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THE LONG-RUN INVESTMENT EFFECT OF TAXATION IN OECD COUNTRIES

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

JEL Classifications: E10, E62, O38, O40

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November 20, 2020

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1 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, 2020) 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.*, 2020).

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). In contrast to post-1960 data, the long historical data benefits from having large variations that enable us to identify the structural parameters that are not driven by common trends between the tax rates and the outcome variables, as occurs in shorter samples.

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), Ferraro *et al.* (2017), Jaimovich and Rebelo (2017), and Jagadeesan (2019).

We test the predictions of the model by assessing the long-run effects of various taxes on investment in fixed investment (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 (auto-regressive distributed lag, ARDL, model) 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).

A key contribution of our paper is our 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. Theoretically, only a few endogenous growth models have analysed the effects of various tax policies on these three growth promoters (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, using the level or the rate of growth in per capita income as outcome variables is problematic because the impact of taxation on investment in education and R&D takes several years, and even decades, to fully materialize as shown in Section 5; thus masking the relationship between taxes and growth. Investment in education affects income with a long delay 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, which can take another four decades. Furthermore, as shown by Madsen (2010), tangible investment is the least influential for growth or income of the three growth promoters considered here.

Empirically, only a few empirical studies have investigated the effects of various tax instruments on investment in education and R&D at the macro level (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]

[1] Another exception is Akcigit *et al.* (2018) who use historical data on taxes and inventors since 1921

The structure of the paper is the following. Section 2 presents the theoretical framework and focuses on the channels through which taxation affects the three types of investment. Section 3 describes the empirical setting and the data used to test the predictions of our theoretical model. Section 4 presents the estimation results on the long-run investment effect of tax policies, whilst Section 5 quantifies the investment response to various tax shocks by means of a simulation analysis. Section 6 concludes.

2 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 the online Appendix Section A for a detailed derivation of the model).

2.1 Households

There is an infinitely-lived, representative household that maximizes the discounted value of the sum of utilities from 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 typical 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.

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 an individual employs in the process of skill formation; $\eta \in (0,1)$ 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 make education choices to maximize utility subject to the following asset-accumulation equation:

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

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 (paying teachers); τ^c is the consumption tax rate; and T represents the lump-sum transfer per capita. We assume that the government's budget is balanced, which requires that the per capita transfer, T, equals the total per capita tax revenue.

Solving the household's maximization problem yields a standard Euler equation:

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

which characterises the dynamic path of consumption per capita.

2.2 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 a constant returns to scale production function, 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 determinates 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 labor's share of income. Economic growth is an outcome of 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 sector, ω, only one firm has access to a technology that transforms one unit of capital into one unit of the intermediate good, that is, $k_\omega = x_\omega$. Each firm produces a different variety of intermediate inputs 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 a generic 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 input requires one unit of capital, denoting $R \equiv r + \delta$ as the before-tax user cost of capital, the intermediate goods firm ω's profits amount to $\pi_\omega = (p_\omega x_\omega - R x_\omega)(1 - \tau^\pi)$, where τ^π is the corporate tax rate.

Given the potential competition from the fringe, it is optimal for each intermediate

[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.

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 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.

2.3 R&D sector

The R&D sector is characterised by free entry. At each point in time, $\dot{A}$ new patents are generated. 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 remains constant provided that the fraction of human capital allocated to R&D remains constant (fully-endogenous growth).[4]

[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 size of the market, given by N (see Dinopoulos and Segerstrom, 1999, p. 459). To ascertain this, notice that, if per capita human capital, h, and per capita labor supply, l, are both constant, then the total skills available in the economy, H, can only grow over time if population, N, also grows ($H \equiv h \cdot lN$). Therefore, as the size of the population expands, R&D difficulty increases and research productivity declines.

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 firms, $\pi(1-\tau^D)/V$, 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 R&D 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.

2.4 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 sector, respectively, both expressed in per capita terms. Eq. (10) states that the available human capital stock, H, is equal to the sum of the sectoral demands for human capital employed in final goods production, R&D activity and education.

Wealth is composed of claims on physical capital and equities in the intermediate goods firms. As there are A intermediate producers, the value of shares in the intermediate goods 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.

2.5 Solving the model

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 the online Appendix Section A, the long-run equilibrium 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:

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

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

[5] According to the asset-accumulation equation (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 $rK/N + (1-\tau^V)\dot{V}A/N + (1-\tau^D)\pi A/N$.

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

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

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

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.

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), Young (1998), and Aghion and Howitt (2008, 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 higher labor income tax has a negative impact on the workforce's educational attainment. Eqs. (13) and (14) show that both the steady-state share of human capital devoted to R&D in total human capital, $\hbar_A$, and the physical capital investment share, i_K, are positively related to the rate of economic growth, g. As shown in the online Appendix Section A, an increase in the corporate 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 taxes therefore negatively affect the rate of economic growth, which results in lower values of $\hbar_A$ and i_K. Like corporate taxes, increases in capital gain taxes also have adverse growth effects as they lead to a decline in $\hbar_A$ and i_K, provided that the condition $g + n > g_A$

[6] Peretto 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.

is satisfied.

2.6 Empirical implications of the model

According to our model, corporate income tax impacts negatively on both the steady-state fraction of human capital devoted to R&D, $\hbar_A$, and the investment share in physical assets, i_K. As Eqs. (13) and (14) show, both $\hbar_A$ and i_K move monotonically with the rate of economic growth, g. Since personal income tax includes salaries, wages, interests, dividends and capital gains as classes of income subject to taxation, the signs of the personal income tax effects on both $\hbar_A$ and i_K are ambiguous as g responds positively to increases in wage taxation and negatively to increases in dividends/capital gains taxation. As taxes derived from wage income are main sources of the personal income taxation, our model predicts a positive correlation between the personal income tax rate and both $\hbar_A$ and i_K. This is due to the fact that an increase in the wage tax rate, τ^w, alters the allocation of human capital in equilibrium by reducing the share of human capital devoted to education, $\hbar_e$. This induces an increase in the share allocated to research, $\hbar_A$, which leads to a higher rate of income growth, g (see Eq. 15). Following the same reasoning, the expected impact of an increase in the personal income tax rate on education investment is a reduction in the steady-state fraction of human capital devoted to education, $\hbar_e$.

3 Empirical setting

3.1 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:

$$I_{it}^{Z} = \alpha_i + \beta_1 \tau_{it}^{Y} + \beta_2 \tau_{it}^{\pi} + \theta \mathbb{X}_{it} + \lambda_i \mathbb{F}_t + \epsilon_{it}, \qquad (16)$$

where I^Z is the share of investment in total income (investment rate); α_i is country fixed effects; τ^Y is the personal income tax rate (which is our empirical counterpart of the tax rates of the model τ^w, τ^D, and τ^V); τ^π is the corporate tax rate; $\mathbb{X}$ is a vector of control variables; $\mathbb{F}$ is common correlated effects (CCEs); ϵ is a disturbance term; and i and t refer to country and time. The investment rate, I^Z, is measured as 1) the share of investment in M&E in total nominal income, (I^T); 2) the share of R&D in total nominal income, ($I^{R\&D}$); and 3) the investment in tertiary education, measured as the gross enrollment rate in tertiary education, (I^{GER}). The common correlated effects terms, $\mathbb{F}$s, capture the impact of unobserved common factors (technology, business cycle, pandemics, etc.), to which the country units can respond with different intensities arising from differences in absorptive capacity (education, R&D), preferences and institutions. These country-specific effects are captured by λ_i.

To mitigate the endogeneity bias introduced 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 to avoid biased estimates for our relevant tax variables, τ^Y 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. The allowance for top income taxes is important as a large share of companies were not incorporated in the earlier years of our estimation period; hence, the investment decisions are likely to have been influenced more by top-income tax rates levied on entrepreneurs than the average level of taxation. Furthermore, 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.*, 2018). Following our theoretical model, the growth rate in per capita GDP is included in the regressions for I^T and $I^{R\&D}$ (see Eqs. 13 and 14). Macroeconomic uncertainty is proxied by the inflation rate. Inflation may also be positively associated with a profit squeeze as not all cost increases can be passed on to consumers.

3.2 Estimation method

We use dynamic regression methods in the baseline regressions and static regressions methods for robustness checks. The following dynamic estimators are applied to our investment models: the Auto-Regressive Distributed Lag (ARDL) model, and the cross-sectional augmented distributed lags model (CS-DL). As static regression methods, we use the fixed-effect OLS estimator and the standard instrumental variable method.

The ARDL estimator yields consistent 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). 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.

The CS-DL estimator 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 estimates. The CS-DL estimator also provides more precise estimates than the ARDL estimator 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 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.

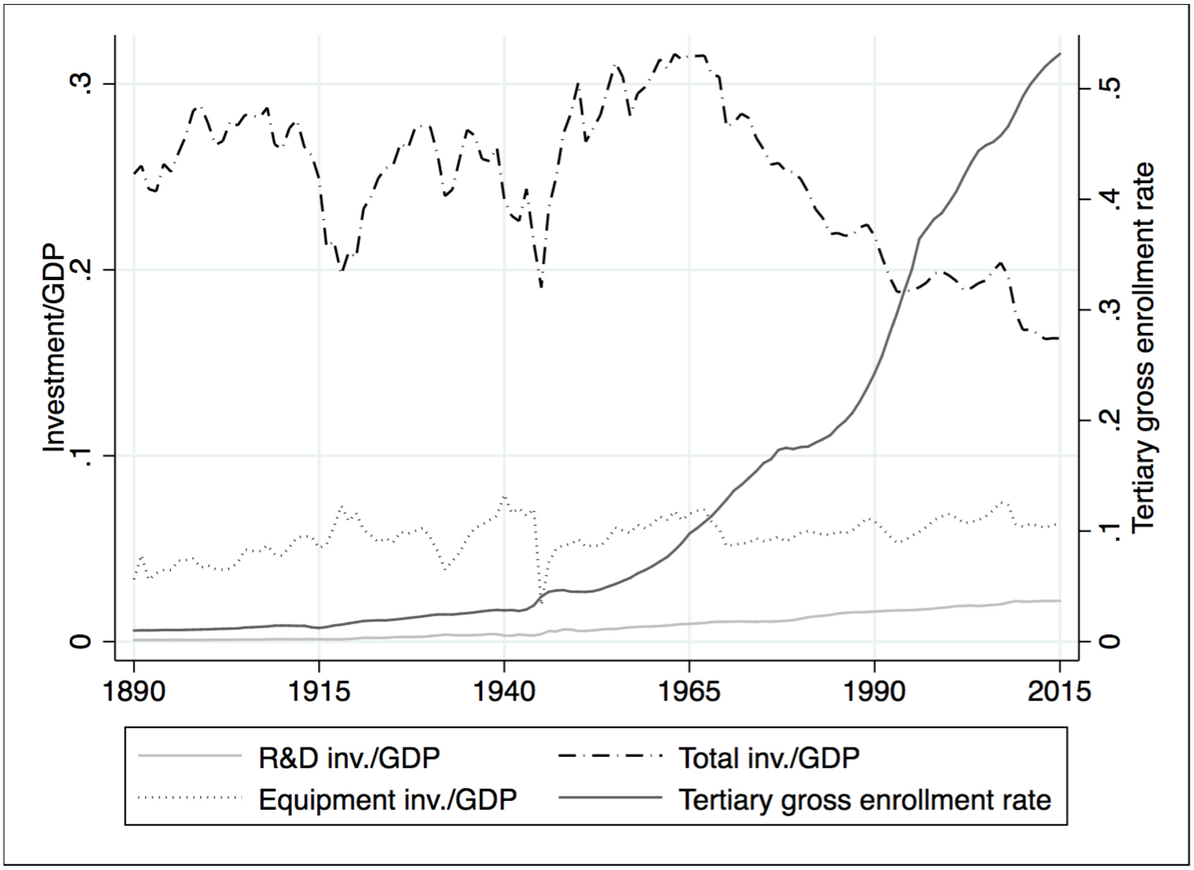
To deal with endogeneity as a supplement to the dynamic estimates, we estimate a static version of Eq. (16) in which the tax rates are instrumented. As instruments for the tax variables we use geographic proximity-weighted foreign tax rates following Chirinko and Wilson (2017) (a similar method is used by Gemmell *et al.*, 2014). Chirinko and Wilson (2017) show that the positive correlation between cross-state tax rates reflects the fact that states in the US synchronously respond to macroeconomic shocks. Hence, when the effects of unobservable common factors are controlled for, a *negative* relationship between tax rates across states emerges. This would be consistent with the slope of the state's reaction function that reflects 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.

3.3 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 profit or dividend, labor income, and land rent earned by individuals as a share of nominal GDP. As most tax systems tax dividend and wage income equally, we cannot make this distinction in the estimates. We disregard the complications introduced by franking/imputation credit offset 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 gain taxation rules as they are complex and vary substantially over time and across countries (see, for the US, Summers, 1981). The corporate 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 the online Appendix Section B.

