The joint impact of carbon pricing and corporate taxation on business investments: Evidence using forward-looking effective tax rates

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Abstract

This paper constitutes a first investigation of the joint effect of corporate income tax and carbon pricing provisions on business investments. Novelty lies in the introduction of the concept of carbon-inclusive effective marginal tax rates (EMTR_CI) - a tax variable that captures the effect of corporate income tax and carbon pricing provisions on the effective tax burden faced by investors. Using a fixed effects approach, firm-level panel data from fourteen OECD countries is regressed on the country-specific EMTR_CI. Baseline results show that on average, a 10 p.p. increase in the EMTR_CI decreases investment rates by 3.2 p.p. whereas the same increase in the EMTR – the tax variable excluding carbon pricing provisions - decreases investment rates by 1.9 p.p. This difference shows the effectiveness of carbon pricing at decreasing carbon-intensive investments and implies that excluding this element from such analyses results in a likely omitted variable bias. Heterogeneity analyses are also conducted and show that most profitable firms are least sensitive to tax changes. This finding differs from that of similar studies that assess heterogenous effects among MNE groups. The contrast could be explained by MNEs tendency to enjoy monopolistic positions but may also be evidence of tax planning behavior.

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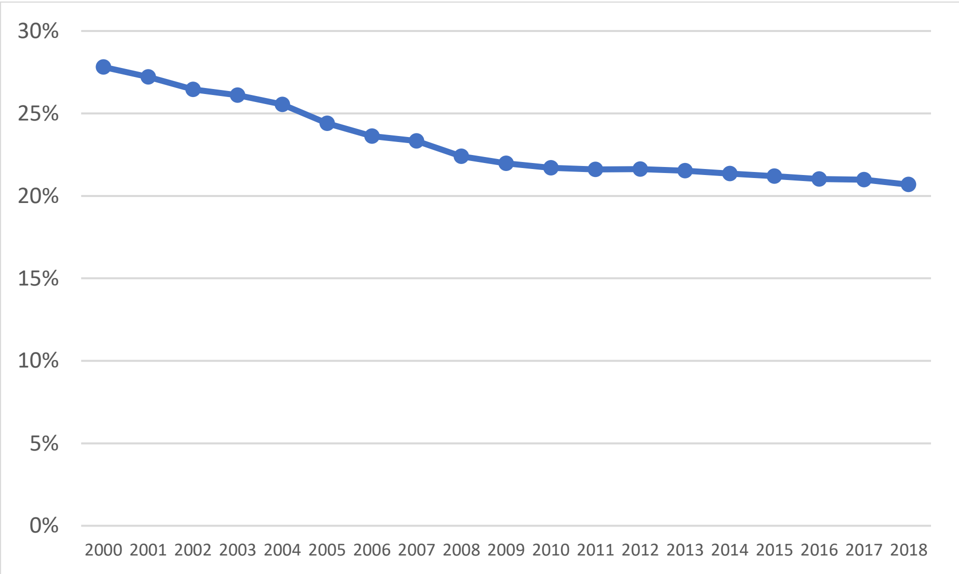
Introduction

There is a shared concern among policymakers that corporate income taxation (CIT) places a high burden on investors and thereby reduces competitiveness and investment rates. Whereas other factors than CIT statutory rates (STR) play an important role in the attractiveness to foreign investment, including among others market structures, demographic characteristics, political institutions, or macroeconomic stability, countries have generally reduced STRs in the last decades in an attempt to attract and encourage investment and promote local economic growth. Figure 1.1 shows that the global average STR decreased from 27.8% in 2000 to 20.7% in 2018, representing a fall of 7.1 percentage points (p.p.) over 18 years (OECD, 2022b).

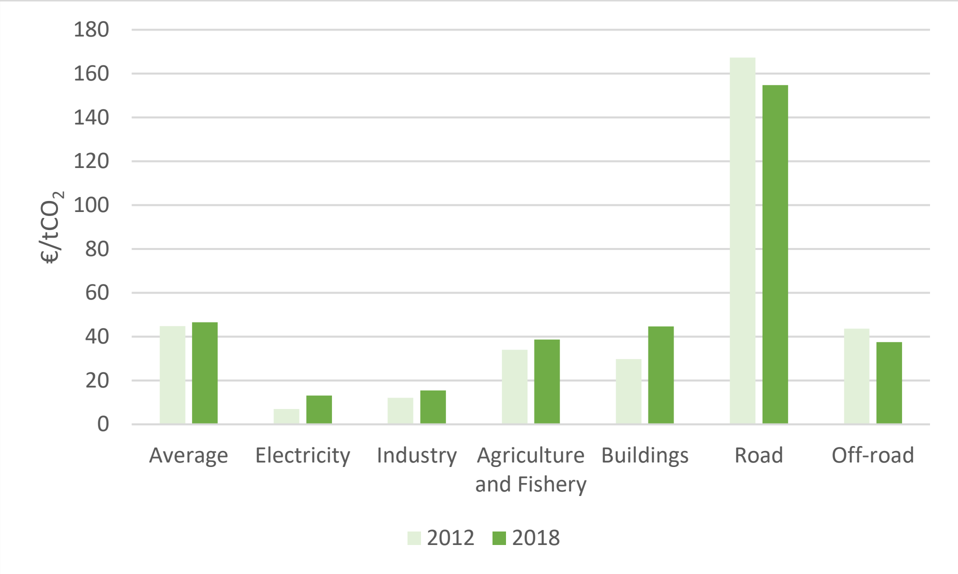
Figure 1.1. Evolution of statutory corporate income tax rates worldwide, 2000-2018



Source: Author's calculation using data from the Corporate Tax Statistics database (OECD 2022b).
Note: Statutory corporate income tax rates are unweighted averages calculated from a sample of 94 jurisdictions worldwide.

In parallel to this trend, recent decades have seen increasing scientific literature linking climate change to carbon dioxide emissions and to human activity. Concerned with the consequences from climate change, policymakers have increasingly implemented provisions that put a price on carbon emissions. The logic behind such policies is that by altering the relative price of economic activities, governments can leverage the price mechanism to drive a substitution effect away from polluting activities and towards a clean economy. Figure 1.2 depicts the evolution of effective carbon rates (ECR) in the years 2012-2018. ECR is a measure constructed by the OECD Secretariat (2022a) which captures the jurisdiction-specific price of carbon emissions through carbon taxes, specific taxes on energy use, and the price of emission trading schemes (ETS). Carbon pricing provisions are sector-specific for multiple reasons including the tendency of governments to provide allowances to sectors at risk of competitiveness loss as in the EU and Californian ETS (Ellis et al., 2019). For this reason, ECRs are measured separately across different economic sectors. Figure 1.2 shows that average ECRs have increased[1] from 44.7€ per ton of CO_2 emitted in 2012 to 46.6€ in 2018 and that this increase took place across most sectors for which data is available (all except transport sectors).

Figure 1.2. Evolution of effective carbon rates worldwide, 2012-2018



Source: Author's calculation using data from the Effective Carbon Rates database (OECD 2022a).
Note: Effective carbon rates are constructed using information from three types of carbon pricing provisions: (i) carbon taxes; (ii) specific taxes on energy use (typically excise taxes); and (iii) the price of tradable emission permits. The data presented are sector-specific unweighted averages from a sample of 44 jurisdictions worldwide. The 'average' sector is an unweighted average of the other six sectors available in the database.

Whereas decreasing STRs have the goal of encouraging investments, the increase in ECRs is aimed at reducing investments insofar as they are carbon intensive. This suggests that governments are currently implementing two sets of possibly opposing policies. The goal of this paper is to empirically estimate the joint impact of these two policy trends on business investment rates within countries.

The empirical investigation consists of multiple fixed effects regressions using firm-level panel data across the years 2013-2019. The dependent variable is the firm investment rate which is derived using data from the Orbis database from Bureau van Dijk. Firm investments are retrieved for a sample of 14 OECD countries during the years of coverage which yields a sample of 199,171 observed firms. The regressor used is the forward-looking effective marginal tax rate (EMTR). Effective tax rates are constructed tax estimators based on hypothetical investments with assumed rates of return and real country-specific corporate tax provisions. ETRs provide a more accurate measure of the impact of the CIT system on investments than STRs since they capture the impact of other CIT provisions such as

[1] The average increase is strongly undermined by a large fall in ECRs of the transport sectors. Excluding the transport sectors, ECRs increased on average from 20.8€ in 2012 to 28€ in 2018.

various capital allowances on the incentive to invest (Hanappi 2018). Novelty in this paper grounds in the extension of the ETR model to include carbon price provisions and in the use the resulting carbon-inclusive effective marginal tax rate (EMTR_CI) as a regressor.

The baseline specification consists of two empirical evaluations where firm-specific investment rates are regressed separately on the lagged EMTR_CI and the lagged EMTR (i.e., the tax variable excluding carbon pricing). This separation enables to assess how the inclusion of carbon pricing affects the results. The evaluation using the EMTR also enables to compare results with those from similar studies. A heterogeneity analysis is subsequently introduced where firms are categorised by profitability levels. This follows recent findings in the literature showing that tax sensitivity of investments varies by firm type (see e.g. De Mooij and Liu, 2020; Millot et al., 2020). Finally, as means of robustness checks, additional specifications are estimated where more control variables are added, and changes are made to the sample selection.

Results show that on average, a 10 p.p. increase in the carbon-inclusive effective marginal tax rate reduces the investment rate by 3.2 p.p. Using the baseline EMTR as a regressor shows that a 10 p.p. tax increase is associated with a 1.9 p.p. fall in investment rates. This estimate is of a similar order of magnitude as found in similar studies which strengthens the credibility of the assessment. The difference between the two estimates is in line with expectations in that carbon pricing is effective at reducing carbon-intensive investments. This suggests that similar studies that exclude carbon pricing likely suffer from an OVB where carbon pricing affects both taxation (more precisely, the cost of capital[2]) and investments. The heterogeneity analysis indicates that firm profitability matters in that the more profitable are firms, the more sensitive they are to taxation. This finding contrasts with that of Millot et al. (2020) who find that the most profitable MNEs are least sensitive to tax changes. While this difference might be due to commercial motivations from MNEs, this could also be evidence of tax planning behavior.

The assessment contributes to academic literature on the impact of corporate taxation on investment as it offers an empirical evaluation with a new sample of firms and set of effective tax rates. It also extends this literature by providing new evidence on the importance of firm heterogeneity in this matter. The study also contributes to the literature that seeks to understand how carbon pricing affects investment decisions. This research constitutes what is, to my knowledge based on a review of the literature, a first attempt to estimate the joint impact of such provisions on investments which contributes to both literatures. Of relevance to the policy sphere, the carbon-inclusive effective marginal tax rate provides a new policy analysis tool to understand how changes in carbon pricing

[2] This concept is elaborated in the theoretical setting.

and/or in the carbon intensity of investments affect the tax liability of firms. The remainder of the paper is structured as follows. Section 2 offers a review of related literature. Section 3 introduces the theoretical setting. Section 4 elaborates on the derivation of carbon-inclusive ETRs. The next section sets up the empirical framework and is followed by a section that describes the results. The final section discusses the findings as well as limitations of the analysis.

2. Literature review

This section provides an overview of the literature related to the topics covered in this study. It is divided into three parts, each of which corresponds to one central theme of the research. This includes (i) the tax sensitivity of business investments, (ii) carbon pricing and business investments, and (iii) effective tax rates. The section on effective tax rates (ETR) provides an overview of the main concepts in the ETR methodology and elaborates on why ETRs should be used in empirical assessments.

2.1. Tax sensitivity of business investments

The idea that CIT systems have an impact on business investments dates at least as far as Jorgensen and Hall's (1967) neo-classical investment theory which posits that taxation discourages investment through the increase in the user cost of capital. Since then, a wide literature has studied the nature and magnitude of the relationship between corporate taxation and investments. One branch of this research focuses on tax sensitivities of investments at the jurisdiction level using macroeconomic data. An important contribution from Feld and Heckemeyer (2011) offers a meta-analysis of studies exploring the link between foreign direct investment (FDI) flows and taxation. The authors perform literature sampling to obtain 704 estimates from 45 different studies. The estimate of interest is the tax semi-elasticity of FDI[3] which reflects how a percentage point increase in taxation affects a percentage change in FDI. The methodology involves the use of fixed and random effects meta-analysis to obtain pooled effects estimates[4]. Results show that the median tax semi-elasticities of FDI using fixed effects and random effects, are 1.07 and 2.14 (in absolute terms), respectively. Criticism of the use of macroeconomic data centres on the difficulty of identification since CIT reforms are rare and associated with other reforms in the tax code, and many other country-level parameters may affect economic activity (Millot et al., 2020).

Another branch of the literature focuses on data at the firm-level with the objective to understand more specific questions surrounding firm type and the tax sensitivity of investments. Such studies leverage large microdata sets which provide greater variability in investment rates than studies using

[3] The semi-elasticity is calculated as the derivative of the log of FDI with respect to the tax rate. When studies use different estimates, the authors calibrate their results to the definition of semi-elasticity.
[4] The authors also perform more complex meta-regression analyses. These are beyond the scope of the literature review.

macroeconomic data, thereby improving identification. Schwellnus and Arnold (2008) analyse the relation between firm-level total factor productivity growth (TFP) and corporate taxation. They use Amadeus Bureau van Dijk (BvD) firm-level data from OECD countries[5] for the years 1996-2004. Firm-level TFP is regressed on a tax variable that, similarly to effective tax rates, combines the STR and the user cost of capital. The empirical strategy is a difference-in-difference (DD) where identification grounds on differences in TFP levels between firms from same sectors but from countries with different levels of corporate taxes. The authors find significant negative effects of CIT on productivity and investment and that firm size and age drive heterogeneity in responses to taxation. The results are robust to multiple changes in the sample and specification which strengthens the credibility of the results.

