Technological change and the decline of public investment*

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Abstract

Over the past 40 years public investment has declined in most developed countries. This paper argues that such pattern can be the consequence of investment-specific technological progress. Public investment, mostly on infrastructures, experienced a slower rate of innovation than private investment, composed primarily by equipment and software. Within a simple neoclassical growth model with a public sector, we show that such type of technological progress reduces the incentives to invest in public capital, and accounts for 80 percent of the observed decline. The implied co-movements of other fiscal instruments are also consistent with observed trends.

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1 Introduction

Over the past four decades most developed countries have experienced a sharp decline in public investment. As shown in Figure 1, in the G7 countries public investment has declined from 4.5 to below 3 percent of GDP. As a consequence, the stock of public capital relative to private capital has fallen from 30 percent to around 22 percent. At the same time governments are allocating more resources to government consumption and shifting the taxation burden from corporate profits to labour income.[1]

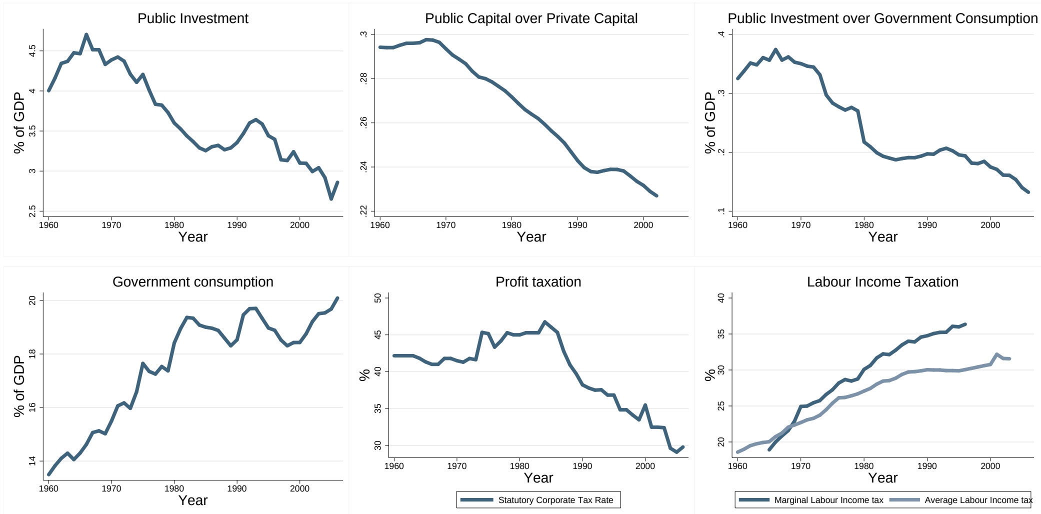
The decline of the corporate tax rate and the increase of the government consumption have been widely discussed in the literature. For instance, the decline in the corporate tax rate has been attributed to tax competition, in consequence of higher capital and profit mobility [see Devereux et al. (2008), Devereux et al. (2002) or Elitzur and Mintz (1996)]. The increase in government consumption has been related to the increase in openness, either because of the risk-reducing role of government consumption in countries subject to foreign shocks [Rodrik (1998)] or because of terms-of-trade effects shifting the taxation burden abroad [Epifani and Gancia (2009)].[2]

Explaining the decline in public investment remains instead a largely open question. Some of the natural conjectures are not fully satisfactory. First, the reconstruction effort after World War II can explain a high investment at the beginning of the sample, but would not be consistent with the actual decline in public capital observed since the 1970s. Second, privatization of public owned enterprizes is unlikely to have affected public investment because any investment undertaken by public owned enterprises is attributed in national accounts to the private sector. Third, the increase of public-private partnerships is a recent phenomenon that could not account for the pattern observed

[1] In a separate appendix we show the variables disaggregated by country as well as for an average of 20 OECD countries. Public investment declined sharply in all G7 countries with the exception of Japan. For a more detailed survey see Gramlich (1994).

[2] Other political economy explanations for the increase in the size of governments include the extension of voting rights [Meltzer and Richard (1981) and Aidt and Jensen (2009)], or to the increase in the female labor force participation [Cavalcanti and Tavares (2011)].

Figure 1: Public investment and other fiscal instruments 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. Public and private capital series are from Kamps (2006). Series are an arithmetic mean for Canada, France, Germany, Italy, Japan, United Kingdom and the United States.

since the 1970s.[3] Alternatively, the decline in public investment may be related to the existing explanations for the other fiscal trends. However, such hypothesis raises further questions. 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 would governments increase consumption but lower investment?

In this paper we argue that the decline of public investment can be the direct consequence of investment-specific technical change, that has been shown by Greenwood et al. (1997), among others, to account for the major part of post-war growth. A key feature of our 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

[3]See Mehrotra and Välilä (2006) for a more extensive discussion.

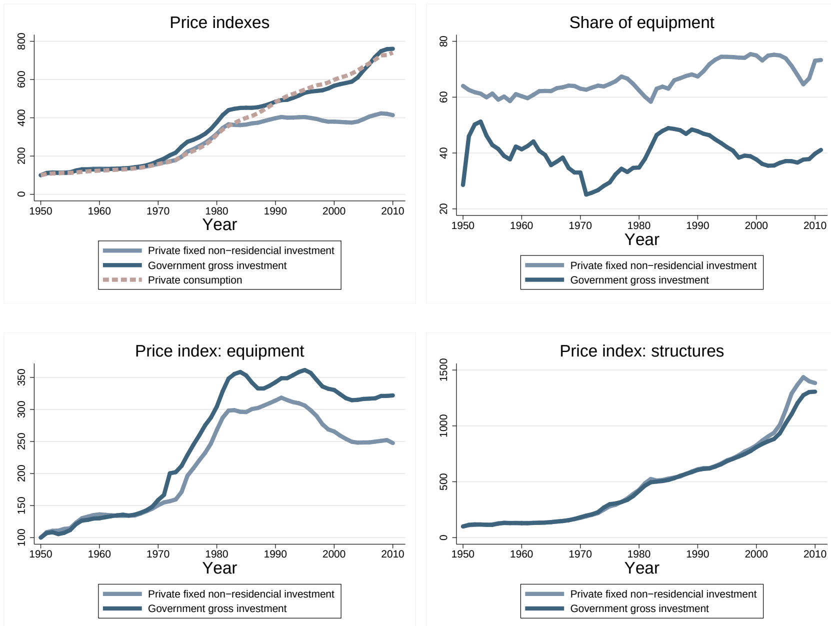
in equipment and software, rather than in structures. Also, in the United States private non-residential investment consists mainly of equipment and software (70 percent on average), while the government invests primarily in structures (around 65 percent) – see Figure 2. It then follows that private 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 in the private sector than in the public sector, with an average growth rate of 2.4% and 0.8% per year, respectively.

We embed this concept into a standard neoclassical growth model with a public sector, where a government, which may or may not share the preferences of society, chooses how to allocate the public expenditure between public consumption and investment in productive public capital. Public expenditures are financed by levying distortionary taxes on labour income and corporate profits. The main mechanism of our model is intuitive. The decline in productivity of public infrastructure relative to private capital induces the government to reduce its investment, and to free resources for private investment.

The presence of public capital also 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. In the presence of investment-specific technological progress, distortions in the private capital become more costly, and firms enjoy fewer rents. Thus, the government reduces the profit tax and compensates by increasing the labour income tax. At the same time, public expenditures is shifted towards government consumption. Quantitatively, we find that investment-specific technological changes alone account for 80 percent of the decline in public investment and 10 to 40% of the change in the other fiscal instruments.