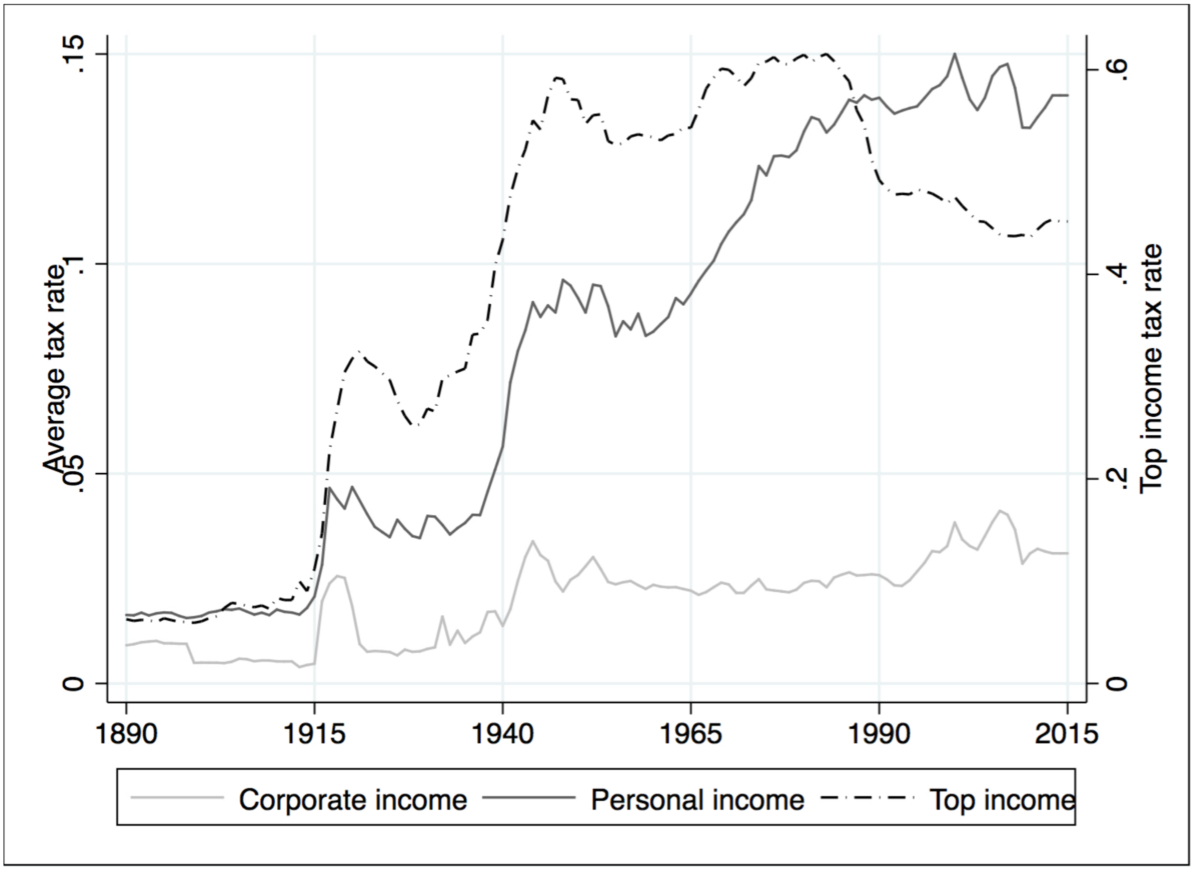
Figure 1: Investment rates in physical capital and R&D (left-hand side) and tertiary enrollment rate (right-hand side), 1890-2015



3.4 Graphical analysis and summary statistics

Figure 1 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 has declined since then, predominantly due to a decline in the 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

Figure 2: Corporate and personal income tax rates (left axis) and top income tax rates (right axis), 1890-2015



of the 20th century. Over the entire time span, the average R&D intensity has been 1.3%. Investment in tertiary education, I^{GER}, has increased markedly over the past few decades. Overall, Figure 1 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 2 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 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 1: **Summary statistics**

	M&E inv./ GDP	R&D expenses/ GDP	Tertiary gross enrollment rate	Corporate 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

4 Empirical results

In this section we present the regression results for tangible investment (Section 4.1), R&D (Section 4.2) and education (Section 4.3).

4.1 Tangible investment

Table 2 reports the estimation results for the tangible investment rate. Consider first the bivariate regressions in columns (1)-(4) in which the tax rates are entered individually (corporate 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).[7] The larger investment effects of corporate taxes found here compared to the literature may reflect the longer time span of our data, which enables

[7]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 elasticity of investment to the user cost of capital estimated in earlier papers, we have also included the relative price of investment in our regressions. However, the coefficients of the corporate tax rates were unaffected by the inclusion of the real price of investment.

us to better identify the long-run response of tangible investment to changes in tax policies. The coefficients of the other tax rates in columns (2)-(4) are insignificant. In one of the elaborated 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.

Next, in columns (5)-(10), we include the corporate tax rate, the per capita income growth rate, and the consumer inflation rate in the regressions. The per capita income growth rate is included following the prediction of our model. The inflation rate is included in the model as a proxy for macroeconomic instability and as a proxy for a profit squeeze, as discussed above.[8]

Consider first the regressions in which the rate of investment in M&E is the outcome variable (columns (5), (7)-(10)). The coefficients of income growth are significantly positive and the coefficients of inflation are significantly negative. The coefficient of the corporate tax rate remains significantly negative regardless of whether the ARDL, the CS-DL or the static fixed-effects model is estimated. In our baseline regression in column (5), the coefficient is approximately 25% more negative than the estimate without controls in the first column. This is likely to reflect the correlation between the corporate tax rate and income growth (negative) as well as the inflation rate (positive), which means that the coefficient of τ^{π} was upward biased in the bivariate regression in column (1) due to an omitted variable problem.

In the regression in column (6) the outcome variable is the total investment rate. In this regression, the coefficient of the corporate income tax rate is substantially higher

[8]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 is unobservable, and, for levered firms, also the bank lending rates.

Table 2: **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***				-1.460***	-4.217**	-1.512***	-1.461***	-1.096**	-2.290***
		(0.402)				(0.489)	(1.978)	(0.143)	(0.264)	(0.477)	(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**	1.716*	0.187***	0.045	0.066***	0.067**
						(0.236)	(0.875)	(0.064)	(0.028)	(0.023)	(0.031)
Inflation rate						-0.299***	-2.679***	-0.048*	-0.081**	-0.088***	-0.133***
						(0.094)	(0.666)	(0.026)	(0.033)	(0.029)	(0.023)
Instruments:	yr lag									*1st stage*	
Foreign import tariff rate	1									-4.536***	-5.211***
										(1.265)	(1.147)
Foreign corporate tax rate	5									-2.515***	-2.966***
										(0.714)	(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 cols. (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 (CCEs). Standard errors are in parentheses and p-value 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%.

than that of the regressions in which the rate of investment in M&E is the outcome variable. This result is exactly what we should expect since the returns to buildings are capitalized over a much longer period than investment in M&E.

Quantitatively, based on the coefficients in column (5), a 1 percentage point increase in the corporate tax rate, and in the rates of income growth and inflation is associated with a -1.5, 0.6 and -0.30 percentage point change in the investment rate, respectively. Thus, a one standard deviation increase in each of these variables is associated with a percentage point change in the investment rate of -2.2, 3.6, and -3.0, respectively. These results suggest that changes in corporate tax rates are highly influential for investment in machinery and equipment relative to inflation and income growth.

Finally, in the FE-IV regressions in the last two columns in Table 2, geographic proximity-weighted foreign import tariff rates, foreign corporate tax rates, and the lagged domestic corporate tax rate are used as instruments for the corporate tax rate, where tariff rates are measured as tariff duties divided by nominal imports. Following the finding of Chirinko and Wilson (2017), once the effects of common responses to unobservables is accounted for through CCEs, there may not be tax competition among countries to attract mobile capital that would lead to a positive correlation between corporate taxation at home and abroad. Furthermore, it is reasonable to assume that the higher are the external barriers to trade, the more difficult it is to penetrate foreign markets, and hence governments may be incentivised to enhance the competitiveness of domestic companies through lower taxation. The lagged endogenous variable is used as instrument to cater for the dynamic correlation between domestic corporate taxation and the investment rate, which, if not accounted for, may undermine the orthogonality condition between external instruments and the outcome variable.

The first-stage regressions in the lower panel in Table 2 indicate significantly negative effects of the foreign corporate and tariff tax rates on the domestic corporate tax rates. Although the sign of foreign corporate tax rates is contrary to the common assumption of tax competition, these findings are consistent with our reasoning above and the results for the US states in Chirinko and Wilson (2017), noting that they undertake a battery of robustness tests to substantiate their findings. 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

11 and 14 and Sargan's over-identification p-values are 0.13 and 0.38.

The second-stage regressions yield coefficients of corporate tax close to those obtained from the ARDL estimates. Conversely, the absolute magnitude of the coefficients of the controls are much lower than their ARDL-counterparts, suggesting that the static regression models do not fully capture the dynamic adjustment towards the long-run equilibrium.

4.2 R&D investment

The regression results for R&D intensity as the outcome variable are presented in Table 3. Consider first the bivariate regressions in columns (1)-(4) in which the different types of taxes are entered individually. Consistent with the predictions of our theory, the coefficient of the corporate tax rate is significantly negative and has a long-run coefficient of -0.23, implying that a one standard deviation increase in the corporate tax rate is associated with a 0.35 percentage point reduction in R&D intensity: a result that is consistent with the results of Akcigit *et al.* (2018) for the United States. The coefficients of consumption taxes and the top income tax rates are insignificant, while personal income taxes have significant *positive* effects on R&D intensity. In line with our theory, personal income taxes (on wage income) impact positively on R&D investment because it gives a disincentive to invest in education; thus freeing up resources for R&D activities.

Next, in columns (5)-(9) we focus on the corporate and the personal income tax rates as they are the only significant variables in the bivariate regressions. In addition, we include the per capita income growth rate and the consumer inflation rate as control variables. The absolute values of the coefficients of the corporate and personal income tax rates are highly significant and are higher in the ARDL regression than the other regressions because the ARDL estimator captures the long-run effects of the explanatory variables more precisely than the other estimators, a factor that is important when the dependent variable is highly persistent, as in 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

Table 3: **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 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:	yr lag								*1st stage*	
Foreign import tariff rate	1								-3.717***	-3.531***
									(1.113)	(0.985)
Foreign corporate 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 (CCEs). Standard errors are in parentheses and p-value 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%.

R&D by dampening the returns to innovation (Oikawa and Ueda, 2018). Conversely, according to Chu *et al.* (2017), the relationship between inflation and R&D investment is inverted U-shaped when firms' entry costs are large.

The coefficients of corporate taxes remain statistically 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 estimates in column (5), a one standard deviation increase in the corporate tax rate and personal income tax rate is associated with a change in the investment rate of -0.51 and 1.12 percentage points, respectively, suggesting that tax rates are quantitatively significant determinants of R&D intensity.

To deal with endogeneity, we instrument the domestic corporate tax rate in the static regression by the inverse distance-weighted rates of foreign corporate and import taxation as well as the lagged value of the endogenous variable in column (9), where the underlying rationale for these instruments is the same as for the M&E regressions. Like the M&E investment model, the first-stage regressions in the lower panel in Table 3 show significantly negative effects of our set of instruments on the domestic corporate 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 regressions, the results are comparable with the other results in Table 3.

The opposite signs of the coefficients of corporate and personal tax rates are noteworthy and imply that tax switch policies can be used to enhance growth: A tax revenue neutral switch from corporate to personal taxes can boost R&D-induced income growth. In a general equilibrium setting, the time-profile of the growth effect of this switch will be slightly different when the growth effects from the tax switch through investment in education (shown below) and tangible investment effects are accounted for. However, in the long run, the 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 have, at best, only small long-run growth effects, as evidenced by Madsen (2010, 2014) (see the discussion below in Section 6).

4.3 Tertiary education investment

As the last model in our long-run regression analysis, we estimate the education investment equation (Table 4). 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)). The other tax variables are insignificant in the bivariate regressions (columns (2)-(4)). In the regressions in columns (5) and (7)-(10) we include, as controls, the population growth rate as it increases the demand for education, and the minimum working age, which may capture the institutionally imposed opportunity costs of education; a dimension that is approximately independent of market forces and individual preferences.

The coefficient of the personal income tax rate is statistically significantly negative in all cases in which the investment in education is measured at the tertiary level. Economically, the personal income tax rate is also significant. 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. Finally, the coefficients of population growth and minimum working age are mostly insignificant.

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 coefficient 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 we instrument the domestic personal income with inverse geographic proximity-weighted foreign personal income tax rate and the share of the foreign tax revenue in total GDP and, in the last column, the lagged dependent variable. The share of total foreign tax revenue in total foreign GDP captures the tendency of advanced countries to adopt increasingly coordinated deficit policies as a result of their larger degree of integration (note that the principal results are unaffected by the exclusion of this instrument). Consistent with this line of reasoning, we find a positive

Table 4: **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 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:	yr lag									*1st stage*	
Foreign personal income tax	2									-8.297***	-7.065***
										(0.970)	(0.906)
Foreign tax revenues/GDP	3									0.712*	0.535**
										(0.377)	(0.256)
Lagged endog. var.	5										0.232***
											(0.038)
F-test of excluded 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 variable: Gross enrollment rate in tertiary education (columns (1)-(5) and (7)-(9)). Gross enrollment rate in secondary institutions (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 (CCEs). Standard errors are in parentheses. *p*-value in brackets. The standard errors in the ARDL regressions are based on delta method. The standard errors in the Static FE regressions are robust to heteroskedasticity and within serial correlation. ***,**,* significant at 1, 5 and 10%.

correlation between this instrument and personal income taxation. Again, in line with Chirinko and Wilson (2017)'s reasoning, there is a strong negative correlation between the domestic and foreign personal income tax rates. Finally, 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 37 and 55 and Sargan's over-identification p-values are 0.74 and 0.41. Finally, the second-stage regressions results are comparable with the ARDL and the CS-DL regressions.

4.4 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 ARDL estimates with one-period lags of the dependent and the explanatory variables. The principal results are broadly 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 the extent to which the results are affected by the public budget constraint and to account for the fact that the government budget is a closed system with tax revenues being employed for (un)productive public expenditure (see Gemmell *et al.*, 2011), we include the ratio of public deficit/savings and the total tax revenues to nominal GDP as controls in our three investment regressions. When using the latter control, we deduct the relevant tax variable under inspection from the share of government revenues in total GDP. The results, which are reported in Tables C.2-C.4 of the online Appendix, show that our principal results remain unaltered by the inclusion of the government budget balance.

5 Dynamic adjustment to tax shocks

In this section, 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 focus tax rates for each model; that is, the corporate tax rate for M&E and R&D investment rates, and the personal tax rate for R&D and tertiary education. The simulations are based on the parameter estimates in the bivariate regressions in Tables 2-4.