In this vein, De Mooij and Liu (2020) use multinational enterprise (MNE) data from Orbis BvD from 27 countries in the years 2006-2014 to assess the sensitivity of MNE investments to transfer pricing regulations (TPRs)[6]. The empirical strategy is a DD where the common trend assumption is validated by a statistical test that confirms there is no difference in pre-TPR effects which strengthens the credibility of identification. Results show that the introduction of TPRs hampers investment (the DD estimate is -0.049 and significant at the 1% level). The authors also find that MNEs with more profitability and cash flows (capturing firm liquidity) tend to invest more in capital assets.

In recent years, the OECD secretariat published several papers that assess the corporate tax sensitivity of MNE investments. Sorbe and Johansson (2017) use Orbis data from BvD for MNE investments from 19 OECD countries in the years 2000-2010. They use the country-level effective marginal tax rate (EMTR)[7] as a regressor and a fixed effects empirical strategy. They find that a 10 p.p. increase in the EMTR is associated with a 1.0 p.p. fall in MNE investments and that investments from MNEs that benefit from the possibility to shift profits are less sensitive to changes in the EMTR. Millot et al. (2020) also use Orbis data, EMTRs, and a fixed effects approach to estimate the tax sensitivity of investments from MNEs. Their approach differs in that the MNE coverage shrinks to 17 OECD countries but extends to the years to 2007-2016 (which yields a sample size of 162,990 MNEs - more than three times larger than that of Sorbe and Johansson, 2017). Novelty is also introduced through a heterogeneity analysis by profitability levels of MNEs. They find that a 10 p.p. increase in the EMTR reduces MNE investments by 1.3 p.p. They also find an inverted U-shaped relationship between MNE profitability and tax

[5] East European countries are excluded because they were transitioning away from the Soviet Union at the time.
[6] TPRs are introduced by countries to limit tax planning strategies from MNEs that use transfer mispricing to shift profits from high to low tax jurisdictions. Transfer mispricing consists of charging intra-group transactions at prices different from those found in the market to shift profits and losses, as suits them according to different tax rates between countries. TPRs consist of many rules such as the requirement for MNEs to provide documentation linked with transfer pricing and the implementation of transfer pricing penalties in cases of mispricing (de Mooij and Liu, 2020).
[7] This concept is introduced in the subsection below on effective tax rates.

sensitivity where least and most profitable firms are least sensitive to changes in corporate taxes. Whyman and Hanappi (forthcoming) use an almost identical empirical approach and sample as Millot et al. (2020) but augment the evaluation with (i) a comparison between MNEs and non-MNEs and (ii) the analysis of cross-border investment effects within MNE groups, given tax changes in host jurisdictions. They find that a 10 p.p. increase in the EMTR reduces investments in non-MNEs by 1.4 p.p. and in MNEs by 0.9 p.p. They also find that tax changes in the host country of an MNE generates cross-border investments in other countries where the MNE group has subsidiaries.

2.2. Carbon pricing and business investments

The effect of carbon pricing provisions on business investments has been studied to a lesser extent though recent years have seen a growing number of studies in this domain. Ohlendorf et al. (2022) provide empirical evidence of how hypothetical price floors in the EU Emissions Trading Scheme (ETS) would affect investments in energy firms. The study uses ex ante information from survey responses about potential investment choices by 113 high-level managers from German firms in industry and energy sectors. Dependent variables are levels of hypothetical investments and independent variables are different price floor scenarios. The methodology consists of a maximum likelihood strategy where the impact assessment is derived by the probability change in potential investments given changes in the independent variable. Findings suggest that whereas low price floors leave investments unaffected, high price floors increase investment by green firms and reduces investment in fossil energy firms. However, the ex-ante aspect and small sample size of the study suggest a rather weak empirical strategy.

Compernolle et al. (2022) explore the differences between carbon taxes and emission trading schemes (ETS) in their impact on investment decisions. The hypothesis they test is whether differences in price (un)certainty between the two systems impact investment. To do so they build a real options theoretical model where investment costs are either constant (carbon taxes) or volatile (ETS). They run simulations and find that carbon price (un)certainty has a significant impact on investment decisions. Results show that price (un)certainty matters in that uncertainty pushes firms to invest whereas certainty discourages investment. As such, a carbon tax is better suited as discouraging carbon-intensive investment while an ETS is better suited to encourage green investments. Note that these results remain purely theoretical - an empirical assessment would be more convincing.

Ellis et al. (2019) review ex-post empirical assessments on the impact of carbon pricing – through carbon taxes and ETS - on various economic indicators in OECD and G20 countries in the electricity and industrial sectors. The methodology used is a review of previous studies. They find almost no statistically significant relation between carbon pricing and FDI, productivity, and competitiveness.

When statistically significant results are found, they are of small magnitude and may be both positive and negative. The authors highlight that the low levels of carbon pricing might explain these results.

2.3. Effective tax rates

The concept of effective marginal tax rates (EMTR) was introduced by King and Fullerton (1983) and further elaborated by the OECD (1991). Devereux and Griffith (1999, 2003) extended the effective tax rate (ETR) framework to the analysis of infra-marginal investments (profitable investments) through the introduction of effective average tax rates (EATR). Forward-looking ETRs are a credible tax variable to estimate tax sensitivity of investments because unlike backward-looking ETRs – which rely on historical financial accounts and are calculated by taking the ratio of actual tax payments relative to profits earned, they inform on how corporate tax systems affect the current incentive to invest (OECD, 2022b). Furthermore, forward-looking ETRs are calculated using statutory rates as well as other corporate tax provisions such as fiscal depreciation and enhanced allowances. This enables researchers and policymakers to compare the effective tax burden faced by corporations across jurisdictions in a more satisfactory way than a naive comparison of statutory rates - which are misleading because definitions of tax bases and other provisions vary considerably across countries, which in turn might affect effective tax burdens on investors (Hanappi 2018). These two elements are important to policymakers and explain why forward-looking ETRs are consistently calculated by several institutions, including the United States Congressional Budget Office (Congressional Budget Office, 2017), the Centre for European Economic Research – commissioned by the European Commission (Zentrum fuer Europaeische Wirtschaftsforschung (ZEW), 2019) the Oxford University Centre for Business Taxation (CBT, 2017), and the OECD (2022b), among others.

ETRs are synthetic policy instruments since they do not rely on actual tax payments and are forward-looking in the sense that they are derived from prospective investments. They are calculated based on assumptions on macroeconomic parameters and financial returns from hypothetical investments as well as real jurisdiction-specific tax codes, including statutory CIT rates, depreciation schedules, and other tax allowance provisions (Hanappi 2018). Two separate ETRs enable to evaluate two key sources of CIT distortions on business decisions. The EMTR informs on how taxation affects marginal investments. The main channel through which this occurs is the tax-induced increase in the user cost of capital (i.e., the rate of return from the investment required to break-even after tax). The EMTR is used to analyse the impact of CIT on the incentive to expand existing (continuous) investments in a given location, i.e., along the intensive margin. The EATR indicates how taxation affects infra-marginal investments. The core channel here is the tax-induced reduction in the post-tax economic profit earned from investing. EATRs are used to measure the tax effect on investment decisions between two or more profitable projects, i.e., along the extensive margin.

3. Theoretical setting

This section introduces key equations of the ETR model following the literature that developed the model (Devereux and Griffith 1999, 2003; Hanappi, 2018; González Cabral et al., 2021; Celani et al., 2022). Subsequently, the section elaborates on the model extension introduced in this study through the concept of carbon-inclusive EMTRs. The section effectively describes how effective tax rates affect the incentive to invest. As such, it lays the theoretical ground that underlies the empirical assessment.

3.1. Taxation and business investments in the ETR framework

Corporate income taxation (CIT) may affect several business decisions including the decision to incorporate, the source of financing, how much to invest in a given location (intensive margin), or which project to invest in (extensive margin), among others (Kayis-Kumar et al., 2022). With the ETR framework, it is possible to analyse how taxation may affect the two latter decisions differently as the model derives two separate policy tools specific to each margin. The effective marginal tax rate (EMTR) relates to the intensive margin and the effective average tax rate (EATR) to the extensive margin. In this paper, the focus lies in the impact of taxation on continuous investment decisions, i.e., along the intensive margin. Note that the equations below rest on the one-period investment case (OPC) scenario[8] of the ETR model. This scenario assumes that investments only last for one period and that the capital invested in period 0 is sold in period 1. In the model, firms generate revenues in each period, which are based on the rate of return from capital and the economic capital stock. Equation 1 defines the economic capital stock in period t (K_t) as the sum of the capital stock in the previous period (K_{t-1}) net of economic depreciation (δ) and the capital investment in period t (I_t).

$$K_t = K_{t-1} * (1 - \delta) + I_t \tag{1}$$

Equation 2 introduces the net revenue (Q_t) in period t which is defined by assumption net of variable costs. The revenue is derived as the product of the rate of return from capital (p) and the capital stock in the previous period, gross of depreciation, and indexed for inflation[9] (π).

$$Q_t = (p + \delta) * K_{t-1} * (1 + \pi)^t \tag{2}$$

Equation 3 shows that in the absence of taxation, economic rents in period t (R_t^*) are calculated as the revenues generated net of variable costs and investment costs (I_t).

$$R_t^* = Q_t - I_t \tag{3}$$

[8] The other available scenario in the ETR model is the permanent investment case (PIC). In the PIC scenario, investments occur in period 0 and the capital invested in never sold but instead depreciates over time beyond period 1 until the end of its useful life. Annex A offers further elaboration of the differences between PIC and OPC.

[9] Inflation is a proxy for sales price.

Taxation is introduced with two distinct parameters, the statutory corporate income tax rate in period t (τ_t) and the sum of capital allowances in period t (Z_t). Equation 4 defines the net present value of capital allowances ($\boldsymbol{A}$) as the product of τ_t and Z_t, summated for each period and discounted using the nominal interest rate (i). Whereas taxation introduces a tax burden on firms through the parameter τ_t, CIT systems also provide capital allowances that relief the burden from taxation for firms. Capital allowances enable firms to fully deduct investment costs over the lifetime of assets that form the capital stock. Fiscal depreciation schedules orchestrate capital allowance deductions such that they follow the tax (or useful) life of capital assets.

$$\boldsymbol{A} = \sum_s^{\infty}(\tau_{t+s} * Z_{t+s}) \,/\, (1+i)^s \quad (4)$$

In the presence of taxation (equation 5), economic rents in period t (R_t) are defined as the total revenues net of variable costs, net of the tax liability – defined as the product of τ_t and revenues net of capital allowances, and net of investments per period. Equation 5 can be adjusted when combined with equation 4 to obtain a new expression of the product $\tau_t * (Q_t - Z_t) = (\tau_t * Q_t) - A_t$. This yields an alternative definition for economic rents where R_t equals total revenues net of variable costs, net of taxes due ($\tau_t * Q_t$) and net of ($I_t - A_t$). The last expression is defined in the ETR model as the effective cost of investments in the presence of capital allowances. It equals $1 - A$ when assuming that the value of investment is one and is central to the model extension that follows.

$$R_t = Q_t - \tau_t * (Q_t - Z_t) - I_t = Q_t - \tau_t * Q_t - (I_t - A_t) \quad (5)$$

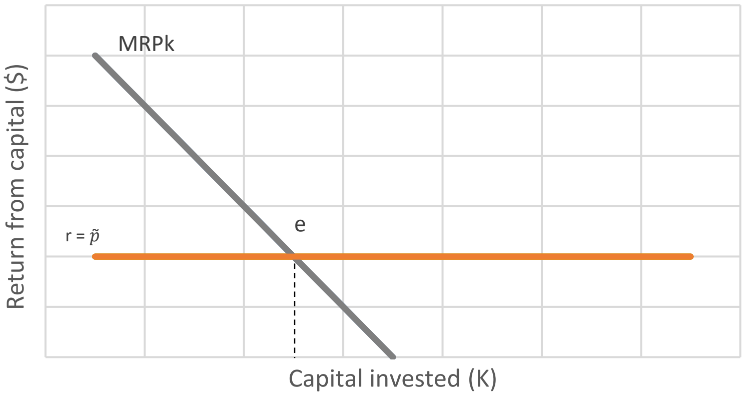
Equation 6 derives the cost of capital which is defined as the required rate of return for firms to break-even after-tax. It is calculated by setting R_t to zero and solving for p (see Annex A). Note that in the absence of taxation, $\boldsymbol{A}$ and τ equal zero and the cost of capital equals the real interest rate.

$$\tilde{p} = [(1 - \boldsymbol{A}) * (r + \delta)]/(1 - \tau) - \delta \quad (6)$$

3.2. A marginal investment

The theoretical setting elaborated in section 3.2 assumes a first-best scenario where there is perfect competition, no externalities, no asymmetries, and price-taking firms. When analysing marginal investment behaviour at the intensive margin, standard economic theory predicts that profit-maximizing firms make capital investments until the marginal return of the investment project equals its marginal cost. The cost of funds captures the cost from investing. It equals the interest rate paid on loans when projects are financed by debt or the opportunity cost if the funds were used to invest in the next best alternative in the case of equity financing. Figure 3.1 depicts investment behaviour at the intensive margin in the absence of taxation. The marginal revenue product (MRP_K) curve captures the rate of return associated with the level of capital a firm is willing to invest in. The MRP_K curve is diminishing as capital invested increases, which follows the conventional diminishing returns assumption. Assuming that the cost of funds in both financing sources equals the real interest rate, firms invest in capital until the MRP_K curve meets r at point e. In line with equation 6, in the absence of taxation, the required rate of return to break even equals r. As such, the cost of capital equals the real interest rate (Creedy and Gemmel 2017; González Cabral et al. 2021).