The model is also used to inspect alternative hypothesis. We show that the

Figure 2: Price indexes of private and public investment, United States



Note: Data from the Bureau of Economic Analysis (NIPA tables).

decline in public investment does not result from budgetary constraints, in response to exogenous increases in government consumption or in the reduction of corporate taxes. On the contrary, an increase in government consumption leads to an increase in tax rates, thus raising the government incentives to subsidize production through higher public investment. We interpret this result as an indication that openness or tax competition does not, at least trivially, lead to a decline in public investment. Similarly, an exogenous fall in public investment – not related to technical change – does not generate the observed co-movements among the remaining fiscal instruments.

From an empirical viewpoint, and as a first attempt to distinguish between the possible explanations, we estimate the determinants of the spending and tax ratios, for 18 OECD countries between 1965 and 2004. We find that both ratios are highly correlated with GDP per capita which suggests that technological changes has played an important role for the evolution of fiscal instruments.

Our work builds on the large fiscal policy literature studying the role of public capital. This includes several works analyzing the effects of public capital 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 Lansing (1998)]. Our paper aims instead at explaining the behavior of public investment and other fiscal instruments, in response to sources of economic growth. From a methodological viewpoint our approach bear similarities with many existing studies in the optimal taxation literature. 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.[4]

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.

[4]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 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.

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, 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.[5] 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.

The assumption of constant returns to scale in the three factors is not essential. The presence of economic profits, and that these profits are increasing in public capital, is only needed to have positive profit taxes also in steady

[5] 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%.

state.[6] In order for the firm's problem to be well-defined, we impose a limit on the 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.

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 $\gamma^k \neq \gamma^p$. We do not explicitly model the investment choice between equipment and structures. Thus, we are implicitly assuming that the expenditure share into those categories remains constant, consistently with the evidence reported in Figure 2.[7]

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

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

[6]An alternative to preserve positive profits, but departing from the constant returns to scale assumption, would be to 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.

[7]More formally, a constant expenditure share could be easily rationalized assuming that each type of investment is obtained through the combination of structures and equipment, with a unitary elasticity of substitution between the two factors.

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

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

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.[8] 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[9]

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

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*

[8] 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.

[9] 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. The effects of technological progress on public investment would also be similar in a model with only lump-sum taxes. However, such model would be silent on the behavior of the tax rates.

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. $k_t \equiv K_t/q_{t-1}^k$ and $p_t \equiv P_t/q_{t-1}^p$, defining the rates of economic depreciation $\delta^k \equiv 1-\left(1-\Delta^k\right)/\gamma^k$ and $\delta^p \equiv 1-\left(1-\Delta^p\right)/\gamma^p$, 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 results 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.

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 how technology affects the supply of public capital and its financing. In particular, suppose the production function is Cobb-Douglas $y = k^{\eta}p^{\alpha-\eta}n^{1-\alpha}$, with $0 < \eta < \alpha < 1$ and constant $q^k = q^p = 1$, that 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 $u(c, n) = \log c + \phi \log(1 - n)$, with $\phi > 0$. In this economy, the equilibrium conditions (8) - (11) evaluated at steady-state, simplify to

$$\hat{c} = 1 - \hat{p} - \hat{g} - \hat{k} \tag{12}$$

$$\hat{p} + \hat{g} = \alpha\tau^{\pi} + (1 - \alpha)\,\tau^{n} \tag{13}$$

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

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

where for a generic variable x we defined $\hat{x} \equiv \frac{x}{y}$.

Let's now consider the problem of a "Leviathan" government, whose only objective is to maximize the steady-state supply of public consumption g.[10] The government chooses the fiscal instruments (τ^{π}, $\hat{g}$, $\hat{p}$) solving the following

[10]Our considerations remain valid also under a benevolent government, and the corresponding derivations are available upon request. The transition dynamics are instead discussed in the following sections.

problem

$$\max_{\hat{g},\hat{p},\tau^{\pi}} \qquad \log \hat{g} + \log y(\hat{g},\hat{p},\tau^{\pi})$$

where

$$\log y(\hat{g},\hat{p},\tau^{\pi}) = \frac{\alpha-\eta}{1-\alpha}\log \hat{p} + \frac{\eta}{1-\alpha}\left[\log(1-\tau^{\pi}) + \log \beta\eta\right] + \log n(\hat{g},\hat{p},\tau^{\pi}) \quad (16)$$

$$n(\hat{g},\hat{p},\tau^{\pi}) = \frac{1-\hat{p}-\hat{g}-\alpha(1-\tau^{\pi})}{(1+\phi)(1-\hat{p}-\hat{g})-(\alpha+\beta\eta\phi)(1-\tau^{\pi})} \quad (17)$$

where eq. (16) is obtained using eq. (15) to replace $\hat{k}$ into the production function, while (17) is obtained using eqs. (12) and (13) to substitute for $\hat{c}_t$ and $(1-\tau^n)$ into eq. (14). The first-order conditions of the above problem give

$$\frac{\eta}{1-\alpha}\frac{1}{1-\tau^{\pi}} = \frac{\phi(\alpha-\beta\eta)(1-\hat{p}-\hat{g})}{[(1+\phi)(1-\hat{p}-\hat{g})-(\alpha+\beta\eta\phi)(1-\tau^{\pi})][(1-\hat{p}-\hat{g})-\alpha(1-\tau^{\pi})]} \quad (18)$$

$$\frac{1}{\hat{g}} = \frac{\eta}{1-\alpha}\frac{1}{1-\hat{p}-\hat{g}} \quad (19)$$

$$\frac{\alpha-\eta}{1-\alpha}\frac{1}{\hat{p}} = \frac{\eta}{1-\alpha}\frac{1}{1-\hat{p}-\hat{g}} \quad (20)$$

Intuitively, eq. (18) equates the marginal distortions on private capital accumulation (left-hand side) to the marginal distortions on the labor supply (right-hand side). Also, eqs. (19) and (20) equate the marginal benefits of the two types of public expenditure (left-hand side) to the marginal cost of raising taxes (right-hand side). We can now show two properties of the optimal policy plan.

Result 1 *The optimal policy plan is characterized by the following properties: (i) the optimal supply of public capital is increasing in the public capital income share $(\alpha-\eta)$; (ii) the optimal profit tax rate is a decreasing function of the private capital income share (η).*

Proof. Result (i) immediately follows from conditions (19) and (20), implying that $\hat{p}^* = \alpha-\eta$ and $\hat{g}^* = 1-\alpha$. This indicates that the higher is the public capital income share, the higher the optimal the supply of public capital.

Result (ii) follows from the fact that at an optimum $1 - \hat{p}^* - \hat{g}^* = \eta$. Then eq. (18) simplifies to

$$[(1+\phi)\eta - (\alpha + \beta\eta\phi)(1-\tau^\pi)][\eta - \alpha(1-\tau^\pi)] - (1-\alpha)\phi(\alpha - \beta\eta)(1-\tau^\pi) = 0$$

Totally differentiating the above expression w.r.t. η it immediately follows that $\frac{\partial \tau^\pi}{\partial \eta} < 0$. ■

The above results imply that as private capital becomes a more important factor of production – say because of an increase in η – the optimal plan prescribes a reduction in the supply of public capital, together with a reduction in the corporate profit tax rate.

3.2 Optimal fiscal policies

We now characterize the solution to the more general problem of a benevolent (Ramsey) planner, choosing the the best possible policies $\{p_{t+1}, g_t, \tau_t^n, \tau_t^\pi\}_{t=0}^\infty$ to maximize eq. (4), subject to the restriction that implied competitive equilibrium allocations satisfy eqs. (8) - (11), for given initial conditions p_0 and k_0.

