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Abstract

This paper presents an empirical analysis of the relationship between the corporate income tax (CIT) and the growth of total factor productivity (TFP) within European firms. Using data from the AMADEUS database over the 2005-2013 period, I measure the TFP of each firm using Wooldridge's (2009) methodology, alongside four alternative approaches introduced by Olley and Pakes (1996), Levinsohn and Petrin (2003), Ackerberg et al. (2015), and ordinary least squares (OLS) regression. The baseline investigation follows the TFP catch-up framework of Griffith et al. (2009). While my analysis corroborates prior findings indicating a negative relationship between CIT rates and the speed with which firms converge to the productivity frontier (productivity catch-up, Gemmell et al., 2018), it also uncovers a positive association between CIT rates and the average growth of productivity. Thus, the evidence reveals a non-linear relationship between corporate taxation and firms' productivity growth. Heterogeneity tests show that corporate income taxation is more relevant for the productivity growth of small-scale enterprises and domestic entities. These findings are robust to a variety of alternative specifications and tests.

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1. Introduction

Total factor productivity (TFP) growth represents the portion of output growth resulting from technological innovation and knowledge advancements that are not attributed to the expansion of conventional inputs. It captures the efficiency gains achieved within the production process, playing a crucial role in fostering sustained economic development. Consequently, comprehending the determinants of TFP holds paramount significance for policymakers and researchers dedicated to enhancing the overall economic performance. Notably, among these determinants, the corporate income tax (CIT) has attracted substantial attention (Gale et al., 2015).

A sustainable and growing body of literature has investigated the impact of tax policy on aggregate output and productivity growth at the country level (e.g., Kneller et al., 1999; Bleaney et al., 2001; Romero-Ávila & Strauch, 2008; Romer & Romer, 2010). However, empirical evidence of the relationship between taxation and firm productivity at micro level remains comparatively limited. Conventionally, scholars within this domain have concentrated on the effects of taxes and tax credits (Brannon & Brannon, 1972; Berger, 1993; Von Brasch et al., 2021), on firms' user cost of capital (Hall & Jorgenson, 1967; Auerbach, 1983), research and development (R&D) activities (Chen et al., 2017; Mukherjee et al., 2017), capital investment (King & Levine, 1993; Bencivenga et al., 1995), or firm entry and exit rates (Da Rin et al., 2011). The overarching consensus of those studies is that higher CIT rates reduce new investments, R&D activities, and firm entry, which might suggest a negative relationship with productivity growth (e.g., Arnold et al., 2011).

More recently, an increasing number of papers has shifted attention towards the impact of corporate taxation on the convergence process, wherein less productive firms endeavor to close the productivity gap to the frontier. These studies provide robust evidence on a negative relationship between CIT rates and the rate of productivity catch-up (Vartia, 2008; Arnold et al., 2011; Bournakis & Mallick, 2018; Gemmell et al., 2018; Romero-Jordán et al., 2020).

Notwithstanding the considerable advancements in the empirical literature, persistent challenges remain. Specifically, productivity catch-up studies have neglected the direct relationship between CIT rates and productivity growth. Thus, a distinct analysis of the direct association between corporate taxes and firms' productivity growth is still conspicuously absent. Additionally, the most recent developments in TFP measurement methodologies (Wooldridge, 2009; Ackerberg et al., 2007; Ackerberg et al., 2015) are often overlooked in recent empirical studies.[1] Moreover, little is known about how firm heterogeneity moderates the relationship of corporate taxation and productivity growth (e.g., Gemmell et al., 2018).

This paper aims to close those research gaps by offering further insights into the relationship between CIT rates, firms' productivity growth, and the productivity convergence process. It is crucial to note that this paper does not delve into the concepts of convergence, especially the differentials between beta (Barro & Sala-i-Martin, 1991) and sigma convergence (Bernard & Durlauf, 1995). The study concentrates on three key inquiries: (i) the association between CIT rates and firms' average TFP growth, (ii) the relationship between CIT rates and the speed of productivity catch-up to the frontier, and (iii) how these relationships are associated with firm size and the multinational status of firms.