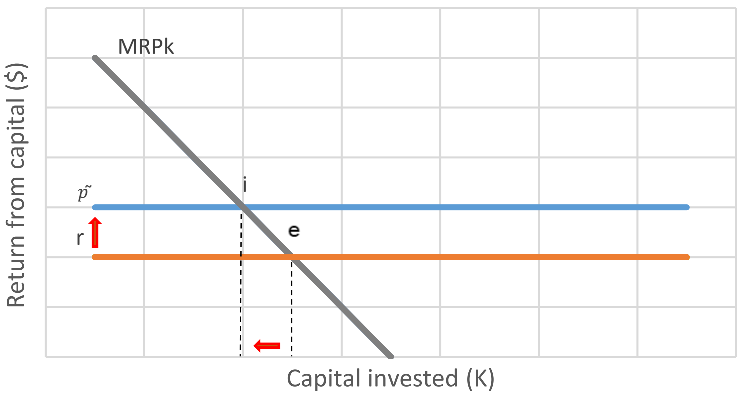
Figure 3.1. Investment behaviour in the absence of taxation



Source: Author's work following González Cabral et al. (2021).

Taxation implies a tax liability on investors which adds an additional cost in the derivation of economic rents (see the difference between equations 3 and 5). When considering marginal investments, this additional burden is captured by an increase in the cost of capital (as seen from equation 6 when $\boldsymbol{A}$ and τ take nonzero values).

Figure 3.2. Investment behaviour in the presence of taxation



Source: Author's work following Gonzalez Cabral et al. (2021).

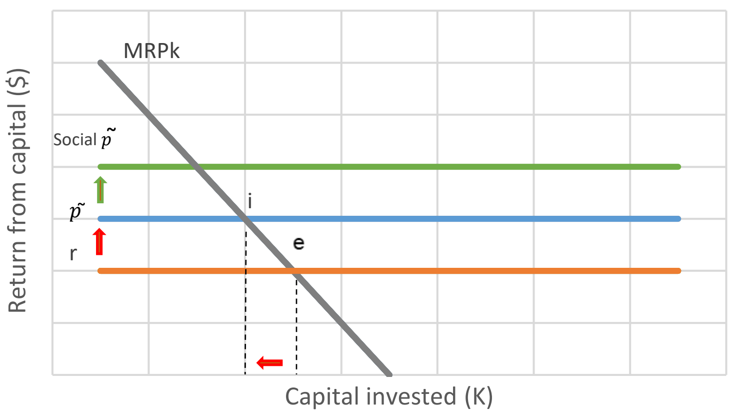
Figure 3.2 shows that in the presence of taxation, the cost of capital increases above the real interest rate (vertical red arrow). In this theoretical setting, this implies that marginal costs and benefits from investing are equal at point i. The corresponding level of capital invested falls relative to the scenario in Figure 3.1 (horizontal red arrow) which captures that taxation reduces the investment level from the first-best scenario. This distortion generates a deadweight loss from business taxation at the intensive margin. The EMTR is defined as the difference between the cost of capital in the presence of taxation and the real interest rate (i.e., the cost of capital in the absence of taxation), as a ratio of the cost of capital in the presence of taxation. It captures the relative increase in the cost of capital from taxation.

$$EMTR = \frac{\tilde{p}-r}{\tilde{p}} \tag{7}$$

3.3. Environmental externalities and marginal investments

To analyse how carbon pricing affects investment decisions in the ETR framework, the first-best theoretical setting from section 3.2 is extended with the introduction of a negative externality from investments. From a Pigouvian perspective (1920), carbon-intensive investments (dirty investments) generate a cost to society that is larger than the private cost incurred by the investing firm. The carbon-induced externality drives a wedge between the private and social cost of investments which is translated in firms investing in capital at levels beyond the social optimum. The wedge between private and social costs is introduced in Figure 3.3 where the social cost of capital increases above the private cost of capital (green vertical arrow).

Figure 3.3. Investment behaviour in the presence of environmental externalities



Source: Author's work.

The presence of externalities in the market provides a setting for efficient government intervention. Mindful of the wedge between social and private costs, governments may set a price on carbon emissions to increase the private costs of dirty investments and equalise them to their social cost. As seen in equation 5, the effective cost of a unit investment is reduced by capital allowances from CIT systems (González Cabral et al., 2021). As such, in the absence of carbon pricing, the effective cost of a unit investment in the presence of capital allowances equals $1 - A$.

Carbon pricing provisions are introduced through an increase in the effective cost of investments. Equation 8 shows that carbon pricing increases the cost of a unit investment by the value of the effective carbon paid per unit invested. The effective carbon paid is the product of the effective carbon rate of a given investment (ECR) in euros per tCO_2 and the carbon intensity of that investment (C) in tCO_2 per euro. To align the model extension with the OPC scenario of the ETR methodology, the carbon intensity captures only emissions from the use of the asset as input for production in one period – i.e., the emissions linked with raw material extraction, creation, and end of life (i.e., waste management) of the asset are not accounted for. Note that the two components in the effective carbon paid measure have opposite units (tCO_2/€ and €/tCO_2). This implies that the effective carbon paid measures the total additional cost per unit invested due to carbon pricing provisions. The effective carbon paid thereby aligns with the scale of investments considered in the ETR model (where investments are also assumed to have a value of one unit).

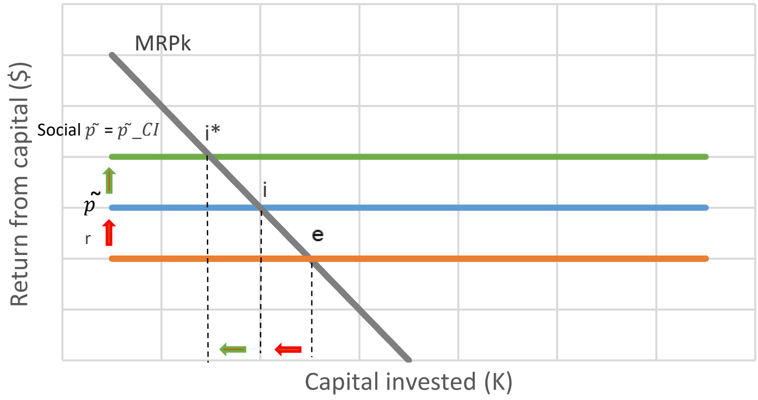
$$Effective\ cost\ of\ a\ unit\ investment = 1 - A + (ECR * C) \tag{8}$$

To facilitate the modelling of the carbon-inclusive ETRs, equation 9 defines A^* as the value of capital allowances net of the effective carbon paid per unit of investment. A^* is substituted in equation 8 to obtain a new expression of the effective cost of a unit of investment in the presence of carbon pricing ($1 - A^*$). Insofar as the effective carbon paid is positive, the conditions $A^* < A$ and $1 - A < 1 - A^*$ always hold. As such, in the presence of carbon pricing provisions and carbon-emitting investments, governments increase the effective cost of investments and the cost of capital – as seen in equation 10 where the carbon-inclusive cost of capital ($\tilde{p}\_CI$) is obtained using $\boldsymbol{A}^*$ instead of $\boldsymbol{A}$.

$$A^* = A - (ECR * C) \tag{9}$$

$$\tilde{p}\_CI = [(1 - \boldsymbol{A}^*) * (r + \delta)/(1 - \tau)] - \delta \tag{10}$$

Figure 3.4. Investment behaviour in the presence of taxation and carbon pricing



Source: Author's work.

Figure 3.4 shows that in the presence of carbon pricing provisions, governments lift the private cost of capital up to the value of the social cost of capital (green vertical arrow). As a result, firms internalise the cost of carbon and adjust investment levels from *i* to *i** (green horizontal arrow). In equation 11, the carbon-inclusive EMTR ($EMTR\_CI$) is obtained using the same formula as in equation 7 but with using $\tilde{p}\_CI$ instead of $\tilde{p}$.

$$EMTR\_CI = \frac{\tilde{p}\_CI - r}{\tilde{p}\_CI} \quad (11)$$

It is important to note that in this theoretical setting, technological progress is kept fixed. Governments set a price on carbon not only to reduce the magnitude of dirty investments but also to affect the relative prices of green technologies. In the presence of carbon pricing provisions, the lower is the carbon-intensity of an investment, the lower is its effective cost. As such, governments induce a substitution effect away from dirty technologies towards green technologies. The inclusion of technological progress in the model would mean that if firms reduce the carbon intensity of their investments until investments no longer emit carbon, the social cost of capital as well as the carbon-inclusive cost of capital will fall until they are equal to the private cost of capital in the absence of carbon pricing. This would yield the scenario depicted in Figure 3.2 where environmental externalities no longer exist. Finally, the contrast between the efficiency loss from business taxation captured in Figure 3.2 and the efficiency gain from carbon pricing captured in Figure 3.4 reflects the complexity of the role played by governments in affecting investment behaviour and may provide an explanation for the contrasting trends in STRs and carbon prices elaborated in the introduction.

4. The derivation of forward-looking effective tax rates

4.1. Baseline calculation of forward-looking ETRs

The calculation of ETRs follows a bottom-up approach. First, ETRs are calculated for different types of investments. Heterogeneity is introduced through diversity in asset types as well as in financing methods. Asset heterogeneity captures the idea that investment projects in different assets are treated differently in corporate tax systems, e.g., through asset-specific depreciation schedules. As in Hanappi (2018), assets are separated into eight groups which are subsequently combined into four categories (further elaboration of the type of assets within the different asset groups is discussed in Annex B):

- The Tangible assets category which includes Industrial machinery, Equipment, Road transport vehicles, Air, rail, and water transport vehicles, and Computer hardware asset groups
- The Intangible assets category which includes the Acquired software asset group
- The Inventories category which includes the Inventories asset group
- The Buildings category which includes the Non-residential structures asset group

Equity and debt are the two sources of financing considered[10]. This separation captures the idea that corporate tax systems provide specific allowances to each source of finance, e.g., through interest deductions and allowances for corporate equity. In total, 32 disaggregated ETRs are calculated, 16 for the EMTR and 16 for the EATR. Second, the aggregated ETRs are built based on the eight asset types and two sources of financing. The five tangible asset ETRs are averaged to form the tangible asset group and in a second stage, the aggregated ETR is calculated as the unweighted average of the four assets groups. This step is calculated separately for both sources of finance. In the third and final step, the aggregated EMTR and EATR are based on the weighted average of the two sources of finance (65% equity and 35% debt).

4.2. Main assumptions and provisions covered

4.2.1. Assumptions

As outlined above, the derivation of ETRs relies on jurisdiction-specific tax legislation that determines CIT rates and bases as well as several assumptions. The traditional ETR methodology makes assumptions on (i) returns to investments, (ii) economic depreciation, (iii) macroeconomic parameters, and (iv) the financing weights. Concerning returns from investments, they are assumed

[10] Retained earnings are considered as an equivalent source of finance as equity insofar as the interaction with the personal income tax is not considered, as is the case in this introductory setting (Hanappi 2018).

to be 20% throughout all calculations, which follows other ETR derivations (see e.g., Hanappi, 2018; OECD 2022b). Economic depreciation rates are assumed at the asset level. Following OECD (2022b), the economic depreciation rates are based on estimates from the literature (see e.g., Bureau of Economic Analysis (BEA) 2003), presented in Table 4.1.

Table 4.1. Economic depreciation by asset category

Asset	**Economic depreciation (δ)**
Non-residential Structures (Buildings)	0.0329
Air, Rail or Water Transport Vehicles (Tangible Asset)	0.0661
Computer Hardware (Tangible Asset)	0.3699
Equipment (Tangible Asset)	0.1546
Industrial Machinery (Tangible Asset)	0.1259
Road Transport Vehicles (Tangible Asset)	0.2014
Acquired Software (Intangible Asset)	0.4033
Inventories	n/a

Source: Economic depreciation rates are derived from BEA (2003).

The model assumes fixed macroeconomic parameters for all jurisdictions. This enables to exclude the influence of macroeconomic parameters in comparative analyses of the ETRs. As such, differences in ETRs between jurisdictions are fully driven by tax codes – which in turn informs on the role CIT systems play with respect to international tax competitiveness. In line with OECD (2022b), inflation is fixed at 1% and the real interest rate at 3%. Using the Fisher equation, the corresponding nominal interest rate is 4.03%. As discussed in Section 4.1., in the final aggregation of the ETRs, the model assumes a 65%-35% weight to equity and debt finance, respectively.