To better understand the government incentives to invest we can combine the first order conditions with respect to government consumption and public capital, which gives

$$\begin{aligned} u_{g,t} \;=\; & \beta\mu_{2,t+1}\left[(1-\delta^p) + f_{p,t+1}\right] + \\ & \beta\mu_{3,t}(1-\tau_t^n) f_{pn,t+1} + \beta\lambda_t u_{c,t+1} \frac{1-\tau_{t+1}^\pi}{1-\zeta\tau_{t+1}^\pi} f_{pk,t+1} + \\ & \beta\mu_{1,t+1}\mathcal{R}_{P,t+1}, \end{aligned} \tag{21}$$

where $\mathcal{R}_{P,t+1} \equiv \left[(1-\delta^p) + \tau_{t+1}^\pi\left(f_{pp,t+1}p_{t+1} + f_{p,t+1}\right) + \frac{\tau_{t+1}^\pi(1-\zeta)}{1-\zeta\tau_{t+1}^\pi} k_{t+1} f_{pk,t+1} + \tau_{t+1}^n f_{np,t+1} n_{t+1}\right]$ 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.[11]

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 only the increase in future aggregate resources (first line), which positively depend on the marginal productivity of public capital. 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 increase the return to public investment in terms of future tax revenues and raise the incentive for the government to invest instead of consume.

The interactions between the tax rates and the composition of public expenditure also emerge from the optimality condition for the corporate tax rate, given by

$$\mu_{1,t}\left[f_{p,t}p_t + \frac{1-\zeta}{\left(1-\zeta\tau_t^{\pi}\right)^2}f_{k,t}k_t\right] = \lambda_{t-1}u_{c,t}f_{k,t}\frac{1-\zeta}{\left(1-\zeta\tau_t^{\pi}\right)^2}, \tag{22}$$

where $\mu_{1,t}$ and λ_{t-1} represent the shadow values of relaxing constraints (9) and (11), respectively.[12] The left-hand side of (22) 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 (22). At

[11] The remaining first-order conditions, together with a description of the numerical algortihm, are reported in appendix A-1.2.

[12] 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.

an optimum, the planner equalizes these marginal costs and benefits. We can rewrite equation (22) as

$$\zeta \tau_t^{\pi} = 1 - \sqrt{\frac{f_{k,t} k_t (\lambda_{t-1} u_{c,t} - \mu_{1,t})(1-\zeta)}{\mu_{1,t} f_{p,t} P_t}}, \tag{23}$$

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 $\mu_{1,t}$.

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]

[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

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.

4.1 Calibration

We specify the per-period utility function

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

As government consumption 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. We also assume a constant elasticity of substitution production function

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

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 $\frac{1}{1-\rho}$.

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 ($\psi_n = 2.678$, $\psi_g = 0.362$, $\theta = 0.268$, $\rho = 0.362$, $\alpha = 0.346$,

from considering the Ramsey re-optimization as an explanation of the observed trends. The corresponding figures are available in an online appendix.

[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 $\rho \to 0$.

$\delta_k = 0.0767$, $\delta_p = 0.088$ 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.

Table 1: Summary statistics: Data vs Model

	G7 countries (Average 1960-1970)	**Model** 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.

As mentioned earlier, a crucial feature of the model is the role of public capital in the production function. The value of $\rho = 0.362$ implies a slight substitutability between private and public capital, remarkably close to the estimates of Otto and Voss (1998). The above parameters' values also imply a relatively low public capital income share of about 6.1%, which is consistent with available estimates.[15] The numbers also imply marginal distortions 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 $q_0^k = q_0^p = A = 1$.

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 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

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

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 Quantitative Results

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.

Our main finding is that investment-specific technological progress accounts for about 80 percent of the observed decline in public investment. As a result, and consistently with the data, 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, we can observe 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.

Quantitatively, investment-specific technological progress also accounts for more than 40% of the decline in the corporate tax rate, around 10% of the labour tax rate and 20% of government consumption. 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

Table 2: Fiscal instruments and technological progress

	Baseline	**Invest. Specific**	**Invest. Specific + TFP**	**TFP Only**	**Data G7 countries** 1960-1970	1995-2005
Government spending						
Public investment$^{\$}$	4.43	3.34 (79)	3.37 (77)	4.44 (-3)	4.43	3.07
Gov't consumption$^{\$}$	14.6	15.4 (19)	16.6 (45)	15.7 (25)	14.6	18.9
i^p/g	0.30	0.22 (61)	0.20 (70)	0.28 (13)	0.30	0.16
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
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.

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

This sections investigates 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 cases, the effects of investment-specific technological progress are qualitatively similar to those obtained under the baseline calibration. Quantitatively, with higher σ_c and σ_g, investment specific technological progress explains a higher share of the decline of public investment (between 85% to 99%), and of government consumption (up to 85%). On the taxation side, it improves the response of the labour tax to around 30 percent, but reduces the percentage explained of the corporate tax rate to around 20%.[17]

[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 $\sigma_g < \sigma_c$.

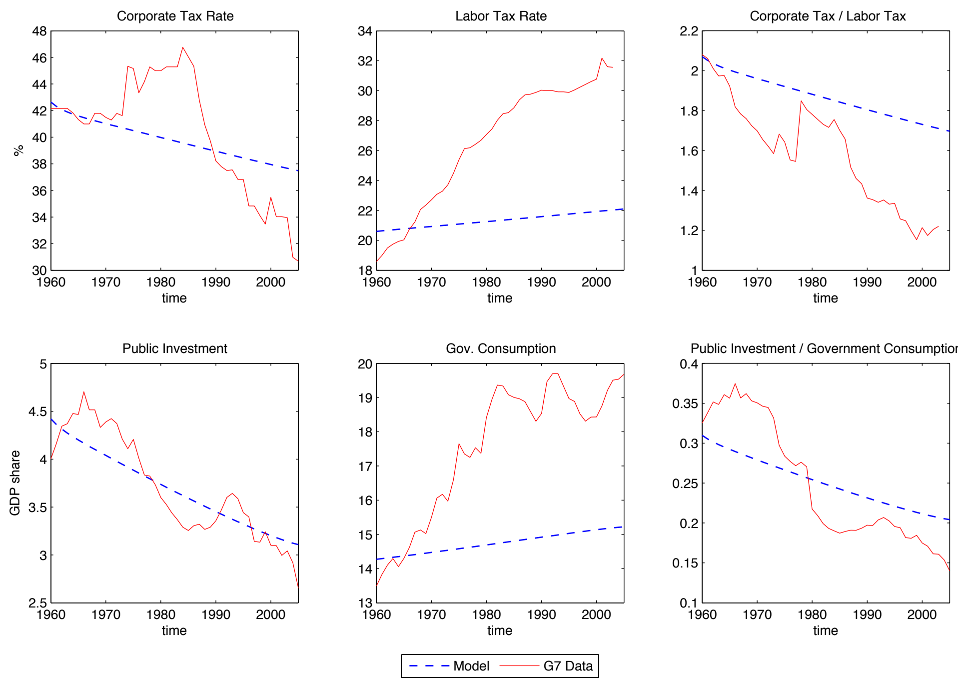
Table 3: Effects on Investment-Specific Technological progress under alternative calibrations

	Baseline		**Alternative**	
	$\sigma_c = 1$, $\sigma_g = 0.85$	$\sigma_c = 1$, $\sigma_g = 0.85$	$\sigma_c = 2$, $\sigma_g = 1$	$\sigma_c = 2$, $\sigma_g = 1$
	$\sigma_n = 1$	$\sigma_n = 4$	$\sigma_n = 1$	$\sigma_n = 4$
Government spending				
Public investment$	3.34 (79)	3.24 (85)	3.29 (82)	3.06 (99)
Gov't consumption$	15.4 (19)	15.2 (18)	18.1 (85)	17.5 (72)
i^p/g	0.21 (64)	0.21 (64)	0.18 (87)	0.18 (92)
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)
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 3, 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.