Table 5: **Dynamic adjustment to fiscal shocks**

	(1)	(2)	(3)	(4)	(5)	(6)
	LR impact	Standardized LR impact	Adjustment speed	Years to close the initial gap		
				50%	75%	90%
			M&E investment/GDP			
Corporate tax	-1.113	-0.298	-0.145	5	8	15
			R&D expenditure/GDP			
Corporate tax	-0.231	-0.347	-0.044	16	32	52
Personal tax	0.080	0.119	-0.034	20	40	66
			Tertiary enrollment rate			
Personal tax	-0.309	-0.145	-0.084	8	16	27

Notes The figures are based on the estimates in column (1) in Table 2 (tangible investment), columns (1) and (2) in Table 3 (R&D investment), column (1) in Table 4 (education investment). Column (1) in the table reports the absolute long-run impact of the tax on the investment. Column (2) 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 the 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.

Column (1) in Table 5 reports the estimated long-run impact of tax changes on investment. In column (2), we make our single-equation estimates more comparable with each other 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 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 (2) 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 tax. This effect is larger than that found for the M&E investment rate and is even larger than the response of R&D investment to a comparable tax *decrease* in the personal tax rate. The latter is less pronounced than the effect of a standardized decrease in the investment in tertiary education in response to the increase in the personal income tax rate.

The figures on the right-hand-side panel in Table 5 show the number of years it takes to close 50, 75 and 90% of the gap between the pre-treatment and the steady-state equilibrium in response to a one-percentage point increase in the focus tax rate. The half-cycle is reached after only 5 years for the M&E investment rate, whereas it takes 16 years for R&D and 8 years for tertiary education to reach their half cycle. These results are intuitive as one would expect adjustment costs to be substantially higher for intangibles than tangibles because of the long-term strategic decisions associated with investment in R&D. Little research is needed to decide whether to invest in computers or trucks, whereas the decision to setup a laboratory is a long-drawn and a heavily involved process. Similarly, the decision to undertake tertiary education as, according to the quantity-quality model of Becker (1960), parents' educational decision for their children is taken at birth; almost 20 years before the child enters tertiary education.[9]

6 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 predicted to put an 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 does not have adverse, or at least not too severe consequences for economic

[9]In the online Appendix Section D, we simulate the dynamic response of each investment type to a standardized change of the relevant tax variable. Based on Monte Carlo simulations with 10,000 replications, we compute the predicted value of the dependent (investment) variable associated with a one-standard deviation reduction in the relevant tax (shock) variable. These results are qualitatively similar to the figures reported in column (2) of Table 5.

growth. Thus far, most empirical studies have focused on tangible investment. In this study, we jointly consider the three most growth enhancing investment types, viz., investment in M&E, education and R&D. This paper takes the literature a step further by examining the tax effects on the most important types of investment in a joint framework, which enables us to analyse the social returns to a revenue-neutral change in the tax structure.

We show theoretically and empirically that taxes are highly influential for investment in M&E, tertiary education, and R&D. Our evidence confirms the well-known results that corporate taxes reduce investment in M&E and R&D. However, our empirical results show that personal income taxes have a dual role for investment in intangibles: While an increase in the personal income tax 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. While the short-run income effect of a personal income tax increase is ambiguous, its long-run effect is likely to be positive because R&D intensity has permanent income growth effects, whereas education has income level effects only (Madsen, 2010, 2014). Investment in R&D has permanent growth effects because researchers develop new products and processes of higher quality than the existing products and processes that, due to creative destruction, expands the technology frontier and promotes economic growth. From this it follows that a tax revenue neutral switch from corporate to personal taxes can boost R&D-induced income growth. Finally, we simulate the response of each investment type to a standardized change of the relevant tax variable, showing that the most expansive effect is associated with a change of corporate income tax on R&D investment. However, we also find that tax incentives for investment in M&E are more effective tools for counter-cyclical policies than tax incentives for the other types of investment, because the half-cycle towards its steady state is 5 years as opposed to 8 years (education) and 16 years (R&D).

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Online Appendix - The Long-run Investment Effect of Taxation in OECD Countries

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A Theoretical setting

In this section, we provide details to support the derivations used in the theory section of the paper. We refer to the main manuscript for all variables that are not defined in the online Appendix.

Household maximization problem

The representative household maximizes utility U under the constraints given by (1), (2), $h \geq 0$, and $\lim_{t\to\infty} a_t e^{-\int_0^t (r_s - n)\, \mathrm{d}s} \geq 0$. We write the current-value Hamiltonian as:

$$\mathcal{H} = \log c + \sigma \log(1-l) + \mu_1(\chi h_e^{\eta} h^{\gamma} - nh) + \mu_2 \left[(r-n)\, a + whl(1-\tau^w) - wh_e - c(1+\tau^c) + T \right],$$

where μ_1 and μ_2 are the co-state variables associated with the constraints (1), (2), respectively.

The household's maximization problem delivers the following optimality conditions:

$$\frac{\partial \mathcal{H}}{\partial c} = 0 \Leftrightarrow 1/c = \mu_2(1+\tau^c), \tag{A1}$$

$$\frac{\partial \mathcal{H}}{\partial l} = 0 \Leftrightarrow \frac{\sigma}{1-l} = \mu_2(1-\tau^w)wh, \tag{A2}$$

$$\frac{\partial \mathcal{H}}{\partial h_e} = 0 \Leftrightarrow \mu_1 \chi \eta h_e^{\eta-1} h^{\gamma} = w\mu_2, \tag{A3}$$

$$\dot{\mu}_1 = (\rho - n)\mu_1 - \frac{\partial \mathcal{H}}{\partial h} \Leftrightarrow \frac{\dot{\mu}_1}{\mu_1} = \rho - n - \chi\gamma h_e^{\eta} h^{\gamma-1} + n - \frac{\mu_2}{\mu_1}(1-\tau^w)wl, \tag{A4}$$

$$\dot{\mu}_2 = (\rho - n)\mu_2 - \frac{\partial \mathcal{H}}{\partial a} \Leftrightarrow \frac{\dot{\mu}_2}{\mu_2} = \rho - r, \tag{A5}$$

$$\lim_{t\to\infty} \mu_1 e^{-(\rho-n)t} h = 0, \tag{A6}$$

$$\lim_{t\to\infty} \mu_2 e^{-(\rho-n)t} a = 0, \tag{A7}$$

Using (A1) and (A2), the fraction of time devoted to leisure can be written as:

$$1 - l = \frac{\sigma c(1+\tau^c)}{wh(1-\tau^w)},$$

so that labor supply amounts to:

$$L = Nl = e^{nt}\left[1 - \frac{\sigma c(1+\tau^c)}{wh(1-\tau^w)}\right].$$

Model dynamics

We now derive the dynamics of the main variables. Differentiating (A1) with respect to time and using (A5), we get the Euler equation:

$$\frac{\dot{c}}{c} = r - \rho. \tag{A8}$$

Differentiating (A3) with respect to time and using the human capital accumulation equation (1) and Eqs. (A3), (A4) and (A5), we obtain:

$$\frac{\dot{h}_e}{h_e} = \frac{1}{(1-\eta)}\left[r - n\gamma - (1-\tau^w)\frac{\chi\eta h^\gamma}{h_e^{1-\eta}} l - \frac{\dot{w}}{w}\right]. \tag{A9}$$

The growth rates of human capital per capita, h, and number of varieties, A, are derived respectively from Eqs. (1) and (7) of the main text, namely:

$$\frac{\dot{h}}{h} = \chi h_e^\eta h^{\gamma-1} - n, \tag{A10}$$

$$\frac{\dot{A}}{A} = \frac{H^A/H}{\nu} = \frac{h_A/(hl)}{\nu}, \tag{A11}$$

where $h_A \equiv H_A/N$ is the amount of human capital engaged in R&D expressed in per capita terms. Using the asset-accumulation equation (2), per capita asset holdings, a, grow according to the following equation:

$$\frac{\dot{a}}{a} = r - n + \frac{whl(1-\tau^w)}{a} - \frac{wh_e}{a} - \frac{c(1+\tau^c)}{a} + \frac{T}{a}. \tag{A12}$$

Next, we define $\tilde{\Omega} \equiv \Omega A^{-\frac{\alpha(m-1)}{1-\alpha}}$ for $\Omega \in \{c, a, w, T\}$. Using (A8), we find that the growth rate of

$\tilde{c}$ is:

$$\frac{\dot{\tilde{c}}}{\tilde{c}} = r - \rho - \frac{\alpha(m-1)}{1-\alpha}\frac{\dot{A}}{A}, \tag{A13}$$

whereas, using (A12), the growth rate of $\tilde{a}$ can be expressed as:

$$\frac{\dot{\tilde{a}}}{\tilde{a}} = r - n + \frac{\tilde{w}hl(1-\tau^w)}{\tilde{a}} - \frac{\tilde{w}h_e}{\tilde{a}} - \frac{\tilde{c}(1+\tau^c)}{\tilde{a}} + \frac{\tilde{T}}{\tilde{a}} - \frac{\alpha(m-1)}{1-\alpha}\frac{\dot{A}}{A}.$$

Since $p_\omega = p = \vartheta R$, using (5) it follows that $x_\omega = x = \frac{\alpha Y}{A}\frac{1}{\vartheta R}$. Final output in (4) can be written as $Y = A^{\frac{\alpha(m-1)}{1-\alpha}}\left(\frac{\alpha}{\vartheta R}\right)^{\frac{\alpha}{1-\alpha}} H_Y$. Using these results, profits amount to:

$$\pi_\omega = \pi = (1-\tau^\pi)\frac{(\vartheta-1)}{\vartheta}\frac{\alpha Y}{A}.$$

Now replacing Y into the previous equation and recalling that $R = r + \delta$, profits can be written as:

$$\pi_\omega = \pi = (1-\tau^\pi)(\vartheta-1)\left(\frac{\alpha}{\vartheta}\right)^{\frac{1}{1-\alpha}} A^{\frac{\alpha(m-1)}{1-\alpha}-1}(r+\delta)^{-\frac{\alpha}{1-\alpha}} H_Y. \tag{A14}$$

Since $w = (1-\alpha)Y/H_Y$, using the expression for Y, we get that $w = A^{\frac{\alpha(m-1)}{1-\alpha}}(1-\alpha)\left[\frac{\alpha}{\vartheta(r+\delta)}\right]^{\frac{\alpha}{1-\alpha}}$ and, consequently, $\tilde{w}$ can be expressed as:

$$\tilde{w} = (1-\alpha)\left[\frac{\alpha}{\vartheta(r+\delta)}\right]^{\frac{\alpha}{1-\alpha}}. \tag{A15}$$

Let us define $\tilde{q} \equiv VA^{1-\frac{\alpha(m-1)}{1-\alpha}}/N$. Differentiating $\tilde{q}$ with respect to time and, then, using the no-arbitrage condition for the capital market (8) and the expression for firm profits (A14), we get that the growth rate of $\tilde{q}$ is equal to:

$$\frac{\dot{\tilde{q}}}{\tilde{q}} = \left[1 - \frac{\alpha(m-1)}{1-\alpha}\right]\frac{\dot{A}}{A} - n + \frac{r}{(1-\tau^V)} - \frac{(1-\tau^D)(1-\tau^\pi)(\vartheta-1)\left(\frac{\alpha}{\vartheta}\right)^{\frac{1}{1-\alpha}}(r+\delta)^{-\frac{\alpha}{1-\alpha}} h_Y}{\tilde{q}(1-\tau^V)}. \tag{A16}$$

Profits in the R&D sector amount to $\Pi = V\dot{A} - wH_A$. Since there is free entry in the R&D sector, $\Pi = 0$ in equilibrium. Imposing this condition and using Eq. (7), we easily get:

$$V = \nu\frac{wH}{A}. \tag{A17}$$

Finally, using the definition of $\tilde{q}$ into the free-entry condition in the R&D sector, $\Pi = 0$, we obtain that human capital devoted to R&D expressed in per capita terms, h_A, is equal to:

$$h_A = \frac{\tilde{q}\dot{A}/A}{\tilde{w}}. \tag{A18}$$

Steady-state analysis

In steady state $\tilde{c}$ is stationary. Imposing $\dot{\tilde{c}} = 0$ into (A13), we get:

$$r = g + \rho, \tag{A19}$$

with $g \equiv \frac{\alpha(m-1)}{1-\alpha} g_A$ and $g_A \equiv \dot{A}/A$. Replacing r into (A15) gives the stationary value for $\tilde{w}$. Setting $\dot{h} = 0$ into (A10) gives the per capita human capital, h, namely:

$$h = \left(\frac{\chi}{n}\right)^{\frac{1}{1-\gamma}} (h_e)^{\frac{\eta}{1-\gamma}}. \tag{A20}$$

Setting $\dot{h}_e = 0$ into (A9) and then replacing r from (A19), h from (A20) and $\dot{w}/w = g$, we get:

$$h_e = \left[\frac{(1-\tau^w)\eta l}{\rho - n\gamma}\right]^{\frac{1-\gamma}{1-\gamma-\eta}} \left(\frac{\chi}{n^\gamma}\right)^{\frac{1}{1-\gamma-\eta}}. \tag{A21}$$

Using (A20) and (A21), the steady-state ratio of human capital in education to total human capital, $\hbar_e$, can be expressed as:

$$\hbar_e \equiv \frac{h_e}{hl} = \frac{\eta(1-\tau^w)n}{\rho - \gamma n},$$

which coincides with Eq. (12) in the main text.