4.2.2. Provisions

The ETR methodology enables to capture the effect of a range of provisions on the effective tax burden faced by corporations. The main provisions that affect corporate tax bases are outlined in what follows. For the years 2017-2018, data on baseline CIT provisions is derived from the Corporate Tax Statistics database (OECD 2022b). For the years 2012-2016, data was collected from desk research from the author using ZEW (2019) and the EY Worldwide Corporate Tax Guide 2022.

Fiscal depreciation

Fiscal depreciation is a key component in determining the tax base of firms. If fiscal depreciation is more rapid than economic depreciation, then the fiscal capital stock shrinks faster than the economic capital stock over time. By narrowing the tax base, this reduces the tax liability of firms and drives down the ETRs. Fiscal depreciation is affected by fiscal depreciation rates, recovery methods, and first- and second-year allowances. Fiscal depreciation rates indicate what share of the capital stock is lost at the end of each year. Depreciation rates typically vary per asset group in each jurisdiction, as tax codes aim to imitate economic depreciation. Several recovery methods exist, each of which affect how the depreciation of capital assets evolves over time. The most basic recovery method is straight line where the depreciation of the asset is assumed to be linear. For instance, for an asset of an assumed useful life of five years, the straight line method would ascribe a 20% depreciation rate per year of the life of the asset, reaching a value of zero at the end of the five years. Other recovery methods include declining balance[11] and expensing[12], among others.

Interest deductibility

When investments are financed by debt, most CIT systems allow firms to deduct interest payments from the corporate tax base. This important provision is included in the model, however, interest limitation rules – which limit the amount deductible – are not included. In practice interest limitations rules matter a great deal to firms' investment decisions. However, the model fixes debt financing to 35% of the hypothetical investment (by assumption), therefore the amount of debt financing permitted by tax codes becomes less relevant.

Allowance for corporate equity

Interest deductibility distorts financing decisions as it encourages debt-financing. Some jurisdictions allow firms to deduct investment payments when they are financed by equity to avoid this bias. Allowances for corporate equity usually work in tandem with notional interest rates. The deduction is based on the notional interest deduction which typically follows the interest rate of each jurisdiction. Allowances for corporate equity lower the ETRs insofar as the notional interest rate is positive.

Inventory valuation methods

The ETR for inventories is calculated separately from that of other asset groups because typical capital allowances captured by the NPV of capital allowances (parameter ***A*** in equation 4) do not apply to the fiscal depreciation of inventories. Instead, fiscal depreciation of inventories is determined by the inventory valuation method. The model differentiates between three methods including "first-in-first-out (FIFO)", "last-in-first-out (LIFO)" and "valuation at average between LIFO and FIFO". The methods differ in how sensitive they are to the impact of inflation on the valuation of inventories[13].

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[11] The declining balance method works as follows. For a depreciation rate of 20% per year, in the first year, the asset loses 20% of its total value for fiscal purposes. In the second year, the asset loses 20% of the total remaining value of the asset (i.e., 20% of the remaining 80%, so 16% of the initial asset value). This implies that assets lose more value in the early years of their useful life and less value per annum in later years.

[12] Expensing implies that the full value of an asset is deductible for tax purposes in the year it was purchased.

[13] FIFO implies that items are sold at the purchase value of the oldest remaining identical item in the inventory. FIFO implies that items are sold at the purchase value of the most recently purchased identical item in the inventory. In times of inflation, FIFO enables firms to further reduce their tax base as compared to LIFO since the purchase value likely increased between of the oldest and most recent acquisitions of identical items.

4.3. The carbon pricing model extension

Equations 8 and 9 from Section 2.3 show that the carbon pricing extension to the ETR model grounds on the effective carbon rate and the carbon intensity applicable to each asset group of the ETR framework. The effective carbon rate (ECR) constitutes an additional provision in the model. ECRs are calculated by the OECD Secretariat and reported in the *Effective Carbon Rates* database which currently includes ECRs for the years 2012-2018 for 41 jurisdictions (OECD, 2022a). ECRs measure the sector-, country-, and year-specific total price in euros of a ton of carbon emitted resulting from market-based policy instruments, including three components: (i) carbon taxes; (ii) specific taxes on energy use (typically excise taxes); and (iii) the price of tradable emission permits (OECD, 2016). The ECRs are calculated separately for six sectors and 30 individual users according to differences in emissions linked with the energy use respective to each sector (OECD, 2016). The disaggregated aspect of ECRs is leveraged to attempt to mirror the disaggregation at the asset level of the ETR methodology, as shown in the first two columns in Table 4.2. To align with the assumption that only carbon emissions from the use of an asset as capital input in production processes are included in the model (Section 3.3.), the coupling between ECR sectors and ETR assets is based on common types of energy use when the asset is used as capital input. This implies that computer hardware, equipment, industrial machinery, and acquired software are matched with the electricity sector which follows the idea that when used as capital input for production, these asset groups emit carbon only through electricity use. Where possible, assets in the ETR model are coupled with users rather than sectors of the ECR methodology which offers a more precise matching. This is the case for the sector buildings which is subdivided into commercial, residential, and other buildings. The non-residential structures asset group is thereby matched with the commercial buildings (sub)sector.

The last column in Table 4.2 is the carbon intensity in ton of CO_2 per euro invested for assets corresponding to each sector. It is calculated as the average of the ratio of total energy use in ton of CO_2 per sector, year, and jurisdiction relative to the total value of capital stocks in euros matched to the same sector, year, and jurisdiction (for each jurisdiction and year for which data is available in both measures). The energy use is an indicator capturing the emissions by sector in kiloton (kt) of CO_2 equivalents, derived from the Effective Carbon Rates (ECR) database (OECD, 2022a). Values of capital stocks are approximated using the Net Capital Stocks in current replacement values (CAPN) indicator, retrieved from the OECD Structural Analysis (STAN) database (OECD, 2020). The matching of sectors between ECR and STAN databases can be seen in columns two and three of Table 4.2. To ensure an appropriate matching in the sectors between the two databases, the following transformations are applied:

- The capital stock values of construction are multiplied by 0.33 which captures that the energy use in construction of buildings used for commercial purposes accounts for about 33% of total energy use in construction (OECD, 2022a)
- The energy use in the Off-road vehicles sector is calculated as the sum of energy use in the users Navigation, Air, Rail, and Other to match with the sector in STAN "Other transport equipment" which captures the stock value of all non-road transport assets (OECD, 2020).

Table 4.2. Carbon intensity by asset and sector

Asset group (ETR)	**Sector (ECR)**	**Sector (STAN)**	**Average energy use (kt of CO_2)**	**Average CAPN (€, millions)**	**Carbon intensity (tCO_2/€)**
Non-residential structures	Commercial buildings	Construction	16774	14162.36	0.001093
Road transport vehicles	Road vehicles	Motor vehicles, trailers, and semi-trailers	86077	95337	0.001402
Air, rail, and water transport vehicles	Off-road vehicles	Other transport equipment	2917	8585	0.000432
Equipment	Electricity	Electricity, gas, steam, and air conditioning supply	71886	110947	0.000557
Industrial Machinery	Electricity	Electricity, gas, steam, and air conditioning supply	71886	110947	0.000557
Computer hardware	Electricity	Electricity, gas, steam, and air conditioning supply	71886	110947	0.000557
Acquired software	Electricity	Electricity, gas, steam, and air conditioning supply	71886	110947	0.000557

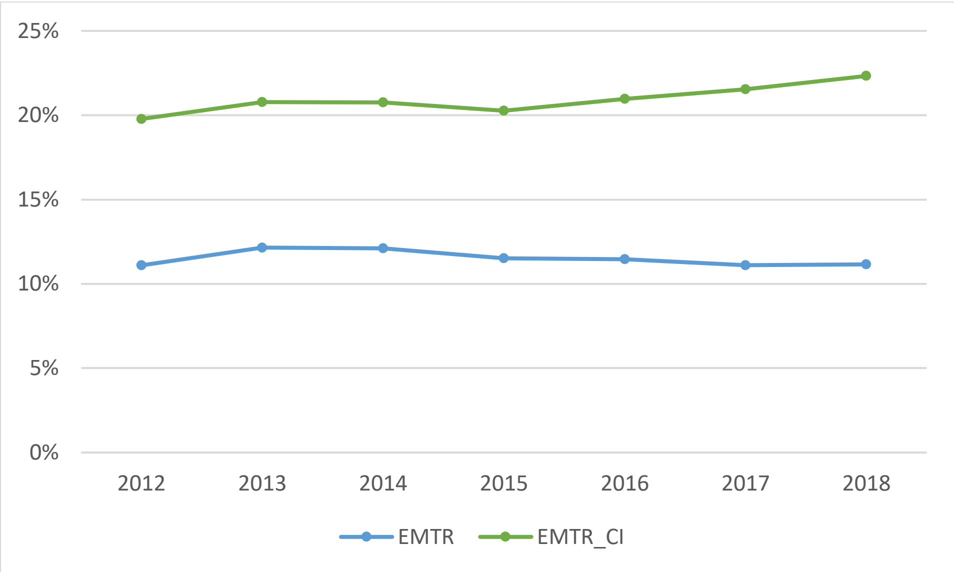
Source: Carbon intensity values per asset are derived using data from the Effective Carbon Rates (ECR) (OECD 2022a) and Structural Analysis (STAN) (OECD 2020) databases. Asset groups are listed as in the Corporate Tax Statistics database (OECD 2022b).

Note: Due to data availability limitations in STAN and ECR databases, the data collection used to calculate carbon intensities is restricted to the following countries: Austria, Belgium, France, Germany, Italy, and the Netherlands. Note also that the sector electricity, gas, steam, and air conditioning supply is more exhaustive than the desired sector which would have ideally been restricted to electricity only. This results in a likely upward bias in the Net Capital Stocks in current replacement values (CAPN) of that sector and a downward bias in the resulting carbon intensities. Note finally that the calculation of carbon intensities is done at sector-, jurisdiction-, and year-level and not at the average level, implying that taking the ratio of average values in columns IV and V does not yield the exact same result found in column VI.

4.4. Calculating carbon inclusive effective marginal tax rates

The calculation of carbon-inclusive ETRs can be conducted for both EMTRs and EATRs. However, in line with the focus on the EMTR in the theoretical and empirical sections, this section considers only the carbon-inclusive EMTR (EMTR_CI). As elaborated in the theoretical setting, the model extension of the ETR framework grounds on ECR as well as carbon intensity data. During the years of coverage (2012-2018), the ECR data is available only for the years 2012, 2015, and 2018. To enable panel data estimation over seven years, the ECR data is assumed to evolve linearly in the years for which no data is available. This explains the linear evolution of the EMTR and EMTR_CI between 2012 and 2015 and between 2015 and 2018 seen in Figure 4.1. The Figure shows the evolution of average EMTRs and EMTR_CIs over the years of coverage.

Figure 4.1. Evolution of the average EMTR and EMTR_CI, 2012-2018

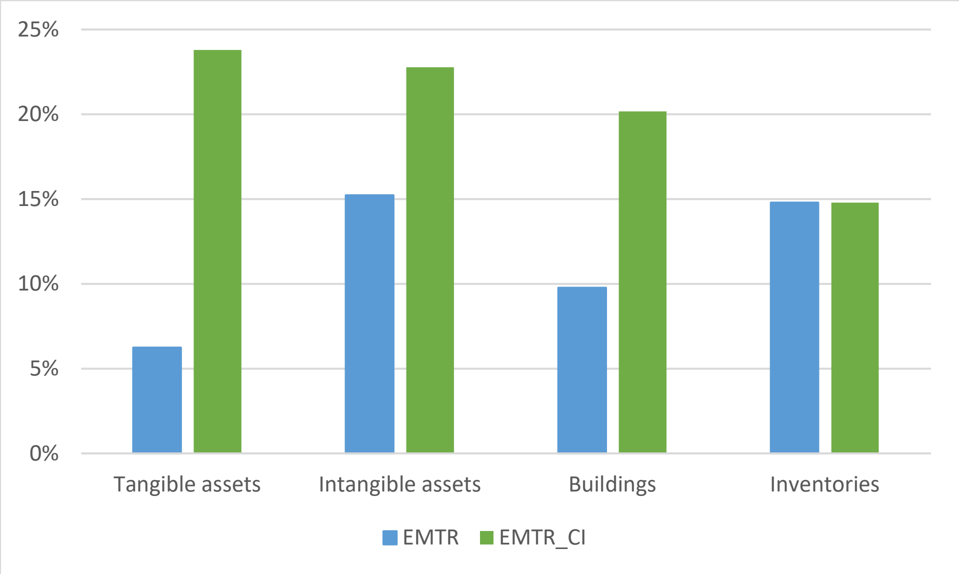


Source: Author's calculation. The baseline tax parameters to calculate the EMTR for the years 2017 and 2018 are derived from Corporate Tax Statistics (2022b). Baseline tax parameters for the years 2012-2016 were collected by the author using ZEW (2019) and EY Worldwide Corporate Tax Guide 2022.
Note: Yearly values of EMTRs and EMTR_CIs are unweighted averages from a sample of the 15 jurisdictions used in the empirical assessment.

The average EMTR_CI and EMTR for the years 2012-2018 is 20.9% and 11.5%, respectively. The difference between the two measures is worth 8.7 p.p. in 2012 and increases to 11.2 p.p. in 2018. This follows the increase in average ECRs over the years 2012-2018 as depicted in Figure 1.2 in the introduction.

