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Published Version:
Madsen J.B., Minniti A., Venturini F. (2023). The long-run investment effect of taxation in OECD countries. ECONOMICA, 90(358), 584-611 [10.1111/ecca.12457].

Published:
DOI: http://doi.org/10.1111/ecca.12457

Madsen, J. B., Minniti, A., & Venturini, F. (2023). The long-run investment effect of taxation in OECD countries. ***Economica*****,** ***90*****(358), 584-611.**

https://doi.org/10.1111/ecca.12457

The Long-run Investment Effect of Taxation in OECD Countries*

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November 7, 2022

Abstract

The gradually changing nature of production and the move away from tangible investment towards intangible investment over the past century suggests that the effects of the tax structure on investment need to be reassessed. To address this issue, we establish an endogenous growth model in which investment in tangible assets, R&D and education are influenced by different types of taxes. We test the long-run implications of the model using annual data for 21 OECD countries over the period 1890-2015. We find that corporate income taxes reduce investment in tangible assets and R&D. However, while personal income taxes reduce investment in tertiary education, they enhance investment in R&D. Thus, a revenue-neutral switch from corporate to personal income taxes is growth enhancing.

Keywords: Taxation, Innovation, Tangible and Intangible Capital, Economic Growth

JEL classification: E10, E62, O38, O40

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[*] Declarations of interest: none

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Introduction

Since Adam Smith's *The Wealth of Nations*, the role of investment in the process of economic development has been extensively analyzed by scholars, and a variety of theoretical and empirical research has assessed the importance of tangible investment as a driver of long-run growth (De Long and Summers, 1991; Greenwood *et al.*, 1997; Temple, 1998).

More recently, the growth literature has broadened its scope by showing that investment in human capital (Mankiw *et al.*, 1992; Klenow and Bils, 2000) and intangible assets (Madsen, 2010; Peretto, 2021) are at least as important for economic growth as the accumulation of physical capital. While total investment has long been dominated by tangible assets, this dominance has tilted towards investment in intangibles in most countries in the world over the past few decades. Over the period 1900-2016, for example, gross enrollment rates in tertiary education have increased from 0.5% to 40%, and the share of intellectual property products in total non-residential fixed investment has increased from 15% to 36% (Madsen *et al.*, 2021).

Despite the increasing focus on intangibles in the growth literature, there is only little empirical evidence of the growth-effects of taxes through the channels of intangible investment, such as investment in tertiary education and R&D relative to more traditional forms of investment in tangible assets. While taxes have long been considered vital for investment, as shown by Hall and Jorgenson (1967) and Summers (1981), the focus has mainly been on tangible investment. For example, more recent developments have used information on international tax differences (Bond and Xing, 2015), specific episodes of tax changes (Yagan, 2015) and heterogeneity in firms' responses to fiscal shocks (Zwick and Mahon, 2017) in order to analyze how tax policy affects firms' investment in tangible assets.

However, the continual changing nature of production and the associated investment raise questions about the effectiveness of various tax policies to cater for the emergence of new types of assets (Bloom *et al.*, 2019). From this perspective, the literature is still lacking as most studies only focus on one type of investment and one type of tax at time, whilst those considering various investment types, or more tax instruments, are often limited to post-1965 or post-1970 data (see Marsden, 1983 for a pioneering study).

Looking at a time-horizon of more than a century, this paper investigates the extent to which tax policies have affected the investment profile in the OECD countries since the Second Industrial Revolution while accounting for the changing composition of investment and, particularly, the increasing role of intangible assets. To this end, we construct a large macro data set on the main forms of growth-enhancing investments (fixed investment, R&D and education) and a consistent set of average tax rates (corporate income taxation, personal income taxation, top income taxes, and indirect taxation).

To guide our empirical analysis, we establish an endogenous growth model with R&D-driven innovation, physical capital investment and human capital accumulation. In the model, physical capital is an input used in production activities. Education sustains the process of human capital accumulation and the acquisition of skills by individuals. Human capital has the dual role of being a factor of production and the driving force of R&D. R&D, in turn, leads to the creation of new product varieties, and technological progress is the main engine of economic growth. In this set-up, we explore how taxation policies affect various types of investment activities in the economy.

Our theoretical framework builds on a family of models with physical, human capital, and R&D (Funke and Strulik, 2000; Papageorgiou and Perez-Sebastian, 2006; Strulik *et al.*, 2013). In the model of Funke and Strulik (2000), advanced economies typically follow three phases of economic development in which growth is first driven by physical capital accumulation followed by human capital and then by innovation. However, Funke and Strulik (2000) do not consider taxes in their model. Most traditional theories on the nexus between taxes and growth, or taxes and investment, such as the influential papers of Summers (1981) and King and Rebelo (1990), only focus on tangible investment. More recent theories focusing explicitly on the key growth drivers, such as human capital and R&D include Peretto (2003, 2007, 2011), Chen *et al.* (2017), Jaimovich and Rebelo (2017), Chu and Cozzi (2018), Ferraro *et al.* (2020), and Chu *et al.* (2021).

We test the predictions of the model by assessing the long-run effects of various taxes on investment in tangible assets (primarily, machinery and equipment, M&E), R&D, and tertiary education for 21 OECD countries over the period 1890-2015. Our analysis addresses the simultaneity that may affect the constructed measures of average income taxation by adopting a dynamic specification (the Cross-Sectionally augmented Auto-regressive Distributed Lag model, CS-ARDL) based on a rich set of lags of the variables and, as a robustness check, a static model estimated with instrumental variables (IV), where the domestic taxation rates are instrumented using geographic proximity-weighted foreign tax variables, following Chirinko and Wilson (2017).

Based on Monte Carlo simulations, we also simulate the timing at which investments adjust to their long-run equilibrium values after a standardized fiscal shock. From a policy making perspective, this exercise is useful as it allows to us identify which tax policy (corporate vs personal income tax) is the most effective in promoting investment. We find that the most expansive effect is associated with a change of corporate income tax on R&D investment. Conversely we find that tax shocks to equipment investment are more effective counter-cyclical policy measures, as the half-time adjustment towards the steady state by this investment type is only 5 years, as opposed to 8 years for education and 16 years for R&D.

A key contribution of our paper is the focus on the three most important growth promoters in the endogenous growth literature, viz., education, R&D and physical capital investment, and the effects on these outcome variables of different types of taxes. Only a few endogenous growth models have analysed the effects of various tax policies on these three growth promoters theoretically (see, e.g., Böhm *et al.*, 2015; Grossmann *et al.*, 2016). Empirically, almost all work on the growth effects of taxes has been based on per capita income or tangible investment as outcome variables (see, for an overview, Gemmell *et al.*, 2016). However, assessing the growth impact of taxation may be difficult for at least two reasons. First, tangible investment is the least influential driver of income growth among the three considered in the present paper (Madsen, 2010). Second, investment decisions in education and R&D take several years, and even decades, for their effects to fully materialize on the aggregate rate of income growth (see Section IV). For instance, investment in education can affect production with a delay of several decades because students first have to finish their studies, which can take up to 17 years for the youngest age cohorts, and then replace the existing workers in the labor force.

Only a few empirical studies have investigated the effects of various tax instruments on investment in education and R&D at the macro level empirically (see, for micro-oriented studies, Hoxby and Bulman, 2016 and references therein). For R&D, the pioneering study by Bloom *et al.* (2002) assesses the responsiveness of business research to R&D tax credits for nine OECD countries over the period 1979-1997. Though their study uses much more detailed tax data than we do, their study is limited by the short estimation period in which the time variation in R&D intensity is small.[1]

The structure of the paper is the following. Section I presents the theoretical framework and focuses on the channels through which taxation affects the three types of investment. Section II describes the empirical setting and the data used to test the predictions of our theoretical model. Section III presents the estimation results on the long-run investment effect of tax policies, whilst Section IV quantifies the investment response to various tax shocks by means of a simulation analysis. Section V concludes.

I Model

To guide our empirical analysis, we develop an endogenous growth model with R&D-driven innovation, physical capital investment and human capital accumulation (see Sections A.1-A.3 of the Online Appendix for a detailed derivation of the model).

Households

There is an infinitely-lived, representative household that maximizes the discounted stream of utilities from the consumption and leisure of its members. The household size, N, grows at a constant rate, $n \geq 0$. Each individual is endowed with one unit of time. Normalizing the initial population size to one, the household has the following utility function:

$$U = \int_0^\infty e^{-(\rho - n)t} \log u \; \mathrm{d}t,$$

where $\rho > n$ is the subjective discount rate. Instantaneous utility is:

$$\log u = \log c + \sigma \log(1 - l),$$

where c is consumption per capita; $(1 - l)$ is the fraction of time devoted to leisure; and $\sigma > 0$ is the elasticity of instantaneous utility with respect to leisure.

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[1] Another exception is Akcigit *et al.* (2021) who use historical data on taxes and inventors since 1921 for the US to investigate the effects of taxation on inventions by individuals and firms (micro level) and on states over time (macro level). Our study complements their study by considering multiple countries and longer historical data.

Human capital per capita, h, accumulates according to a Lucas (1988)-type production function:

$$\dot{h} = \chi h_e^{\eta} h^{\gamma} - nh, \qquad \chi > 0, \tag{1}$$

where h_e denotes the education input that an individual employs in the process of skill formation (teachers); $\eta \in (0, 1)$ captures decreasing returns to education; and $\gamma \in (0, 1)$ is a parameter that determines the degree to which newborns benefit from the generational transmission of human capital within the household. We assume that $\eta + \gamma < 1$, which guarantees that h is constant along the balanced growth path. Since newborns are uneducated, the term nh in Eq. (1) represents the cost of upgrading the human capital of the newborns to the average level of human capital of the existing population. Thus, the rate of population growth, n, operates like depreciation of human capital per capita (for a similar assumption, see Dalgaard and Kreiner, 2001 and Strulik, 2005).

Individuals save, supply labor and choose their demand for educational input that maximizes utility subject to the following asset-accumulation law:

$$\dot{a} = (r - n)\, a + wh(1 - \tau^w) - wh_e - c(1 + \tau^c) + T, \tag{2}$$

where all variables are expressed in per capita terms. Here, a is asset holdings; r is the after-tax rate of return on financial assets, w is the wage rate per unit of human capital, τ^w is the tax rate on wage income; wh_e denotes education expenditure (teachers salaries); τ^c is the consumption tax rate; and T represents the lump-sum transfer per capita. We assume that the governments budget is balanced, which requires that the per capita transfer, T, equals the total per capita tax revenue.

Solving the households maximization problem yields a standard Euler equation:

$$\frac{\dot{c}}{c} = r - \rho, \tag{3}$$

which characterises the dynamic path of consumption per capita.

