{1-\zeta}{(1-\zeta\tau_t^\pi)^2}f_{k,t}k_t\right] - \lambda_{t-1}u_{c,t}f_{k,t}\frac{1-\zeta}{(1-\zeta\tau_t^\pi)^2} = 0$$

$$\tau_t^n: \quad \mu_{1,t}f_{n,t}n_t - \mu_{3,t}f_{n,t} = 0$$

$$c_t: \quad u_{c,t} - \mu_{2,t} - \mu_{3,t}\frac{u_{n,t}u_{cc,t}}{u_{c,t}^2} - \lambda_t u_{cc,t} + \lambda_{t-1}u_{cc,t}\left(1 + \frac{1-\tau_t^\pi}{1-\zeta\tau_t^\pi}f_{k,t}\right) = 0$$

$$g_t: \quad u_{g,t} - \mu_{2,t} - \mu_{1,t} = 0$$

$$n_t: \quad u_{n,t} + \mu_{2,t}f_{n,t} + \mu_{1,t}\left[\tau_t^n\left(f_{n,t} + f_{nn,t}n_t\right) + \tau_t^\pi\left(\frac{1-\zeta}{1-\zeta\tau_t^\pi}f_{kn,t}k_t + f_{pn,t}p_t\right)\right] +$$
$$\mu_{3,t}\left[\frac{u_{nn,t}}{u_{c,t}} + f_{nn,t}(1-\tau_t^n)\right] + \lambda_{t-1}u_{c,t}\frac{1-\tau_t^\pi}{1-\zeta\tau_t^\pi}f_{kn,t} = 0$$

$$k_{t+1}: \quad -\mu_{2,t} + \beta\mu_{2,t+1}[(1-\delta^k) + f_{k,t+1}]+$$
$$\beta\mu_{2,t+1}\left[\tau_{t+1}^n\left(f_{kn,t+1}n_{t+1}\right) + \tau_{t+1}^\pi\left(\frac{1-\zeta}{1-\zeta\tau_{t+1}^\pi}f_{k,t+1} + \frac{1-\zeta}{1-\zeta\tau_{t+1}^\pi}f_{kk,t+1}k_{t+1} + f_{pk,t+1}p_{t+1}\right)\right]$$
$$+\beta\mu_{3,t+1}\left[f_{kn,t+1}(1-\tau_{t+1}^n)\right] + \lambda_t\left[\beta u_{c,t+1}\frac{1-\tau_{t+1}^\pi}{1-\zeta\tau_{t+1}^\pi}f_{kk,t+1}\right] = 0$$

$$p_{t+1}: \quad -\mu_{2,t} + \beta\mu_{2,t+1}[(1-\delta^p) + f_{p,t+1}] - \mu_{1,t}+$$
$$\beta\mu_{1,t+1}\left[(1-\delta^p) + \tau_{t+1}^n\left(f_{pn,t+1}n_{t+1}\right) + \tau_{t+1}^\pi\left(\frac{1-\zeta}{1-\zeta\tau_{t+1}^\pi}f_{kp,t+1}k_{t+1} + f_{p,t+1} + f_{pp,t+1}p_{t+1}\right)\right] +$$
$$+\beta\mu_{3,t+1}\left[f_{pn,t+1}(1-\tau_{t+1}^n)\right] + \lambda_t\left[\beta u_{c,t+1}\frac{1-\tau_{t+1}^\pi}{1-\zeta\tau_{t+1}^\pi}f_{kp,t+1}\right] = 0$$

where μ_1, μ_3 and λ are the Lagrange multipliers associated with constraints (9) - (11), respectively, and μ_2 is the Lagrange multiplier associated with the feasibility constraint (8).

A-1.3 A simple example with a leviathan government

Consider the same economic environment described in section 3.1, with the only difference that public consumption (g) is endogenously supplied by a "leviathan" government maximizing the utility function $u(\cdot) = \log g$, subject to the competitive equilibrium conditions evaluated at steady state.

Defining the variable $x \equiv (1 - \tau^{pi})/(1 - \hat{p} - \hat{g})$, the problem of the leviathan government can be written as

$$\max_{x,\hat{p},\hat{g}} \ V(x,\hat{p},\hat{g}) = \log g = \log \hat{g} + \log y(x,\hat{p},\hat{g})$$

where $\log y(x,\hat{p},\hat{g}) = \frac{\alpha-\eta}{1-\alpha}\log\hat{p} + \frac{\eta}{1-\alpha}\left[\log x + (1-\hat{p}-\hat{g}) + \log\beta\eta\right] + \underbrace{\frac{1}{\phi}\frac{1-\alpha x}{1-\beta\eta x}}_{\log n}.$

As for the case of the Ramsey planner, the problem is separable in the variables x, $\hat{p}$ and $\hat{g}$. Hence, the optimal value of x is independent of the level of $\hat{p}$ and $\hat{g}$. Moreover, from the first-order conditions w.r.t. $\hat{p}$ and $\hat{g}$ it follows that at an optimum, $\hat{p} = \alpha - \eta$ and $\hat{g} = 1 - \alpha$. It then follows immediately that the three properties established for the

Ramsey problem are also valid in this case, and in particular, (i) the optimal profit tax rate is a strictly increasing linear function of $\hat{p}$, i.e. $\tau\pi = 1 - x^* [1 - (1-\eta)/(\alpha - \eta)\hat{p}]$, (ii) the optimal supply of public capital is increasing in the public capital income share and (iii) the tax - ratio τ^π/τ^n is increasing in $\hat{p}^*$ if and only if $x^* > 1$.