Figure 3: Ramsey plan under perfect foresight technological progress



4.4 Assessing alternative explanations

Our model provides a laboratory to investigate the effects of exogenous movements in a particular fiscal instrument – say for political or economic conditions. To that end, we study whether constraining one instrument to the value observed at the end of the sample would drive the other instruments in a way consistent with the data.

Results are shown in Table 4. An exogenous reduction of the corporate tax from 41% to 33% (second column) would lead to reduction of public investment, but it would only account for 12% of the observed decline. However, it would also imply a counterfactual decrease in government consumption. Instead, in response to an exogenous increase in government consumption from 14.6% to 18.9% of GDP (fourth column) both taxes go up in order to raise revenue, particularly the labour income tax. And although the government

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
Government spending							
Public investment$^\$$	4.43	4.24 (12)	5.07 (-49)	4.53 (-10)	*	4.43	3.10
Gov't consumption$^\$$	14.6	14.4 (-5)	17.5 (67)	*	14.7 (3)	14.6	18.9
i^p/g	0.31	0.29 (5)	0.29 (8)	0.24 (44)	0.21 (65)	0.30	0.16
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
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.

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.

Finally, in the fifth column we assume that public investment is driven by an exogenous factor, unrelated to technological progress. In that case, we would observe only a negligible increase in government consumption, and a small but counterfactual decline in labor income taxes. When one instrument changes for exogenous reasons, there is a revenue and a substitution effect. The substitution effect comes directly from the optimality conditions of the Ramsey problem, altering the ratios of spending and taxes. The revenue effect comes from the government budget constraint. When the government exogenously decreases public investment, it will require lower revenues, which will push both tax rates down. In most of the cases considered the revenue effects overcomes the substitution effect.

In summary, our analysis suggests that technological changes may have played an important role in explaining the decline of public investment, and is also consistent with the other three fiscal trends observed in the data. On the contrary, we found that exogenous changes in fiscal instruments would be 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 ($\frac{i^g_{it}}{g_{it}}$) and the tax ratio ($\frac{\tau^\pi_{it}}{\tau^n_{it}}$), 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 change is an important driver of fiscal variables. Therefore, we estimate both equations with panel fixed effects.

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:

$$\frac{i^g_{it}}{g_{it}} = \beta_i + \delta_1 \frac{\tau^\pi_{it}}{\tau^n_{it}} + \delta_2 \frac{p_{it}}{k_{it}} + \delta_3 \frac{k_{it} + p_{it}}{y_{it}} + + \delta_4 GDPpercapita_{it} + Controls_{it}. \quad (26)$$

The model predicts that the composition of taxes should affect the composition of spending so we include $\frac{\tau^\pi_{it}}{\tau^n_{it}}$ 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 $\frac{p_{it}}{k_{it}}$.

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, the log of population and the long-term interest rate.

Tax structure

We run a similar regression for the tax structure

$$\frac{\tau_{it}^{\pi}}{\tau_{it}^{n}} = \alpha_i + \rho_1 \frac{p_{it}}{k_{it}} + \rho_2 \frac{k_{it} + p_{it}}{y_{it}} + \rho_3 GDPpercapita_{it} + Controls_{it} \tag{27}$$

where we include 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. We use the same controls described above, with the exception of the long-term interest rate.

Data

We gather data for 18 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.*

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).

[18] 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.

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 composition of spending (first three columns) and tax structure (last three columns). Columns (1) and (4) only include the main regressors. Columns (2) and (5) include the additional controls, and in column (3) and (6) further include country time trends.[20]

Overall, the main correlations suggested by the model are present in the data. 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 130 percent of the decline in the government investment-consumption ratio and a 40 percent of the decline in the tax ratio.

Also, we find that 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

[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

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

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.

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.

Openness, on the other hand, is not correlated with 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 related to growth.

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

This paper argues that investment-specific technological progress can account for a significant proportion of the decline in public investment observed in most countries over the past 40 years. Additionally, it generates co-movements in government consumption and tax rates that are consistent with the data. 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 behind public investment 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 or associated with policymakers' myopia, but is instead desirable in response to technological progress that is affecting the production structure. Perhaps public expenditure should be allocated to other categories with higher returns. For instance, skill-biased technological progress – another widely accepted source of technological change – may call for higher investment in education or R&D.

Our analysis abstracts from considering more complex political factors, that might lead to public underinvestment. In this respect, we hope that our framework 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 $k_t \equiv K_t/q^k_{t-1}$ and $p_t \equiv P_t/q^p_{t-1}$. Thus, using the capital accumulation equation (2) the household budget constraint (5) can be written as

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

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

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

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

with $(1-\delta^p) \equiv \left(1-\Delta^k\right)/\gamma^p$ and $f(k_t,p_t,n_t) \equiv F(q^k_{t-1}k_t, q^p_{t-1}p_t, n_t)$, 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

$$\begin{aligned} -\frac{u_{n,t}}{u_{c,t}} &= f_{n,t}(1-\tau^n_t) \\ u_{c,t} &= \beta u_{c,t+1}\left[1 + \frac{1-\tau^\pi_t}{1-\zeta\tau^\pi_t} f_{k,t+1} - \delta^k\right], \end{aligned}$$

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 derivatives to the corresponding Lagrangean formulation, the resulting optimality conditions are:

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

$$\tau_t^n: \quad \mu_{1,t}f_{n,t}n_t - \mu_{3,t}f_{n,t} = 0 \tag{A-2}$$

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

$$g_t: \quad u_{g,t} - \mu_{2,t} - \mu_{1,t} = 0 \tag{A-4}$$

$$\begin{aligned} n_t: \quad & u_{n,t} + \mu_{2,t}f_{n,t} + \mu_{1,t}\left[\tau_t^n\left(f_{n,t} + f_{nn,t}n_t\right) + \tau_t^\pi\left(\tfrac{1-\zeta}{1-\zeta\tau_t^\pi}f_{kn,t}k_t + f_{pn,t}p_t\right)\right] + \\ & \mu_{3,t}\left[\tfrac{u_{nn,t}}{u_{c,t}} + f_{nn,t}(1-\tau_t^n)\right] + \lambda_{t-1}u_{c,t}\tfrac{1-\tau_t^\pi}{1-\zeta\tau_t^\pi}f_{kn,t} = 0 \end{aligned} \tag{A-5}$$

$$\begin{aligned} k_{t+1}: \quad & -\mu_{2,t} + \beta\mu_{2,t+1}[(1-\delta^k) + f_{k,t+1}] + \\ & \beta\mu_{2,t+1}\left[\tau_{t+1}^n\left(f_{kn,t+1}n_{t+1}\right) + \tau_{t+1}^\pi\left(\tfrac{1-\zeta}{1-\zeta\tau_{t+1}^\pi}f_{k,t+1} + \tfrac{1-\zeta}{1-\zeta\tau_{t+1}^\pi}f_{kk,t+1}k_{t+1} + f_{pk,t+1}p_{t+1}\right)\right] \\ & +\beta\mu_{3,t+1}\left[f_{kn,t+1}(1-\tau_{t+1}^n)\right] + \lambda_t\left[\beta u_{c,t+1}\tfrac{1-\tau_{t+1}^\pi}{1-\zeta\tau_{t+1}^\pi}f_{kk,t+1}\right] = 0 \end{aligned} \tag{A-6}$$