Firms

In the economy there is a unique final good, taken as the numeraire, which is produced by fully competitive firms using a continuum of intermediate goods and human capital. Assuming constant returns to scale, final output, Y, is produced according to:

$$Y = \left(\int_0^A x_\omega^{1/m} \, \mathrm{d}\omega \right)^{\alpha m} H_Y^{1-\alpha}, \qquad \alpha \in (0,1), \tag{4}$$

where H_Y is the amount of human capital employed in the final goods sector; A is the existing number of intermediate goods; x_ω denotes the quantity of intermediate input of type ω; and $m \in [1, 1/\alpha]$ is a technology parameter that determines the elasticity of substitution between two generic varieties of intermediates, $m/(m-1)$.[2] The parameter α measures the intermediate goods' share of total income, whereas $1-\alpha$ is the fraction of income accruing to production workers. Economic growth stems from the creation of new product varieties (horizontal innovations). The number of varieties, A, is interpreted as the stock of knowledge of the economy.

In each intermediate production sector, ω, only one firm has access to a technology that transforms (one unit of) capital input into (one unit of) output, that is, $k_\omega = x_\omega$. Each firm produces a different variety of intermediate goods and capital depreciates at the rate $\delta \geq 0$. Following Aghion and Howitt (2005) and Acemoglu *et al.* (2006), we assume that the monopoly power of intermediate goods producers is limited by the existence of a competitive fringe of firms that can produce one unit of the same intermediate input using ϑ units of capital, with $\vartheta \in (1, m]$.

Profit maximization of the perfectly competitive firms in the final goods sector implies the following demand for the intermediate good of type ω:

$$x_\omega = \alpha Y \frac{p_\omega^{-\frac{m}{m-1}}}{P^{-\frac{1}{m-1}}}, \tag{5}$$

where p_ω is its price and $P \equiv \left(\int_0^A p_\omega^{\frac{1}{1-m}} \, \mathrm{d}\omega \right)^{1-m}$ is the aggregate price index.

As one unit of intermediate good requires one unit of capital, denoting $R \equiv r + \delta$ as the before-tax

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[2] The assumption $m \leq 1/\alpha$ assures that profits accruing to an intermediate goods producer in a symmetric equilibrium are non-increasing in the number of the existing varieties.

user cost of capital, profits of the intermediate goods firm ω amount to $\pi_\omega = (p_\omega x_\omega - R x_\omega)(1-\tau^\pi)$, where τ^π is the corporate income tax rate.

Given the potential competition from the fringe, it is optimal for each intermediate good producer ω to charge the limit price $p_\omega = p = \vartheta R$. In equilibrium, the competitive fringe is not active.[3] Using Eq. (5), it follows that $x_\omega = x = \alpha Y/(A\vartheta R)$ which, once substituted into Eq. (4), gives:

$$Y = A^{\frac{\alpha(m-1)}{1-\alpha}} \left(\frac{\alpha}{\vartheta R}\right)^{\frac{\alpha}{1-\alpha}} H_Y. \tag{6}$$

Moreover, since $w = (1-\alpha)Y/H_Y$, we get that $w = A^{\frac{\alpha(m-1)}{1-\alpha}} [\alpha/(\vartheta R)]^{\frac{\alpha}{1-\alpha}}$. The total stock of physical capital, K, can be expressed as $\int_0^A k_\omega \, \mathrm{d}\omega = \int_0^A x_\omega \, \mathrm{d}\omega = Ax = \alpha Y/(\vartheta R)$. This result suggests that, if r is stationary in the long run (and so also R), then the capital/income ratio is stationary along the balanced growth path.

R&D sector

The R&D sector is characterised by free entry. $\dot{A}$ are new patents generated at each point in time. Having access to the same stock of knowledge, A, a research firm uses only human capital to develop new ideas according to the following constant returns-to-scale R&D technology:

$$\dot{A} = H_A A/\psi, \qquad \psi \equiv \nu H, \qquad \nu > 0, \tag{7}$$

where H_A denotes the human capital engaged in R&D, ψ is an index that measures the difficulty of performing R&D, ν is a positive parameter and $H \equiv h \cdot lN$ is the aggregate stock of human capital, defined as human capital per worker times labor input. Accordingly, for a given R&D technology, productivity growth will remain constant in the long run provided that the fraction of human capital allocated to R&D remains constant (fully-endogenous growth).[4]

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[3] The existence of a binding competitive fringe that limits the markup is introduced for tractability. In the absence of a competitive fringe, firms would charge the unconstrained monopoly price. This model-variation would deliver similar results, but the analysis is more cumbersome.

[4] Eq. (7) stems from the Jones's (1995) critique of the strong scale effect of the first-generation Schumpeterian growth models. In particular, the term $\psi \equiv \nu H$ captures the idea that R&D difficulty grows with the aggregate stock of human capital, which represents the overall scale of the economy. See Chu *et al.* (2013) and Chu *et al.* (2019b) for Schumpeterian growth models with human capital accumulation adopting a similar formulation for the dilution effect and Laincz and Peretto (2006) for empirical evidence supporting this feature of the model.

Let V be the present discounted value of the after-tax stream of profits generated by an innovation, which represents the stock market valuation of an intermediate goods producing firm. In equilibrium, all arbitrage possibilities in the capital market are exhausted. Denoting the tax on distributed dividends and the tax on capital gains as τ^D and τ^V, respectively, the after-tax rate of return on financial assets, r, must be equal to the dividends paid out by an intermediate goods firm, $\pi(1-\tau^D)/V$, plus capital gains, $\dot{V}(1-\tau^V)/V$. Therefore, the no-arbitrage condition for the capital market requires:

$$r = \frac{\pi}{V}(1-\tau^D) + \frac{\dot{V}}{V}(1-\tau^V). \tag{8}$$

Profits in the R&D sector amount to $\Pi = V\dot{A} - wH_A$. Free entry into the sector drives profits to zero. Imposing the zero-profit condition, $\Pi = 0$, and using Eq. (7), we get:

$$V = \nu \frac{wH}{A}, \tag{9}$$

which says that the expected discounted profit from innovation is matched by its cost.

Labor and financial markets

The labor market is perfectly competitive, and the wage adjusts instantaneously to equate labor demand to labor supply. In our setup, this amounts to requiring that human capital is fully employed in the three sectors. The labor market-clearing condition therefore becomes:

$$H \equiv h \cdot lN = H_Y + H_A + H_e = Nh_Y + Nh_A + Nh_e, \tag{10}$$

where h_Y and h_A denote the human capital employed in the final good and R&D sectors, respectively, both expressed in per capita terms.

Wealth is composed of claims on physical capital and equities of the intermediate goods firms. As there are A intermediate goods producers, the value of the shares of these firms equals VA. Thus, the aggregate stock of assets held by the representative household can be written as:

$$Na = K + VA, \tag{11}$$

which represents the financial market-clearing condition.[5] This completes the description of the model.

Steady state

We now focus on the steady-state properties of the model. In any steady-state equilibrium, all endogenous variables grow over time at constant, but not necessarily identical, rates. In our model, human capital per capita, h, is stationary and the shares of human capital employed in the three sectors are constant over time. The labor market-clearing condition (10) then implies that the human capital stock, H, grows at the same rate as population, n. Moreover, according to the Euler equation (3), the interest rate, r, is constant over time. Then, denoting the steady-state growth rate of the number of ideas by $g_A \equiv \dot{A}/A$, using Eq. (6), it follows that the growth rate of per capita income, g, must be equal to $\frac{\alpha(m-1)}{(1-\alpha)} g_A$. Since $w = A^{\frac{\alpha(m-1)}{1-\alpha}} \left[\alpha/(\vartheta R)\right]^{\frac{\alpha}{1-\alpha}}$ and $K = \alpha Y/(\vartheta R)$, we get that both the wage rate, w, and the per capita physical capital stock, K/N, grow at the rate g. Dividing both sides of the free-entry condition (9) by N, it follows that per capita equity holdings, VA/N, grow at the same rate g. As a result, using the financial market-clearing condition (11), we can conclude that per capita asset holdings, a, grow at the rate g as well.

As shown in Section A.3 of the Online Appendix, in the long run, there exists a unique balanced growth equilibrium, where the allocation of human capital devoted to education and R&D activities, $\hbar_e \equiv h_e/(hl)$ and $\hbar_A \equiv h_A/(hl)$, respectively, and the physical capital investment share, $i_K \equiv (\dot{K} + \delta K)/Y$, are given by:

$$\hbar_e = \frac{\eta(1-\tau^w)n}{\rho - \gamma n}, \tag{12}$$

$$\hbar_A = g\frac{(1-\alpha)\nu}{(m-1)\alpha}, \tag{13}$$

$$i_K = \frac{\alpha(n+g+\delta)}{\vartheta\,(g+\rho+\delta)}, \tag{14}$$

where the rate of economic growth, g, amounts to:

$$g = f(\tau^V, \tau^D, \tau^\pi)\frac{(m-1)\alpha}{(1-\alpha)\nu}, \tag{15}$$

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[5] According to the asset-accumulation law (2), the after-tax income from asset holdings of the representative household is equal to ra. Using the no-arbitrage condition (8) and the financial market-clearing condition (11), ra is equivalent to $rK/N + (1-\tau^V)\dot{V}A/N + (1-\tau^D)\pi A/N$.

where $f(\tau^V, \tau^D, \tau^\pi) \equiv \frac{\left[1-\hbar_e-\left(\frac{1-\alpha}{\alpha}\frac{\vartheta}{\vartheta-1}\nu\right)\frac{\rho-n(1-\tau^V)}{(1-\tau^\pi)(1-\tau^D)}\right]}{1+\left\{1+(1-\tau^V)\left[\frac{1-\alpha}{\alpha(m-1)}-1\right]\right\}\frac{\frac{(m-1)\vartheta}{\vartheta-1}}{(1-\tau^\pi)(1-\tau^D)}}$ is a function that depends on the tax rates and the other parameters of the model. Notice that, according to Eqs. (13) and (14), both the steady-state share of human capital devoted to R&D, $\hbar_A$, and the physical capital investment share, i_K, are positively related to the rate of economic growth, g.

The scale effect is absent in the long-run growth equilibrium as growth, g, is independent of the population size and the total number of researchers. Similar to the models of Dinopoulos and Thompson (1998), Peretto (1998, 2018), Young (1998), and Aghion and Howitt (1998, ch. 12), growth is fully endogenous, in that public policies can affect the long-run growth rate of the economy.[6]

Eq. (12) shows that an increase in the tax rate on labor income, τ^w, reduces the steady-state fraction of human capital devoted to education, $\hbar_e$. Thus, taxation of wages acts as a disincentive to invest in education and skill acquisition, suggesting that a higher labor income tax has a negative impact on the workforce's educational attainment. This tax change, in turn, induces a reallocation of human capital from teaching to research, which results in an increase in $\hbar_A$, i_K and g (see Eqs. 13-15).[7] As discussed in Section A.4 of the Online Appendix, an increase in the corporate income tax rate, τ^π, (and/or the tax on distributed dividends, τ^D) reduces the rate of return on R&D investment, thereby reducing the incentives to invest in R&D. Increases in corporate income taxes therefore negatively affect the rate of economic growth, which results in lower values of $\hbar_A$ and i_K. Finally, if the condition $g + n > g_A$ holds, higher capital gains taxes have adverse growth effects, leading both $\hbar_A$ and i_K to decline. We summarize the fiscal policy implications of the model in the following proposition.