In steady state $\dot{\tilde{q}} = 0$. Imposing this condition into (A16) and then simplifying the resulting expression by noting that $g \equiv \frac{\alpha(m-1)}{1-\alpha} g_A$ and $g_A \equiv \dot{A}/A$, we obtain:

$$\tilde{q} = \Psi h_Y, \tag{A22}$$

with $\Psi \equiv \frac{(1-\tau^D)(1-\tau^\pi)(\vartheta-1)\left(\frac{\alpha}{\vartheta}\right)^{\frac{1}{1-\alpha}}}{(1-\tau^V)(r+\delta)^{\frac{\alpha}{1-\alpha}}\left[\frac{r}{1-\tau^V} - n - g + g_A\right]}$. Replacing $\tilde{q}$ into (A18) and then using the resulting expression into the full employment condition (10), it follows that human capital employed in the final good sector expressed in per capita terms, h_Y, is given by:

$$h_Y = \frac{hl - h_e}{1 + \frac{\Psi g_A}{\tilde{w}}}. \tag{A23}$$

Replacing h_Y into (A22) and then substituting $\tilde{q}$ into (A18), we get:

$$h_A = \frac{hl - h_e}{\frac{\tilde{w}}{\Psi g_A} + 1}. \tag{A24}$$

Using $g_A = \frac{1-\alpha}{\alpha(m-1)} g$ and $\tilde{w}$ from (A15) into (A24) and then dividing h^A by hl, we find the steady-state fraction of human capital employed in the R&D sector, namely:

$$\frac{h_A}{hl} = \frac{1 - \hbar_e}{1 + \Lambda}, \tag{A25}$$

with $\Lambda \equiv \frac{\left(\frac{r}{1-\tau^V} - n - g + g_A\right)(m-1)(1-\tau^V)}{g\frac{\vartheta-1}{\vartheta}(1-\tau^D)(1-\tau^\pi)}$. Substituting $h^A/(hl)$ from (A25) into (A11) and then replacing $g_A = \frac{1-\alpha}{\alpha(m-1)}g$ and r from (A19), we obtain the equilibrium growth rate of the economy, namely:

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

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 depending on the tax rates and all the other parameters of the model. The steady-state ratio of human capital employed in R&D activities to total human capital can be expressed as:

$$\hbar_A \equiv \frac{h_A}{hl} = f(\tau^V, \tau^D, \tau^\pi) = g\frac{(1-\alpha)\nu}{(m-1)\alpha},$$

which corresponds with Eq. (13) in the main text.

The physical capital investment share is given by $i_K = (\dot{K} + \delta K)/Y = (\dot{K}/K + \delta)K/Y$. Since the total amount of physical capital amounts to $K = Ax$ and $x = \frac{\alpha Y}{A}\frac{1}{\vartheta R}$, the K-Y ratio is equal to $\alpha/(\vartheta R)$. Moreover, since the physical capital stock grows at the rate $n + g$ and $R = r + \delta$, using r from (A19), the physical capital investment share can be written as:

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

which coincides with Eq. (13) in the main text.

To complete the solution of the model, we show that the transversality conditions (A6) and (A7) hold under the assumption that $\rho > n$. Differentiating (A3) with respect to time, we get:

$$\frac{\dot{\mu}_1}{\mu_1} + (\eta - 1)\frac{\dot{h}_e}{h_e} + \gamma\frac{\dot{h}}{h} = \frac{\dot{w}}{w} + \frac{\dot{\mu}_2}{\mu_2}.$$

As $\dot{h}_e = \dot{h} = 0$ and $\dot{w}/w = g$ in the steady state, the previous equation can be written as:

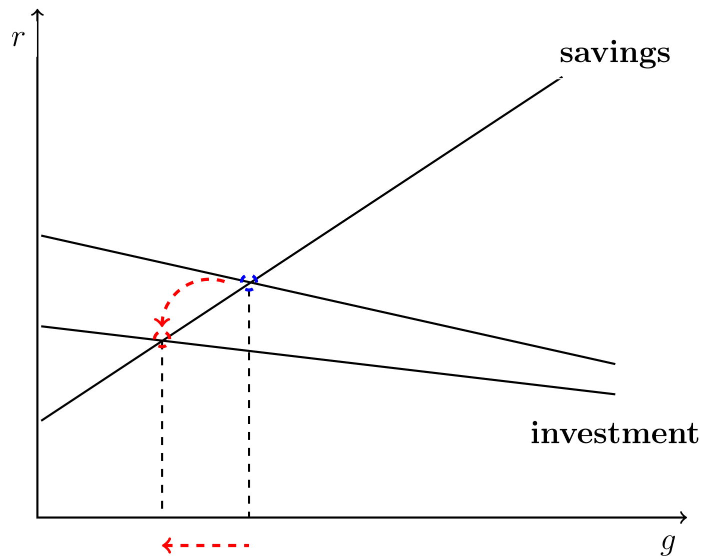
$$\frac{\dot{\mu}_1}{\mu_1} = g + \frac{\dot{\mu}_2}{\mu_2}.$$

Since, from (A5) and (A19), $\dot{\mu}_2/\mu_2 = -g$, it follows that $\dot{\mu}_1/\mu_1 = 0$. As h becomes stationary, (A6) holds if $\lim_{t\to\infty} e^{-(\rho-n)t} = 0$, which requires that $\rho > n$. Similarly, using $\dot{\mu}_2/\mu_2 = -g$ and the fact that

a grows at the rate g in the steady state, we find that (A7) holds if $\rho > n$.

Comparative statics of tax rates and its implication for economic growth

Figure A.1 – The effect of taxes on the market equilibrium.



To assess the impact of taxes on the rate of growth, it is useful to provide a graphical representation of the steady state in (g, r) space, as shown in Figure A.1. Let us first consider the no-arbitrage condition for the capital market (8). Replacing π from (A14) and V from (A17), and taking into account that $w = A^{\frac{\alpha(m-1)}{1-\alpha}}(1-\alpha)\left[\frac{\alpha}{\vartheta(r+\delta)}\right]^{\frac{\alpha}{1-\alpha}}$ and $\dot{V}/V = g + n - g_A$, we obtain:

$$r = \frac{(1-\tau^{\pi})(1-\tau^{D})(\vartheta-1)\alpha}{\nu(1-\alpha)\vartheta}\left(\frac{h_Y}{lh}\right) + (g+n-g_A)(1-\tau^{V}). \tag{A26}$$

Replacing Ψ and $\tilde{w}$ into (A23) and, then substituting h_Y into (A26), after some rearranging, we get:

$$r = \frac{(1-\tau^{\pi})(1-\tau^{D})(\vartheta-1)\alpha(1-\hbar_e)}{\nu(1-\alpha)\vartheta} + n(1-\tau^{V}) - g\left\{(1-\tau^{V})\left[\frac{1-\alpha}{\alpha(m-1)} - 1\right] + \frac{(1-\tau^{D})(1-\tau^{\pi})(\vartheta-1)}{(m-1)\vartheta}\right\},$$

which represents the rate of return on investment delivered by the market which can be obtained at a given rate of growth g. This relation can be seen as the demand schedule for savings. Instead, the supply of savings is ruled by (A19), according to which:

$$r = g + \rho,$$

which expresses the required reward on savings as a function of the rate of growth g. Both loci are depicted in Figure A.1. The vertical axis measures the rate of return r and the horizontal axis the rate of economic growth g. The investment locus is depicted as a straight line with negative slope, whereas the savings locus as a straight line with positive slope. The unique intersection between the two loci determines the steady-state values of r and g. The tax on profits (and/or dividends) has a negative effect on economic growth. When τ^{π} (and/or τ^{D}) increases, the investment locus shifts downwards and becomes flatter. By calculating the derivative of r with respect to τ^{π}, it is possible to ascertain that, for a given g, the rate of return on investment decreases. The resulting movement along the savings locus results in a lower g. An increase of the tax rate on capital gains, τ^{V}, has similar qualitative effects. In this case, for a given g, the rate of return on investment decreases when τ^{V} increases provided that $g + n > g_A$.[1] When this condition holds, the downward shift of the investment locus leads to a lower g, which means that an increase in the tax rate on capital gains has a negative impact on economic growth.

[1]Under this condition, using the free-entry R&D condition (9), one can easily ascertain that the stock market evaluation of an intermediate goods firm, V, grows at a positive rate in steady state.

B Historical data

In this Section, we provide a detailed description of data sources.

Real and Nominal GDP

General Note: The principal data source is the OECD. Stat's Real Gross Domestic Product (GDP) (http://stats.oecd.org/index.aspx?), accessed on 10/4/2018. The data are backdated by splicing figures from different sources as mentioned below:

Australia. 1890-1958 GDP Deflator, Snooks, Graeme D., 1994. *Portrait of the Family within the Total Economy-A Study in Long-run Dynamics, Australia 1788-1990*, Cambridge University Press; **Real & Nominal GDP** 1959-2010 OECD.Stat. **Austria. Real GDP** 1890-1913 Schulze, M.S., 2000. Patterns of Growth and Stagnation in the Late Nineteenth Century Hasburg Economy, *European Review of Economic History*, 4, pp. 311-340; 1914-1969 Maddison, A., 2007. *The World Economy: A Millennial Perspective/Historical Statistics (Development Centre Studies)*, OECD: Paris, France; 1970-2011 OECD.Stat, **Nominal GDP** 1890-1913 Schulze, M. S. (2000). Patterns of growth and stagnation in the late nineteenth century Habsburg economy. *European Review of Economic History*, *4*(3), 311-340; 1914-1919 Real GDP × CPI of Austria (Mitchell, B. R., 2007. *International Historical Statistics: Europe 1750-2005*, Palgrave Macmillan, New York); 1920 Osterreichischen Institutes Fur Wirtschaftsforschung 1965, *Monatsberichte des Osterreichischen Institutes fur Wirtschaftsforschung - Osterreichs Volkseinkommen 1913 bis 1963*, Sonderheft, No. 14, Austria, pp. 1-44; 1921-1923Interpolated figures using Growth & Trend; 1924-1937& 1948-1963 Osterreichischen Institutes Fur Wirtschaftsforschung 1965, *Monatsberichte des Osterreichischen Institutes fur Wirtschaftsforschung - Osterreichs Volkseinkommen 1913 bis 1963*, Sonderheft, No. 14, Austria, pp. 1-44 1938-1947 Real GDP × CPI of Austria (Mitchell, B. R., 2007. *International Historical Statistics: Europe 1750-2005*, Palgrave Macmillan, New York.); 1964-1969 Mitchell, B. R., 2007. *International Historical Statistics: Europe 1750-2005*, Palgrave Macmillan, New York. 1970-2011 OECD.Stat. **Belgium. Real & Nominal GDP** 1890-1969 Groningen Growth and Development Centre (GGDC), 2009. *Historical National Accounts Database*, accessed on 10/07/2012 (http://www.rug.nl/feb/Onderzoek/Onderzoekscentra/GGDC/data/hna); 1970-2011 OECD.Stat. **Canada. Real GDP** 1890-1926 Urquhart, M. C., 1986. New Estimates of Gross National Product, Canada, 1870-1926 Some Implications for Canadian Development,in Stanley, L. E. & Gallman, R. E., *Long-Term Factors in American Economic Growth,* National Bureau of Economic Research Inc., No. 9678, Cambridge, Massachusetts; 1927-1960 GNE in constant 1971 million dollars, Social Science Federation of Canada and Statistics Canada, 1983. *Historical Statistics of Canada,* 2ndEd., Table F33-35, accessed on 10/07/2012 (http://www.statcan.gc.ca/pub/11-516-x/sectionf/4057751-eng.htm#1); 1961-2011 Statistics Canada, 2012. *Gross domestic product (GDP),* *expenditure-based,* Table 380-0017, accessed on 10/07/2012 (http://www5.statcan.gc.ca/cansim/a05), **Nominal GDP** 1890-1926 Urquhart, M. C., 1986. New Estimates of Gross National Product, Canada, 1870-1926 Some Implications for Canadian Development,in Stanley, L. E. & Gallman, R. E., *Long-Term Factors in American Economic Growth*, National Bureau of Economic Research Inc., No. 9678, Cambridge, Massachusetts 1927-1960Social Science Federation of Canada and Statistics Canada, 1983. *Historical Statistics of Canada,* 2nd Ed., Table F33-35, accessed on 10/07/2012 (http://www.statcan.gc.ca/pub/11-516-x/sectionf/4057751-eng.htm#1) 1961-2011 Statistics Canada, 2012. *Gross domestic product (GDP), expenditure-based,* Table 380-0017, accessed on 10/07/2012 (http://www5.statcan.gc.ca/cansim/a05). **Denmark. Real & Nominal GDP** 1890-1965 Hansen, S. A., 1972. *Økonomisk vækst i Danmark Bind II: 1914-1970*, 2nd Ed., Universitetsforlaget**,** Copenhagen; 1966-2011OECD.Stat. **Finland. Real & Nominal GDP** 1890-1969 Groningen Growth and Development Centre (GGDC), 2009. *Historical National Accounts Database*, accessed on 10/07/2012 (http://www.rug.nl/feb/Onderzoek/Onderzoekscentra/GGDC/data/hna) 1970-2011 OECD.Stat. **France. Real & Nominal GDP** 1890-1949 Toutain, Jean-Claude, 1987. *Le Produit Interieur Brut De La France De 1789 A 1982*, Cahiers de I'I. S. M. E. A, Serie Historie Quantitative de I'Economie Francaise, No. 15 ; 1950-2011 OECD.Stat. **Germany. Real & Nominal GDP** 1890-1969 Fremdling, Rainer, 1995. German National Accounts for the 19th and Early 20th Century, *Scandinavian Economic History Review*, 43(1), pp. 77-100; 1970-2011 OECD.Stat, **Greece. Real GDP** 1890-1938 Kostelenos, G. C., 1995. *Money and Output in Modern Greece: 1858-1938*, Centre of Planning and Economic Research, Athens; 1939-1947 Maddison, A., 2007. *The World Economy: A Millennial Perspective/Historical Statistics (Development Centre Studies)*, OECD: Paris, France; 1948-1959General Directorate of Economic Policy and Programming, 1967. *National Accounts of Greece 1948-1965*, accessed on 10/07/2012 (http://dlib.statistics.gr/portal/page/portal/ESYE/showdetails?p_id=10096778&p_derive=book&p_topic=10007939); 1960-2011 OECD.Stat, **Nominal GDP** 1890-1938 Kostelenos, G. C., 1995. *Money and Output in Modern Greece: 1858-1938*, Centre of Planning and Economic Research, Athens; 1939-1945 Real GDP × CPI of Greece (Mitchell, B. R., 2007. *International Historical Statistics: Europe 1750-2005*, Palgrave Macmillan, New York.); 1946-1947 Mitchell, B. R., 2007. *International Historical Statistics: Europe 1750-2005*, Palgrave Macmillan, New York.; 1948-1959General Directorate of Economic Policy and Programming, 1967. *National Accounts of Greece 1948-1965*, accessed on 10/07/2012 (http://dlib.statistics.gr/portal/page/portal/ESYE/showdetails?p_id=10096778&p_derive=book&p_topic=10007939); 1960-2011 OECD.Stat. **Ireland. Real GDP** 1890-1946 Mitchell, B. R., 1988. *British Historical Statistics*, the Press Syndicate of the University of Cambridge, Cambridge; 1947-1969, Mitchell, B. R., 2007. *International Historical Statistics: Europe 1750-2005*, Palgrave Macmillan, New York; 1970-1995 Central Statistics Office Ireland, 2012. *T04 Gross Value Added at Factor Cost by Sector of Origin and Gross National Income at Constant Market Prices by Item and Year,* NAH04, accessed on 18/07/2012, (http://www.cso.ie/px/pxeirestat/Database/eirestat/National%20Accounts%20Historical%20Series%201970%20to%201995/National%20Accounts%20Historical%20Series%201970%20to%201995_statbank.asp?sp=National%20Accounts%20Historical%20Series%201970%20to%201995&Planguage=0); 1996-2001 Central Statistics Office Ireland, 2002. *2002 Statistical Yearbook*, Cork, accessed on 18/07/2012, (http://www.cso.ie/en/releasesandpublications/statisticalyearbookofireland/statisticalyearbookofireland2002edition); 2002-2004 Central Statistics Office Ireland, 2007. *2007 Statistical Yearbook*, Cork, accessed on 18/07/2012, (http://www.cso.ie/en/releasesandpublications/statisticalyearbookofireland/statisticalyearbookofireland2007edition/); 2005-2006 Central Statistics Office Ireland, 2011. *2011 Statistical Yearbook,* Cork, accessed on 18/07/2012, (http://www.cso.ie/en/releasesandpublications/statisticalyearbookofireland/statisticalyearbookofireland2011edition); 2007-2011 Central Statistics Office Ireland, 2012. *Gross value added at constant factor cost by sector of origin and gross national income at constant market prices (chain linked annually and referenced to year 2010)*, accessed on 18/07/2012, (http://www.cso.ie/en/statistics/nationalaccounts/principalstatistics, **Nominal GDP** 1890-1925 Mitchell, B. R., *British Historical Statistics*, Cambridge: Cambridge University Press; 1926-1959 Mitchell, B. R., 2007. *International Historical Statistics: Europe 1750-2005*, Palgrave Macmillan, New York.; 1960-1969 Central Statistics Office Ireland, 2002. *2002 Statistical Yearbook*, Cork, accessed on 18/07/2012, (http://www.cso.ie/en/releasesandpublications/statisticalyearbookofireland/statisticalyearbookofireland2002edition/; 1970-2007 Central Statistics Office Ireland, 2011. *2011 Statistical Yearbook,* Cork, accessed on 18/07/2012, (http://www.cso.ie/en/releasesandpublications/statisticalyearbookofireland/statisticalyearbookofireland2011edition/; 2008-2011 Central Statistics Office Ireland, 2012. *National Income (Current Market Prices) €m*, accessed on 18/07/2012**,** (http://www.cso.ie/en/statistics/nationalaccounts/principalstatistics/nationalincomecurrentmarketpricesm/). **Italy. Real GDP** 1890-1913 Malanima, P., 2011. The Long Decline of a Leading Economy: GDP in Central and Northern Italy, 1300-1913, *European Review of Economic History*, 15, pp. 169-219; 1914-1969 Growth and Development Centre (GGDC), 2009. *Historical National Accounts Database*, accessed on 14/07/2012 (http://www.rug.nl/feb/Onderzoek/Onderzoekscentra/GGDC/data/hna); 1970-2011 OECD.Stat, **Nominal GDP** 1890-1913 Malanima, P., 2011. The Long Decline of a Leading Economy: GDP in Central and Northern Italy, 1300-1913, *European Review of Economic History*, 15, pp. 169-219; 1914-1969 Rossi, Nicola; Sorgato, Andrea and Toniolo, Gianni, 1993. *I Conti Economici Italiani:Una Ricostruzione Statistica,1890-1990*, *Revista di Storia Economica*, 10(1), pp. 1-47; 1970-2011 OECD.Stat. **Japan. Real GDP** 1890-1939 J.P. Smits, P.J. Woltjer and D. Ma (2009), 'A Dataset on Comparative Historical National Accounts, ca. 1870-1950: A Time-Series Perspective', Groningen Growth and Development Centre Research Memorandum GD-107, Groningen: University of Groningen; 1940-1954 Ohkawa, K. *et al.*, 1957. *The Growth Rate of The Japanese Economy Since 1878,* Kinokuniya Bookstore Co. Ltd, Tokyo; 1955-1969 Statistics Bureau, 2008. *Table 3-3-a, Gross Domestic Product Classified by Economic Activities (Major Industry*