To achieve these objectives, I first estimate TFP at the firm level using the AMADEUS database for the period from 2005 to 2013. The dataset includes the financial statements and ownership information of approximately 137,193 observations from 16 European countries. TFP estimation employs Wooldridge's (2009) methodology and also considers alternative estimators proposed by Olley and Pakes (1996), Levinsohn and Petrin (2003), Ackerberg et al. (2015), and ordinary least squares (OLS) regression. Subsequently, I identify the technological frontiers, representing the top 5% of the most productive firms within each country-industry-year cell, and calculate the gap of less productive firms to this frontier. I adopt a methodological framework that integrates the TFP catch-up model (Griffith et al., 2009) with measures of the corporate taxes and their interaction with the TFP gap. This approach allows for an examination of the direct relationship of CIT rates and productivity growth as well as for the association between CIT rates and productivity convergence. To test for robustness, I test specifications including and excluding control variables used by Gemmell et al. (2018).

The main findings of this paper can be summarized as follows. If I do not account for TFP catch-up, I find a positive and statistically significant association between CIT rates and TFP growth. This result reinforces existing theoretical presumptions that taxes may have positive effects on the evolution of average productivity levels, for instance, by squeezing out less productive firms. If I consider TPF catch-up, I obtain economically relevant and statistically robust evidence for a

[1] Gemmell et al. (2018) rely on the Levinsohn and Petrin (2003) estimator for total factor productivity. The use the Wooldridge (2009) estimator as a robustness check, but do not consider the Ackerberg et al. (2007, 2015) estimator in their analysis.

negative association between CIT rates and productivity catch-up. This finding aligns with earlier empirical studies, such as Arnold et al. (2011) and Gemmell et al. (2018) that similarly adhere to the catch-up framework of Griffith et al. (2009). In addition, the direct association between CIT rates and TFP growth becomes quantitatively stronger and remains significantly positive and robust. From a theoretical perspective, this positive direct association can be justified by 1) a favorable effect of corporate taxation on the quality of investments (e.g., Eichfelder et al., 2023), 2) a squeeze-out effect of corporate taxation on low-productivity firms from the market, and 3) positive effects of public investments on productivity growth (e.g., by enhancing infrastructure).

Taken together, the results of this study provide evidence of a nonlinear relationship between the burden of corporate taxes and firms' productivity growth, underscoring the moderating role of productivity disparity between frontier and laggard firms. While the CIT rate shows a positive relationship with overall firms' productivity growth, it is negatively associated with the productivity convergence of less productive firms. My baseline regression results suggest that a 1 percentage point increase in the corporate income tax rate is associated with a 0.389% increase in TFP growth at the frontier, with a 0.13% increase in TFP growth for the firm with the average TFP gap and for a 0.747% reduction in TFP growth for the firm with the maximum TFP gap. Evidence from heterogeneity tests also implies that corporate taxation is more relevant for the TFP growth of a) small and medium-sized firms (SMEs) and b) domestic firms.

These findings are robust to a wide range of specifications and sensivity tests: a) specifications with and without control variables; b) alternative fixed effects specifications (firm fixed effects, year fixed effects, country fixed effects, industry fixed effects, industry-country fixed effects); c) various TFP measures (OLS; Olley & Pakes, 1996; Levinsohn & Petrin, 2003; Ackerberg et al., 2015); d) the use of alternative input-output proxies in TFP measurement; e) the exclusion of firms with higher profit-shifting opportunities; and f) alternative definitions of the technological frontier. Regarding alternative tax burden measures replacing the statutory corporate income tax rates (CITR) in the baseline setting, I find robust evidence for effective average tax rates (EATR) but not for effective marginal tax rates (EMTR). This finding implies that marginal tax burdens hold limited relevance for firms' productivity growth, whereas the average tax burden is more relevant. In addition, I find statistically significant and economically robust evidence that the top personal income tax rate (PITR) is positively associated with firms' productivity growth, but no significant association between the top PIT rate and productivity catch-up.