Proposition 1. *In the long run:*

(i) An increase in the tax rate on labor income, τ^w, reduces the fraction of human capital devoted to

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[6] Peretto (2003) has assessed how taxation affects economic growth using the Schumpeterian growth framework. Peretto (2003) observes that, as a consequence of market fragmentation, policy variables that work through the size of the aggregate market do not affect steady-state growth, whereas fiscal variables working through the interest rate channel do have long-run growth effects. As a result, although they expand the demand, labor and consumption taxes do not affect long-run growth, whereas taxes on household asset income or corporate income do. Peretto (2007, 2011) extends this type of analysis to study transitional dynamics and social welfare.

[7] In order to remove the strong scale effect from the model, we could reformulate Eq. (7) by dividing the aggregate human capital in the R&D sector, H_A, by population, N. This different formulation does not significantly change the model solution but, more importantly, does not affect the direction of the final effect that a change in wage income taxation has on the allocation of human capital in the education and R&D sectors. We could alternatively consider a semi-endogenous growth version of the model. Under this specification, the R&D share of human capital plays a role only in the short run as population growth is the sole determinant of growth in the long run. However, also in this version of the model, an increase in wage income taxation causes a reallocation of human capital from education to R&D as in our formulation.

education, $\hbar_e$. This tax change increases the fraction of human capital devoted to R&D, $\hbar_A$, and the investment share in physical assets, i_K;

(ii) An increase in the corporate income tax rate, τ^π, (and/or the tax on distributed dividends, τ^D) reduces both $\hbar_A$ and i_K;

(iii) Provided that $g + n > g_A$, an increase in the tax rate on capital gains, τ^V, reduces both $\hbar_A$ and i_K.

Proof. See the discussion in Section A.4 of the Online Appendix. □

Quantitative exercise

To check whether the predictions in Proposition 1 are borne out, we calibrate the model using data for the United States and, through a numerical exercise, quantify the impact of the tax changes on $\hbar_E$, $\hbar_A$ and i_K. This quantification is useful to assess whether changes in personal income taxation, by affecting investment activities, can promote economic growth.[8]

We calibrate the model using data on the US economy over the period 1981-2020. Table 1 summarizes the calibration strategy that differentiates between the externally and internally calibrated parameter values (see Section A.5 in the Online Appendix for details of the calibration). The observable endogenous variables take the initial steady-state values under the status quo policy.

Personal income tax includes taxes on salaries, wages, interests, dividends and capital gains. Therefore, the signs of the personal income tax effects on both $\hbar_A$ and i_K are theoretically ambiguous as these variables respond positively to increases in wage taxation and negatively to increases in dividends/capital gains taxation. However, as taxes derived from wage income are main sources of the personal income taxation, we expect a positive correlation between the personal income tax rate and the investment rates in innovation and physical capital, $\hbar_A$ and i_K. Following the same reasoning, an increase in the personal income tax rate is expected to reduce the fraction of human capital devoted to education, $\hbar_e$.

In order to test these predictions, we build the tax rate on personal income –which is the weighted mean of wage income and capital income tax rates– by collecting data on the main sources of personal

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[8] This exercise will also provide key parameter values used below for studying the transitional dynamics of the model.

Table 1: **Calibration - US economy (1981-2020)**

Endogenous observables	**Value**	**Source**
g	0.021	World Bank
$\frac{wH}{Y}$	0.6	FRED Economic Data
$\frac{wH_A}{Y}$	0.023	OECD (2022)
$\frac{wH_e}{Y}$	0.062	OECD (2022)

Parameters set	**Value**	**Source**
n	0.0089	World Bank
τ^{π}	0.34	OECD tax database
τ^{D}	0.38	OECD tax database
τ^{V}	0.1	American tax laws
τ^{w}	0.3	OECD tax database

Parameters calibrated internally	**Value**	**Target**
ρ	0.02	After-tax (long-run) rate of return
α	0.3	Labor allocation across sectors
m	2.2	Implied by Eqs. (13) and (15)
ν	0.63	Implied by Eqs. (13) and (15)
γ	0.15	Related to ν through Eqs. (1) and (12)
η	0.18	Implied by Eq. (12)
σ	1.26	Labor/leisure time allocation
ϑ	1.24	Capital-income ratio
δ	0.04	Physical capital investment rate
χ	1	Normalization (no impact on $\hbar_e$, $\hbar_A$, i_K and g)

income, namely wages and salaries, capital gains, interests and dividends, and related statutory tax rates (source: Tax Foundation).[9] Wages represent the largest source of total income (89%), while capital gains (8.1%) and dividends (2.9%) only account for a smaller share of personal income. Using these income shares as weights, and considering the statutory tax rates in Table 1 (τ^D, τ^V and τ^w), the personal income tax rate, τ^{PI}, is found to average 28.6% in our calibrated economy.

Starting from this basis, in Table 2, we quantify the impact of a one-percentage point increase in the tax rates on $\hbar_E$, $\hbar_A$ and i_K. In the first column, we reproduce the economic effects of a shock to the overall personal income taxation. As is evident, the tax increase reduces $\hbar_e$ (-1.27%) significantly and increases $\hbar_A$ and i_K by +0.07% and +0.03%, respectively. This finding confirms our conjecture that the positive effect of wage taxation on R&D (and growth) dominates the adverse effect exerted by taxation of capital gains and dividends. Column (2) shows the effects of an increase in wage taxation. As expected, the effects on $\hbar_A$ and i_K is stronger than in the case of an increase in the overall income tax rate (+0.12% and +0.05%, respectively). Finally, in column (3), it is seen that a one-percentage point increase in the corporate income taxation, τ^π, reduces $\hbar_A$ by 1.5 percentage points.

Table 2: **Quantification of the investment effects of tax changes**

	$\Delta\tau^{PI}$=1% (1)	$\Delta\tau^{w}$=1% (2)	$\Delta\tau^{\pi}$=1% (3)
$\%\Delta\hbar_e$	-1.27	-1.27	nil
$\%\Delta\hbar_A$	+0.07	+0.12	-1.47
$\%\Delta i_K$	+0.03	+0.05	-0.06

Transitional dynamics

So far, we have restricted our analysis to the long-term effects of the fiscal policy. However, it is important to consider transitional dynamics to understand the speed of adjustment of investment towards the new steady state in response to tax shocks. In this section, we simulate the transitional dynamics of the main variables of interest by applying the Relaxation algorithm (Trimborn *et al.*, 2008). A parallel analysis will be developed in Section IV where we simulate the response function of each investment type to tax shocks using a century of data for the OECD countries

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[9] Tax Foundation dataset, Sources of Personal Income (indicators).

Starting from a steady state under the status quo policy corresponding to the values in Table 1, we simulate the dynamic transition paths of $\hbar_e$, $\hbar_A$ and i_K induced by a one-time, one-percentage point increase in the tax rates. In all the simulations, the government budget is balanced by a lump-sum tax/transfer.[10]

Panel (a) of Figure 1 displays the time paths of the shares of human capital devoted to education, $\hbar_e$, and to R&D, $\hbar_A$, in response to a one percentage point increase in the tax rate on labor income, τ^w, from 0.30 to 0.31. Compared to the reference scenario, $\hbar_e$ drops and then gradually increases, remaining permanently below the old steady-state level. Conversely, $\hbar_A$ jumps up and remains high, converging to an equilibrium value above the reference steady-state. Panels (b) and (c) display the time paths of the share of human capital devoted to R&D, $\hbar_A$, and of the physical capital investment share, i_K, in response to a one percentage point increase in the corporate income tax rate, τ^π, from 0.34 to 0.35 and the tax rate on dividends, τ^D, from 0.38 to 0.39. Compared to the reference (status quo) scenario, both $\hbar_A$ and i_K fall on impact and then converge quite rapidly to their final steady-state values. The response of $\hbar_A$ to these policy changes is more pronounced than than of i_K.[11]

II Empirical setting

Model specification

Following the predictions of the model developed above, we focus on three types of investment: M&E, R&D and tertiary education. We estimate the following generic investment model:

$$I_{it}^Z = \alpha_{i0} + \alpha_1 \tau_{it}^z + \alpha_2 \mathbb{X}_{it} + \lambda_i \mathbb{F}_t + \epsilon_{it}, \tag{16}$$

where I^Z is the investment rate, measured as *(i)* the share of investment in M&E in total nominal income, I^K; *(ii)* the share of R&D in total nominal income, I^A; and *(iii)* the investment in tertiary education, measured as the gross enrollment rate in tertiary education, I^e. Here, τ^z is the relevant