$$\begin{aligned} p_{t+1}: \quad & -\mu_{2,t} + \beta\mu_{2,t+1}[(1-\delta^p) + f_{p,t+1}] - \mu_{1,t} + \\ & \beta\mu_{1,t+1}\left[(1-\delta^p) + \tau_{t+1}^n\left(f_{pn,t+1}n_{t+1}\right) + \tau_{t+1}^\pi\left(\tfrac{1-\zeta}{1-\zeta\tau_{t+1}^\pi}f_{kp,t+1}k_{t+1} + f_{p,t+1} + f_{pp,t+1}p_{t+1}\right)\right] \\ & +\beta\mu_{3,t+1}\left[f_{pn,t+1}(1-\tau_{t+1}^n)\right] + \lambda_t\left[\beta u_{c,t+1}\tfrac{1-\tau_{t+1}^\pi}{1-\zeta\tau_{t+1}^\pi}f_{kp,t+1}\right] = 0 \end{aligned} \tag{A-7}$$

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).

The steady-state of the model is obtained numerically through a Newton-type method, solving for the values of our endogenous variables satisfying the non-linear system of equations (8)-(11) and (A-1)-(A-7). Similarly, and for given initial conditions, the transition dynamics are obtained solving for the deterministic path of the endogenous variables satisfying the equilibrium conditions in every period $t = 0, \ldots, T$. The model is solved for an arbitrarily large number of periods (say $T = 1000$) so that the terminal conditions are inconsequential for the horizon under consideration (about 50 years).

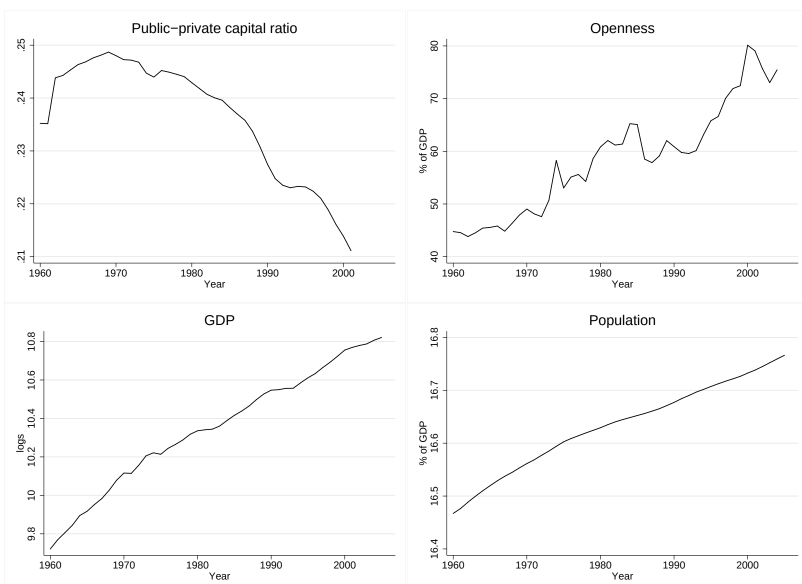
A-2 Data

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)

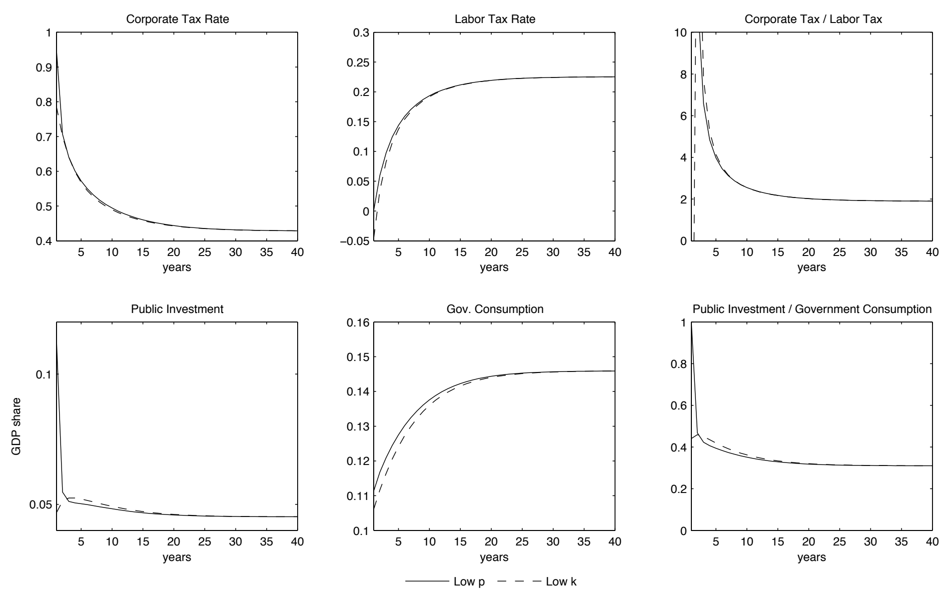


Additional material

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

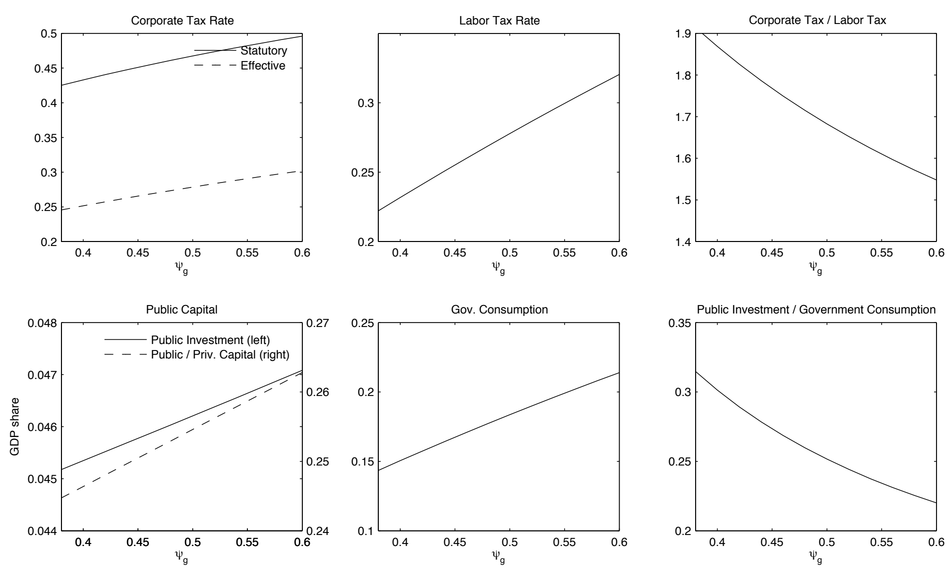
[21] Additional transition dynamics between different steady-states are omitted for brevity and available from the authors upon request.

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.