This paper makes substantial contributions to the existing literature. First, it is, to the best of my knowledge, the first paper that provides evidence on a nonlinear relationship between CIT rates and firms' productivity growth. By emphasizing the role of the firm-frontier distance in moderating the association of CIT rates and productivity growth, the study provides a rationale for the ongoing debate concerning the CIT-TFP relationship. Despite the acknowledged presence of catch-up and spillover effects, previous reports by the OECD and the U.S. indicate a persistent and widening gap between less productive firms and the technological leaders across country levels (Hartmann et al., 2021). This paper suggests that taxes may positively affect average productivity levels but also widen the gap between more and less productive firms.

Second, the paper introduces various measures of TFP, employing four advanced estimators along with the conventional OLS. This innovative approach allows for a comparison of the results using difference TFP measures. Interestingly, the findings of the paper remain robust for all analyzed TFP measures and produce qualitatively and quantitatively robust results. Therefore, TFP measurement does not seem to be the main concern, when analyzing the association between CIT rates and TFP growth using the Griffith et al. (2009) framework.

Third, the study enriches the existing literature by conducting comparisons between large and small firms, as well as multinational enterprises (MNEs) and domestic firms, providing valuable insights into the relevance of CIT rates for different firm types. Our findings suggest that corporate taxation is especially relevant for domestic firms and SMEs, which have both more relatively limited resources for a) productivity enhancing investments and b) tax avoidance activities.

The subsequent sections of this paper are organized as follows. In Section 2, I present a review of the related literature and derive hypotheses for the empirical analysis. Section 3 outlines the empirical methodology, while Section 4 provides information on the data and descriptive statistics. The empirical results followed by a thorough examination of the robustness are discussed in Section 5. Finally, Section 6 concludes.

2. Related Literature and Hypotheses

2.1 Corporate Income Tax and Productivity Growth

In the literature, adverse effects of the CIT on firm productivity are typically attributed to two interconnected mechanisms that both reduce productivity-enhancing investments: a) the impact of the CIT on the user cost of capital and b) liquidity constraints resulting from higher tax costs. First, higher tax liabilities typically increase the user cost of capital, which reduces the incentives of firms for new capital investments (Jorgenson, 1963; Fullerton, 1987; Devereux & Griffith, 2003; Hubbard, 1998). This can undermine business investment in both tangible (Auerbach & Hines, 2002; Almeida & Philippon, 2007) and intangible assets (Hall & Van Reenen, 2000), thereby impeding productivity growth. Second, high corporate tax liabilities can impose financial and liquidity constraints that impede firms' ability to invest in technologies that enhance productivity (e.g., Zwick & Mahon, 2017), resulting in a deceleration of productivity growth. Specifically, increased CIT burdens reduce post-tax income, intensifying the moral hazard between external creditors and the firm, weakening the firms' borrowing capacity (Kanbur et al., 2008).

In contrast, recent research finds insignificant or even positive associations of CIT rates and economic growth (Gechert & Heimberger, 2022; Kate & Milionis, 2019), suggesting a more complex relationship between corporate taxation and productivity. First, despite the negative impact on investment volumes, the CIT can have positive effects on the quality of investment and innovation (Akcigit & Stantcheva, 2020). Higher tax rates increase the marginal user costs of capital, which can motivate firms to invest in high-quality projects that yield greater returns. Eichfelder et al. (2023) provide such evidence for German bonus depreciation regimes. If higher tax burdens increase investment quality, they can also increase productivity.