Group), accessed on 14/07/2012, (http://www.stat.go.jp/english/data/chouki/03.htm); 1970-2011 OECD.Stat, **Nominal GDP** 1890-1939, J.P. Smits, P.J. Woltjer and D. Ma (2009), 'A Dataset on Comparative Historical National Accounts, ca. 1870-1950: A Time-Series Perspective', Groningen Growth and Development Centre Research Memorandum GD-107, Groningen: University of Groningen; 1940-1954Ohkawa, K. *et al.*, 1957. *The Growth Rate of The Japanese Economy Since 1878,* Kinokuniya Bookstore Co. Ltd, Tokyo; 1955-1969 Statistics Bureau, 2008. *Table 3-3-a, Gross Domestic Product Classified by Economic Activities (Major Industry Group),* accessed on 14/07/2012, (http://www.stat.go.jp/english/data/chouki/03.htm); 1970-2011 OECD.Stat. **Netherlands. Real GDP** 1890-1939 Centraal Bureau voor de Statistiek, 2001. *Tweehonderd jaar statistiek in tijdreeksen, 1800-1999*, Voorburg; 1940-1968 Maddison, A. 2010, Historical Statistics on World Population, GDP and Per Capita GDP, Accessed on 10/07/2012 (http://www.ggdc.net/MADDISON/oriindex.htm; 1969-2011 OECD.Stat, **Nominal GDP** 1890-1939 Centraal Bureau voor de Statistiek, 2001. *Tweehonderd jaar statistiek in tijdreeksen, 1800-1999*, Voorburg; 1940-1945 Mitchell, B. R., 2007. *International Historical Statistics: Europe 1750-2005*, Palgrave Macmillan, New York.; 1946-1968 Centraal Bureau voor de Statistiek, 2001. *Tweehonderd jaar statistiek in tijdreeksen, 1800-1999*, Voorburg; 1969-2011 OECD.Stat. **New Zealand. Real GDP** 1890-1987 Statistics New Zealand, 2004. *Table E1.2 New ZealandLong Term Data Series – Real Gross Domestic Product (GDP)*, accessed on 11/07/2012, (http://www.stats.govt.nz/browse_for_stats/economic_indicators/NationalAccounts /long-term-data-series/national-income.aspx); 1988-2011 Statistics New Zealand, 2012. *Table SND087AA,* Infoshare database, accessed on 11/07/2012, (http://www.stats.govt.nz/infoshare/ViewTable.aspx?px ID=1d64d347-c981-4556-8744-b8055c53a6d5), **Nominal GDP** 1890-1971 Statistics New Zealand, 2004. *Table E1.2 New Zealand Long Term Data Series – Real Gross Domestic Product (GDP)*, accessed on 11/07/2012, (http://www.stats.govt.nz/browse_for_stats/economic_indicators/National accounts/long-term-data-series/national-income.aspx); 1972-2011 Statistics New Zealand, 2012. *Table SNC046AA,* Infoshare database, accessed on 11/07/2012, (http://www.stats.govt.nz/infoshare/Vi ewTable.aspx?pxID=d32556a0-967d-4c86-b1b5-0ed9bbb03311). **Norway. Real & Nominal GDP** 1890-1969 Grytten, O.H., 2004. The gross domestic product for Norway 1830-2003, pp.241-288, in Eitrheim, Ø., J.T. Klovland and J.F. Qvigstad (eds.), Historical Monetary Statistics for Norway 1819-2003, Norges Bank Occasional Papers no. 35, Oslo, 2004; 1970-2011 OECD.Stat. **Portugal. Real & Nominal GDP** 1890-1969 Nunes, A. B., Mata, E. and Valerio, N., 1989. Portuguese Economic Growth 1833-1985, *Journal of European Economic History*, 18(2), 291-330; 1970-2011 OECD.Stat. **Spain. Real GDP** 1890-1958 J.P. Smits, P.J. Woltjer and D. Ma (2009), 'A Dataset on Comparative Historical National Accounts, ca. 1870-1950: A Time-Series Perspective', Groningen Growth and Development Centre Research Memorandum GD-107, Groningen: University of Groningen; 1959-1969 Bardini, C., Carreras, A. and Lains, P., 1995. The National Accounts for Italy, Spain and Portugal, *Scandinavian Economic History Review*, 43(1), 115-146; 1970-2011 OECD.Stat,

Nominal GDP 1890-1958 J.P. Smits, P.J. Woltjer and D. Ma (2009), 'A Dataset on Comparative Historical National Accounts, ca. 1870-1950: A Time-Series Perspective', Groningen Growth and Development Centre Research Memorandum GD-107, Groningen: University of Groningen; 1959-1969 Real GDP × CPI of Spain (OECD.Stat); 1970-2011 OECD.Stat. **Sweden. Real & Nominal GDP** 1890-2010 Edvinsson, R., 2011. *New Estimates of Swedish GDP by Activity, 1665-2010*, Stockholm Papers in Economic History No. 12, Stockholm University, pp. 55-61. **Switzerland. Real & Nominal GDP** 1890-1912 Ritzmann-Blickenstorfer, Heiner, 1996. *Historical Statistics of Switzerland,* Zurich: Chronos; 1913-1979 Real GDP (Bolt, Jutta, Robert Inklaar, Herman de Jong, and Jan Luiten Van Zanden. "Rebasing 'Maddison': new income comparisons and the shape of long-run economic development." *GGDC Research Memorandum* 174 (2018).) & Nominal GDP (Ritzmann-Blickenstorfer, 1996, *Historical Statistics of Switzerland*, Zurich: Chronos); 1980-2010 OECD.Stat. **United Kingdom. Real & Nominal GDP** 1890-1947. Mitchell, B. R., British Historical Statistics, Cambridge: Cambridge University Press; 1948-1969 Office for National Statistics, 2011. *United Kingdom National Accounts - Blue Book 2011*, Newport, South Wales, accessed on 18/07/2012, (http://www.ons.gov.uk/ons/rel/naa1-rd/united-kingdom-national-accounts/2011-edition/tsd—blue-book-2011-dataset.html); 1970-2011 OECD.Stat. **United States of America. Real & Nominal GDP** 1890-1928 Johnston, L. and Williamson, S. H., 2011. *What Was the U.S. GDP Then? Measuring Worth*, accessed on 18/07/2012, (http://www.measuringworth.com/); 1929-2011 US Department of Commerce, Bureau of Economic Analysis, 2012. *Current-Dollar and "Real" Gross Domestic Product*, accessed on 18/07/2012, (http://www.bea.gov/national/index.htm#gdp).

Investment Machinery and Equipment (M&E)

The post-1950/80 data are from OECD, *National Accounts, Vol. II,* Paris *, (NA)* and the OECD online database, where the starting year varies across countries as detailed for each country below. Before 1950/80 the following sources and methods are used.

Canada. 1890-1925: Non-residential investment is split up in M&E and B&S using the investment shares provided by Firestone, O. J. (1958). *Canada's Economic Development, 1867-1953: With Special Reference to Changes in the Country's National Product and National Wealth*. London: Bowes & Bowes. Canada's economic development, 1890-1953: with special reference to changes in the country's national product and national wealth. The investment shares are available every 10 years. The non-residential gross fixed investment are from Urquhart, M.C., (1986), *New Estimates of Gross National Product, Canada, 1870-1926, Some Implications for Canadian Development*, in Stanley Engerman and Robert E. Gallman (Eds.) *Long-Term Factors in American Economic Growth. Chicago*: The University of Chicago Press, p. 16 (Table 2.2). Investment is deflated by the GDP-deflator (Urquhart, Table 2.9). 1926-1960: F33-F55, F. H. Leacy (ed.), 1983, *Historical Statistics of Canada*, Statistics Canada: Ottawa.

United States. M&E 1890-1950: Maddison, A., (1995), *Explaining the Economic Performance of Nations. Essays in Time and Space*, Edward Elgar: Aldershot, p. 156. B&S. 1789-1850. Scaled gross fixed capital formation. Berry, T.S., (1988), *Production and Population since 1789: Revised GNP Series in Constant Dollars*, Botswick Paper No. 6, Richmond, VA: The Botswick Press, p. 17, Table 1. 1950-1959: Maddison, A., (1995), *Explaining the Economic Performance of Nations. Essays in Time and Space*, Edward Elgar: Aldershot, Table 8f.

Japan. 1890-1950. 1890-1988: Maddison, A., (1995), *Explaining the Economic Performance of Nations. Essays in Time and Space*, Edward Elgar: Aldershot, p. 156. 25.7% war damage to the 1945 capital stock is incorporated into the capital stock following Maddison, A., (1995), *Explaining the Economic Performance of Nations. Essays in Time and Space*, Edward Elgar: Aldershot, p. 156.