A-2 Data

Table A-1: Summary statistics and sources

Variable	Description	Mean	Sd	Min	Max	Source
τ^π	Top bracket corporate tax	41.72	8.50	9.8	56	Michigan World Tax Database
τ_1^n	Marginal labour income tax	34.06	9.63	12.40	53.58	Mendonza et al. (1994)
τ_2^n	Average labour income tax	27.32	9.94	5.60	83.50	CEP-OECD Institutions Data Set
p	Public capital (% GDP)	0.57	0.17	0.27	1.07	Kamps (2006)
k	Private capital (% GDP)	2.54	0.53	1.25	3.81	Kamps (2006)
i^p	Public investment (% GDP)	3.48	1.65	1.49	10.08	Kamps (2006)
g	Gov. consumption (% GDP)	19.57	3.90	7.95	30.13	OECD-MEI
$GDPpc$	Log of GDP per capita	10.59	1.52	9.15	15.17	Penn World Tables
$Openness$	Openness (% GDP)	53.01	26.42	11.25	145.42	WB - WDI
Pop	Population	16.99	1.28	14.97	19.41	WB -WDI
$Balance$	Budget Balance	-2.10	3.74	-15.71	17.99	WB -WDI
τ_1^c	Consumption tax	15.61	8.13	4.35	40.27	Mendonza et al. (1994)
$Unemp.$	Unemployment rate	5.46	3.77	.01	20.15	OECD-MEI
$Education$	Average years of schooling	8.24	2.08	1.86	12.05	CEP-OECD Institutions Data Set
$Interest.$	Long term interest rate	8.61	3.85	1.10	31.03	OECD-MEI
$Left$	Left party votes (% total)	36.81	16.55	0	65	Comparative parties dataset
$Election$	Dummy for election year	0.31	0.46	0	1	Comparative parties dataset

Note: The variable education is only available every five years and it is interpolated in between. MEI-Main Economic Indicators; the comparative party dataset was created by Duane Swank and is available on http://www.mu.edu/polisci/Swank.htm. CEP-OECD Institutions Data Set is available http://cep.lse.ac.uk/_new/publications/abstract.asp?index=2424.

Figure A-1: Key explanatory variables (Average for 20 OECD countries)
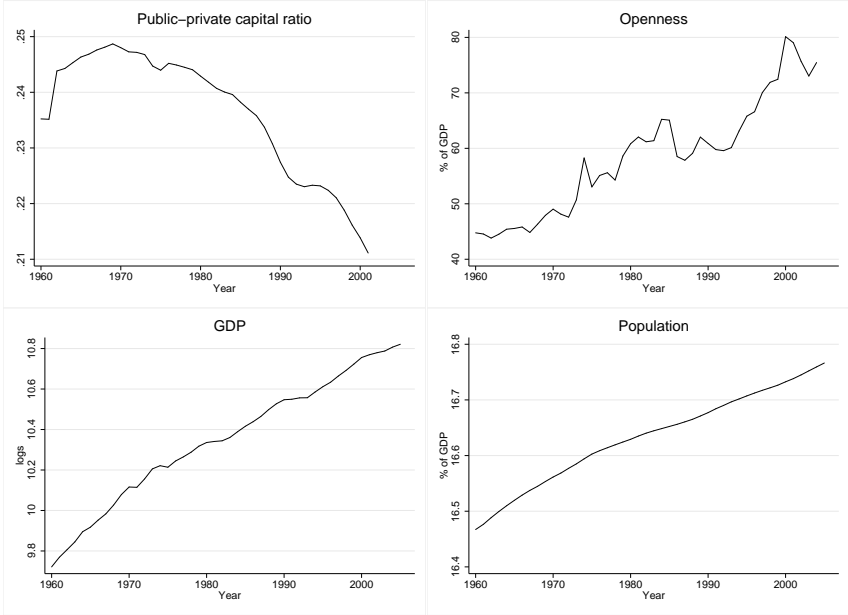
Figure A-2: Price indexes of private and public investment, United States
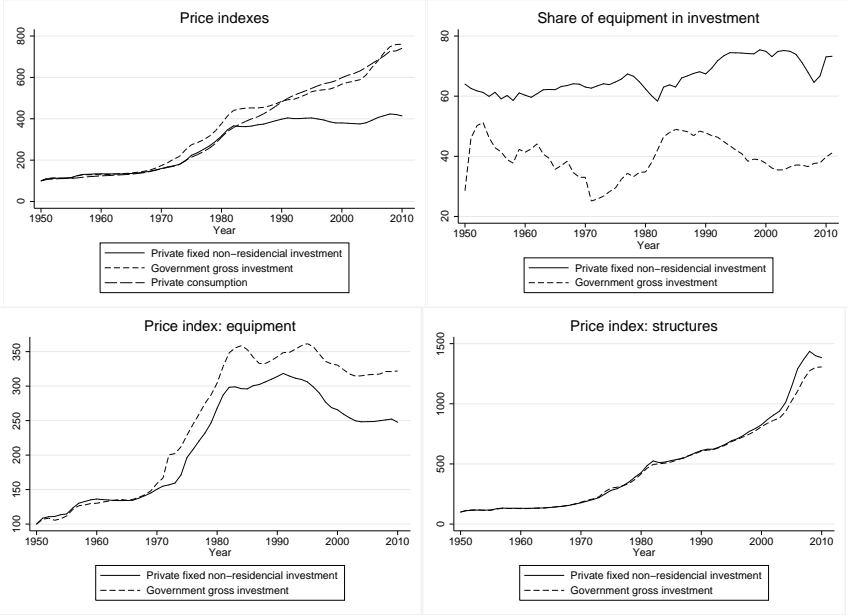
Note: Data from the Bureau of Economic Analysis (NIPA tables).