Figure 4.2 depicts important heterogeneity in the impact of carbon pricing between asset categories. As seen in Figure 1.2 in the introduction, ECRs are significantly larger in the road transport sector. This drives the average EMTR_CI of the tangible assets group (23.8%) almost four times above the equivalent baseline EMTR (6.2%). The increase is intangible assets and non-residential structures is more modest but remains economically significant (7.5 p.p. and 10.4 p.p., respectively). There are no differences between the two measures for inventories because the model extension does not apply to inventories[14].

Figure 4.2. Difference between EMTR and EMTR_CI by asset category



Source: Author's calculation.
Note: Values of EMTRs and EMTR_CIs are unweighted averages for all values for the years 2012-2018 from a sample of the 15 jurisdictions used in the empirical assessment.

5. Empirical assessment

The empirical assessment that follows evaluates the joint effect of corporate taxation and carbon pricing on business investments. It uses a fixed effects approach where microeconomic firm-level panel data is regressed on the jurisdiction-specific EMTR_CI. The section is divided into three parts. First it introduces the investment data, then it provides descriptive statistics, and finally it presents a thorough overview of the empirical framework.

5.1. Investment data

Investment data is retrieved from the Orbis database developed by Bureau Van Dijk (BvD). Orbis includes millions of observations which provide comprehensive information about the evolution of business investment choices across time and space. The investment variable in the assessment represents real changes in the level of fixed assets in an entity over time. Investment is calculated as the change in fixed assets plus (positive) depreciation[15]. In a second stage, the investment rate is calculated as the ratio of investment relative to the lagged fixed assets (which scales down investments to firm size and removes the impact of heterogenous currencies). The investment rate is

[14] This follows the assumption that there are no carbon emissions linked with the use of inventories in production processes.
[15] Specifically, investment is calculated as the difference between fixed assets and lagged fixed assets, plus depreciation.

constructed using information from the variable fixed assets that is found in the financial table[16]. Data from the financial table is divided into entity (unconsolidated) and group (consolidated) levels. For the purposes of this assessment, only unconsolidated level data is used. This implies that the tax effect on investment is studied within and not across jurisdictions which is in line with the focus on the intensive rather than extensive margin of tax sensitivity.

The selected sample consists of firms from fourteen countries for which data coverage in Orbis is considered most exhaustive (Millot et al. 2020), which includes: Austria, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Luxembourg, the Netherlands, Slovenia, Spain, Sweden, and the United Kingdom[17]. For these countries, selected data is restricted to the years 2013-2019 such that it matches the lagged EMTR_CI data which is available for the years 2012-2018[18]. As in Sorbe and Johansson (2017) and Millot et al. (2020), firms belonging to industries with a NACE code above 81 are excluded (these are industries that most often belong to the public sector such as education and defence, among others). The resulting initial sample size is 2,142,645 observed firms.

Several data cleaning steps are included to remove extreme values, missing values, and improve data quality. Following Millot et al. (2020) and Whyman and Hanappi (forthcoming), this includes:

- The removal of firms for which the yearly financial data is not aligned to the 31st of December. Those firms are excluded since it is not clear whether the financial data captures all investments made by the firm in the calendar year. This lowers the sample size to 1,673,002 observations.
- The removal of firms for which data for the constructed investment variable is missing. This lowers the sample size to 464,022 observations.
- The removal of firms belonging to the bottom and top 10% of the distribution of the investment rate which removes extreme values from the sample (this step is relaxed in the robustness section). This lowers the sample size to 371,216 observations.
- The removal of duplicates in any of the following variables: Fixed assets, operating revenue turnover, and profit before taxes[19]. This lowers the sample size to 293,231 observations.

[16] Orbis data is structured by type of information into different tables, including the financial table among others.
[17] The sample in Millot et al. (2020) also includes Japan, Portugal, and Italy. In this study, Japan is excluded due to too many missing values whereas Portugal and Italy are excluded because the corresponding EMTR_CI values are negative throughout the years of coverage. Negative EMTRs occur when the cost of capital falls below the real interest rate which is often the result of very generous depreciation schedules or other capital allowances (e.g., ACE).
[18] The logic behind the use of lagged EMTRs is explained in the empirical framework section below.
[19] Operating revenue turnover and profit before taxes are variables necessary in the heterogeneity analysis, as elaborated in the empirical framework section.

- The removal of observations where data is missing for the variables used in the regression equation which includes: the investment rate, the carbon-inclusive effective marginal tax rate, and industry growth[20]. The lowers the sample size to 199,171 observations.

5.2. Descriptive statistics

The selected sample of 199,171 observations includes firm investments from 14 OECD countries spanning across the years 2013-2019. This sample size is of similar order of magnitude as that in Millot et al. (2020) whose final sample includes 162,990 observations[21]. Table 5.1 provides summary statistics of the variables of interest used in the empirical analysis.

Table 5.1. Summary statistics

	Observations	Mean	St. deviation	Min.	Max.
Investment rate	199,171	0.144	0.177	-0.057	0.758
EMTR_CI	199,171	0.205	0.038	0.072	0.286
Industry growth	199,171	0.27	1.73	-0.982	65.9
Profitability ratio	179,656	0.063	0.203	-1.00	1.00

Source: Author's calculation using data from the Orbis database for the investment rate, Corporate Tax Statistics database and desk research for the EMTR_CI, and Structural Analysis (STAN) for industry growth.
Note: The profitability ratio variable is used in the heterogeneity analysis elaborated below. It is bounded to -100% and +100% for reasons explained below, which explains the smaller sample size and values of the minimum and maximum.

The mean values shown in Table 5.1 hide important differences between countries and years. Concerning investment rates, the mean drops to 0.116 when including only firms from Spain in the sample. By contrast, average investment rates rise to 0.162 when considering only firms from Austria. Similarly, the average EMTR_CI fluctuates across countries reaching as high as 0.273 in Finland and as low as 0.087 in Estonia. Industry growth shows high variation across years with an average of -0.0014 in 2013 and 1.40 in 2018. Finally, profitability ratios also include large variability with among others, average ratios of 0.051 in Estonia, 0.069 in Germany, and 0.073 in the United Kingdom.

5.3. Empirical framework

5.3.1. Baseline specification

The empirical framework follows that of similar studies including Sorbe and Johansson (2017), Millot et al. (2020), and Whyman and Hanappi (forthcoming) – which all regress Orbis investment data on forward-looking effective tax rates to estimate the tax sensitivity of investments in different settings.

[20] Industry growth is introduced as a control variable as elaborated in the empirical framework section.
[21] The smaller sample is explained by the fact that despite using a broader year and country coverage, Millot et al. (2020) restrict the sample to observations available at both consolidated and unconsolidated levels (to enable a focus on MNEs).

In line with these studies, the approach used is a fixed effects regression where the dependent variable is the investment rate (i.e., the ratio of investment to the lagged capital stock as in Millot et al., 2020) and the regressor is the lagged EMTR_CI. Firm and year fixed effects are introduced as controls as well as lagged industry growth. Data for industry growth is obtained from the OECD STAN (2020) database. That the tax variable and industry growth are included as lags reflects the idea that firms typically plan investment decisions in advance, and it takes time (by assumption, about a year) for investments to adjust to changes in fiscal policy or the economy (as in Sorbe and Johansson, 2017 and Millot et al., 2020). The following equation is estimated on a panel of 199,171 firms across 14 countries for investments occurring during the years 2013-2019:

$$IR_{f,t,i,c} = \beta_1 \, EMTR\_CI_{t-1,c} + \beta_2 \, g_{t-1,c,i} + \alpha_f + \lambda_t + \varepsilon_{fct} \quad , \qquad (12)$$

$$\text{where} \qquad \varepsilon_{fct} = \nu_{ct} + \mu_{fct} \quad . \qquad (13)$$

The dependent variable $IR_{f,t,i,c}$ is the book value investment rate of firm *f* in year *t* of industry *i* and country *c*. β_1 is the coefficient of interest which is attached to $EMTR\_CI_{t-1,c}$, the one-year lag of the carbon inclusive effective marginal tax rate in country c. $g_{t-1,c,i}$ is the lag of industrial growth in country c for industry i which controls for the possibility of an upward bias in investment in rapidly growing industries[22]. α_f and λ_t are firm and year fixed effects, respectively. ε_{ft} is the error term specific to firm *f* in country *c* and year *t* . As shown in equation 13, ε_{fct} can be separated into the sum of ν_{ct} which are country-year shocks, and μ_{fct} which is an idiosyncratic individual component (Angrist and Pischke 2009) - the relevance of which is further discussed in the identification section below.

Equation 14 complements the baseline analysis with a subsequent fixed effects regression estimation that is identical to equation 12 except for the regressor which is replaced with the lag of the country-specific EMTR – i.e., the tax variable excluding the impact of carbon pricing provisions. This analysis contributes to the purposes of the paper in two ways. Firstly, it enables comparison between the tax sensitivity of investments with and without the carbon pricing element. Secondly, given that other studies in the literature have estimated similar regression equations, it offers a means to compare the magnitude of the results using the EMTR with results found in similar studies.

$$IR_{f,t,i,c} = \beta_1 \, EMTR_{t-1,c} + \beta_2 \, g_{t-1,c,i} + \alpha_f + \lambda_t + \varepsilon_{fct} \qquad (14)$$

Note that the definition of ε_{fct} is identical to equation 13.

[22] This could occur for example in an industry where a technological innovation boosts productivity so much that most firms from that industry decide to rapidly invest in the space of a few years in a set of assets that can better benefit from the new technology. Such a productivity boost might encourage new investments despite changes in CIT rates, thereby biasing results.

5.3.2. Identification

Omitted variable bias and reverse causality

In this setting, identification revolves around the question of whether there are reasons to believe that some of the unobserved variables in the error term ε_{fct} are correlated with the regressor and with the dependent variable. Such omitted variable bias (OVB) would interfere with the interpretation of the estimated coefficients by driving up or down the estimate of interest away from the true effect of carbon-inclusive effective marginal tax rates on investment rates. Another way in which the results of this study may be biased is the possibility of reverse causality, which may occur if there are reasons to believe that changes in investment rates of firms in a given country have an effect on the EMTR_CI of that country. This subsection explores the likelihood of these biases to affect the baseline specification.

Several aspects of the empirical strategy support identification. First there is the fixed effects approach. The within fixed effects specification above consists of a two-step procedure: (i) the average of all (observed and unobserved) variables is taken across the seven years of coverage and (ii) each year-specific variable is demeaned. As a result, the estimated effect now reflects how a deviation between the EMTR_CI from its mean in a given country affects the deviation between the investment rate from its mean of firms in that country. The advantage of this specification is that all variables that are time-invariant vanish from the error term which removes all time-invariant candidates for OVB such as time-invariant firm characteristics. This includes for example the geographic location of a firm which may be correlated with the regressor (since tax codes are jurisdiction- and sometimes region-specific) and with investment rates (e.g., through the proximity to a cheap supplier of input materials for production that would save in transportation costs and encourage greater investment in capital).

Second, there is the use of the EMTR as a regressor. In the literature, there is an emerging adoption of the forward-looking ETR framework to assess tax elasticities of investments (see e.g., Sorbe and Johansson 2017, Millot et al. 2020, Whyman and Hanappi forthcoming). ETRs improve the credibility of identification in such analyses for several reasons. The forward-looking element enables to capture CIT systems' impact on the current incentive to invest. The synthetic element makes them more exogenous to investment than backward-looking ETRs, as they are computed based on hypothetical investment projects rather than based on taxes actually paid. This relative exogeneity comes from the idea that whereas there may be reasons to believe that firms choose to set foot in regions with low STRs, there are less reasons to believe that firms choose regions given a specific EMTR. In addition, the discernability between intensive or extensive margins can be leveraged to narrow down precise tax variables depending on the research question.

Third, controlling for industry growth further supports identification as industry growth might be candidate for biasing investment rates in rapidly growing industries (as elaborated in footnote 22). This control variable is necessary despite the fixed effects approach because industry growth is a time variant variable.

To conclude, the empirical strategy removes time-invariant candidates for OVB which strengthens identification. Nonetheless, time variant effects, including country and year specific shocks, remain contenders for biasing the results. The subsection below focuses on standard errors and discusses this possibility. Reverse causality also remains possible given that investment rates are time variant. Conceptually, it is plausible to believe that as a result of low investments in previous years, a country decides to decrease effective tax rates in an attempt to boost investment. However, the fact that it is the lagged EMTR_CI that is used as a regressor reduces this possibility (i.e., it is unlikely that firm investments in 2017 affect effective tax rates in 2016). The robustness analysis includes the lagged investment as a control variable to further reduce likelihood of reverse causality.

Heteroscedasticity, intra-group correlation, and serial correlation

In the above specification, without adjusting the standard errors, the error term risks to generate biased standard errors or biased estimates due to heteroscedasticity, intra-group correlation, and serial correlation. Ordinary least squares regression assumes that errors are homoscedastic, meaning that the variance of the error term is homogenous across units of observation. Failing this assumption would imply that standard errors are biased which – given their centrality in deriving confidence intervals - can lead to incorrect conclusions about the statistical significance of estimators. One way to relax this assumption is to use standard errors that are robust to heteroscedasticity, resulting in unbiased standard errors (Angrist and Pischke 2009).