Australia. 1890-1901. M&E. Sum of nominal gross capital formation in mining, shipping and half of manufacturing investment from Butlin, N. G. (1955). Private capital formation in Australia: estimates 1861-1900 (Vol. 5). Australian National University High Wycombe, Eng.: University Microfilms. The data are deflated by the overall investment deflator, Vamplew, W. (1987). Australians Historical Statistics. Fairfax, Syme & Weldon Associates. New South Wales, ANA 71 and 78. B&S: sum of gross capital formation in shops, industry investment divided by two and investment in Agriculture. All from Butlin, N. G. (1955). Private capital formation in Australia: estimates 1861-1900 (Vol. 5). Australian National University High Wycombe, Eng.: University Microfilms. The data are deflated by the overall investment deflator, Vamplew, W. (1987). Australians Historical Statistics. Fairfax, Syme & Weldon Associates. New South Wales, ANA 71 and 78. 1901-1960. M&E: Sum of private and public investment, where public investment is investment in machinery and equipment plus investment in rail, all from Butlin, M. W. (1977). A preliminary annual database 1900/01 to 1973/74 (No. rdp7701). Reserve Bank of Australia. Butlin (1977) only provides values of on capital stock and depreciation in fixed prices. Thus gross capital formation is created as K_t - $K_{t\text{-}1}$+ Depreciation$_{t\text{-}1}$. B&S: Sum of private and public investment in non-residential building and structures from Butlin, M. W. (1977). A preliminary annual database 1900/01 to 1973/74 (No. rdp7701). Reserve Bank of Australia.

New Zealand. 1890-1900. Non-residential private gross capital formation from Dowie, J. A. (1966). The course and character of capital formation in New Zealand—1871–1900. New Zealand Economic Papers, 1(1), 38-58. 1900-1939: The private non-residential investment-income ratio is linearly interpolated. 1939-1950. The private non-residential investment-income ratio in New Zealand Statistical Yearbooks: http://www.stats.govt.nz/browse_for_stats/economic_indicators/nationalaccounts/long-term-data-series.aspx, assessed 21-10-2018. 1950-1970. Real gross capital formation distributed on B&S and M&E from Philpott, B. (1991), "Real Gross Capital Formation in 22 SNA Sectors, 1950–1989", Research Project on Economic Planning Internal Paper 226b, Victoria University of Wellington, Wellington, August.

Austria. 1890-1913: Real gross capital formation is generated from the capital series of Schulze, M. S. (2005). An estimate of imperial Austria's gross domestic fixed capital stock, 1870-1913: methods, sources and results. WP 2005/5 Department of Economic History LSE. Gross capital formation is recovered from the capital stock using 17% depreciation rates for M&E and 3% for B&S. M&E is computed as the sum of the following categories: Railway tracks, rolling stock, ships, machinery. B&S is computed as the sum of the following categories: Roads/bridges, agricultural buildings, public buildings and common, non-residential, buildings. 1913-1945. Total real capital formation from Österreichs volkseinkommen 1913 bis 1963, Monatsberichte des Österreichischen Instituts für Wirtschaftsforschung, Sonderheft 14. The total investment-GDP ratio is decomposed into M&E and B&S using their respective investment-GDP ratios at the endpoints. 1945-1960. Sieder, R., Steinert, H., & Tálos, E. (Eds.). (1995). *Österreich 1945-1995: Gesellschaft, Politik, Kultur* (Vol. 60). Verlag für Gesellschaftskritik.

Belgium. 1890-1913. Amsterdam: Aksant. 1880-1899, noting that the Netherlands and Belgium were united over the period 1815-1830. Gross capital formation in agriculture, Table 4.4 (B&S) and Table 4.5 (M&E) from van Meerten, M., (2003), *Capital Formation in Belgium, 1900-1995*, Leuven: Leuven University Press, are spliced with overall economy M&E and B&S in 1900. 1900-1950: van Meerten, M., (2003), *Capital Formation in Belgium, 1900-1995*, Leuven: Leuven University Press. War damage correction: WWI. 15.5% of 1913 GDP spread out evenly between the years 1914-1917. WWII 7.1% spread out evenly on the years 1943-45. The correction for war damage follows van Meerteen, 2003, (see his footnote no. 39).

Denmark. 1890-1950: Table V in Bjerke, Kjeld, and Niels Ussing. Studier over Danmarks nationalprodukt, 1870-1950. GEC Gad, 1958. B&S is scaled total gross fixed investment in building and construction, thus includes residential investment. 1950-1980: OECD National Accounts, Vol. II.

Finland. 1890-1950: Hjerppe, R., (1989), *The Finnish Economy, 1860-1985*, Helsinki: Bank of Finland, Government Printing Centre. The data, which are in nominal values from Table 9A at the disaggregated levels, are deflated with the overall investment deflator (nominal investment in Table 3C, divided by real investment from Table 3A).

France. 1890-1913: Lévy-Leboyer, M. (1978). Capital investment and economic growth in France, 1820-1930. The Cambridge economic history of Europe, 7 (Part I), 231-95. Building and structures include residential housing investment. 1913-1939: Villa, P., (1993), *A Macroeconomic Analysis of 20th Century France.* Paris: CNRS- Editions. 1939-1946: interpolation (construction sector employment from Liesner (1989, p. 191) used to bridge the two series). 1946-1950 interpolated. War damage of 2% is assumed each year over the periods 1914-17 and 1942-1945 following Maddison, A., (1995), *Explaining the Economic Performance of Nations. Essays in Time and Space*, Edward Elgar: Aldershot, p. 156.

Germany. 1890-1913 Table 35 in Hoffmann, Walther G. "Erster Teil."*Das Wachstum der deutschen Wirtschaft seit der Mitte des 19. Jahrhunderts.* Springer, Berlin, Heidelberg, 1965. There are no separate categories for M&E and B&S. Thus, M&E is estimated as the sum of the following categories: Investment in agricultural M&E, rail, and half of business investment in M&E plus structures. B&S are estimated as total non-residential investment minus the investment in M&E. 1913-1950: Kirner, W., (1968), *Zeitreihen fur das Anlagevermogen der Wirtschaftsbereiche in der Bundesreplublik Deutschland*, Deutsches Institut fur Wirtschaftsforschnung, Duncker & Humbolt: Berlin. The data are adjusted for war damage in the source. Non-residential buildings and structures. The following categories are added together: Land und Forstwirtschaft, Energiewirtschaft, Bergbau, Grundstoff- und Produktionsgüterindustrie, Investeringsgüterindustrie, Verbrauchengüterindustrie, Nahrings- und Genussmittel-industrie, Industrie Klainbetrieb und Handwerk, Baugewerbe, Handel, Eisenbahnen, Schifffahrt, Übriger Verkehr, Nachrichtenübertragung, Kreditintitutionen und Vers. gew., Wohnungsvermietung, Sonst. Dienstleist., Strassen und Brukken, Wasser strassen und Hafen, and Übrige staatliches Bereiche, and maintainance (Eisenbahnen, Strassen und Bracken, Strassen, Wasser, Häfen).

Greece. 1890-1920. M&E is computed as the share of machinery in total imports from T12.2 in Socrates D. Petmezas, "Foreign Trade and Capital Flows in Nineteenth-century Greece", in Edhem Eldem and Socrates Petmezas (eds), The Economic Development of Southeastern Europe in the 19th Century, Athens: Alpha Bank Historical Archives, 2011, pp. 447-491, multiplied by real GDP and the share of nominal imports in total GDP. Imports are from the statistical yearbooks of Greece and nominal GDP is from George C. Kostelenos (2003) "Historical estimates of National Accounts Magnitudes in Greece: 1830-1939", *Spoudai*, Vol. 53, No. 1, pp. 37-64, esp. Table 2a, pp. 46-47. B&S. Backdated assuming it to be a constant fraction of GDP at the 1920 level. 1920-1948: Derived from consumption of steel (M&E) and cement (B&S), Svennilson, I., (1954) *Growth and stagnation in the European economy.* United Nations Economic Commission for Europe, Geneva. 1948-1948. National Accounts of Greece, 1948-65, T23, Statics Greece.

Ireland. 1890-1920. The investment-income ratios for M&E and B&S are based on that of the UK since Ireland was a part of the UK during almost all of this period. 1920-1952. B&S: Derived from consumption of cement, Svennilson, I., (1954) *Growth and stagnation in the European economy.* United Nations Economic Commission for Europe, Geneva., up to 1950 and bridged to 1953 using the B&S investment-income ratio for the UK. M&E: 1926-1947, based on M&E gross fixed investment from Nevin, E. (1963). The Capital Stock of Irish Industry. Economic and Social Research Institute (ESRI) Research Series. 1920-1925: consumption of steel, Svennilson, I., (1954) *Growth and stagnation in the European economy.* United Nations Economic Commission for Europe, Geneva., up to 1950 and bridged to 1953 using the M&E investment-income ratio for the UK. 1953-1970. M&E and B&S: Slattery, D. G. (1975). Fixed capital stock estimation: an empirical exercise using Irish data.

Journal of the Statistical and Social Inquiry Society of Ireland, 23(2), 90-133. 1970-1995. Central Statistical Office, T17 Gross Domestic Physical Capital Formation (excluding FISIM), assessed on 21-11-2018 on https://www.cso.ie/px/pxeirestat/Statire/SelectVarVal/Define.asp?maintable=NAH17&PLanguage=0.

Italy. 1890-1970: Baffigi, A. (2011). Italian National Accounts. A project of Banca d'Italia, Istat and University of Rome Tor Vergata. Economic History Working Papers, Banca d'Italia No 18. Investment in non-residential buildings and structures is estimated as the sum of public investment, other investment and investment non-residential buildings.

Netherlands. 1890-1913. M&E include transport. Albers, R. M., 2002. *Machinery Investment and Economic Growth, The Dynamics of Dutch Development 1800-1913*, Amsterdam: Aksant. 1913-1960. Groote, P., Albers, R., & De Jong, H. (1996). A standardised time series of the stock of fixed capital in the Netherlands, 1900-1995. Groningen Growth and Development Centre, Faculty of Economics, University of Groningen. B&S is the sum of civil engineering and non-residential construction. 10% war damage is evenly spread out over the years 1943-1945.

Norway. 1890-1929. Norway, Statistisk Sentralbyrá. "Nasjonalregnskap 1900-1929". Statistics Norway, Oslo (1953). M&E. Sum of non-transport M&E investment and investment in transport. B&S. Total investment in building and structures. 1930-1960. Sentralbyra, Statistisk. "Nasjonal Regnskap, 1865–1960". (1965). Norges offisielle statistikk XII, No. 163. 1930-1960. M&E. Sum of non-transport M&E investment and investment in transport. B&S. Total investment in non-residential buildings and structures.

Portugal. 1890-1911. The investment-income ratios are assumed to follow that of Spain. 1911-1960. da Silva, E. G., & Lains, P. (2013). Capital formation and long-run growth: Evidence from Portuguese data, 1910-2011. *Iberometrics VI, May*, 16-17. Machinery and equipment is computed as the sum of transport, machinery, equipment and other with depreciation rates of 8.25 % (0.11 after 1960) for M&E, 5.5% % (9.1 % after 1960) for transport and 11% (16% after 1960) for other investment.

Spain. 1890-1950. Table A7.2a De La Escosura, Leandro Prados. El progreso económico de España. Fundación BBV, 2003. M&E include investment in transport equipment.

Sweden. 1890-1949. Edvinsson, R., 2005: Growth, Accumulation, Crisis: With New Macroeconomic Data for Sweden. Almqvist & Wiksell. All the data are deflated by the deflator for total investment. B&S. Investment in building and structures minus investment in buildings. M&E include investment in transport.

Switzerland. M&E. 1890-1914. Nominal investment in M&E divided by the GDP deflator, Table R1 in Ritzmann-Blickenstorfer, 1996, *Historical Statistics of Switzerland*, Zurich: Chronos.1914-1920. Interpolated using the investment-income ratio. 1920-1948: Derived from consumption of steel, Svennilson, I., (1954) *Growth and stagnation in the European economy.* United Nations Economic

Commission for Europe, Geneva; 1948-1979. Table R3 in Ritzmann-Blickenstorfer, H. (Ed.). (1996). *Historische Statistik der Schweiz.* Chronos-Verlag. B&S. 1890-1914. Nominal investment in M&E divided by the GDP deflator, Table R1 in Ritzmann-Blickenstorfer, H. (Ed.). (1996). *Historische Statistik der Schweiz.* Chronos-Verlag. Computed as total nominal non-residential investment (sum of the columns entitled "investment in structures" and investment in M&E and non-residential buildings) minus investment in M&E. The data are deflated by the GDP deflator. 1914-1920. Interpolated based on the investment-GDP ratio. 1920-1926. 1920-1948: Derived from consumption of cement, Svennilson, I., (1954) *Growth and stagnation in the European economy.* United Nations Economic Commission for Europe, Geneva. 1927-1947. Nominal investment in building and structures minus investment in residential buildings deflated by the GDP deflator, Table R4 in Ritzmann-Blickenstorfer, H. (Ed.). (1996). *Historische Statistik der Schweiz.* Chronos-Verlag. 1948-1970. Sum of real investment in government buildings, civil engineering and non-residential buildings, Bundesamt für Statistik: Langfristige Reihen der Nationalen Buchhaltung der Schweiz. Haupttabellen 1948–1990; Detailtabellen und Konti 1970–1990. Bern 1992 Eidg. Statistisches Amt: Revidierte Reihen der Nationalen Buchhaltung der Schweiz 1948–1976 sowie Produktionskonto 1970 (Beiträge zur schweizerischen Volkswirtschaftliche Gesamtrechnungen).

UK. 1890-1920: Feinstein, C.H., Pollard, S., (1988), *Studies in Capital Formation in the United Kingdom, 1750-1920*, Oxford: Clarendon Press, p. 431, Table X. 1920-1960. Feinstein, C. H. (1976). Statistical Tables of National Income, Expenditure, and Output of the UK, 1855-1965. Cambridge: Cambridge University Press, Table 40.

Residential Investment

General Note:

Except for the cases where actual references are given, all data were backdated to 1800 by splicing with 'computed investment' obtained by multiplying the average Residential Inv/GDP ratio for all countries with data available up to the base year by the Real GDP. The detailed references for each country are as follows:

Canada. 1926-1976, from Historical statistics Canada, http://www.statcan.gc.ca/pub/11-516-x/sectionf/4057751-eng.htm#3, accessed on 5 December 2014; 1971-2013, OECD database. All preceding data before 1971 is spliced to the level of OECD database.