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 fiscal instruments

Figure B.2.3: Steady-state effects of exogenous changes in profit tax

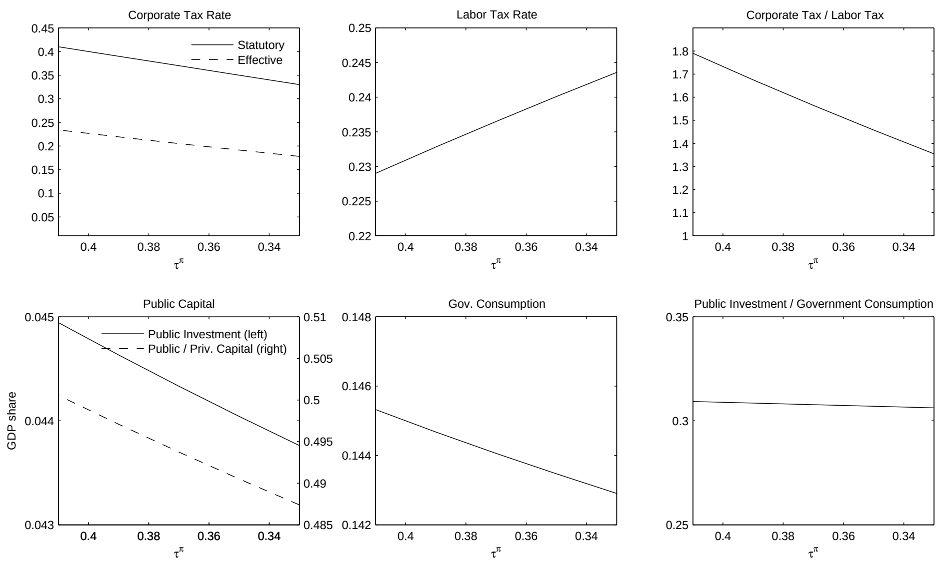


Figure B.2.4: Steady-state effects of exogenous changes in labor tax

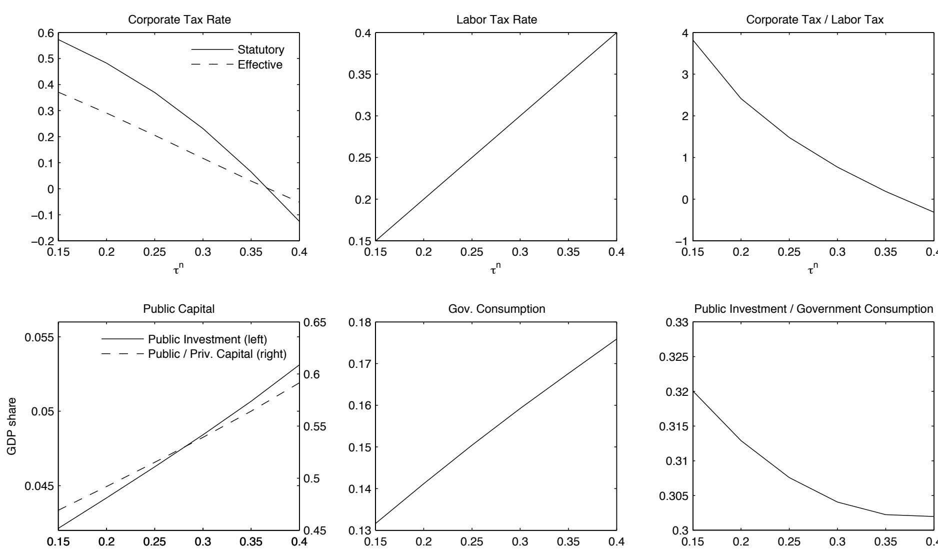


Figure B.2.5: Steady-state effects of exogenous changes in government consumption

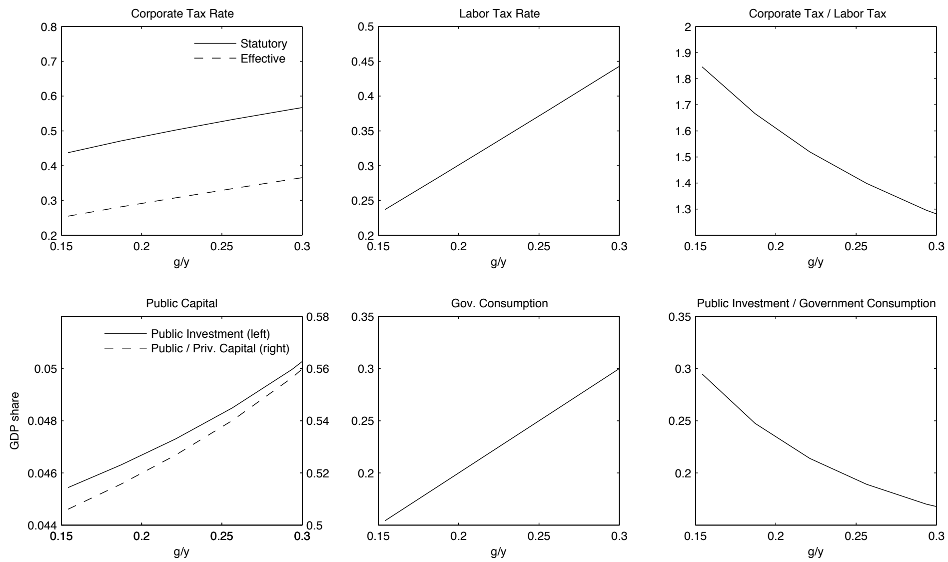
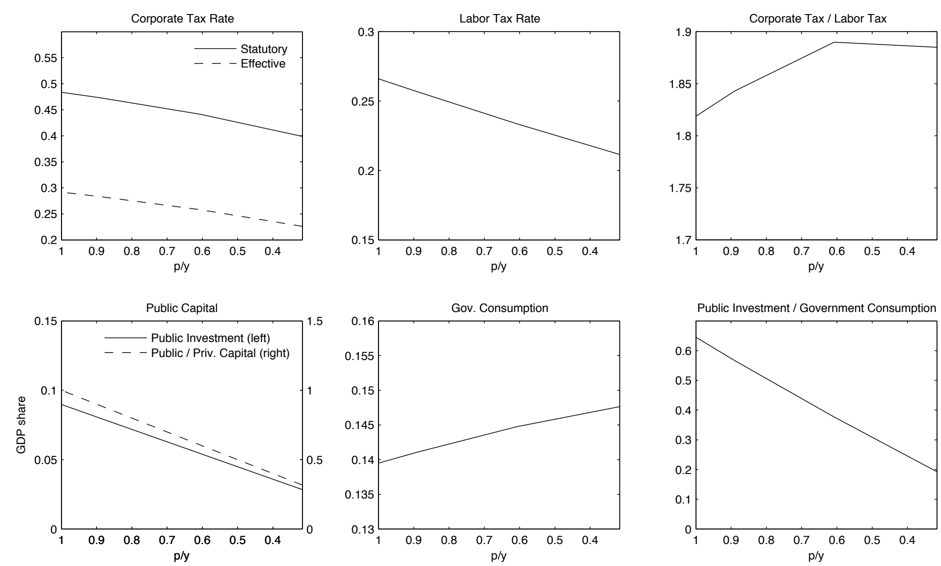