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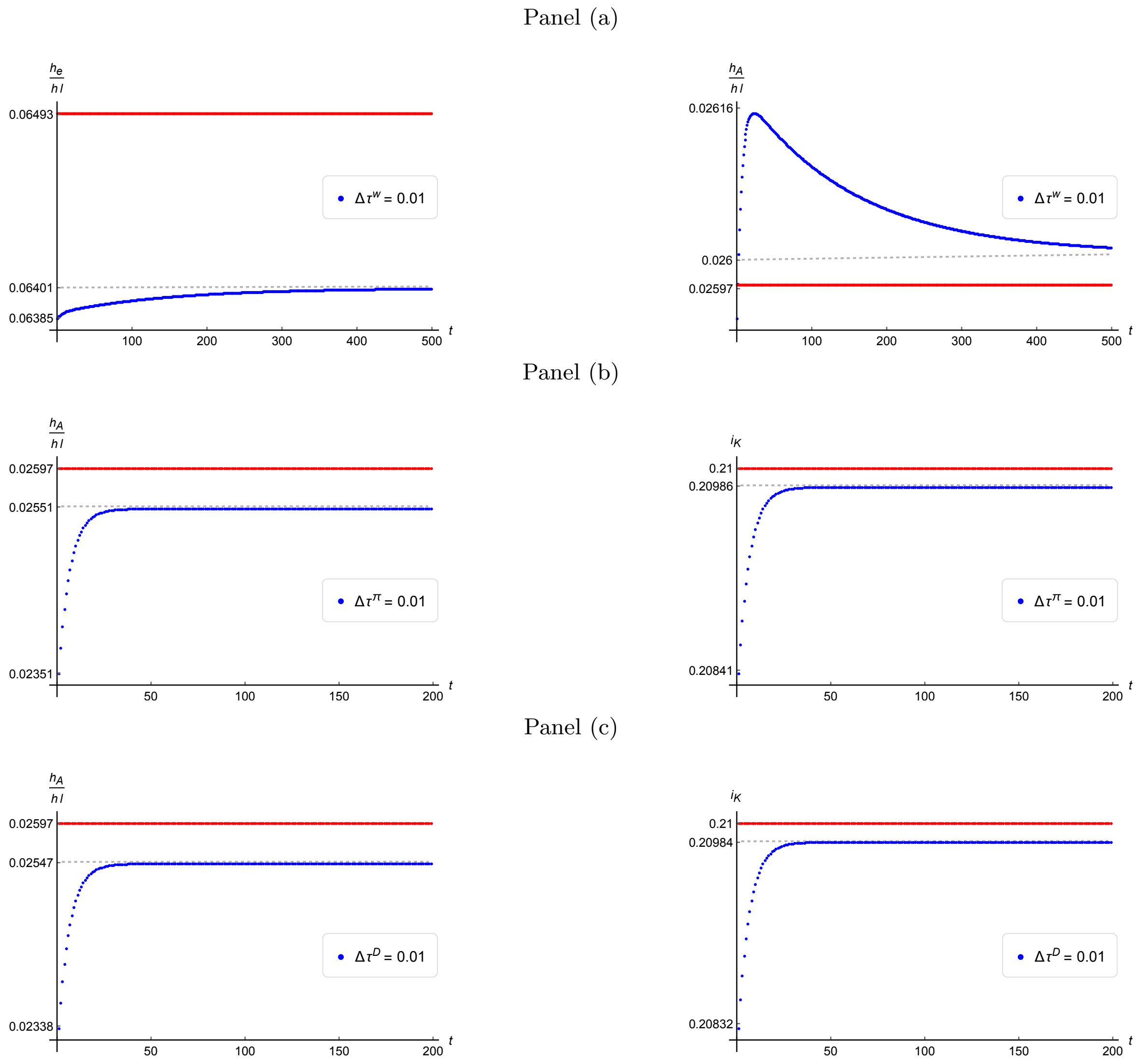
[10] We employ the Relaxation method to solve the transitional dynamics of the scale-adjusted variables given the initial conditions. Details of the complete dynamical system used in the numerical simulations are provided in Section A.6 of the Online Appendix.

[11] The transitional dynamics of the model when the tax rate on capital gains, τ^V, increases are qualitatively similar to those of panels (b) and (c), provided that the condition $g + n > g_A$ holds.

Figure 1: **Impulse responses to policy shocks**



Panel (a)

Panel (b)

Panel (c)

Notes The horizontal line corresponds to the reference (status-quo) scenario of no policy shock. All parameter values are as in Table 1.

tax variable suggested for each equation by our theoretical setting. In the equation for educational investment, the main regressor is the personal income tax rate ($\tau^z = \tau^{PI}$), which is our empirical counterpart of the tax rates of the model (τ^w, τ^D, and τ^V). In the equations for the tangible and intangible investment, we use the corporate income tax rate as the reference tax variable ($\tau^z = \tau^\pi$).

In Eq. (16), i and t refer to country and year, respectively. α_{i0} are country fixed effects, $\mathbb{X}$ is a vector of control variables, whilst $\mathbb{F}$ collects common correlated effects (CCEs), computed as cross-sectional mean values of the dependent variable and regressors (Pesaran, 2006). These terms capture the impact of unobserved common factors (technology, business cycle, pandemics, etc.), to which countries respond asymetrically due to differences in absorptive capacity (education and R&D), preferences and institutions. Such country-specific effects are captured by λ_i. Finally, ϵ is a disturbance term.

To mitigate the endogeneity bias induced by omitted variables, we include as controls the consumption tax rate, the top personal income tax rate, the rate of inflation, and per capita income growth. In our theoretical setting, the consumption tax rate does not alter investment choices in equilibrium, a condition that may not hold empirically and that we need to assess in order to avoid biased estimates for our relevant tax variables, τ^{PI} and τ^{π}. Another challenging issue is that our theoretical set-up assumes tax proportionality, implying that the average and marginal tax rates coincide. However, marginal tax rates are *de facto* more relevant for the agents' decisions than average taxes. To account for the gap between the average and the marginal taxes rates, we include the top income tax rates in the regression. This control is also important as a large share of companies were not incorporated in the earlier years of our estimation period; hence, the investment decisions may have been influenced more by top-income tax rates levied on entrepreneurs than taxation on corporate income. For instance, in the US, top income taxation has been found to significantly affect the location decision of the highly mobile superstar inventors (Moretti and Wilson, 2017, Akcigit *et al.*, 2021). Following our theoretical model, the growth rate of per capita GDP is included in the regressions for I^K and I^A (see Eqs. 13 and 14). Macroeconomic uncertainty is proxied by the inflation rate. Inflation, however, may also be positively associated with investment due to profit squeeze, as not all cost increases can be passed on to consumers.

Estimation method

We use dynamic regression methods to identify the long-run (equilibrium) effect of tax variables and static regressions methods for robustness checks. The following dynamic estimators are applied to our investment models: the Cross-Sectionally Augmented Auto-Regressive Distributed Lag (ARDL) model, and the Cross-Sectionally augmented Distributed Lags model (CS-DL). As static regression methods, we use the fixed-effect OLS estimator and the standard instrumental variable method (2SLS).

The cross-sectionally augmented version of the ARDL model, with p lags both in the dependent and the explanatory variables,[12] takes the following shape (control variables omitted for simplicity):

$$I_{it}^{z} = \beta_{0i} + \sum_{p=1}^{5} \beta_{1p} I_{it-p}^{z} + \sum_{p=0}^{5} \beta_{2p} \tau_{it-p}^{z} + \sum_{p=0}^{5} \lambda_{ip} \mathbb{F}_{t-p} + \varepsilon_{it}, \tag{17}$$

where the long-run impact of the tax variable τ^{z}, defined in Eq. (16), is derived from the estimates of short-run parameters in Eq. (17), namely $\alpha_1 = \sum_{p=0}^{5} \beta_{2p}/(1 - \sum_{p=1}^{5} \beta_{1p})$.

The CS-DL regression model estimates the long-run elasticity, α_1, directly from Eq. (16), by augmenting it with current and lagged values of first-differenced regressors and CCE terms:

$$I_{it}^{Z} = \alpha_{i0} + \alpha_1 \tau_{it}^{z} + \sum_{p=0}^{5} \theta_p \Delta \tau_{it-p}^{z} + \sum_{p=0}^{5} \lambda_{ip} \mathbb{F}_{t-p} + \varepsilon_{it}. \tag{18}$$

The ARDL estimator yields consistent long-run estimates that are robust to reverse causality when the lag structure of the variables is correctly specified, irrespective of their order of integration (Pesaran and Shin, 1999). The CS-DL estimator exploits first-differenced regressors to remove the bias associated to simultaneity feedbacks. This regression model tends to provide more precise estimates than the ARDL estimator under various conditions, particularly if the coefficients of the lagged dependent variables are estimated imprecisely in the ARDL regression (β_{1p} in Eq. 17). The CS-DL estimator also provides more precise estimates in the presence of unit roots, arbitrary serial correlation, heterogeneity/homogeneity in short/long-run parameters, weak/strong cross-section dependence, and an unknown number of common factors. The main drawback of the CS-DL estimator is its sensitivity to reverse causality, i.e., when there are feedback effects from the lagged dependent variable to the regressors, the CS-DL approach is not consistent.

To deal with endogeneity, as a supplement to the dynamic estimates, we estimate a static version of Eq. (16) in which the impact of the tax variables is predicted through instrumental variables. As instruments we use geographic proximity-weighted foreign tax rates following Chirinko and Wilson (2017) (a similar method is used by Gemmell *et al.*, 2014). These authors show that the positive correlation between cross-state tax rates would reflect the synchronic response of the US states to

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[12] Following Chudik *et al.* (2016), we adopt the $p = T^{1/3}$ rule-of-the-thumb to select the number of lags in the dynamic model, where T is the number of years. In all estimations, we assume homogeneity of slope parameters across countries.

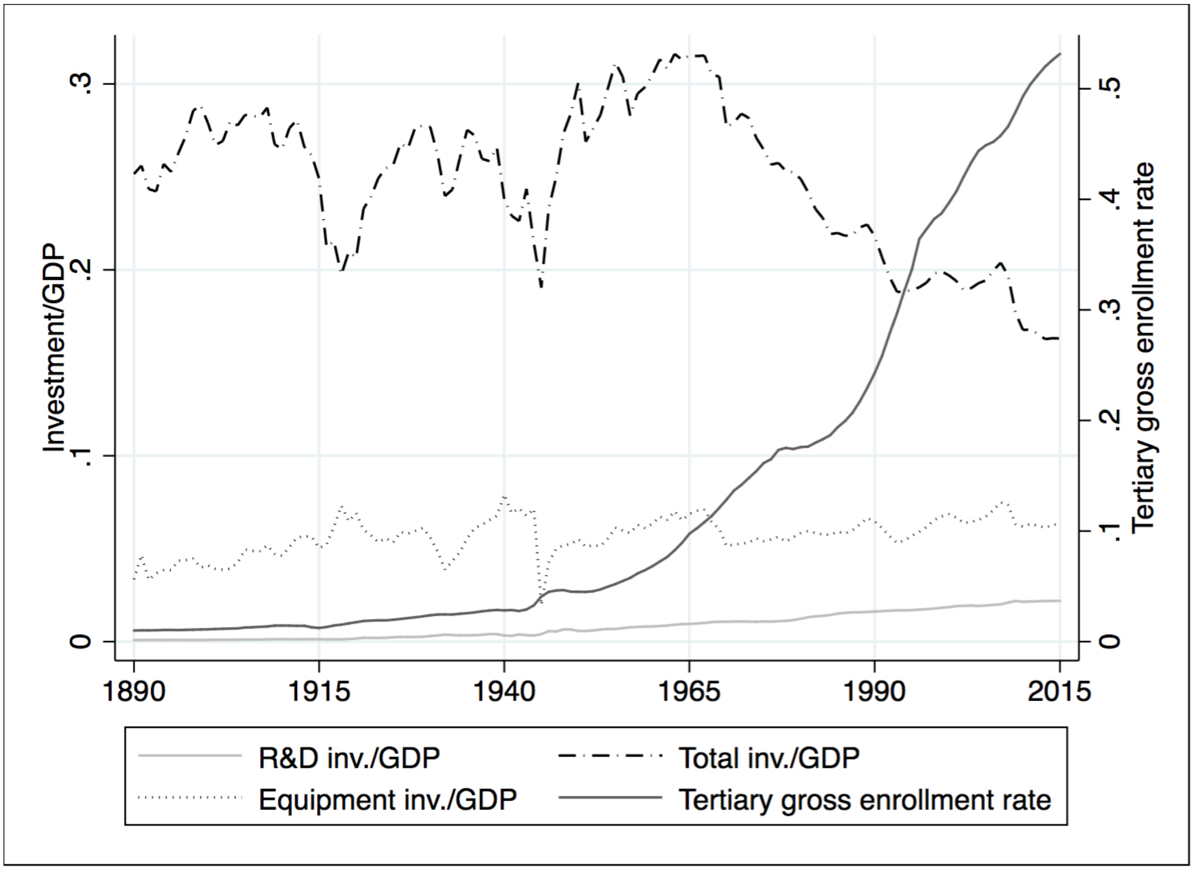
macroeconomic shocks. Hence, when the effects of unobservable common factors are controlled for, a *negative* relationship between tax rates emerges across states. This would be consistent with the slope of the state's reaction function depending on foreign (out-of-state) tax rates, preferences for government services, as well as home/foreign states' economic and demographic conditions. The negative correlation between domestic and foreign tax rates stands in contrast to the "race to the bottom" hypothesis, but supports the idea of "riding on a seesaw" in tax policies across states or countries.