USA. 1890-1950 number of housing units from Cater et al (2006), spliced to the level of OECD data in 1950. 1950-1968; from National Accounts of OECD countries and 1970-2013 from OECD database. All pre 1970 data is spliced to the level of OECD database.

Japan. 1890-1945 from Ohkawa K., Shonohara M., and Meissneer L., (1979). Patterns of Japanese Economic Development A Quantitative Appraisal, New haven and London, Yale University

Press, 1979; 1952-1968 from National Accounts of OECD countries; 1969-1980 interpolated using the Investment to GDP ratio; 1981-2013 from the OECD database.

Australia. 1890-2010, real residential construction as a percent of GDP from Ville Simon and Withers Glenn., (2015), The Cambridge Economic History of Australia, Cambridge University Press. Data is used to compute real residential construction which is then spliced to the level of National Accounts of OECD countries in 1958; 1958-2013 from OECD database.

New Zealand. 1890-1976 total residential dwellings from Bloomfield G. T., (1984). New Zealand: A Handbook of Statistics, spliced to the level of OECD in 1976; 1976-1986 from OECD National accounts; 1986-2013 from OECD database.

Austria. 1890-1950 from Österreichisches Statistisches Zentralamt., (1979), Geschichte und Ergebnisse der zentralen amtlichen Statistik in Österreich 1829-1979: Festschrift aus Anlass des 150jähr. Bestehens d. zentralen amtl. Statistik in Österreich, Issue 550 of Beiträge zur. To obtain housing investment, population per dwelling data is used to compute the total stock of housing using total population from Maddison (2010) Historical GDP Database (http://www.worldeconomics.com/Data/MadisonHistoricalGDP). Investment is then computed from housing stock assuming a depreciation rate of 3% annum and the figures are subsequently spliced to the OECD national accounts level; 1950-1975 from OECD National Accounts of OECD countries; 1975-2013 from OECD database.

Belgium. 1900-1953 from Meerteen, Michalangelo va., (2003), Capital formation in Belgium, 1900-1995, Leuven Lewen University Press; page 386; 1954-1994 interpolated using the residential capital to GDP ratio; 1995-2013 from OECD database.

Denmark. 1919-1980, number of flats constructed per year from Johansen Hans C., (1985), Dansk Okonomisk Statistik, 1814-1980. The data is spliced to the level of OECD database 1980-2013 from OECD database.

Finland. 1890-1985 from Hjerppe, Riita., (1989), The Finnish Economy 1860-1985: Growth and Structural Change, Front Cover, Bank of Finland, Government Printing Centre. Spliced to the level of the OECD data in 1975; 1975-2013 from the OECD database.

France. 1890-1896 from Levy-Leboyer and Bourguignon, (1985), 1896-1939 and 1946-1950 from Villa, P. (1993)., Une Analyse Macroéconomique de la France au XXe, Siècle, Paris, CNRS Éditions; 1950-1968; from National Accounts of OECD countries and 1970-2013 from OECD database.

Germany. 1890-1959 from Kunkel W, Peters H, Presier E., (1965). Enzyklopadie Der Rechts- Und Staatswissenchaft' Springer - Verlag, Berlin, Heidelberg, New York; 1959-1980 National Accounts of OECD countries; 1980-2013 from the OECD database.

Greece. 1950-1960 from Statistics of National Accounts: 1950-1961; 1960-2013 from OECD database.

Ireland. 1950-1956, Statistics of National Accounts: 1950-1961; 1956-1995 National Accounts of OECD countries; 1995-2013 from the OECD database.

Italy. 1890-1970 from Toniolo Gianni., (2013), The Oxford Handbook of The Italian Economy since Unification, Oxford University Press; 1970-2013 from the OECD database.

Netherlands. 1890-1980 from Groote P., Albers R., and Jong H De., (1996), A Standardised Time Series of the Stock of Fixed Capital in the Netherlands, 1900-1995.; 1980-2013 from OECD database.

Portugal. 1911-2000 Capital formation and long-run growth: Evidence from Portuguese data, 1910-2011. EG da Silva, P Lains - Iberometrics VI, May, 2013. The investment data are recovered from capital stock data using 1.3% depreciation rate as they have used. Backdated using constant Inv/Y ratio.

Norway. 1930-1949 from Nasjonalregnskap 1865-1960, National Accounts 1865-1960, Statistisk Sentralbyrå, Central Bureau of Statistics of Norway; 1950-1970 from OECD National accounts; 1970-2013 from the OECD database.

Spain. 1890-1958 nominal housing investment data from Prados de la Escosura, Leandro., (2003), EL Progreso Economico De Espana (1850-2000) Bilbao: Fundación BBVA. The data is deflated using the construction cost index; 1958-2008 from National Accounts of OECD countries, various issues; 2008-2013 obtained by splicing the real housing investment with total real gross fixed capital formation from the OECD database.

Sweden. 1890-1970, Nominal residential investment adjusted using the CC cost index from Rodney Edvinsson, Historical national accounts for Sweden 1800-2000 (Historiska nationalräkenskaper för Sverige 1800-2000) Version 1.0, accessed Last updated (senast uppdaterad), 050404; 1970-2013 from OECD database.

Switzerland. 1890-1910, nominal residential investment is obtained from Ritzmann-Blickenstorfer, 1996, Historical Statistics of Switzerland, Chronos: Zurich, and deflated using the constuction costs index; 1910-1956 total buildings from Ritzmann-Blickenstorfer, 1996, Historical Statistics of Switzerland, Chronos: Zurich; 1956-1968 National Accounts of OECD countries; 1968-1991 total buildings from Ritzmann-Blickenstorfer, 1996, Historical Statistics of Switzerland, Chronos: Zurich. All pre-1992 data is spliced to the level of OECD National accounts (1956-1968); 1992-2013 from the OECD database.

UK. 1890-1980, Lisner T (1989), One hundred years of Economic Statistics. Facts on File, New York, Oxford. Data is spliced to the level of OECD in 1980; 1980-2013 is from the OECD database.

Gross enrollment rates in secondary and tertiary education.

Madsen, J. B. (2014), "Human Capital and the World Technology Frontier." *Review of Economics and Statistics*, 96(4), 676-692.

R&D expenditure

Madsen, J. B. and J. B. Ang (2016), "Finance-Led Growth in the OECD Since 1870: How does Financial Development Transmit to Growth?" *Review of Economics and Statistics*, 98(3), 552-572.

Consumer prices

Madsen, J. B. and J. B. Ang (2016), "Finance-Led Growth in the OECD Since 1870: How does Financial Development Transmit to Growth?" *Review of Economics and Statistics*, 98(3), 552-572.

Tariff rates

Import duties divided by total imports. B. R Mitchell, 1975, *European Historical Statistics 1750-1975*, Macmillan: London, B. R Mitchell, 1983, *International Historical Statistics: Americas and Australasia*, Macmillan: London, and B. R Mitchell, 1982, *International Historical Statistics: Asia and Africa*, Macmillan: London. Updated using World Development Indicators.

Minimum working age

Australia: Law passed 1873-1897 Labour legislation complimented the Education Acts in that no school age children were allowed in factories/shops, Swain, S., 2009. Australia, development of child welfare policy in Australia. In Hindman, H.D. (ed.) *The World of Child Labor: An Historical and Regional Survey.* 949-952. New York: Routledge; circa 1917 legislation had been passed which prohibited children 14 years of age and under (Hindman, 2009). Child labour age laws followed compulsory schooling laws; 1964 -1972 Education Acts raised to 16 years (Burke, Gerald, and Andrew Spaull. "Australian schools: participation and funding 1901 to 2000." *Year Book Australia* 1301 (2001)). ***Austria:*** 1854 Austrian Code prohibits children under the age of 12 to work in the industry, from 1859 educational requirements had to be monitored, from 1859 they prohibit industry work, from 1884 laws prohibit mining work below age 12 (Anderson and Wright, 1911); 1987 Federal Act sets minimum working age to 15, requires the completion of compulsory education to start work and prohibits most occupations (ILO, 2000). ***Belgium:*** 1889 bill prohibited the labour of children below 12 years, limited hours of 12-16 years of age, restrictions only applied to industrial work Hindman, H.D. (ed.) 2009. *The World of Child Labor: An Historical and Regional Survey.* New York: Routledge; 1914 bill restricted industrial work for 14 and under (Hindman, 2009); 1971 Labour Act restricts employment of children under 15 in all industries except for arts (Hobbs, S., Mckechnie, J., and Lavealette, M., 1999. Child Labour: A World History Companion. Oxford: ABC-CLIO Ltd). ***Canada:*** 1883 children under 14 not allowed in factory; 1907

Educational requirements (literacy rest) for those over 14 who want to work (Hindman, H.D. (ed.) 2009. *The World of Child Labor: An Historical and Regional Survey.* New York: Routledge); Compulsory education and child labour regulation followed each other, school leaving age changed in 1961 to 9 years of compulsory schooling, schooling leaving age 15 (Hindman, 2009); (Oreopoulos, P. 2005. *Canadian* Compulsory *School Laws and their Impact on Educational Attainment and Future Earnings,* Statistics Canada Catalogue no. 11F0019 No. 251, p 3-41, viewed 4 April 2012, http://publications.gc.ca/collections/Collection/Statcan/11F0019MIE/11F0019MIE2005251.pdf.

Denmark: 1873 Factory Labour Act, no children under the age of 10, hour restrictions for those 10-14 years of age (Hindman, H.D. (ed.) 2009. *The World of Child Labor: An Historical and Regional Survey.* New York: Routledge); 1901 previous act amended to increase the age to 12 as well as the hours (Hindman, 2009); 1913 school children were banned from factories and agriculture was restricted to 10 years; 1925 14 and over only in industrial, craft and transport (Hindman, 2009); No.138 Convention ILO, raised to 15 years in 1997. ***Finland:*** 1868 children under 12 were not allowed to work for more than 6 hour; 1879 no factory work for children under the age of 12, under 15 had restrictions; 1889 children under the age of 15 had to complete compulsory schooling (1889-1921 4 years of schooling) (Hindman, H.D. (ed.) 2009. *The World of Child Labor: An Historical and Regional Survey.* New York: Routledge); Saarivitra, (2008); No. 138 Convention ILO, raised to 15 years in 1976; 1993 compulsory schooling needed to be completed in order to be employed (ILO, 2014). ***France:*** 1841 Child Labour Law no child under the age of 8, the other ages restricted hours, the law also insisted on education of kids who were working until 12 years of age (Hindman, H.D. (ed.) 2009. *The World of Child Labor: An Historical and Regional Survey.* New York: Routledge); 1874 Law allowed the 1841 Law to be more enforceable (Hindman, 2009); 1891 minimum age raised to 13 years (Hindman, 2009); No.138 Convention ILO, raised to 16 years in 1990. Child labour law complimentary to compulsory schooling during the 20th century – 1936 and 1967 education changes (Hindman, 2009). ***Germany:*** 1839 no children under 9 years of age, restricted hours for the other ages, employment of under 16s who are illiterate is forbidden (GHDI, 2014); 1853 no children under 12 in industry, others limited, under 14s must attend school 3 hours a day if they want to work (Hindman, H.D. (ed.) 2009. *The World of Child Labor: An Historical and Regional Survey.* New York: Routledge); 1891 no children under 13s, over 13 must have completed primary education (Hindman, 2009); No.138 Convention ILO, raised to 15 years in 1976. ***Greece:*** Circa 1919 no children under 14 years of age in industry work (Hindman, H.D. (ed.) 2009. *The World of Child Labor: An Historical and Regional Survey.* New York: Routledge); No.138 Convention ILO, raised to 15 years in 1986. ***Ireland:*** 1833 no child under the age of 9 in textile mills (highly enforceable) (Hindman, H.D. (ed.) 2009. *The World of Child Labor: An Historical and Regional Survey.* New York: Routledge); 1867 the 1833 law was applicable to factories and workshops (Hindman, 2009); 1875 no child under the age of 10 (Hindman, 2009); 1891 no child under the age of 11 (Hindman, 2009); 1926 compulsory education was linked and age raised to 14 (Hindman, 2009); No.138 Convention ILO, raised to 15 years in 1977. ***Italy:*** 1886 no children under the age of 9 in industry work; 1902 no children under the age of 12 (Toniolo, G., & Vecchi, G., 2007). ITALIAN CHILDREN AT WORK, 1881—1961. *Giornale degli economisti e Annali di economia*, 401-427.); 1967 Law passed to prevent children under the age of 15 entering the workforce (Toniolo, G., & Vecchi, G., 2007). ITALIAN CHILDREN AT WORK, 1881—1961. *Giornale degli economisti e Annali di economia*, 401-427). ***Japan:*** 1916 no children under age of 12, restrictions for the other ages (Matsuoka, Asa, and W. N. Doak. *Labor conditions of women and children in Japan.* Bureau of Labor Statistics, United States Department of Labor, Washington, 1931); 1947 no children under the age of 15 (Kazutoshi Koshiro ed., *Volume 6: Fifty Year History of Industry and Labor in Postwar Japan* (Tokyo, 2000)). ***New Zealand:*** Child labour regulation based on compulsory schooling laws, (Hindman, H.D. (ed.) 2009. *The World of Child Labor: An Historical and Regional Survey.* New York: Routledge) – 1877 age 13, 1901 age 14, 1944 age 15, 1993 age 16. ***Netherlands:*** 1874 under 12s prohibited to work unless its agriculture or domestic, (Hindman, H.D. (ed.) 2009. *The World of Child Labor: An Historical and Regional Survey.* New York: Routledge); 1889 restrictions on the hours work (Hindman, 2009); 1911 children under 13 not allowed (Hindman, 2009); 1919 children under 14 not allowed (Hindman, 2009); 1960 children under 15 not allowed (Hindman, 2009). ***Norway:*** 1892 Factory Act no work for children under age of 12, restriction of hours for the others. Employers responsible for children finishing elementary school, (Hindman, H.D. (ed.) 2009. *The World of Child Labor: An Historical and Regional Survey.* New York: Routledge); No.138 Convention ILO, raised to 15 years in 1980. ***Portugal:*** 1891 no children under the age of 12 – not well enforced, (Hindman, H.D. (ed.) 2009. *The World of Child Labor: An Historical and Regional Survey.* New York: Routledge); 1934/1936 made the 1891 legislation more enforceable (Hindman, 2009); 1969 age lifted to 14 years, Goulart, P., & Bedi, A. S. 2008. Child labour and educational success in Portugal. *Economics of Education Review*, *27*(5), 575-587.; No.138 Convention ILO, raised to 16 years in 1988. ***Spain:*** 1902 no children under the age of 10, other ages restricted (Anderson and Wright, 1911); 1945 compulsory schooling lead to no under 12s; No.138 Convention ILO, raised to 16 years in 1977. ***Sweden:*** 1720 no children under the age of 10, (Hindman, H.D. (ed.) 2009. *The World of Child Labor: An Historical and Regional Survey.* New York: Routledge); 1846 no children under the age of 12 could work as apprentices, factory or craft workers – compulsory schooling was introduced in 1842 leading to minimum requirements to be set in regards to employment of children (Hindman, 2009); 1881 no children under the age of 12 in factory work, other ages restricted (Hindman, 2009); 1912 no children under the age of 13 in industry work (Hindman, 2009); 1949 no children under the age of 14 at all, industry no under 15s (Hindman, 2009); No.138 Convention ILO, raised to 16 years in 1990. ***Switzerland:*** 1815 no children under the age of 10 (Hans R Wiedmer: *Arbeit im Industrialisierungsprozess: Veränderungen industrieller Arbeitsbedingungen in der Schweiz 1880-1914.* Chronos 1989); 1877 no children under the age of 14 (Hans R Wiedmer: *Arbeit im Industrialisierungsprozess: Veränderungen industrieller Arbeitsbedingungen in der Schweiz 1880-1914*. Chronos 1989); No.138 Convention ILO, raised to 15 years in 1999. ***UK:*** 1833 no children under the age of 9 in textile mills (enforced), (Hindman, H.D. (ed.) 2009. *The World of Child Labor: An Historical and Regional Survey.* New York: Routledge); 1867 the law extended to factories and workshops (Hindman, 2009); 1874 no children under 10; 1891 no children under 11 (Hindman, 2009); 1933 no children under 15, compulsory education linked to labour laws (LOC, 2014); No.138 Convention ILO, raised to 16 years in 2000. ***US:*** 1842 no children under the age of 12 (Massachusets), (Hindman, H.D. (ed.) 2009. *The World of Child Labor: An Historical and Regional Survey.* New York: Routledge); (Walter Trattner, *Crusade for the Children: A History of the National Child Labor Committee and Child Labor Reform in America* (1970)); 1848 no child under age of 12 in textiles (Pennsylvania) (Hindman, 2009); 1866 no child under 10 in manufacturing, 10-14 if want to work need to show records of school attendance for 6 months of the year (Hindman, 2009); 1899 28 states follow the 1848 law (Hindman, 2009); 1903 Alabama and Carloinas restrict age to 12 for manufacturing (Hindman, 2009;); 1938 Federal legislation no employment of children under the age of 16, compulsory schooling tied to employment (Hindman, 2009).