Additional material

B.1   Transition to steady state

When examining the transition dynamics of the model, our aim is to understand the role of the accumulation of both private and public capital along the path to steady-state.[21] We then consider two starting points: one with low public capital, where public and private capital are 60 and 20 percent below steady state, and one with low private capital with the inverse proportions. The results are shown in Figure B.1.1.

Figure B.1.1: Dynamic transition to steady state
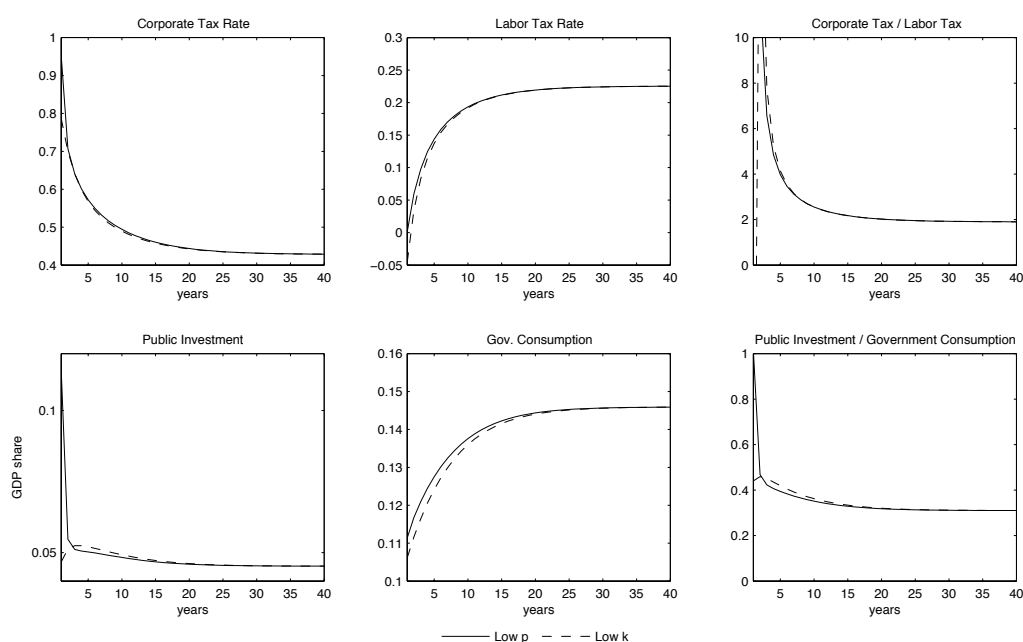
Note: The figure plots the transition dynamics from low initial levels of public capital (solid line) and low levels of private capital (dash line).

When we start with a lower public capital stock, as the government re-optimizes and the previous plan is made obsolete, it sets the profit tax at the maximum possible. The corporate tax stays at the maximum value for several periods and the labour income goes to very low levels. Together with the reduction of government consumption, it allows for a rapid accumulation of public capital. Along the transition path that takes roughly 20 years, public investment goes down, government consumption increases, corporate tax decreases and labour income tax goes up.

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[21]Additional transition dynamics between different steady-states are omitted for brevity and available from the authors upon request.

When starting from a low private capital, the decline of labour income tax is so strong that it turns into a subsidy. Also, the corporate tax rate is not set at the maximum. This is achieved with a sharp reduction of public consumption and a disaccumulation of public capital. In our model, the only savings instrument the government has is public capital. If the level of public capital, relative to private capital, is already high enough the government wants to disinvest and therefore it does not want to set the profit tax to its maximum.