Data

We construct the data set for the following 21 OECD countries over the period 1890-2015: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the UK and the US. The tangible investment ratio is measured as nominal investment in M&E over nominal GDP and, in the robustness checks, as the total gross investment divided by GDP. R&D intensity is measured as the share of total nominal GDP spent on R&D by the private sector, universities and government, as estimated by Madsen and Ang (2016). The pre-WWII R&D data are mostly the R&D outlays of universities. Gross enrollment rates in tertiary education are estimated as the student enrollments divided by the population of the 18-22 age cohort, as estimated by Madsen (2014).

The personal income tax rate is estimated as total direct tax revenues from profits or dividends, labor income, and land rent earned by individuals as a share of nominal GDP. As most tax systems treat dividends and wage income equally, we cannot make this distinction in the estimates. We disregard the complications introduced by franking/imputation credit offsets in which corporate income tax payments are deducted from taxes paid on dividends. Franking credit offsets are currently in place in Australia and New Zealand and partially in place in Canada and the UK. We also disregard capital gains taxation rules as they are complex and vary substantially over time and across countries (see, for the US, Summers, 1981). The corporate income tax rate is measured as corporate tax revenue divided by nominal GDP. Compared to the statutory tax rate, the downside of measuring tax rates from the revenue side is that they are influenced by firms' and households' endogenous responses to tax policies. Conversely, our tax measure captures the effective tax rate of corporations and, therefore, overcomes the complications associated with cross-border transfer of earnings, depreciation of fixed capital for tax purposes, deductions of interests on non-equity capital, tax rebates, etc. We provide a detailed description of data sources in Section B of the Online Appendix.

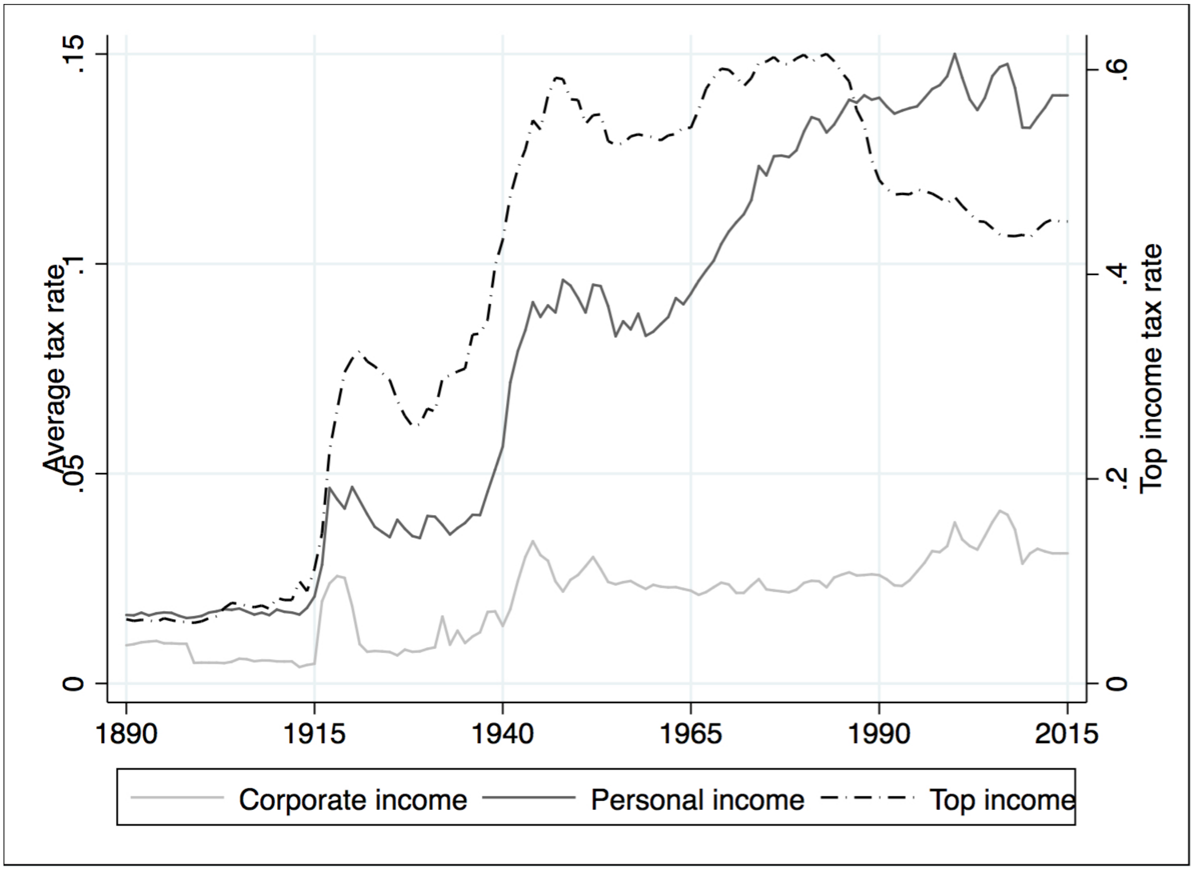
Figure 2: **Investment rates in physical capital and R&D (left-hand side) and tertiary enrollment rate (right-hand side), 1890-2015**



Graphical analysis and summary statistics

Figure 2 displays the shares of total fixed investment (residential and non-residential investment) and machinery and equipment investment in GDP, the ratio of R&D expenses in GDP (left-hand side), and the gross enrollment rate for tertiary education (right-hand side); all estimated as unweighted averages for the 21 OECD countries considered here. The fixed investment rates fluctuated around the 25% mark until the 1970s and have declined since then, predominantly due to a decline in the

Figure 3: **Corporate and personal income tax rates (left axis) and top income tax rates (right axis), 1890-2015**



investment rates for structures and non-residential buildings. Conversely, the M&E investment rate has been relatively stable over time. R&D intensity has increased at a steady rate throughout the entire period to reach a plateau of approximately 2% since the turn of the 21th century. Over the entire time span, the average R&D intensity has been 1.3%. Investment in tertiary education has increased markedly over the past few decades. Overall, Figure 2 underscores that, over the latest decades, the most advanced countries have progressively increased the investment share in intangible assets, such as R&D and tertiary education.

Figure 3 shows the evolution of the tax rates on corporate income, personal income and top personal income. Common for all tax rates is a large and almost permanent upward shift during the world wars. While the corporate income tax rate has fluctuated around constant levels since WWII, the personal income tax rate increased during the 1960s and 1970s to a new plateau that has remained relatively constant since. Finally, like the personal income tax rate, the top income tax rate jumped up during the world wars, stayed at the 60% mark up to the mid 1980s, and has since declined along with the weakening political support for high top income tax rates, partly in an attempt to reduce capital flight to tax havens and an out-migration of high income earners.

Table 3: **Summary statistics**

	M&E inv./ GDP	R&D expenses/ GDP	Tertiary gross enrollment rate	Corporate income tax	Personal income tax	Top income tax	GDP p.c. growth	Inflation rate
mean	0.056	0.010	0.134	0.025	0.087	0.405	0.019	0.044
median	0.043	0.004	0.043	0.022	0.082	0.450	0.021	0.026
SD	0.069	0.009	0.180	0.015	0.063	0.225	0.057	0.101

III Empirical results

In this section we present the regression results for the demand equation for tangible investment (Section III), R&D (Section III) and education (Section III).

Tangible investment

Table 4 reports the estimation results for the tax impact on the investment rate in M&E. In columns (1)-(4), we run a set of bivariate regressions in which the tax rates are entered individually (corporate income tax, personal income tax, consumption tax, and top income tax). Consistent with the predictions of our theory, the coefficient of the corporate tax rate is significantly negative and has a long-run coefficient of -1.1, which is in the lower bound of the elasticities found in earlier works (see, e.g., Hassett and Hubbard, 2002 and Djankov *et al.*, 2010).[13] The larger effect of corporate income taxes found here compared to the literature may reflect the longer time span of our data, which enables us to fully identify the response of tangible investment to tax changes. The coefficients

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[13] Earlier works relate the investment ratio to the user cost of capital. In the absence of historical data on investment tax discounts and other tax allowances, differences in the user cost of capital would reflect cross-country variation in the corporate income tax rate and in the investment price relative to GDP (Bond and Xing, 2015). To make our estimates comparable to the user cost of capital elasticity of investment estimated in earlier papers, we have also included the relative price of investment in our regressions. The coefficients of the corporate income tax rates were unaffected by the inclusion of the real price of investment.

of the other tax variables in columns (2)-(4) are insignificant. In one of the elaborate analyses of tax effects on the investment decision, Summers (1981) shows analytically that personal income tax rates may affect tangible investment through a complex interaction between leverage and dividend taxation; however, he did not identify any empirical effects of personal income tax on tangible investment (see also Djankov *et al.*, 2010, Table 5 and related discussion). The insignificance of the personal income tax rate in our estimates is compatible with our theory, which predicts that the effect of income taxes on tangible investment is ambiguous, but more likely positive.