Population

Madsen, J. B., P. E. Robertson, and L. Ye (2019), "Malthus Was Right: Explaining a Millennium of Stagnation." *European Economic Review*, 118, 51-68.

Taxes

B. R Mitchell, 2013, *International Historical Statistics, 1750-2010*, online database, Palgrave Macmillan: New York.

Top income tax rates

Roine, Jesper, Jonas Vlachos, and Daniel Waldenström (2009). "The Long-run Determinants of Inequality: What Can We Learn from Top Income Data?." *Journal of Public Economics*, 93, no. 7-8: 974-988.

C Additional estimation results

In this section, we provide empirical results that are not included in the main manuscript.

Table C.1: **ARDL estimates based on data on 5-year non-overlapping intervals: long-run parameters**

Dep variable:	M&E inv. /GDP		R&D expenditure/GDP		Tertiary GER	
	(1)	(2)	(3)	(4)	(5)	(6)
Corporate income tax	-1.309***	-2.593***	-0.221**	-0.473*		
	(0.445)	(0.654)	(0.094)	(0.278)		
Personal income tax				0.263***	-0.300*	-0.266
				(0.097)	(0.168)	(0.198)
Inflation rate		-0.320***		-0.036		
		(0.099)		(0.027)		
GDP p.c. growth		0.182		-0.031		
		(0.306)		(0.066)		
Minimum working age						0.064
						(0.064)
Population growth						-1.294
						(0.957)
Obs.	299	299	299	299	472	462
R-squared	0.812	0.761	0.899	0.914	0.914	0.914

Notes Dependent variable: Physical (equipment) investment over GDP (cols. 1-2). R&D expenditure over GDP (cols. 3-4). Gross enrollment rate on tertiary institutions (Cols. 5-6). Long-run parameter estimates based on ARDL(1,1) model. All estimates include country fixed effects and country-specific common correlated effects (CCEs). Standard errors in parentheses computed with the delta method. ***,**,* significant at 1, 5 and 10% respectively.

Table C.2: **ARDL estimates controlling for government budget: Physical investment/GDP (annual data)**

	(1)	(2)	(3)	(4)	(5)	(6)
Corporate income tax	-1.113***			-1.556***	-1.493**	-1.015**
	(0.402)			(0.497)	(0.589)	(0.511)
Public savings (deficit)/GDP		0.264			-0.0890	
		(0.243)			(0.158)	
Total tax revenues/GDP			0.0343			-0.0936
			(0.0827)			(0.167)
GDP p.c. growth				0.679***	0.877***	0.333*
				(0.249)	(0.309)	(0.171)
Inflation rate				-0.329***	-0.349***	-0.0913
				(0.0968)	(0.114)	(0.0657)
Obs.	1,483	2,520	2,520	1,483	1,483	1,483
R-squared	0.944	0.933	0.929	0.954	0.956	0.960

Notes: Dependent variable: Equipment investment over GDP. Total tax revenues exclude corporate income tax revenues. All estimates include country fixed effects and country-specific common correlated effects (CCEs). Standard errors in parentheses computed with the delta method. ***,**,* significant at 1, 5 and 10% respectively.

Table C.3: **ARDL estimates controlling for government budget: R&D expenditure/GDP (annual data)**

	(1)	(2)	(3)	(4)	(5)	(6)
Corporate income tax	-0.231***			-0.339***	-0.355***	-0.206***
	(0.0883)			(0.104)	(0.138)	(0.0728)
Public savings (deficit)/GDP		0.000850			-0.00745	
		(0.0131)			(0.0161)	
Total tax revenues/GDP			0.0388**			-0.0369
			(0.0162)			(0.0355)
GDP p.c. growth				-0.0473*	-0.0112	-0.0645***
				(0.0283)	(0.0348)	(0.0222)
Inflation rate				0.0354***	0.0414***	0.0158**
				(0.0104)	(0.0140)	(0.00761)
Personal income tax				0.177***	0.147***	0.175***
				(0.0404)	(0.0497)	(0.0561)
Obs.	1,483	2,520	2,520	1,483	1,483	1,483
R-squared	0.991	0.995	0.995	0.992	0.991	0.992

Notes: Dependent variable: R&D investment over GDP. Total tax revenues exclude corporate income tax revenues. All estimates include country fixed effects and country-specific common correlated effects (CCEs). Standard errors in parentheses computed with the delta method. ***,**,* significant at 1, 5 and 10% respectively.

Table C.4: **ARDL estimates controlling for government budget: Tertiary GER (annual data)**

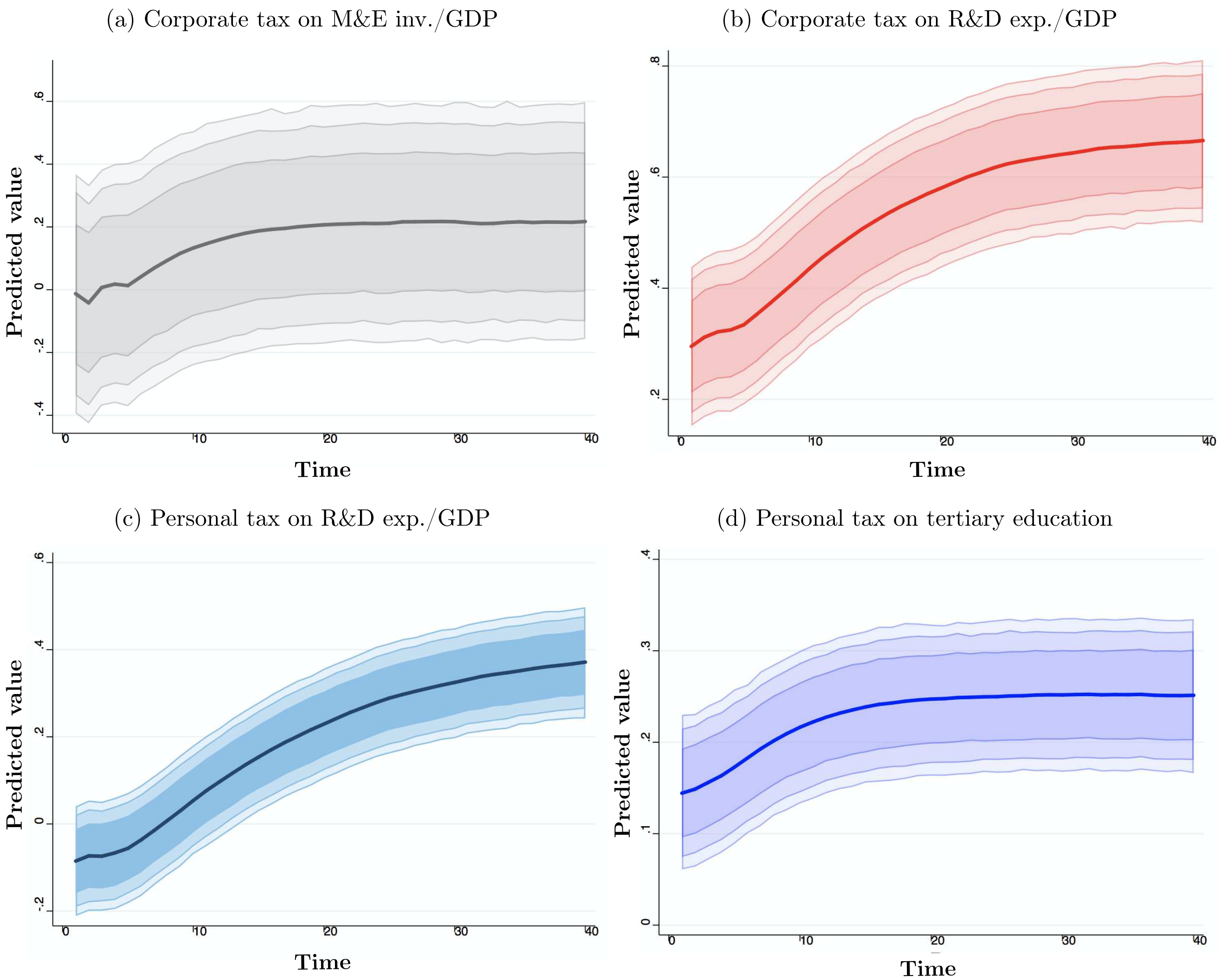
	(1)	(2)	(3)	(4)	(5)	(6)
Personal income tax	-0.309**			-0.323**	-0.158	-0.359**
	(0.143)			(0.158)	(0.165)	(0.176)
Public savings (deficit)/GDP		-0.0392			-0.129	
		(0.619)			(0.0964)	
Total tax revenues/GDP			0.205			0.186
			(0.153)			(0.166)
Minimum working age				0.0395	0.0286	0.0212
				(0.0605)	(0.0587)	(0.0622)
Population growth				-0.317	-0.494	-0.150
				(0.828)	(0.859)	(0.820)
Obs.	2,286	2,520	2,520	2,252	2,252	2,252
R-squared	0.998	0.998	0.998	0.998	0.998	0.998

Notes: Dependent variable: Tertiary Gross enrollment rate. Total tax revenues exclude personal income tax revenues. All estimates include country fixed effects and country-specific common correlated effects (CCEs). Standard errors in parentheses computed with the delta method. ***,**,* significant at 1, 5 and 10% respectively.

D Simulation results

In this section, we simulate the dynamic response of each investment type to a standardized shock to the relevant tax rate (see Figure D.1). To this end, 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). Based on Monte Carlo simulations with 10,000 replications, we draw the mean level of the response variable (solid line) and its interval confidence of 95% (light), 90% (medium) and 75% (dark) over a horizon of 40 periods, in Figure D.1.

Figure D.1 – Dynamic adjustment of investment to fiscal shocks (ARDL simulation)



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).

The figure shows that a one-standard deviation *decrease* in the rate of corporate income tax induces a long-run 0.20 point increase in the M&E investment rate; an equilibrium that is almost reached after 15 years (Fig. D.1-a). Note, however, that 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 the M&E investment rate 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 R&D investment rate in the long run; a substantially larger impact than that of M&E investment rate (Fig. D.1-b). Then, we simulate the timing of the adjustment to a standard deviation *increase* in personal income tax in order to illustrate how innovative investment reacts to a shock in personal income tax with respect to a comparable *decrease* in corporate tax (Fig. D.1-c). The figure shows that the pattern of adjustment of R&D intensity is similar to what emerges for a shock to corporate tax. However, in line with the values reported in column 2 of Table 5 of the main text, the impact size of the standardized shock to personal income on R&D is smaller than a shock to corporate tax. Overall, the adjustment of R&D to fiscal shocks is sensibly slower than that found for investment in tangible assets and education.

Finally, we illustrate the response pattern of student enrollment rates to a standardized shock on personal income tax (Fig. D.1-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. D.1-a. However, compared to investment in equipment, our simulation for the gross enrollment rate in tertiary education is more precise, as evidenced by the narrow confidence interval.