Intra-group correlation can occur if the data and regressor of interest is structured by groups, as is the case with the EMTR_CI which for a given year, varies between and not within countries. In the baseline specification, there are reasons to believe that firms within a same country have correlated investment behavior. For instance, suppose the United Kingdom (UK) recently signed a trade deal with Brazil which increases availability and reduces the price of a series of raw materials in the UK. As a result, investment costs in assets produced from these materials fall and firms throughout the UK increase their investments in the years following the trade deal. In the presence of intra-group correlation as well as large group sizes[23], standard errors are likely to be significantly lower than what their correct value should be (Moulton 1986). One solution consists of using clustered standard errors

[23] In the analysis, the groups are relatively large with on average 14,226 firms by country.

to allow for clustering and heteroscedasticity (Angrist and Pischke 2009). To relax assumptions of homoscedasticity and no intra-group correlation, in this study, robust standard errors are clustered at the country*year level. This clustering implies that standard errors are no longer independent across firms but instead assumes that they are correlated at the country and year level. By increasing the value of standard errors, clustering hampers statistical significance but ensures lower likelihood of biased standard errors.

The serial correlation problem - the tendency of observations to be correlated with their own lags - may occur in specifications where the regressor of interest varies at group and time levels as is the case in the baseline specification of this study. Recall that the error term ε_{fct} can be conceptualised as the sum of country-year shocks (ν_{ct}) and an idiosyncratic individual component (μ_{fct}). Country-year shocks are problematic for statistical inference. Suppose that in 2013, while other countries of the sample enjoy a year of economic growth, Slovenia suffers from an economic downturn due to say, the election of an unpredictable head of state. This uncertainty could lead to lower investment rates throughout the economy and interfere with the interpretation of the estimated effect of effective tax rates on investment in Slovenia. Assuming that there is no serial correlation, i.e., that the average effect of country-year shocks on investments is zero would solve this issue. However, this is a strong assumption given that if the economic situation in Slovenia was bad in 2013, it is not unlikely that it was also bad in 2014 and future years. The assumption is easier to defend in cases with many groups and many years but the relatively low number of countries (14) in this study implies that serial correlation constitutes the most likely bias in the estimation (Angrist and Pischke 2009). To assess the potential effect of serial correlation, the robustness section below includes estimations that remove one country at a time from the sample.

5.3.3. Heterogeneity analysis

Recent literature on the relation between firm type and tax sensitivity of investments shows that different firms react differently to changes in corporate tax rates. Millot et al. (2020) show that investments from MNEs with a negative profitability ratio (i.e., the ratio between pre-tax profits and total revenues[24]) are less sensitive to changes in tax rates as compared to MNEs with a profitability ratio between 0 and 10%. This finding, they argue, can be explained by the fact that such firms do not pay corporate taxes and that they are often leveraging loss-carryover provisions[25] to limit their tax burden. In this vein, Dreßler and Overesch (2013) find that the tax sensitivity of investments is smaller

[24] Profitability is taken as a ratio of total revenues in order to scale down profits to firm size (Millot et al., 2020).

[25] Loss carryover provisions allow firms to carry to future periods losses made in past periods to offset profits. For instance, if a firm makes a loss in 2020 and a profit in 2021 of equal amount to the loss in 2020, the firm can use loss-carryover provisions to report the loss from 2020 in 2021. As such, the profit earned in 2021 is offset and the tax liability in both periods falls to zero.

for MNEs that make use of loss carryovers. The logic behind lower tax sensitivities in such firms is that since they are not liable to pay taxes, they have no reasons to adapt investments as a response to changes in CIT rates.

Millot et al. (2020) also find that MNEs with a relatively high profitability ratio (above 10%) are less sensitive to changes in tax rates, relative to those with a profitability ratio between 0% and 10%. The authors provide several mechanisms to explain this finding. First, highly profitable firms likely have more liquidity which makes them better equipped to make tax payments in cases of tax increases, while keeping their investment choices unaffected. Second, those firms are more likely to enjoy monopolistic positions thanks to for example the protection from a patent or "winner takes all dynamics[26]". This implies that they might prefer to keep investment rates unchanged despite higher tax burdens if that means that they can keep their monopolistic position. A third argument is highlighted by Sorbe and Johansson (2017) who find that in the case of MNEs, high profitability encourages tax planning, which in turn yields lower sensitivity to changes in domestic tax rates.

To test for the occurrence of heterogenous effects between firms of different profitability ratios, this specification leverages the firm-level microdata used in the baseline analysis to perform a heterogeneity analysis. Following Millot et al. (2020), this analysis consists of dividing firms into different categories according to profitability ratios. The heterogeneity analysis uses five groupings, i.e., with profitability <0%, 0 – 5%, 5 - 10%, 10 - 15%, and above 15%[27] and is modelled through an interaction term between the EMTR_CI and the categorical variable capturing firm profitability. In R (the software used to run the regressions), running a regression with an interaction implies by default the inclusion of the categorical variable as a control in the specification. As such, the heterogeneity analysis takes the following specification:

$$IR_{f,t,i,c} = \beta_1 \, EMTR\_CI_{t-1,c} + \beta_2 \, \boldsymbol{\pi}_{f,t} + \beta_3\left(\pi_{1,f,t} * EMTR\_CI_{t-1,c}\right) +$$

$$\beta_4 \left(\pi_{2,f,t} * EMTR_{CI_{t-1,c}}\right) + \beta_5 \left(\pi_{3,f,t} * EMTR_{CI_{t-1,c}}\right) + \beta_6 \left(\pi_{4,f,t} * EMTR_{CI_{t-1,c}}\right) +$$

$$\beta_7 \, g_{t-1,c,i} + \alpha_f + \lambda_t + \varepsilon_{fct} \quad (15)$$

Equation 15 changes from equation 12 in two aspects. First, there is the inclusion of $\boldsymbol{\pi}_{f,t}$ as a control variable. $\boldsymbol{\pi}_{f,t}$ is a vector that includes all profitability ratio dummy variables which are firm and year specific, thereby allowing for the possibility that firms change between categories over the years of coverage. Second, there are the four interaction terms between $\pi_{f,t}$ and $EMTR\_CI_{t-1,c}$ which allow

[26] The phenomenon where highly digitalised firms globally dominate (large) portions of markets (Autor et al., 2017).

[27] Negative profitability ratios are bonded at -100% and positive profitability ratios are bounded at +100% such that firms with profits or losses larger than total revenues are omitted. This lowers the sample size to 179,656.

for the analysis of the impact of the tax variable on investments separately for each category. π_1 is the category of firms with profitability ratios between 0 and 5% and the notation follows chronological order[28]. Note that the category of loss-making firms is omitted – the relevance of which is discussed in the interpretation of results. Note also that the definition of ε_{fct} is identical to that in equation 13.

6. Results

6.1. Baseline and heterogeneity analyses

The section discusses the results of the baseline and heterogeneity analyses as presented in Table 6.1. Panel 1 shows the results from estimating equation 12, i.e., the baseline specification using the EMTR_CI as regressor. The estimate of the EMTR_CI suggests that, on average, a 10 p.p. increase in the lagged carbon-inclusive effective marginal tax rate is associated with a decrease in 3.2 p.p. in investment rates. Panel 2 shows the results from equation 14, i.e., where the regressor changes to the EMTR. The estimate of the EMTR suggests that, on average, a 10 p.p. increase in the lagged effective marginal tax rate decreases investment rates by 1.9 p.p.

The results from panel 2 (where the estimated coefficient of the EMTR is -0.195) are in the same order of magnitude as those found in similar studies. Sorbe and Johansson (2017) and Millot et al. (2020) who both assess MNE investments obtain an EMTR estimate of -0.104 and -0.131, respectively. Whyman and Hanappi (forthcoming) find an EMTR estimate for non-MNE investments of -0.138. These similarities strengthen the credibility of the analysis. Importantly, the analysis also points to an economically significant difference between the estimated coefficients of the tax variable in panels 1 and 2. The estimate in panel 1 is more than 50% larger than that in panel 2 which, in line with expectations, shows that carbon pricing provisions impact firms' investment decisions and reduce investment rates. This result suggests that when excluded from the specification, carbon pricing constitutes an OVB in the assessment of the relation between CIT systems and investment.

[28] π_2 is the category of firms with profitability ratios between 5 and 10%, π_3 between 10% and 15%, and π_4 above 15%.

Table 6.1. Results: Baseline, heterogeneity, and robustness analyses

	(1)	(2)	(3)	(4)	(5)	(6)
EMTR_CI	-0.319		-0.427	-0.742	-0.175	0.297
	(0.221)		(0.337)	(0.719)	(0.195)	(0.331)
EMTR		-0.195				
		(0.166)				
Industry growth	0.0002	0.00028	0.00037	-0.0013*	0.0002	0.0002
	(0.0002)	(0.00016)	(0.0002)	(0.0004)	(0.0002)	(0.0004)
Lagged investment rate			-3.8e-09			-1.8e-09
			(1.9e-09)			(1.6e-09)
EMTR_CI X $\pi_{0\text{-}0.05}$					-0.103	-0.107
					(0.039)	(0.069)
EMTR_CI X $\pi_{0.05\text{-}0.1}$					-0.107	-0.099
					(0.063)	(0.101)
EMTR_CI X $\pi_{0.1\text{-}0.15}$					-0.092	-0.114
					(0.045)	(0.076)
EMTR_CI X $\pi_{0.15\text{-}1}$					-0.226**	-0.251
					(0.047)	(0.087)
Clustered S.E.	YES	YES	YES	YES	YES	YES
Firm fixed effects	YES	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES
Extreme values	NO	NO	NO	YES	NO	NO
Observations	199,171	199,171	143,296	245,446	179,656	130,327
R^2	0.545	0.545	0.604	0.373	0.549	0.607
Adjusted R^2	0.352	0.352	0.375	0.163	0.353	0.375

Source: Source: Author's calculation using data from the Orbis database for the investment rate and profitability ratio, Corporate Tax Statistics database and desk research for the EMTRs, and Structural Analysis (STAN) for industry growth.

Note: Panel 1 shows the results for the baseline fixed effects regression specified in equation 12. Each of the remaining panels differs from the baseline scenario in a distinct way. Panel 2 results differ through the regressor (using the EMTR instead of EMTR_CI). Panel 3 includes the lagged investment rate as control variable. Panel (4) includes more observations as it includes extreme values for the investment rate (bounded at the 1% instead of 10% level on either side of the distribution). Panel 5 includes a control variable for firm profitability and interaction terms between the EMTR_CI and profitability ratio. Panel 6 is identical to panel 5 except for the inclusion of the lagged investment rate as control variable. Panels 1 and 2 show baseline scenario results. Panel 5 is the heterogeneity analysis. Panels 3, 4, and 6 constitute the robustness checks. All panels include firm and year fixed effects. Robust standard errors are all clustered at the year*country level and represented in parentheses below the estimate. ** indicate statistical significance at the 5% level and * at the 10% level.

Panel 5 shows the results of the heterogeneity analysis where firms are grouped by profitability. Recall that given the interaction term in the specification, the estimate for the coefficient of the EMTR_CI is the one applicable to firms with negative profitability (i.e., the omitted category). The results show that on average, a 10 p.p. increase in the EMTR_CI reduces the investment rate of unprofitable firms by 1.7 p.p. Panel 5 shows that as firms become more profitable, investments become more sensitive to taxation. On average, for firms with a profitability ratio between 0 and 5%, a 10 p.p. increase in the EMTR_CI reduces investments by 2.7 p.p. (i.e., a reduction by 1.0 p.p. relative to unprofitable firms). The gap between firm categories becomes statistically significant at the 5% level when comparing the most profitable firms to the omitted group. On average, for firms with a profitability ratio between 15 and 100%, a 10 p.p. increase in the EMTR_CI reduces investments by 4.0 p.p.

The finding that unprofitable firms are less sensitive to taxation than profitable firms is in line with Dreßler and Overesch (2013) and Millot et al. (2020). However, unlike Millot et al. (2020) who find that most profitable MNEs are least sensitive to taxation, panel 5 shows that most profitable firms are the most sensitive to taxation. A possible explanation for this difference is that this study includes only data from entities derived in Orbis at the unconsolidated level, i.e., without considering whether they are part of an MNE group, whereas the study from Millot et al. (2020) assesses exclusively MNEs. The contrast between the two studies may shed light on the mechanisms that explain lower sensitivity of the most profitable MNEs. Of the three listed mechanisms in Millot et al. (2020), i.e., (i) better liquidity, (ii) monopolistic positions, and (iii) tax panning incentives, there are no strong reasons to believe that MNEs have more liquidity than domestic firms. However, the global aspect of MNEs likely provides them with better propensity to enjoy monopolistic positions. Furthermore, ownership of foreign entities among MNE groups facilitates (aggressive) tax planning (De Mooij and Liu, 2020). As such, this finding suggests that low tax sensitivity in highly profitable groups may be explained by monopolistic positions but could also be evidence of tax planning practices.

6.2. Robustness checks

This section aims to test the robustness of the results to various changes of the baseline analysis. Panel 3 in Table 6.1 provides estimates of an augmented version of the baseline specification where the lagged investment rate is included as a control variable. Lagged investments may affect the results since (i) there are reasons to believe that capital investments of a given firm depend on the amount invested in the past[29] and (ii) past investments may incentivise tax policy changes - thereby driving potential reverse causality. The inclusion of lagged investments in the specification strengthens credibility in that the magnitude of the estimate of the coefficient of the EMTR_CI does not change substantially. Nonetheless, the change has remarkable economic significance in that it increases the estimate of the EMTR_CI from -0.319 to -0.427. This change suggests that the baseline result suffers from OVB from lagged investments.