Second, greater tax burdens impose financial constraints that promote the elimination of less productive firms from the market, thus increasing average productivity (Lentz & Mortensen, 2008; Hamano & Zanetti, 2022). Acemoglu et al. (2018) demonstrate that corporation taxation can lead to productivity gains by encouraging the exit of less productive firms, which frees up skilled resources for the more productive firms. This finding highlights that taxes, despite their distortionary effects on liquidity and firm entry, can serve an allocative function by selecting viable firms and reallocating resources from less productive to more productive firms (Foster et al., 2008). Additionally, higher CIT rates may stimulate companies to prioritize enhancing productivity to maintain competitiveness, resulting in increased demand for highly skilled workers subsequently raising firms' productivity levels (Jovanovic, 1982; Hopenhayn, 1992).

Third, tax revenues generate resources for public investments in infrastructure, transportation, education, and R&D, creating an environment conducive to growing productivity. Such public investments can increase agglomeration economies (Eberts & McMillen, 1999; Abiad et al., 2016), where firms benefit from proximity to a large pool of skilled workers, suppliers, and customers. Duranton and Puga (2004) find that firms located in urban agglomerations experience higher productivity growth rates due to the advantages derived from proximity to other firms and public investments.

Drawing from the divergent perspectives, I outline the mechanisms through which higher CIT rates can influence firms' productivity growth in Table 1 and impose two opposing hypotheses concerning the tax-productivity relationship:

H1a (The effects of user cost of capital and liquidity constrains dominate): Higher CIT rates are associated with a lower firm productivity growth.

H1b (The effects of investment quality, selection effects and public investments dominate): Higher CIT rates re associated with a higher firm productivity growth.

Table 1 - Effects of Higher CIT Rates on Productivity Growth

Factor	**Expectation**	**TFP Growth**
User cost of capital↑	Higher CIT rates increase the user cost of capital and reduce the incentive for new investments	–
Liquidity constraints↑	Higher CIT rates reduce liquidity and weaken borrowing capacity for productivity-enhancing investments	–
Investment quality↑	Higher CIT rates promote high-quality investment projects with higher returns	+
Competition and selection↑	Higher CIT rates squeeze low-productivity firms out of the market	+
Public investments ↑	Higher CIT rates increase public investment and expenditures in infrastructure or human capital	+

2.2 Corporate Income Tax and Productivity Catch-up

As mentioned earlier, the literature provides empirical evidence that higher CIT rates impede the productivity catch-up of less productive firms (e.g., Vahter & Masso, 2008; Gemmell et al., 2018; Romero-Jordán et al., 2020; Shaukat et al., 2020). This empirical finding implies that corporate taxation has a stronger impact on the productivity growth of low-productivity firms compared to their more productive counterparts.

Thus, highly productive firms should be less sensitive to greater tax burdens. Such firms typically possess market power, enabling them to pass on the tax burden to consumers and employees (Fuest et al., 2018; Hager & Baines, 2020). Additionally, they have access to greater economic resources and are more cost-efficient in avoiding taxes (Eichfelder & Vaillancourt, 2014). Consequently, high-productivity firms will continue to invest in activities that enhance productivity, even in the presence of high tax burdens. Conversely, firms lagging behind typically face greater resource constraints and liquidity pressures. Therefore, tax costs can be a serious obstacle for these firms to catch up to the frontier (Bartolini, 2018). Empirical evidence suggests that especially small firms with limited financial resources and lower productivity are hindered by corporate taxation in their productivity catch-up (Romero-Jordán et al., 2020). Building upon this literature, I expect a negative association of CIT rates and productivity catch-up.

H2: Higher CIT rates are negatively associated with the productivity catch-up of low-productivity firms.