B.2   Changes in parameters

Figure B.2.2: Effects of changes in preferences for government consumption
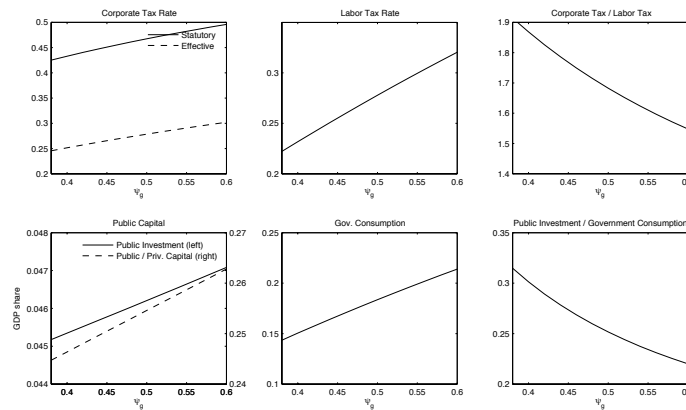
B.2.1   Exogenous changes in instruments

Figure B.2.3: Steady-state effects of exogenous changes in profit tax
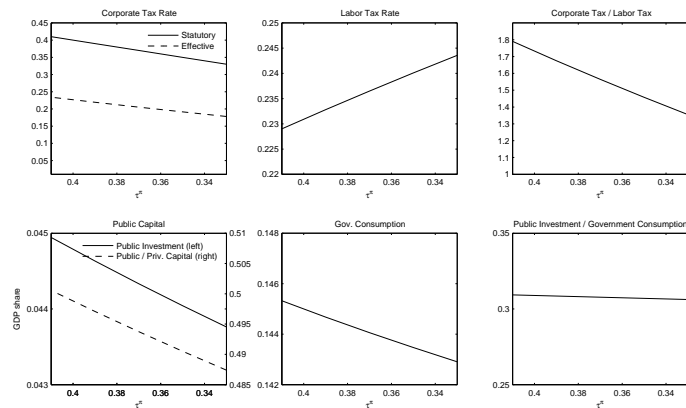
Figure B.2.4: Steady-state effects of exogenous changes in labor tax
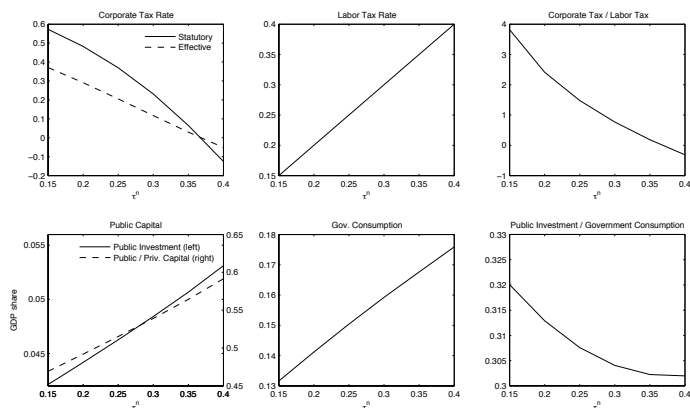
Figure B.2.5: Steady-state effects of exogenous changes in government consumption
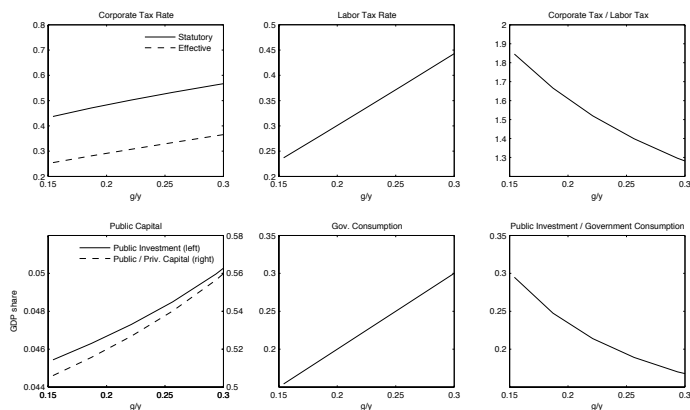
Figure B.2.6: Steady-state effects of exogenous changes in public investment
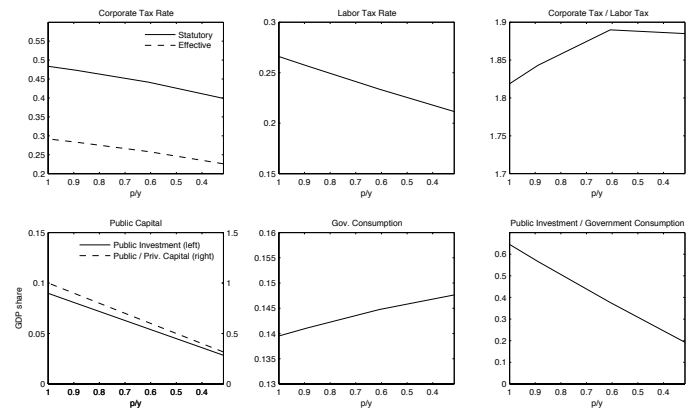
B.3 Disaggregated data on taxes and expenditures