Table 4: **Physical capital investment equation**

Dep. variable:		M&E investment/GDP					Total inv/GDP		M&E investment/GDP		
		ARDL						CS-DL	FE-OLS	IV-2SLS	
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
										2nd stage	
Corporate income tax		-1.113*** (0.402)				-1.460*** (0.489)	-4.217** (1.978)	-1.512*** (0.143)	-1.461*** (0.264)	-1.096** (0.477)	-2.290*** (0.709)
Personal income tax			-0.0287 (0.134)								
Consumption tax				-0.0426 (0.172)							
Top personal income tax					-0.147 (0.115)						
GDP % growth						0.590** (0.236)	1.716* (0.875)	0.187*** (0.064)	0.045 (0.028)	0.066*** (0.023)	0.067** (0.031)
Inflation rate						-0.299*** (0.094)	-2.679*** (0.666)	-0.048* (0.026)	-0.081** (0.033)	-0.088*** (0.029)	-0.133*** (0.023)
Instruments:	year lag									*1st stage*	
Foreign import tariff rate	1									-4.536*** (1.265)	-5.211*** (1.147)
Foreign corporate income tax rate	5									-2.515*** (0.714)	-2.966*** (0.979)
Lagged endogenous variable	10										0.938*** (0.044)
F-test of excluded restrictions										11.13	13.78
Over-identification test [p-value]										[0.13]	[0.38]
Obs.		1,483	2,286	2,408	2,345	1,483	1,483	1,483	1,559	1,555	1,357
R-squared		0.944	0.927	0.932	0.936	0.953	0.918	0.816	0.7991	0.060	0.044

Notes The dependent variables are the share of investment in M&E in total GDP in columns (1)-(5) and (7)-(10) and total investment in total GDP in column (6). The displayed parameters are long-run estimates based on the ARDL model in columns (1)-(6) and CS-DL in column (7). Static FE-OLS estimates are reported in column (8). Static IV-2SLS estimates are reported in columns (9) and (10). All estimates include country fixed effects and country-specific common correlated effects. Standard errors are in parentheses and p-values are in brackets. The standard errors in the dynamic regressions are computed using the delta method. The standard errors in the static fixed effects regressions are robust to heteroskedasticity and serial correlation. ***,**,* significant at 1, 5 and 10%.

Next, we compare the results of the various estimation procedures introduced in Section II: dynamic regressions in cols. (5)-(7) (ARDL and CS-DL), and static regressions in cols. (8)-(10) (FE-OLS vs 2SLS-IV). All these estimates use the corporate income tax rate as the reference tax variable, and the per capita income growth rate and the consumer inflation rate as controls.[14] In such robustness regressions, the impact of income growth is stably positive and statistically significant, whilst the impact of inflation is negative. The magnitude of these effects, however, changes with the procedure of regressions used. More importantly, the coefficient of the corporate income tax rate remains significantly negative and with the same size in all regressions, regardless of whether the ARDL, the CS-DL or the static fixed-effects model is estimated. In column (5), the coefficient is approximately 25% lower than the estimate without controls in the first column. This is likely to reflect the correlation between the corporate income tax rate and income growth (negative) as well as the inflation rate (positive). Overall, this finding would suggest that the coefficient of τ^{π} is upward biased in the bivariate regression in column (1) due to an omitted variable problem.

The regression in column (6) uses the total investment rate as the outcome variable. In this case, the coefficient of the corporate income tax rate is substantially higher than in the regressions using the rate of investment in M&E as the dependent variable. This result is exactly what we should expect since the returns to buildings are capitalized over a much longer period than investment in machinery and equipment.

Quantitatively, based on the coefficients in column (5), a one-percentage point increase in the corporate income tax rate is associated with a -1.5 percentage point change in the investment rate, whereas a similar increase in the rates of income growth and inflation would change the investment rate by 0.6 and -0.30 percentage points, respectively. Thus, a one standard deviation increase in each of these explanatory variables is associated with a percentage point change in the outcome variable of -2.2, 3.6, and -3.0, respectively. These results suggest that changes in corporate income tax rates are highly influential for investment in machinery and equipment relative to inflation and income growth.

Finally, in the IV-2SLS regressions in the last two columns in Table 4, we use the geographic proximity-weighted average of foreign rates of import tariffs and corporate income taxation as well as the lagged domestic corporate income tax rate.[15] Following Chirinko and Wilson (2017), once the

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[14] Another standard determinant of investment behavior is the real interest rate (long government bond rate minus contemporaneous consumer price inflation). However, its coefficient was insignificant in all our baseline regressions - a result that is consistent with the finding in the literature (see, e.g., Hassett and Hubbard, 2002 and Djankov *et al.*, 2010). This result is unlikely to reflect that asset returns are irrelevant for the investment decision but, rather, that the real interest rate is not an adequate proxy for the returns component of the cost of capital. The cost of capital is determined by the required equity returns, which are unobservable, and, for levered firms, also the bank lending rates.

[15] Tariff rates are measured as tariff duties divided by nominal imports.

effects of common responses to unobservable factors are accounted for through CCEs, there may not be tax competition among countries to attract mobile capital that would generate a positive correlation between corporate income taxation at home and abroad. Furthermore, in the presence of higher external barriers to trade, the penetration of foreign markets is more difficult; hence, governments may be incentivised to enhance the competitiveness of domestic companies through lower taxation.

The lagged endogenous variable is used as an instrument to cater for the dynamic correlation between domestic corporate income taxation and the investment rate which, if not accounted for, may undermine the orthogonality condition between external instruments and the outcome variable. Our instruments are robust to the effect of the domestic corporate income tax rate on the tangible investment ratio. As the figures in the lower panel of Table 4 show (colums (9)-(10)), the value of the F-test for excluded instruments is 11 and 14, whilst the p-value of the Sargan's over-identification tests are 0.13 and 0.38. All this ensures that the instruments' relevance and orthogonality conditions are both satisfied.

The results of the first-stage regressions indicate significantly negative effects of the foreign corporate income tax and tariff rates on the domestic corporate income tax rates. Although the sign of foreign corporate income tax rates is contrary to the common assumption of tax competition, these findings are consistent with Chirinko and Wilson (2017). The second-stage regressions yield coefficients of corporate income tax close to those obtained from the ARDL estimates. Conversely, the parameter size of the controls is much lower than their ARDL-counterparts, probably suggesting that the static regression models do not fully capture the dynamic adjustment towards the long-run equilibrium.

R&D investment

The regression results for R&D intensity as the outcome variable are presented in Table 5. Columns (1)-(4) show estimates in which the different types of taxes are entered individually. Consistent with the predictions of our theory, the coefficient of the corporate income tax rate is significantly negative. Its value of -0.23 implies that a one standard deviation increase in the corporate income tax rate is associated with a 0.35 percentage point reduction in R&D intensity, a finding that is consistent with the results provided by Akcigit *et al.* (2021) for the United States. Also in line with our theory, personal income taxes impact positively on R&D investment, while both the consumption and top income tax rates are uninfluential for the cross-country variation in R&D intensity.

Table 5: **R&D investment equation**

Dep. variable:		R&D expenditure/GDP								
				ARDL			CS-DL	FE-OLS	IV-2SLS	
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
									2nd stage	
Corporate income tax		-0.231***				-0.339***	-0.073***	-0.056***	-0.055**	-0.089***
		(0.088)				(0.104)	(0.023)	(0.023)	(0.025)	(0.034)
Personal income tax			0.080***			0.177***	0.108***	0.064***	0.054***	0.065***
			(0.028)			(0.040)	(0.009)	(0.013)	(0.011)	(0.014)
Consumption tax				0.016						
				(0.027)						
Top personal income tax					-0.0112					
					(0.008)					
GDP % growth						-0.047*	0.027***	0.003	-0.002	-0.001
						(0.028)	(0.006)	(0.002)	(0.001)	(0.002)
Inflation rate						0.035***	0.022***	0.011***	0.006***	0.008***
						(0.010)	(0.003)	(0.003)	(0.002)	(0.002)
Instruments:	year lag								*1st stage*	
Foreign import tariff rate	1								-3.717***	-3.531***
									(1.113)	(0.985)
Foreign corporate income tax rate	1								-11.26***	-10.64***
									(0.863)	(0.804)
Lagged endog. var.	5									0.138***
										(0.029)
F-test of excluded restrictions									85.81	80.62
Over-identification test [p-value]									[0.64]	[0.22]
Obs.		1,483	2,286	2,408	2,345	1,483	1,460	1,559	1,559	1,466
R-squared		0.991	0.994	0.995	0.995	0.992	0.907	0.923	0.125	0.154

Notes Dependent variable: R&D expenditure over GDP. The estimates are long-run parameter estimates based on the ARDL model in colums (1)-(5), and CS-DL in column (6). Static FE-OLS estimates are reported in column (7). Static IV-2SLS estimates are reported in columns (8) and (9). All estimates include country fixed effects and country-specific common correlated effects. Standard errors are in parentheses and p-values are in brackets. The standard errors in the dynamic regressions are computed using the delta method. The standard errors in the static FE regressions are robust to heteroskedasticity and serial correlation. ***,**,* significant at 1, 5 and 10%.

In columns (5)-(9) where we consider corporate and personal income tax rates as the reference tax variables. To mitigate any omitted variables' bias, we include the per capita income growth rate and the consumer inflation rate as controls. The coefficients of the corporate and personal income tax rates are larger in the ARDL regression than the empirical models considered so far, as the ARDL estimator is capable to fully capturing the long-run effects of the explanatory variables, especially when the dependent variable is highly persistent, as is the case for R&D intensity. The coefficients of income growth are mixed, while the inflation rate is positively correlated with R&D investment. In the Schumpeterian growth theory, the impact of inflation on innovation is ambiguous. Due to menu costs, price changes should reduce R&D by dampening the returns to innovation (Oikawa and

Ueda, 2018). However, according to Chu *et al.* (2017), the relationship between inflation and R&D investment is an inverted U-shaped when firms' entry costs are large. A similar result is found in the empirical analysis of Chu *et al.* (2019a) using data for developing and advanced countries. The inverted-U shaped profile is consistent with our finding of a positive effect of inflation on R&D when it it is taken into account that the dynamic adjustment of prices towards their long run equilibrium in the OECD countries is relatively slow.

The coefficients of corporate income taxes remain significantly negative in all the regressions with controls, regardless of whether the ARDL, the CS-DL or the static fixed-effects estimator is applied. Based on the ARDL estimate in column (5), a one standard deviation increase in the corporate income tax rate is associated with a change of -0.51 percentage points in the investment rate, whilst a similar shock to the personal income tax rate would change R&D intensity by 1.12 percentage points.

To deal with endogeneity, we instrument the domestic corporate income tax rate in the static regression by the inverse distance-weighted rates of foreign corporate income and import taxation as well as the lagged value of the endogenous variable in column (9). Like the M&E investment model, the first-stage regressions in the lower panel in Table 5 show significantly negative effects of our set of instruments on the domestic corporate income tax rate. In both of the first-stage regressions, the relevance and the exclusion restriction criteria do not give evidence against our identification strategy: the F-tests for excluded instruments are 86 and 81 and Sargan's over-identification p-values are 0.64 and 0.22. Turning to the second-stage results, we find coefficients which are largely comparable to the other estimates of Table 5.