Figure B.2.6: Steady-state effects of exogenous changes in public investment



B.3 Disaggregated data

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

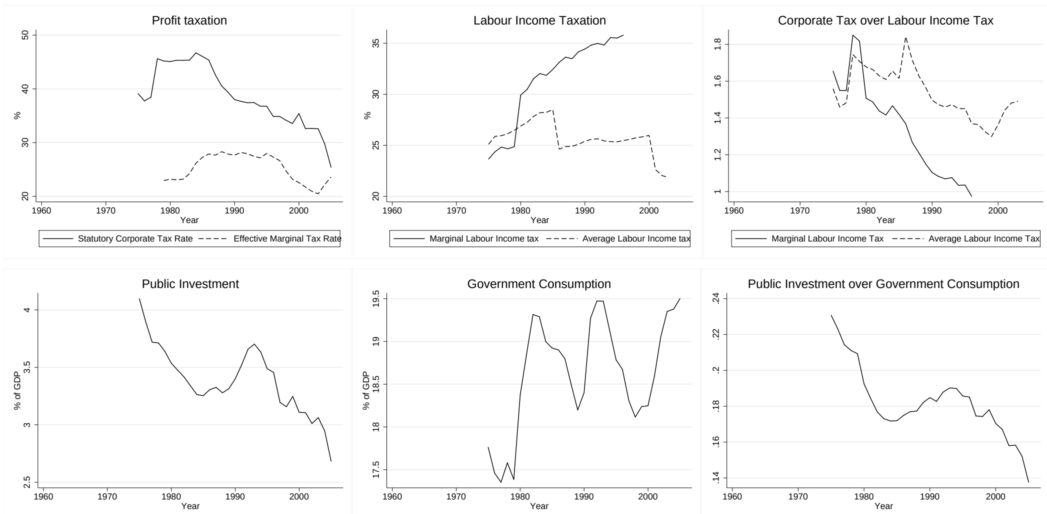


Figure B.3.8: Taxes and allocation of public spending in the G7 countries (weighted by population)

Figure B.3.9: Taxes and allocation of public spending in the OECD countries

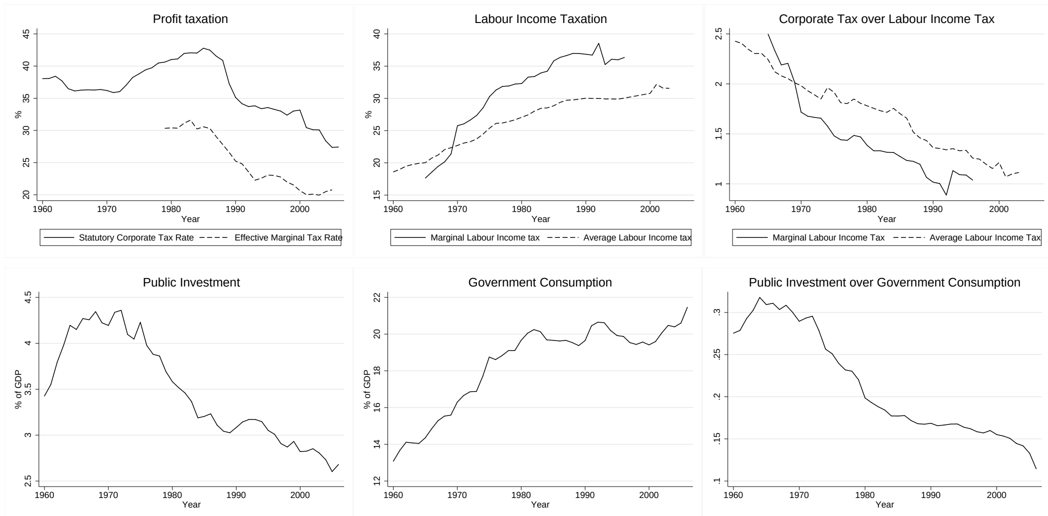
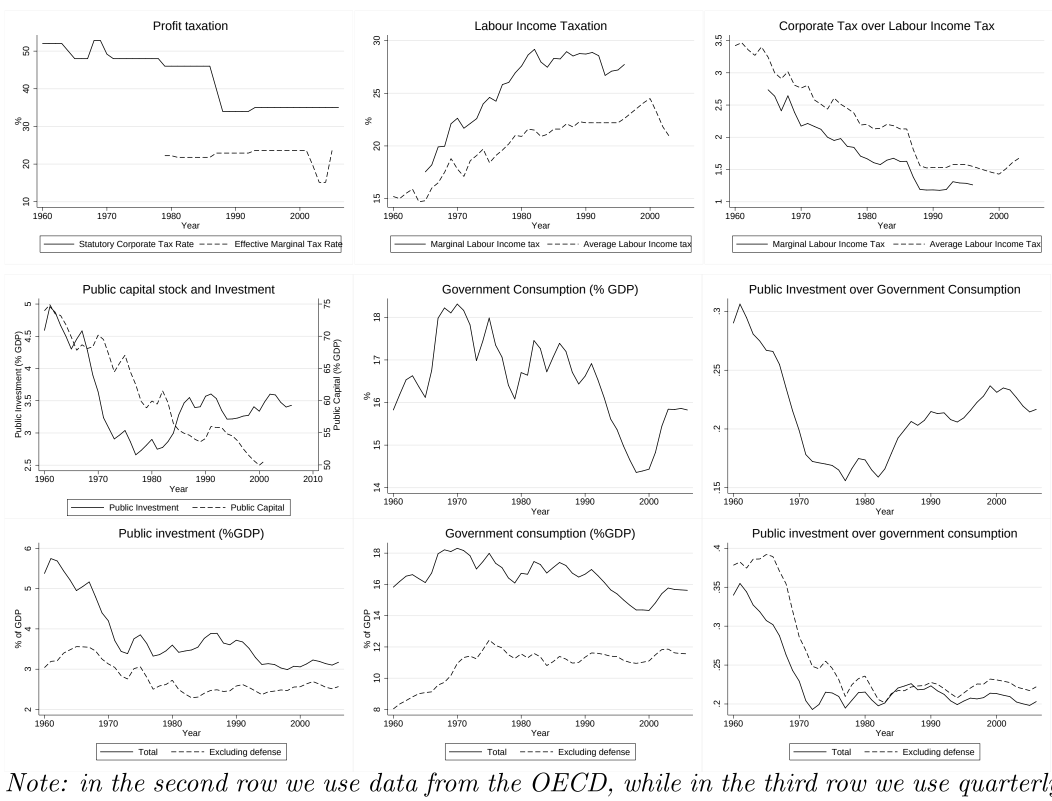