Figure B.3.7: Taxes and allocation of public spending in the G7 countries (weighted by GDP)
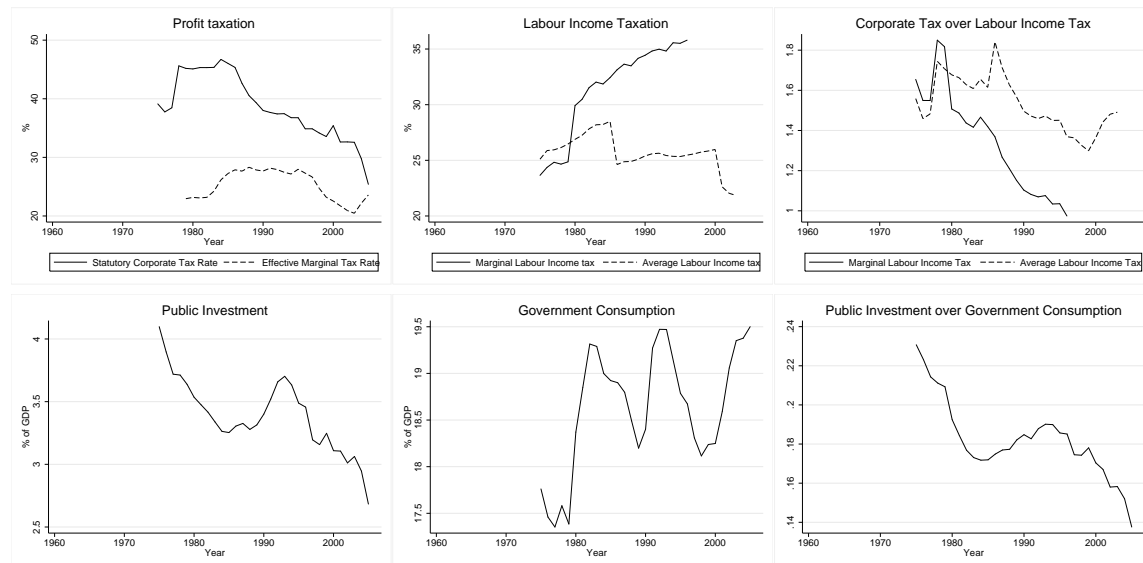
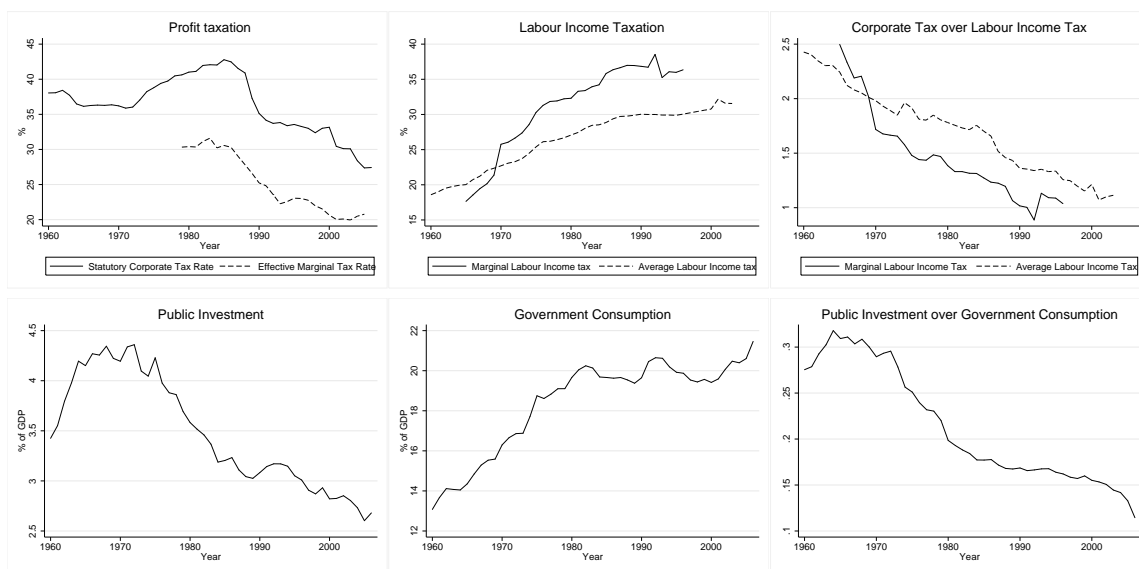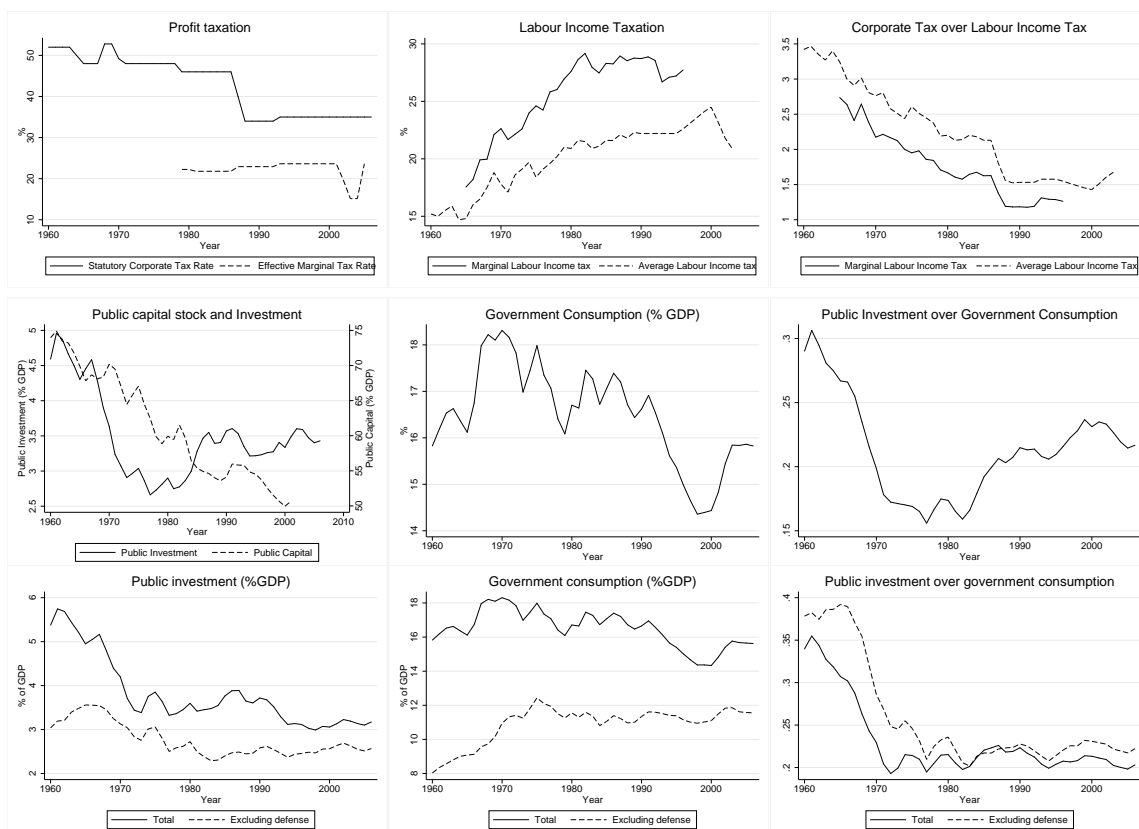Figure