Thus far, we have not explicitly addressed the long-run income growth implications of the R&D-intensity estimates, which ultimately depend on the shape of the ideas production function. If there are scale effects in the ideas production function, then any significant variable in the R&D-intensity estimates will have permanent income growth effects. To see this, consider the following closed-economy, ideas production function (see, e.g., Madsen, 2010):

$$\dot{A} = \zeta \left(\frac{H_A}{Q} \right)^{\iota} A^{\xi}, \quad \iota \in (0, 1], \quad \xi \leq 1,$$

where $\dot{A}$ is new ideas, H_A is the innovative activity, ζ is a research productivity parameter, $Q \propto N^{\kappa}$

is product variety, ι is a duplication parameter (which is zero if all innovations are duplications and 1 if there are no duplicating innovations), A is domestic knowledge stock, ι is returns to scale in knowledge, and κ is a parameter of product proliferation.

Following the literature of endogenous growth, we measure H_A by R&D expenditure and Q by GDP and set $\xi = 1$ so that the ideas production collapses to $g_A = \zeta(H_A/Y)^{\iota}$, (see, e.g., Madsen, 2008; Venturini, 2012). This ideas production function extends first-generation models of knowledge production to allow for product proliferation and decreasing returns to knowledge stock, as highlighted in Schumpeterian second-generation models of economic growth (e.g., Aghion and Howitt, 1998; Peretto, 1998). Here, R&D expenditure is divided by product variety, Q, because R&D spreads thinly across the variety of products as the economy expands. Since, in steady state, product variety is growing at the same rate as population or the labor force, it follows the growth rate of knowledge, g_A. Hence, TFP does not increase in response to an increase in the number of researchers that keeps the number of researchers in a fixed proportion to the population.

Using the Schumpeterian growth framework, we can derive the implications of changes in the tax structure on TFP growth. The results of the opposite effects of corporate and personal income tax rates suggest that tax switch policies can be used to enhance growth: A tax revenue neutral switch from corporate to personal income taxes will permanently increase the research-intensity, R&D, and, therefore, TFP growth. Thus, in the long run, this tax switch has a positive growth impact because R&D has permanent effects on the rate of economic expansion, while the other two investment categories only have marginal long-run growth effects.

Tertiary education investment

As the last step in our long-run regression analysis, we estimate the education investment equation using the personal income tax rate as the main explanatory variable (Table 6). In line with the predictions of our theoretical model, the coefficient of the personal income tax rate is negative as it reduces the expected returns to education (column (1)). Conversely, the other tax variables are insignificant in the bivariate regressions (columns (2)-(4)).

As control variables, we include population growth and the minimum working age in the regressions in columns (5)-(10). The minimum working age is included to capture the institutionally imposed opportunity costs of education; a dimension that is approximately independent of market forces and individual preferences. Consider first the regressions in which tertiary education is the outcome variables (columns (5) and (7)-(10)). The coefficients of population growth and minimum working age are mostly insignificant, while the coefficient of the personal income tax rate is statistically significantly negative in the cases in which investment in education is measured at the tertiary level. The personal income tax rate is also quantitatively important. Based on the estimate in column (5), a one standard deviation increase in the personal income tax rate is associated with a -2.03 percentage point change in the tertiary gross enrollment rate.

Table 6: **Tertiary enrollment equation**

Dep. variable:		Tertiary GER					Secondary GER		Tertiary GER		
		ARDL						CS-DL	FE-OLS	IV-2SLS	
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
										2nd stage	
Personal income tax		-0.309**				-0.323**	0.164	-0.177***	-0.098***	-0.270***	-0.306***
		(0.143)				(0.158)	(0.529)	(0.044)	(0.025)	(0.058)	(0.055)
Corporate income tax			-0.108								
			(1.388)								
Consumption tax				0.136							
				(0.204)							
Top personal income tax					-0.029						
					(0.062)						
Population growth						0.040	0.077	0.034**	-0.024	0.010	-0.125
						(0.061)	(0.182)	(0.017)	(0.105)	(0.108)	(0.109)
Minimum working age						-0.317	4.121*	-0.505**	0.0131	-0.007	-0.010
						(0.828)	(2.415)	(0.235)	(0.012)	(0.010)	(0.010)
Instruments:	year lag									*1st stage*	
Foreign personal income tax	2									-8.297***	-7.065***
										(0.970)	(0.906)
Foreign tax revenue/GDP	3									0.712*	0.535**
										(0.377)	(0.256)
Lagged endog. var.	5										0.232***
											(0.038)
F-test for exclusion restrictions										36.90	54.54
Over-identification test [*p*-value]										[0.74]	[0.41]
Obs.		2,286	1,483	2,408	2,345	2,252	2,241	2,241	2,329	2,297	2,251
R-squared		0.998	0.997	0.998	0.998	0.998	0.994	0.980	0.984	0.006	0.002

Notes Dependent variables: Tertiary gross enrollment rates in columns (1)-(5) and (7)-(10) and secondary gross enrollment rates in column (6). The parameters based on the ARDL model in columns (1)-(6) and the CS-DL model in column (7) are long-run estimates. Static FE-OLS estimates are reported in column (8). Static IV-FE estimates are reported in columns (9) and (10). All estimates include country fixed effects and country-specific common correlated effects. Standard errors are in parentheses and *p*-values in brackets. The standard errors in the ARDL regressions are based on the delta method. The standard errors in the Static FE regressions are robust to heteroskedasticity and within serial correlation. ***,**,* significant at 1, 5 and 10%.

In the regression in column (6), in which the secondary gross enrollment rate is the outcome variable, the coefficients of the personal income tax rate and population growth are insignificant. However, in contrast to the estimates for tertiary education, the parameter of minimum working age is significantly positive. This dichotomy is intuitive in that the minimum working age impacts directly on secondary education, while the ages of the cohorts in tertiary education exceed that of the minimum working age.

In the last two columns of Table 6 we instrument the domestic personal income tax rate with inverse geographic proximity-weighted averages of foreign personal income tax rates and the share of the foreign tax revenue in total GDP. The income share of foreign total tax revenues should capture the tendency of advanced countries to adopt similar tax policies as a result of their high integration. Consistent with this reasoning, we find a positive correlation between this instrument and the domestic rate of personal income taxation as seen from the lower panel of Table 6 (first-stage). In line with the findings of Chirinko and Wilson (2017), there is a strong negative correlation between the domestic and foreign tax rates on personal income. The results of the second-stage regressions are comparable to the ARDL and the CS-DL regressions. As for our earlier IV estimates, our set of instruments satisfy both the relevance and the exclusion restriction criteria. The value of the F-test for excluded instruments is 37 and 55 in columns (9) and (10), whilst Sargan's over-identification p-values are 0.74 and 0.41. Comparing the second-stage results in columns (9) and (10), we can conclude that the second-stage results are quite similar regardless of whether the lagged endogenous variable is included in the instrument set.

Sensitivity to time aggregation and additional controls

To check the robustness of our results to time aggregation, we estimate our three models using 5-year non-overlapping data to assess whether the results in the previous subsections have been significantly influenced by random or cyclical movements in the annual data. In Table C.1 in the Online Appendix Section C, we report the results from 5-year non-overlapping long-run estimates, obtained from an ARDL specification with one-period lags of the dependent and the explanatory variables. The principal results are consistent with those obtained with annual data, except for the tertiary education regression augmented with control variables. In this regression, the coefficient of the personal tax rate falls slightly outside the 10% significance region.

To assess whether our results are affected by the government budget constraint, and to account for the fact that the government budget is a closed system (see, e.g., Gemmell *et al.*, 2011), we include the share of public deficit/savings and the share of total tax revenues in total GDP as controls in our three investment regressions. From the overall tax revenue, we deduct personal income taxes or the corporate tax revenue in the regressions where these tax rates are included. The results, which are reported in Tables C.2-C.4 in the Online Appendix, show that our key results remain unaltered by the inclusion of the government budget balance.

IV Dynamic adjustment to tax shocks

In this section, we first assess the consistency of our long-run estimates with the results of the model's quantification as illustrated in Section I. To this end, we consider the differences in the data used in the two exercises, in terms of sample composition (US vs OECD countries) and time period (1981-2000 vs 1890-2015). Second, based on our regression results, we derive the dynamic adjustment of investment towards equilibrium in response to a tax shock. For each of the three investment variables, we consider the investment response to a one-off, 1-percentage point permanent increase in the corporate income tax rate for M&E and R&D investment, and the personal tax rate for R&D and tertiary education (Table 7). The exercise is based on the parameter estimates in the bivariate regressions reported in Tables 4-6.

In column (1) of Table 7, we report the elasticity of the investment rates by changing the tax rates based on the coefficients in Table 2. The elasticity is derived by dividing the simulated percentage change in the investment ratio by the tax shock expressed in percentage changes rather than as a one-unit change (as in Section I). For instance, the elasticity for R&D investment, implied by our theoretical model, is computed as $(-1.47/100)/[\ln(0.35/0.34)] = -0.507$. Column (2) shows the estimated long-run impact of tax changes on investment based on the results in our earlier regressions. Interestingly, the values of both sets of elasticities are largely similar, with the exception of those concerning the effect of the corporate income tax on the tangible investment ratio, a gap that can be explained by the difference in the data used and the diminishing role of physical capital relative to intangible capital in advanced economies such as the US. Overall, this evidence lends strong support to the use of our theoretical model as a guide for the regression analysis.

In column (3), we make our single-equation, long-run estimates more comparable with each other

Table 7: **Dynamic adjustment to fiscal shocks**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Model	**Regression**					
	US 1981-2020	**OECD countries 1890-2015**					
	Implied elasticity	Long-run elasticity	Standard-ized LR impact	Adjustment speed	Years to close the initial gap		
					50%	75%	90%
Tangible investment ratio							
Corporate income tax	-0.021	-1.113	-0.298	-0.145	5	8	15
R&D investment ratio							
Corporate income tax	-0.507	-0.231	-0.347	-0.044	16	32	52
Personal income tax	0.041	0.080	0.504	-0.034	20	40	66
Tertiary enrollment rate							
Personal income tax	-0.435	-0.309	-0.145	-0.084	8	16	27

Notes The figures in column (1) are elasticities derived from the simulation of the theoretical model as reported in Table 2. The implied elasticity is obtained by dividing the simulated percentage change in the investment ratio by the tax shock expressed in percentage changes rather than as a one-unit change (the relevant tax variable is rescaled on its starting value). The figures in columns (2)-(7) are based on the estimates in column (1) in Table 4 (tangible investment), columns (1) and (2) in Table 5 (R&D investment), column (1) in Table 6 (education investment). Column (2) in the table reports the absolute long-run impact of the tax on the investment. Column (3) reports the standardized long-run impact of the tax change on investment, obtained as $(SD^{\tau} \times \hat{\beta}^{\tau})/\bar{I}$, where SD^{τ} is the standard deviation of the tax variable, $\hat{\beta}^{\tau}$ is its estimated long-run impact and $\bar{I}$ is the average value of the outcome variable (investment). The speed of adjustment is obtained as $\lambda_i = -(1 - \sum_p^P \rho_{it-p})$, where p is the number of lags of the dependent variable used in the regression on which the parameters are derived.

by standardizing the long-run coefficients with the relative size of the investment ratio: $SD^{\tau} \times \hat{\beta}^{\tau}/\bar{I}$, where SD^{τ} is the standard deviation of the tax variable, $\hat{\beta}^{\tau}$ is its long-run impact, and $\bar{I}$ is the average value of the outcome variable (investment). The results in column (3) unequivocally show that R&D investment is affected the most by the tax change, with a standardized effect of -0.35 in response to a one-standard deviation *increase* in the corporate income tax and +0.50 in response to a comparable change in the personal income tax rate.