Figure B.3.10: Taxes and allocation of public spending in the US



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

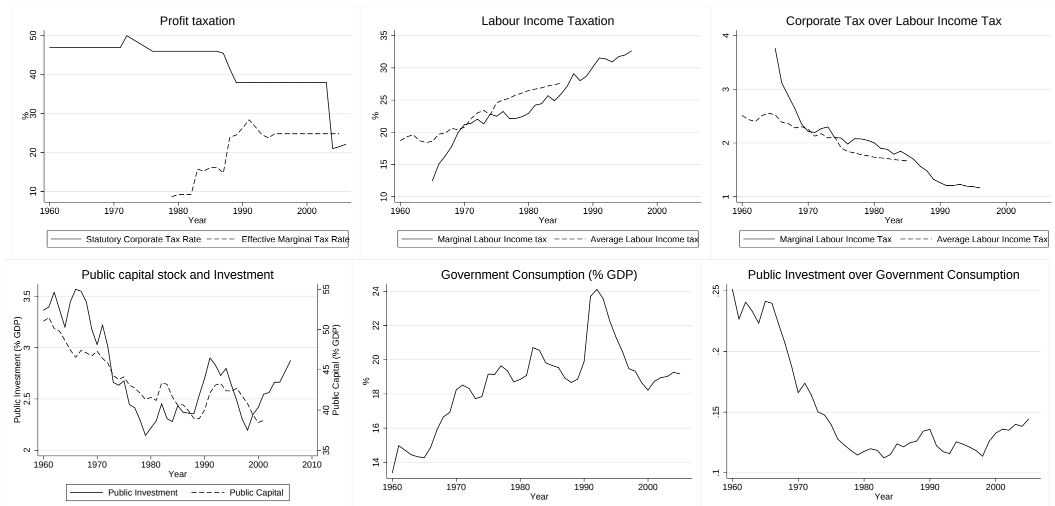


Figure B.3.12: Taxes and allocation of public spending in France

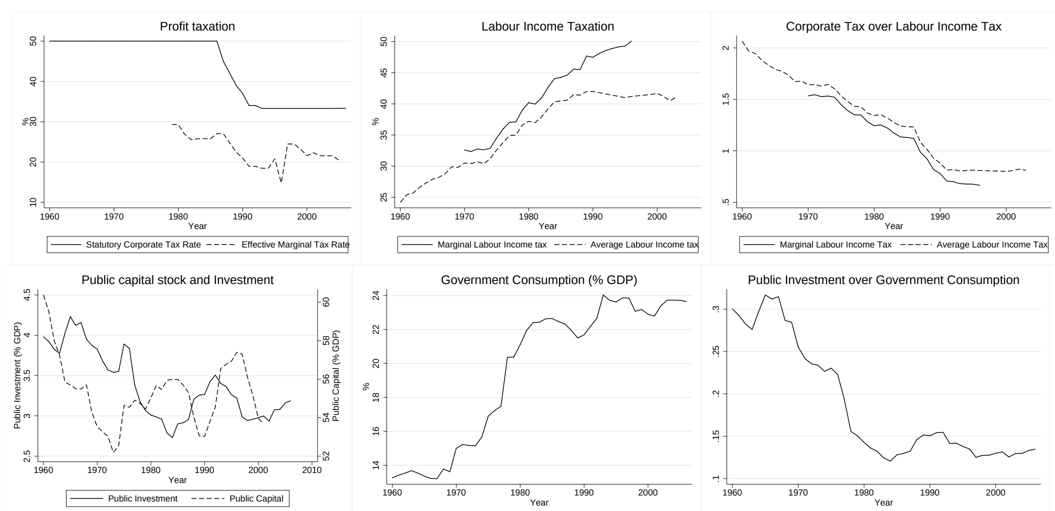


Figure B.3.13: Taxes and allocation of public spending in Germany

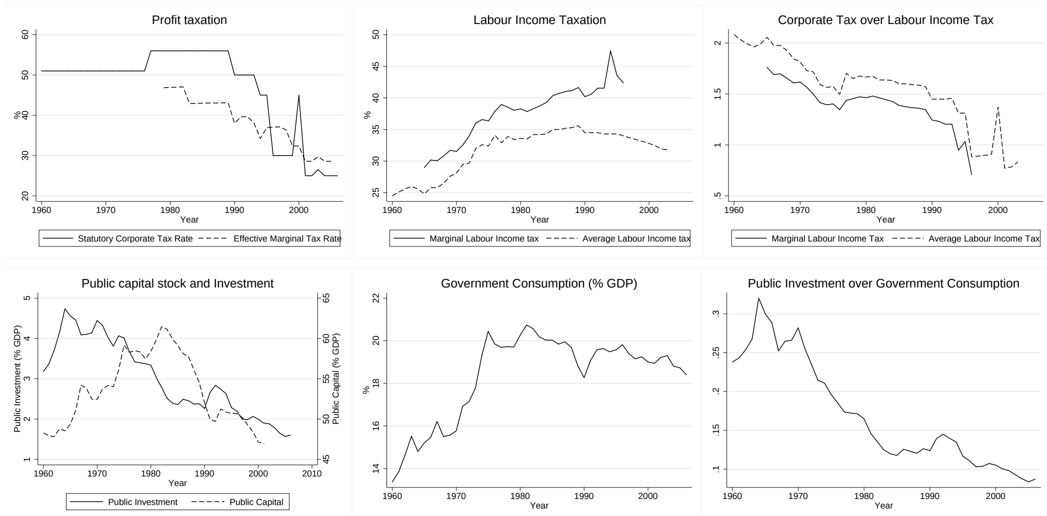


Figure B.3.14: Taxes and allocation of public spending in Italy

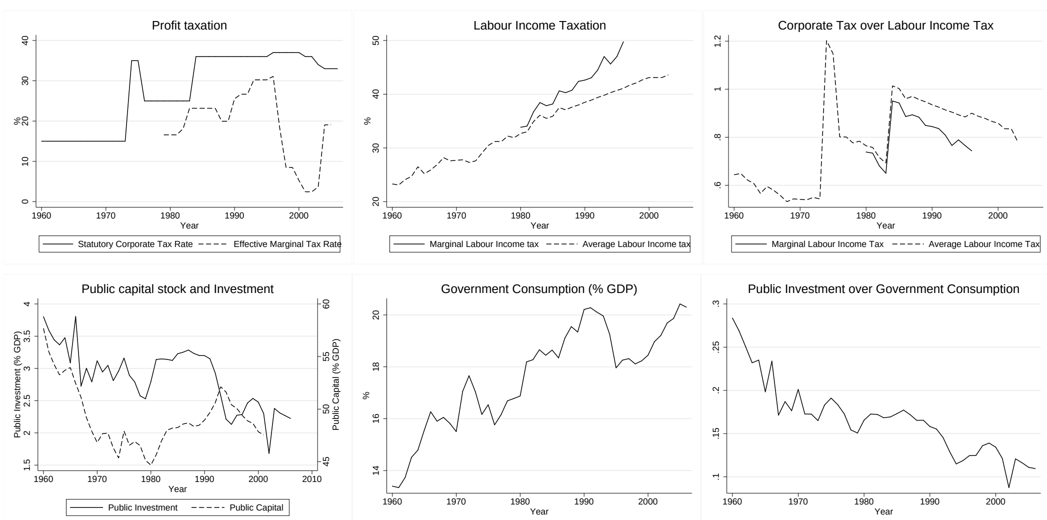


Figure B.3.15: Taxes and allocation of public spending in Japan

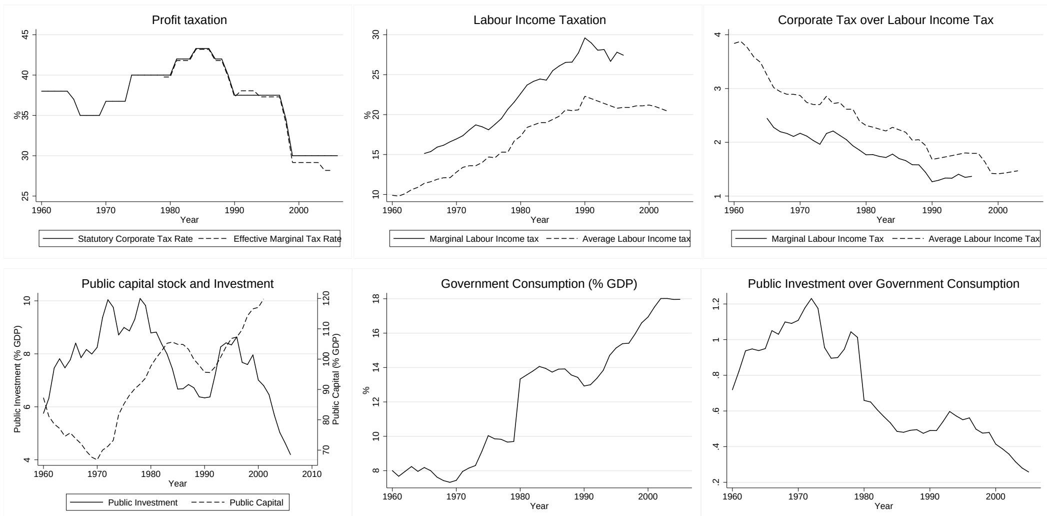


Figure B.3.16: Taxes and allocation of public spending in the UK