B.3.8: Taxes and allocation of public spending in the G7 countries (weighted by population)
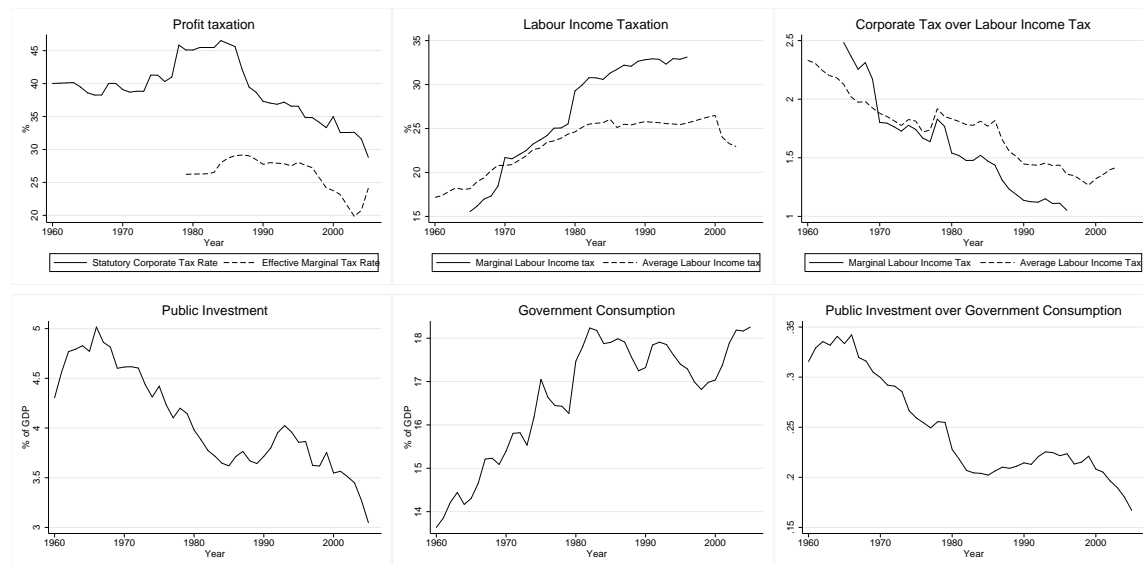
Figure B.3.9: Taxes and allocation of public spending in the OECD countries