Panel 6 in Table 6.1. shows how the inclusion of lagged investment rates as a control variable affects the results from the heterogeneity analysis. The estimate of interest for unprofitable firms switches sign to positive – suggesting that for this type of firms, increases in tax rates encourage investment. Nonetheless, the result that more profitable firms are more sensitive to taxation still holds and the relative differences in tax sensitivities between firm categories are almost unaffected.

[29] Among other reasons, this may be explained by diminishing returns to investments.

Panel 4 in Table 6.1 shows the results of the baseline specification when the data cleaning step involving the removal of extreme values of investment rates is relaxed. Instead of removing firms at the bottom and top 10% of the distribution of investment rates, in panel 4 it is only the 1% at both ends of the distribution that are removed. While the number of observations rises to 245,446, the estimate of interest more than doubles in magnitude (from -0.319 to -0.742). The insights from the heterogeneity analysis would suggest that the extreme values removed in the baseline specification include firms that are, on average, more profitable than those in the middle 80% of the sample. Another explanation could be that relaxing the data cleaning step includes large outliers as compared to the initial sample. Note that industry growth becomes significant at the 10% level in panel 4. This suggests that investments from firms belonging to top and bottom deciles of the distribution of investment rates are, on average, more strongly associated with industry growth.

The final robustness check consists of removing one country at a time from the sample and running again the baseline regression. Table 6.2. depicts the results corresponding to the removal of each country of the sample. The estimate of interest appears to be relatively robust to the removal of all countries except France and the UK. Whereas the estimate fluctuates between -0.319 and -0.355 for all other cases, the removal of France and the UK yields an estimate of -0.519 and -0.052, respectively. This suggests that French firms are relatively less sensitive whereas UK firms are relatively more sensitive to changes in effective tax rates. However, this may also be due to serial correlation from country-shocks in those two countries. In particular, the decision of the UK to leave the EU might have affected investments in 2016 and in subsequent years, thereby biasing results for this country.

Table 6.2. Robustness checks (extended)

Excluded country	EMTR_CI Estimate	EMTR_CI Clustered standard error
Austria	-0.328	0.230
Denmark	-0.319	0.221
Estonia	-0.329	0.228
Finland	-0.326	0.226
France	-0.519	0.288
Germany	-0.326	0.228
Hungary	-0.328	0.230
Ireland	-0.325	0.224
Luxembourg	-0.320	0.222
The Netherlands	-0.325	0.227
Slovenia	-0.329	0.228
Spain	-0.321	0.283
Sweden	-0.355	0.297
United Kingdom	-0.052	0.058

Source: Author's calculation using data from the Orbis database for the investment rate, Corporate Tax Statistics database and desk research for the EMTR_CI, and Structural Analysis (STAN) for industry growth.

Note: Table 6.2 provides the coefficients for the estimate and standard error of the EMTR_CI in the baseline scenario as defined in equation 12. Note also that the results shown in columns II and III are those for the specification where the country listed in column I is excluded from the sample.

7. Discussion

It is an ongoing challenge for governments to generate revenue through taxation without simultaneously harming the economy. The tax sensitivity of investments provides a key policy tool to understand the extent to which business taxation affects economic growth which explains why this question receives broad attention in both academic and policy spheres. Furthermore, recent years have seen a growing political desire to decarbonise economies in an attempt to meet climate goals. The impact that carbon pricing policies have on reducing carbon-intensive investments provides a key policy tool to understand their effectiveness at achieving climate goals which explains why it is a topic increasingly discussed in policy and academia. This paper offers a novel approach to estimate the joint impact of carbon pricing and corporate income tax provisions on business investments.

The assess this effect, the study introduces the concept of and derives carbon-inclusive effective marginal tax rates – a tax variable that captures the impact of both types of provisions on the incentive to invest. The empirical evaluation grounds on a series of fixed effects regressions where firm-level investment panel data from 14 OECD countries over the years 2013-2019 is regressed on country-level EMTR_CIs. The baseline specification controls for year and firm fixed effects as well as industry growth. A heterogeneity analysis is subsequently introduced to assess whether firm heterogeneity plays a role in the tax sensitivity of investments. The empirical evaluation also includes several robustness checks that test how estimates in the baseline specification change with the addition of control variables and changes in the sample selection.

In line with expectations, results show that the estimated coefficient for the EMTR_CI is of larger magnitude (in absolute terms) than that of the EMTR – i.e., the tax variable excluding the carbon pricing element. This finding implies that carbon pricing is an effective tool at reducing carbon-intensive investments. It also suggests that studies assessing the CIT impact on investment that exclude carbon pricing likely suffer from OVB.

The heterogeneity analysis shows that unprofitable firms are least sensitive to taxation and that sensitivity increases as firms get more profitable. That unprofitable firms' investment behavior is relatively less affected by tax changes follows findings from the literature. However, the finding that most profitable firms are most sensitive to taxation contrasts with other studies – including Millot et al. (2020) who find that most profitable MNEs are least sensitive to taxation. This contrast might have to do with the nature of firms included in the sample, which , in the case of this study, are entities for which no differentiation is made about whether they belong or not to an MNE group. The finding can be explained by MNEs' propensity to enjoy monopolistic positions but may also be evidence of tax planning practices.

The fixed effects empirical strategy grounds on the assumption that there are no unobserved time variant variables that correlate to the tax and the investment variables. The most serious problem with this assumption is the possible occurrence of serial correlation. To test for this occurrence, the robustness analysis includes an assessment where countries are excluded one by one from the sample. The estimate of interest in the baseline specification remains around -0.320 upon removal of each country and is bounded at -0.052 and -0.519 upon the removal of the UK and France, respectively. This suggests that there are no countries in the sample that suffer from sufficient serial correlation to drive an economically significant change in the estimate which strongly supports identification.

Remaining limitations in the study include the imperfect match between the sector disaggregation in the effective carbon rates methodology and asset disaggregation in the effective tax rates methodology. Further research could extend the ECR methodology to enable better matching between the two policy variables. The calculation of carbon intensities constitutes a further limitation since the proposed calculation is based on an assessment of six European countries over three years which offers only 18 observations used to calculate carbon intensity averages. In addition, the matching between ECR sectors and the sectors from the Structural Analysis database is also only approximate. Further research on the carbon intensity of different sectors and asset types is needed for future research in this domain. Finally, it is important to note that none of the estimates derived for the EMTR_CI are of statistical significance which implies large confidence intervals and suggests that there may be wide variety between the obtained results and the true effects of carbon-inclusive effective marginal tax rates on business investments.

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Annex A: ETR equations

Following Celani et al. (2022), Annex A elaborates on the theoretical setting described in Section 2. Corporate ETRs can be derived along two scenarios that concern the duration of investments.

Table A.1. One-period investment case (OPC): Evolution of key variables over time			
	Investment (I_t)	Capital Stock (K_t)	Net Revenue (Q_t)
Period 0	+1	+1	0
Period 1	-$(1-\delta)*(1+\pi)$	$(1-\delta)$	$(p+\delta)*(1+\pi)$
Period 2	0	0	0
Period 3	0	0	0
Period 4	0	0	0

Table A.2. Permanent investment case (PIC): Evolution of key variables over time			
	Investment (I_t)	Capital Stock (K_t)	Net Revenue (Q_t)
Period 0	+1	+1	0
Period 1	0	$(1-\delta)$	$(p+\delta)*(1+\pi)$
Period 2	0	$(1-\delta)^2$	$(p+\delta)*(1+\pi)^2*(1-\delta)$
Period 3	0	$(1-\delta)^3$	$(p+\delta)*(1+\pi)^3*(1-\delta)^2$
Period 4	0	$(1-\delta)^4$	$(p+\delta)*(1+\pi)^4*(1-\delta)^3$

Table A.1 provides an overview of the evolution of investment, capital stock, and net revenue over five periods of investment in the one-period investment case (OPC). This scenario assumes that investments only last for one period and that the capital invested in period 0 is sold in period 1. Table A.2 provides an overview of the same variables in the permanent investment case (PIC). In this scenario, investments occur in period 0 and the capital invested in never sold. Unlike in the former scenario, capital depreciates over time beyond period 1. The choice of scenarios affects the assumptions made on investment behaviour in the model. The OPC implies that investors only look at the ETR relevant to the specific period of investment when making investment decisions. The PIC implies that investors may look at ETRs of a set of periods when making investment decisions. The choice of scenarios affects the derivation of the net present value (NPV) of parameters calculated below. In the empirical framework described in Section 3, the EMTR-CI is calculated using the OPC because the assumption surrounding investment strategies fits better the purposes of the research question and corresponding empirical strategy.

Capital Stock

a. Economic capital stock

$$K_t = K_{t-1} * (1 - \delta) + I_t \quad (1)$$

The level of economic capital stock is affected by how much capital the firm had in previous periods, the level of investment and divestment at each period, as well as economic depreciation.

b. fiscal capital stock

$$K_t^T = K_{t-1}^T - Z_t + I_t \quad (2)$$

The level of fiscal capital stock is equivalent to the economic capital stock except for the use of fiscal depreciation (Z_t) instead of economic depreciation. Since it is the fiscal capital stock that is used as the base for tax purposes, the difference between economic and fiscal depreciation determines the generosity of the CIT system in a given country.

c. OPC capital stock

In OPC, investment takes place at t=0. At t=1, the investor divests such that the capital stock returns to the pre-perturbation level.

$$K_0 = 0 * (1 - \delta) + I_0 = I_0 \quad (3)$$

$$K_1 = K_0 * (1 - \delta) - I_0 * (1 - \delta) * (1 + \pi) = 0 \quad (4)$$

d. *PIC capital stock*

In PIC, investment takes place at t=0 after which no more investments take place, but the capital stock remains productive until it has fully depreciated (see Table A.2).

Net Revenue

Firms earn revenue from the capital they own. For a given return on investment (which is typically assumed to be 20% in the model), revenue is mostly determined by how much capital was invested in previous periods. Revenue is defined by assumption net of variable costs. Variables in bold are calculated in NPV.

a. net revenue

$$Q_t = (p + \delta) * K_{t-1} * (1 + \pi)^t \quad (5)$$

b. OPC net revenue

$Q_0 = (p + \delta) * 0 * (1 + \pi)^0 = 0$ (6)

$Q_1 = (p + \delta) * K_0 * (1 + \pi)^1$ (7)

$\boldsymbol{Q} = Q_0 + \frac{Q_1}{1+i}$ (8)

c. PIC net revenue

$\boldsymbol{Q} = \sum_s^\infty [K_{t+s-1} * (1 + \pi)^{t+s} * (1 - \delta)^s / (1 + i)^s]$ (9)

Capital allowances

Capital allowances support firms' economic viability in two ways: (i) they reduce the effective cost of investments and (ii) they reduce the tax base thereby diminishing the tax liability of the firm. They are determined by the statutory corporate income tax rate (τ_t) as well as the sum of capital allowances in each period (Z_t). Variables in bold are calculated in NPV.

a. OPC capital allowances

$\boldsymbol{A} = \tau_0 * Z_0 + [(\tau_1 * Z_1)/(1 + i)]$ (10)

b. *PIC capital allowances*

$\boldsymbol{A} = \sum_s^\infty \tau_{t+s} * Z_{t+s} / (1 + i)^s$ (11)

Economic rent

Economic rent is defined as the total revenue for each period, net of variable costs, tax costs, and investment costs. Variables in bold are calculated in NPV.

a. Economic rent in period t

$R_t = Q_t - \tau_t * (Q_t - Z_t) - I_t$ (12)

b. Economic rent in period t, in the absence of taxation (R_t^*)

$R_t^* = Q_t - I_t$ (13)

c. NPV of economic rent

$$\boldsymbol{R} = \sum_s^\infty \frac{R_{t+s}}{(1 + i)^{t+s}} = \sum_s^\infty \frac{Q_{t+s}}{(1 + i)^s} - \sum_s^\infty \frac{\tau_{t+s} * (Q_{t+s} - Z_{t+s})}{(1 + i)^s} - \sum_s^\infty \frac{I_{t+s}}{(1 + i)^s}$$

(14)

d. NPV of economic rent in the absence of taxation

$$\boldsymbol{R}^* = \sum_{s}^{\infty} \frac{Q_{t+s}}{(1+i)^s} - \sum_{s}^{\infty} \frac{I_{t+s}}{(1+i)^s}$$

(15)

Net income

The pre-tax net income (Y*) differs from the revenue insofar as it is not derived gross of economic depreciation, it is thus simply the product of the rate of return and the capital stock in the previous period, adjusted for inflation.

a. pre-tax net income

$$Y_t^* = pK_{t-1} * (1+\pi)^t \qquad (16)$$

b. NPV of pre-tax net income

$$\boldsymbol{Y_t^*} = \sum_{s}^{\infty} \frac{Y_t^*}{(1+i)^s}$$

(17)

The effective average tax rate (EATR)

The key element in the derivation of the EATR is R and how it differs from its pre-tax counterpart $R*$. The EATR is defined as the difference between R and $R*$, taken as ratio over the NPV of pre-tax net income. This denominator is chosen because whereas profits can be negative in some periods, net income is always positive and nonzero. In this equation, all values are in NPV.