The figures on the right-hand-side panel in Table 7 show the number of years it takes to close 50%, 75% and 90% of the gap between the pre- and the post-treatment equilibrium value of the investment share induced by a one-percentage point increase in the focus tax rate. The half-cycle is reached after only 5 years for the investment rate in M&E, whereas it takes 16 years for R&D and 8 years for tertiary education to reach their half cycle.

In Figure 4, we illustrate the dynamic adjustment to fiscal policies by simulating the response of each investment type to a standardized shock to the relevant tax rate.[16] We compute the predicted value of the dependent variable associated with a one-standard deviation *change* (decrease or increase) in the relevant tax variable, distributed as standard normal, N(0,1). We draw the mean level of the response variable (solid line) and its confidence intervals of 95% (light), 90% (medium) and 75% (dark) over a horizon of 40 periods.

The results of the simulation are fully consistent with the evidence of Table 7. Figure 4 indeed shows that a one-standard deviation *decrease* in the rate of corporate income tax induces a long-run 0.20 percentage point increase in the M&E investment rate in a period of about 15 years (Fig. 4-a). However, the precision of this simulation is low and the mean response parameter does not reach standard levels of significance, probably because of the high volatility of M&E investment sparked by the 1891 and 1921 depressions, the Great Depression, two world wars, two oil shocks and the Great Recession.

For the R&D investment rate, a one-standard deviation *decrease* in the corporate income tax rate yields a 0.65-increase in the investment ratio in the long run, which is a substantially larger impact than that produced by a comparable tax shock on the investment rate in M&E (Fig. 4-b). For

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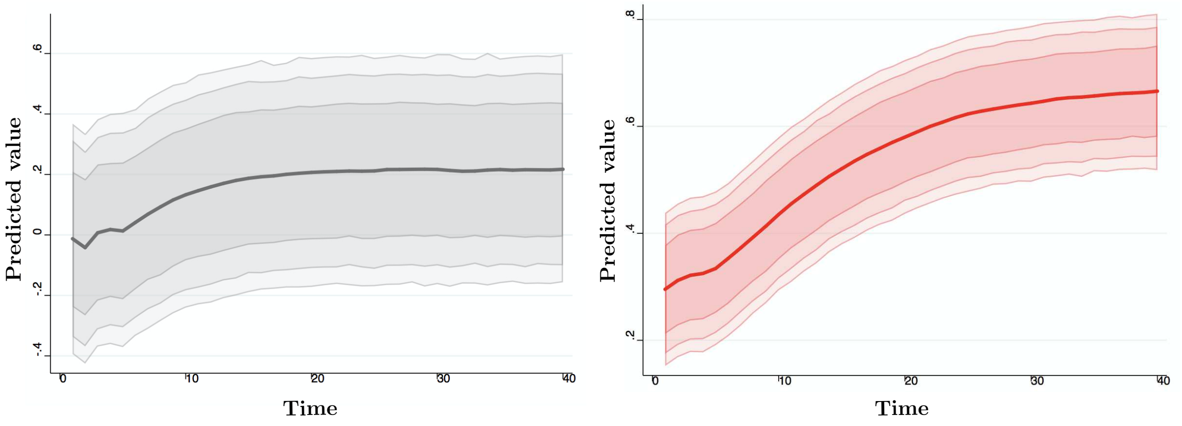
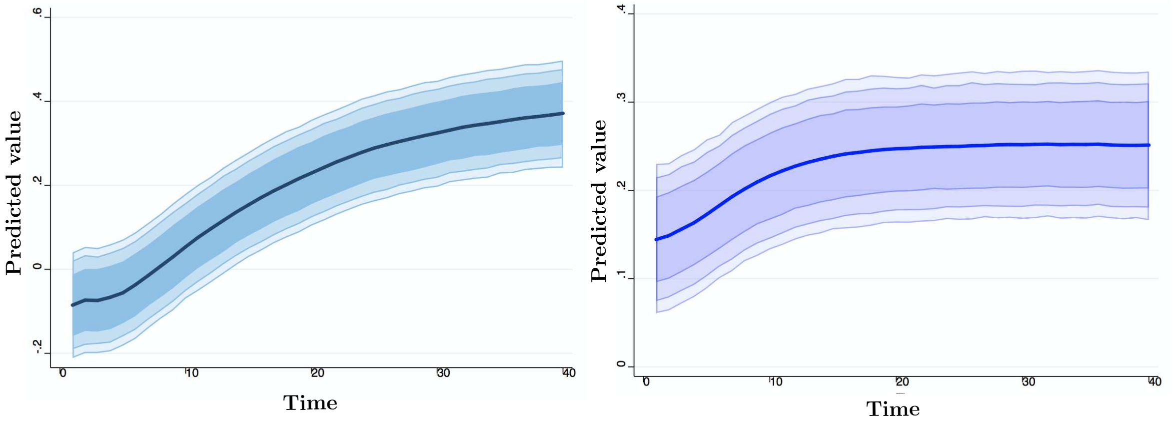
[16] Based on Monte Carlo simulations with 10,000 replications, we simulate the parameter distribution of the fiscal instruments arising from the bivariate ARDL estimations using the mean value to predict the change in the dependent variable. We adopt the procedure devised by Jordan and Philips (2018) who simulate a stochastic parameter distribution around the regression moments using a variance drawn from a scaled inverse χ^2 distribution.

Figure 4: **Dynamic adjustment of investment to standardized tax shocks (ARDL simulation)**



(a) Corporate income tax on M&E inv./GDP

(b) Corporate income tax on R&D exp./GDP



(c) Personal income tax on R&D exp./GDP

(d) Personal income tax on tertiary education

Notes ARDL simulation of the predicted level of in the dependent variable associated with one standard deviation (SD) change in relevant fiscal variable (based on 10,000 replications). Panel (a) uses estimates in col. 1, Table 2 (SD decrease); Panel (b) uses col. 1, Table 3 (SD decrease); Panel (c) uses col. 2, Table 3 (SD increase); Panel (d) uses col. 1, Table 4 (SD decrease). Confidence intervals: 95% (light), 90% (medium), 75% (dark). All variables are scaled so to be distributed as a standard normal, N(0,1).

R&D-intensity, we also simulate the timing of the adjustment to a one-standard deviation *increase* in personal income tax in order to illustrate how investment reacts to a comparable *decrease* in corporate income tax (Fig. 4-c). The figure shows that the adjustment path of R&D-intensity to a personal income tax shock is similar to that of a corporate tax shock, but of a smaller order. This is in line with the results in Table 7. Overall, from this exercise we can conclude that the adjustment of the

R&D investment rate to tax shocks is slower than that of investments in tangibles and education.

Finally, we illustrate the response pattern of student enrollment rates to a standardized personal income tax shock (Fig. 4-d). A one-standard deviation *decrease* in the personal income tax rate is associated with a 0.25 point increase in the gross enrollment rate in the long run. The size of this effect is similar to that found for M&E investment in Fig. 4-a. Compared to investment in equipment, however, our simulation for the gross enrollment rate in tertiary education is statistically more precise.

V Concluding remarks

The recent expansion of government debt following the COVID-19 pandemic, the aging world population, and low productivity advances in the government sector are expected to put enormous pressure on government finances over the next decades. To meet the increasing demand for public resources, tax revenue policies need to be formulated in a way that do not have adverse, or at least not too severe consequences for economic growth. The literature on growth effects of tax policy is vast but, thus far, has paid attention only to tangible investment as a channel of transmission from fiscal policy to economic growth. This paper takes the literature a step further by examining the tax effects on the most important types of investment, viz., Machinery & Equipment, education and R&D, in a joint framework, which enables us to analyse the social returns to a revenue-neutral change in the tax structure. The analysis is conducted by using historical data on the investment profile of the OECD countries since the Second Industrial Revolution. Such a long-run, secular, perspective allows us to better describe the process of change that occurred in the structure of these economies and focus on role that taxation played in driving this process.

By modeling the structural relationships involving economic agents with different preferences and objectives of entrepreneurs, workers and the public sector, our theoretical model serves as a guide to evaluate the overall effects of taxation on investment and as a rationale for the corresponding empirical estimations. Our analysis shows that taxes are highly influential for investment in M&E, tertiary education, and R&D in the long run. We also find that R&D investments are the most sensitive to tax shocks, suggesting that, for instance, cuts to corporate income tax can have long-lasting effects on income growth via this investment channel. In the relatively short run, though, tangible investments are found to be more responsive to fiscal shocks, which act more effectively as counter-cyclical policy tools. Our simulation illustrates that the half-cycle towards the steady state of the tangible investment rate is 5 years as opposed to 8 years for investment in education and 16 years for investment in R&D.

Our empirical results also show that personal income taxes have a dual role for investment in intangibles: While an increase in the personal income taxrate reduces investment in tertiary education, it promotes investment in R&D. These results raise the question of whether personal income taxation deters or promotes technological progress and income growth. The long-run effect of a personal income tax increase is likely to be positive because R&D intensity has permanent income growth effects (Chen *et al.*, 2017), whereas education only has income level effects (Madsen, 2010, 2014). Investment in R&D has permanent growth effects because researchers develop products and processes of increasingly higher quality that expand the technology frontier and promote economic growth. It then follows that a tax revenue neutral switch from corporate to personal income taxes can boost R&D-induced income growth.

Acknowledgements: Helpful comments and suggestions from the Editor, Coralie Simmons, and two anonymous referees are gratefully acknowledged. Antonio Minniti gratefully acknowledges financial support from the Italian Ministry for the University and Scientific Research (PRIN 2015 - 20157NH5TP_004). Francesco Venturini acknowledges the financial support by the University of Perugia, Ricerca di Base 2020. Jakob B. Madsen acknowledges financial support from the Australian Research Council (DP170100339; DP220102557).

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