Figure B.3.10: Taxes and allocation of public spending in the US

Note: in the second row we use data from the OECD, while in the third row we use quarterly data from the NIPA tables (3.9.5). We exclude defence investment from total government investment.

Figure B.3.11: Taxes and allocation of public spending in Canada
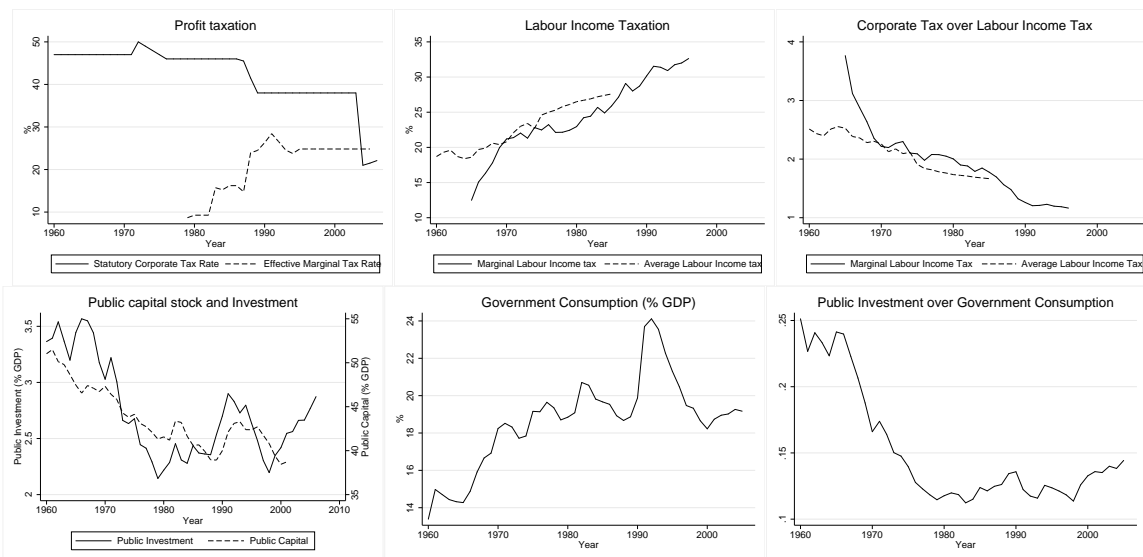
Figure B.3.12: Taxes and allocation of public spending in France
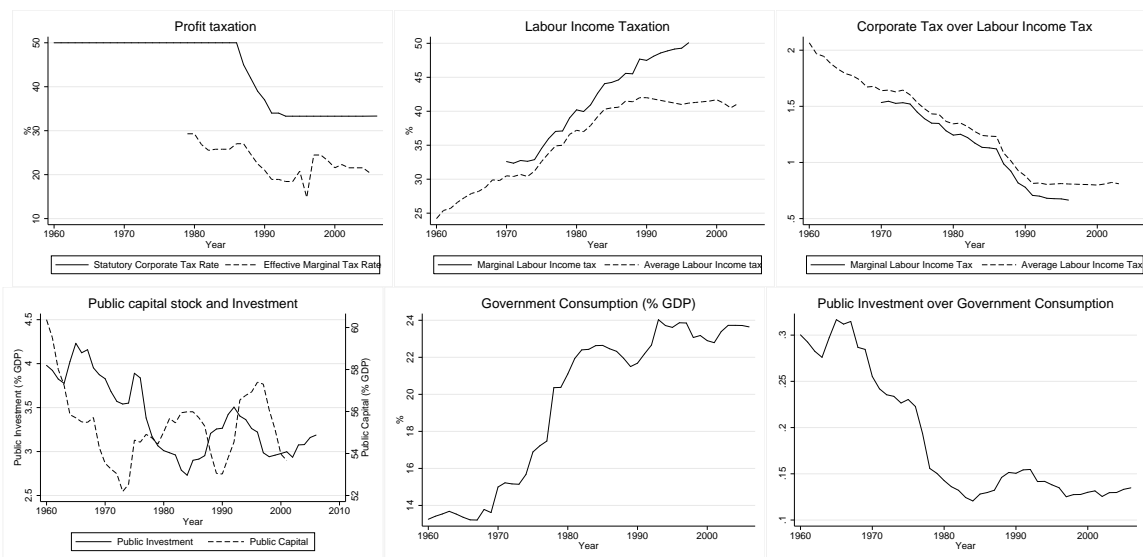
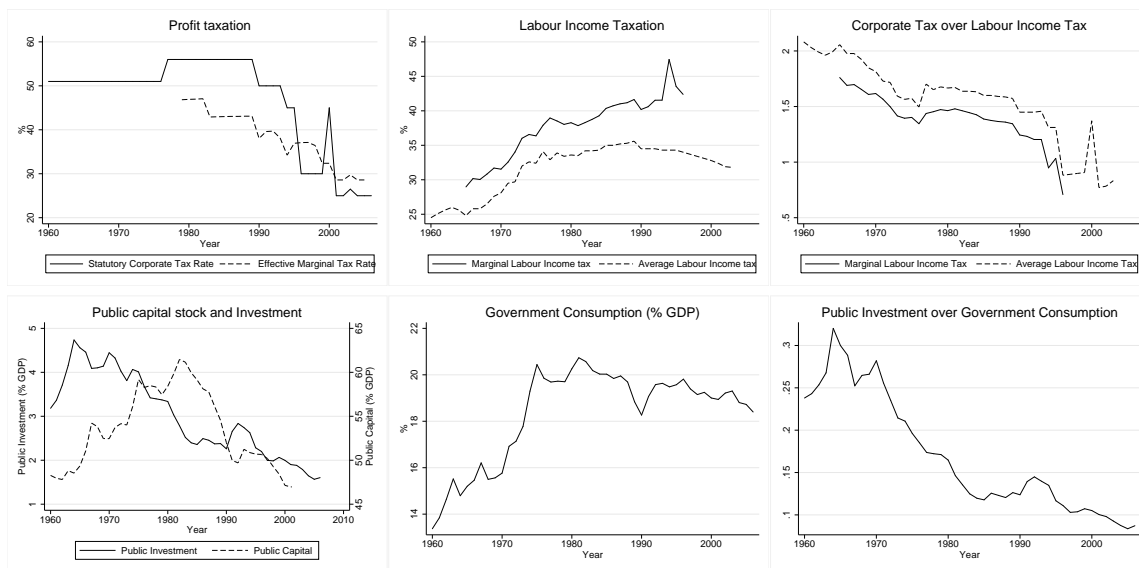Figure B.3.13: Taxes and allocation of public spending in Germany