$$EATR = \frac{R^* - R}{Y^*}$$

(18)

Simplified forms for R, R*, and Y in OPC

Assuming a constant statutory CIT rate τ throughout.

a. NPV of post-tax economic rent $\boldsymbol{R}$

$$\sum_{s}^{\infty} \frac{R_{t+s}}{(1+i)^{t+s}} = R_0 + \frac{R_1}{(1+i)^1}$$

$$= Q_0 - \tau_0 * (Q_0 - Z_0) - I_0 + \frac{Q_1}{(1+i)^1} - \frac{\tau_1 * (Q_1 - Z_1)}{(1+i)^1} - \frac{I_1}{(1+i)^1}$$

Knowing that:

- From Table 1, $Q_0 = 0$; $I_0 = 1$; $K_0 = I_0 = 1$; $I_1 =$ -$(1-\delta) * (1+\pi)$
- From (11), **A** = $A_0 + \frac{A_1}{1+i} = \tau_0 * Z_0 + \frac{\tau_1 * Z_1}{1+i}$
- From (8), $Q_1 = (p+\delta) * K_0 * (1+\pi)^1$

Then:

$$\mathbf{R} = 0 + A_0 - 1 + \frac{(p+\delta) * 1 * (1+\pi)(1-\tau_1)}{(1+i)^1} + \frac{A_1}{(1+i)^1} - \frac{(-1) * (1-\delta) * (1+\pi)(1-\mathbf{A})}{(1+i)^1}$$

$$\mathbf{R} = -(1-\mathbf{A}) + \frac{(p+\delta)(1+\pi)(1-\tau) + (1-\delta)(1+\pi)(1-\mathbf{A})}{1+i}$$

(19)

b. NPV of pre-tax economic rent $\boldsymbol{R}^*$

$$\boldsymbol{R}^* = \sum_{s}^{\infty} \frac{Q_{t+s}}{(1+i)^s} - \sum_{s}^{\infty} \frac{I_{t+s}}{(1+i)^s}$$

$$\boldsymbol{R}^* = Q_0 - I_0 + \frac{Q_1}{(1+i)^1} - \frac{I_1}{(1+i)^1} = 0 - 1 + \frac{(p+\delta)(1+\pi) + (1-\delta)(1+\pi)}{1+i}$$

$$\boldsymbol{R}^* = -1 + \frac{(1+\pi)(p+1)}{1+i}$$

Knowing that:

- From Fisher equation: 1 + r = $\frac{1+i}{1+\pi}$

$$\boldsymbol{R}^* = \frac{(p+1)}{1+r} - \frac{1+r}{1+r} = \frac{p+r}{1+r}$$

(20)

c. NPV of pre-tax net income $\boldsymbol{Y}^*$

$$\boldsymbol{Y}_{\boldsymbol{t}}^* = \sum_{s}^{\infty} \frac{Y_t^*}{(1+i)^s} = Y_0^* + \frac{Y_1^*}{1+i} = 0 + \frac{p\, K_0 (1+\pi)^1}{1+i} = \frac{p}{1+r}$$

(21)

The cost of capital

The cost of capital is derived from the formula of the economic rent by introducing the condition that the after-tax economic rent (R) equals 0. By solving the equation for the rate of return (p), we obtain a formula for the cost of capital ($\tilde{p}$) which captures the required rate of return for an investment to break even after tax. Before tax economic rents equal 0 when the rate of return equals the opportunity cost of investing (r).

a. *Cost of capital in OPC*

$$\mathbf{R} = -(1-\mathbf{A}) + \frac{(p+\delta)(1+\pi)(1-\tau)+(1-\delta)(1+\pi)(1-\mathbf{A})}{1+i} = 0$$

$$(1-\boldsymbol{A}) - \frac{(1-\delta)(1+\pi)(1-\mathbf{A})}{1+i} = \frac{(p+\delta)(1+\pi)(1-\tau)}{1+i}$$

$$\frac{(1-\boldsymbol{A})(1+r)-(1-\delta)(1-\mathbf{A})}{1+r} = \frac{(p+\delta)(1-\tau)}{1+r}$$

$$\frac{(1-\boldsymbol{A})(r+\ \delta)}{(1-\tau)} - \delta = p$$

$$\tilde{p} = \frac{(1-\boldsymbol{A})(r+\ \delta)}{(1-\tau)} - \delta$$

(22)

The effective marginal tax rate (EMTR)

The EMTR is defined as the difference between the post-tax cost of capital and the pre-tax cost of capital, as a ratio of the post-tax cost of capital.

$$EMTR = \frac{\tilde{p}-r}{\tilde{p}}$$

(23)

Simplified forms for R, R*, and Y in PIC

Assuming a constant statutory CIT rate τ throughout.

*a. NPV of post-tax economic rent **R***

$$\sum_{s}^{\infty}\frac{R_{t+s}}{(1+i)^{t+s}}=R_0+\frac{R_1}{(1+i)^1}+\frac{R_2}{(1+i)^2}+\frac{R_3}{(1+i)^3}+\frac{R_4}{(1+i)^4}$$

$$=Q_0-\ \tau_0*(Q_0-Z_0)-I_0+\frac{Q_1}{(1+i)^1}-\frac{\tau_1*(Q_1-Z_1)}{(1+i)^1}-\ \frac{I_1}{(1+i)^1}+$$

$$\frac{Q_2}{(1+i)^2}-\frac{\tau_2*(Q_2-Z_2)}{(1+i)^2}-\frac{I_2}{(1+i)^2}+\frac{Q_3}{(1+i)^3}-\frac{\tau_3*(Q_3-Z_3)}{(1+i)^3}-\frac{I_3}{(1+i)^3}+$$

$$\frac{Q_4}{(1+i)^4}-\frac{\tau_4*(Q_4-Z_4)}{(1+i)^4}-\frac{I_4}{(1+i)^4}$$

$$=0+A-1+\frac{(p+\delta)(1+\pi)(1-\tau_1)}{(1+i)^1}+\ \frac{A_1}{(1+i)^1}+\frac{(p+\delta)(1+\pi)^2(1-\delta)(1-\tau_2)}{(1+i)^2}+\ \frac{A_2}{(1+i)^2}$$

$$+\frac{(p+\delta)(1+\pi)^3(1-\delta)^2(1-\tau_3)}{(1+i)^3}+\ \frac{A_3}{(1+i)^3}+\frac{(p+\delta)(1+\pi)^4(1-\delta)^3(1-\tau_4)}{(1+i)^4}+\ \frac{A_4}{(1+i)^4}$$

$$=\ -(1-\boldsymbol{A})+\sum_{s}^{\infty}\frac{(p+\delta)(1+\pi)^s(1-\delta)^{s-1}(1-\tau)}{(1+i)^s}$$

$$=-(1-\boldsymbol{A})+\frac{(p+\delta)(1-\tau)}{1+r}\sum_{s}^{\infty}\frac{(1+\pi)^{s-1}(1-\delta)^{s-1}}{(1+i)^{s-1}}$$

$$=-(1-\boldsymbol{A})+\frac{(p+\delta)(1-\tau)(1+\pi)}{1+i}*\frac{1}{1-\dfrac{(1+\pi)(1+\delta)}{1+i}}$$

$$=-(1-\boldsymbol{A})+\frac{(p+\delta)(1-\tau)(1+\pi)}{1+i}*\frac{1}{\dfrac{1+i-((1+\pi)+\delta(1+\pi)}{1+i}}$$

$$=-(1-\boldsymbol{A})+\frac{(p+\delta)(1-\tau)(1+\pi)}{1+i}*\frac{1+i}{i-\pi+\delta(1+\pi)}$$

$$=\frac{(p+\delta)(1+\pi)(1-\tau)}{i-\pi+\delta(1+\pi)}-(1-\boldsymbol{A})$$

(24)

*b. NPV of economic rent in the absence of taxation **R****

$$\boldsymbol{R}^*=\ \sum_{s}^{\infty}\frac{Q_{t+s}}{(1+i)^s}-\sum_{s}^{\infty}\frac{I_{t+s}}{(1+i)^s}=0-1+\sum_{s}^{\infty}\frac{(p+\delta)(1+\pi)^s(1-\delta)^{s-1}}{(1+i)^s}$$

$$=\ -1+\frac{p+\delta}{1+r}*\frac{1}{1-\dfrac{1-\delta}{1+r}}=-1+\frac{p+\delta}{1+r}*\frac{1}{\dfrac{r+\delta}{1+r}}=-1+\frac{p+\delta}{1+r}*\frac{1+r}{r+\delta}=\frac{p-r}{r+\delta}$$

(25)

c. NPV of net income before tax $\boldsymbol{Y_t^*}$

$$\boldsymbol{Y_t^*} = \sum_{s}^{\infty} \frac{Y_t^*}{(1+i)^s} = 0 + \sum_{s}^{\infty} \frac{p\,K_{s-1}(1+\pi)^s}{(1+i)^s} = \sum_{s}^{\infty} \frac{p(1+\pi)^s\,(1-\delta)^s}{(1+i)^s} = \frac{p}{1-\frac{1-\delta}{1+r}} = \frac{p}{r+\delta}$$

(26)

Annex B: ETR results and other notes

B.1. ETR results

Table B.1. EMTR_CI results by jurisdiction, 2012-2018

Code	2012	2013	2014	2015	2016	2017	2018
AUT	0.227555	0.227208	0.226857	0.2265	0.238414	0.244008	0.249403
DEU	0.236084	0.236129	0.236156	0.236228	0.241863	0.247381	0.252371
DNK	0.097599	0.223638	0.221233	0.217163	0.221512	0.230464	0.239051
ESP	0.197897	0.253548	0.25431	0.193817	0.190499	0.1983	0.205804
EST	0.079138	0.076943	0.074686	0.072364	0.087401	0.101683	0.11527
FIN	0.281827	0.285714	0.260331	0.263687	0.268491	0.273163	0.277707
FRA	0.175054	0.176554	0.179841	0.183019	0.200023	0.203939	0.22945
GBR	0.179326	0.197476	0.208724	0.220654	0.224839	0.22442	0.228069
HUN	0.217989	0.217641	0.217274	0.216889	0.220193	0.203874	0.205992
IRL	0.175017	0.173838	0.172635	0.171407	0.184213	0.196275	0.207659
JPN	0.27126	0.264303	0.264592	0.245361	0.238758	0.241702	0.243527
LUX	0.185049	0.184856	0.183272	0.181678	0.181181	0.17344	0.168954
NLD	0.227362	0.213647	0.233975	0.237137	0.250915	0.263718	0.275665
SVN	0.145662	0.144694	0.147176	0.149603	0.161126	0.179427	0.190095
SWE	0.270238	0.241021	0.233363	0.224596	0.237311	0.249182	0.260291

Sources: Corporate tax statistics (OECD 2022b), Effective carbon rates (OECD 2022a), Structural analysis (OECD 2020), ZEW (2020), EY Worldwide Corporate Tax Guide 2022.

Table B.2. EMTR results by jurisdiction, 2012-2018

Code	2012	2013	2014	2015	2016	2017	2018
AUT	0.159463	0.159463	0.159463	0.159463	0.166804	0.166804	0.166804
DEU	0.167379	0.167672	0.167951	0.168279	0.168454	0.168768	0.168804
DNK	-0.05557	0.09047	0.089537	0.087498	0.084041	0.084041	0.084041
ESP	0.135065	0.200915	0.200915	0.129021	0.118686	0.118686	0.118686
EST	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FIN	0.1901	0.1901	0.16272	0.16272	0.16272	0.16272	0.16272
FRA	0.096386	0.090816	0.090816	0.090816	0.099167	0.085758	0.099167
GBR	0.094801	0.093783	0.090549	0.088404	0.088404	0.085947	0.085947
HUN	0.078222	0.078222	0.078222	0.078222	0.078222	0.040538	0.040538
IRL	0.105072	0.105072	0.105072	0.105072	0.105072	0.105072	0.105072
JPN	0.197969	0.194921	0.194921	0.181248	0.173101	0.173101	0.172166
LUX	0.132638	0.133983	0.133983	0.133983	0.133983	0.126848	0.123031
NLD	0.142121	0.117843	0.142121	0.142121	0.142121	0.142121	0.142121
SVN	0.068556	0.065433	0.065433	0.065433	0.065433	0.071561	0.071561
SWE	0.153971	0.134165	0.134165	0.134165	0.134165	0.134165	0.134165

Sources: Corporate tax statistics (OECD 2022b), ZEW (2019), EY Worldwide Corporate Tax Guide 2022.

B.2. Type of assets found in each asset group.

These are the asset types considered in each asset group in the ETR methodology of the OECD Secretariat (OECD, 2022b).

- Non-residential structures: manufacturing plants, large engineering structures, office or commercial buildings.
- Acquired Software: Pre-packaged or custom software.
- Road transport vehicles: Autos, light trucks, utility vehicles, farm or construction tractors.
- Air, rail, and water transport vehicles: Ships and boats, railroad equipment, aircraft.
- Computer Hardware: personal computers, mainframes, printers, storage devices, terminals.
- Equipment: communications, medical and non-medical instruments, office equipment, engines, appliances, furniture or other equipment (except computer hardware).
- Industrial machinery: machinery used for metalworking, agriculture or construction, mining and oilfield machinery, service industry machinery, general industrial machinery.
- Inventories: inventories.