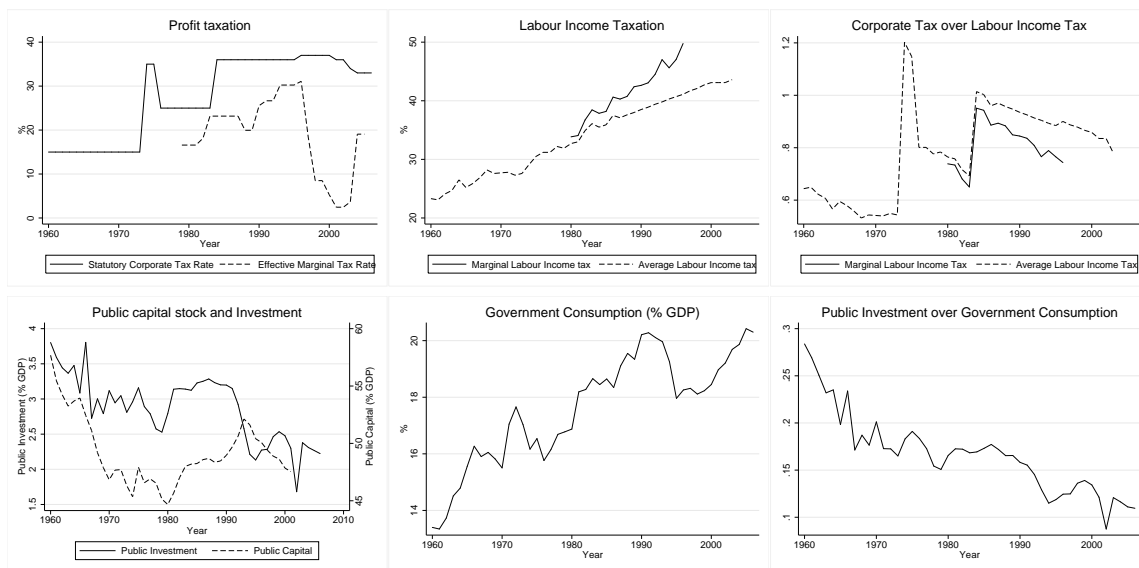Figure B.3.14: Taxes and allocation of public spending in Italy

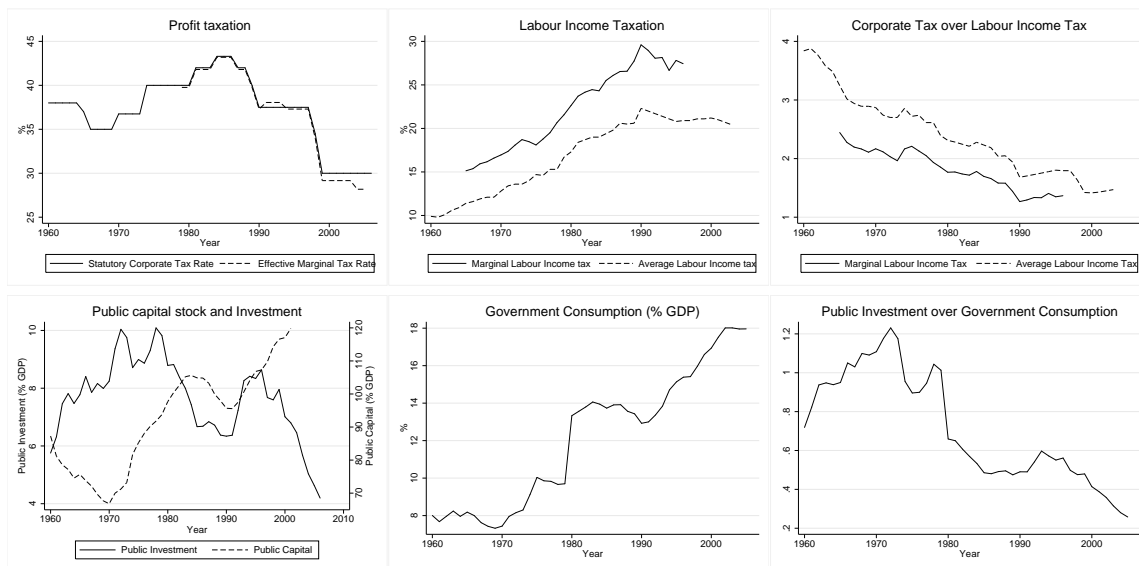Figure B.3.15: Taxes and allocation of public spending in Japan

Figure B.3.16: Taxes and allocation of public spending in the UK