3. Methodology

3.1 Baseline Tests

My baseline regression equation is based upon the TFP catch-up framework proposed by Griffith et al. (2009) and applied by Gemmell et al. (2018), Romero-Jordán et al. (2020) and others to the association between corporate taxes and TFP growth.

$$\begin{aligned}\Delta lnTFP_{ijct} = {} & \alpha_0 + \alpha_1 \Delta lnTFP_{Fjct} + \alpha_2 lnTFPGap_{ijct-1} + \alpha_3 CITR_{ct} \\ & + \alpha_4 lnTFPGap_{ijct-1} \times CITR_{ct} + \alpha_5 I_{jt} + \alpha_6 lnTFPGap_{ijct-1} \times I_{jt} \\ & + \delta_{ct} X_{ct} + \delta_i + \delta_t + \varepsilon_{ijct} \qquad (1)\end{aligned}$$

The dependent variable $\Delta lnTFP_{ijct}$ is the TFP growth for firm *i* operating in industry *j*, in country *c*, at time *t*. TFP is measured by a logarithmic function of value added following the methodology of Wooldridge (2009) (see Subsection 4.2). The technological frontier F is defined as the TFP level of the firm at the 95th percentile of the TFP distribution in each country-industry-year cell, with industry measured by the two-digit NACE code. I adopt the 95th percentile and not the maximum TFP level or the 99th percentile to mitigate measurement error arising from year-on-year fluctuations in TFP measurements (Griffith et al., 2009; Gemmell et al., 2018). In alternative robustness tests, I also rely on the 99th percentile and the highest TFP level, and I also define the frontier at the industry-year level instead of the country-industry-year level to account for globalized competition and the economic integration of the European market (Table 10). The coefficient α_1 represents the diffusion of knowledge and technology from the frontier to less productive firms. Technological advancements at the frontier should be positively associated with TFP growth (α_1> 0).

$lnTFPGap_{ijct-1}$ is the ratio of the TFP level of the firm *i* to the TFP level of the corresponding frontier in the period *t-1*. Thus, the coefficient α_2 identifies the speed of TFP catch-up (Bernard & Jones, 1996; Cameron, 2005) by estimating the relationship between firms' TFP growth and its distance from the frontier. Based on Griffith et al. (2009), a larger productivity gap implies greater potential for TFP improvements and a higher speed of catch-up, suggesting α_2> 0.

The tax coefficient α_3 represents the direct relationship between the corporate income tax rate (CITR) and firms' productivity growth. If the negative effects of corporate taxation on TFP growth (e.g., lower liquidity and higher user costs) dominate (Hypothesis H1a), we expect a negative association α_3<0. Otherwise, if the effects of corporate taxes on investment quality, firm selection and public investments dominate (Hypothesis H1b), α_3 should be positive.

The coefficient α_4 captures the interaction term between the CIT rate and the TFP Gap, reflecting the relationship between tax rates and productivity catch-up. In line with Hypothesis H2 and the empirical literature (Gemmell et al., 2018; Romero-Jordán et al., 2020), α_4 should be negative. I measure CITR as the statutory corporate income tax rate. I also perform robustness tests (Table 9) using the effective marginal tax rate (EMTR) and the effective average tax rate (EATR).

I further consider control variables proposed by Gemmell et al. (2018). These involve an interaction term of the TFP gap and an industry indicator variable measured at NACE-two-digit level (I_{jt})[2] to account for industry-specific convergence rates. Additionally, a set of country-level control variables X_{ct} includes the ratio of government expenditure to gross domestic product (*GE*) and of the government revenue to GDP (*GR*) to capture positive effects of public policy measures on TFP growth. In alternative specifications (Appendix E), I also perform regressions without (potentially endogenous) control variables.

[2] To minimize concerns about the endogeneity of this variable and to capture the inherent profitability of an industry rather than any effect of CIT in a country on this variable, I follow Arnold et al. (2011) to use the industry profitability level for the U.S. as a proxy. Data source is derived from the 2007 U.S. Benchmark Input–Output Database. For each ISIC industry, a profitability ratio is calculated as gross operating surplus divided by value added, and it is then applied to the 2005-2013 period.

The baseline model incorporates a firm-fixed effect δ_i to capture the firm's unobserved constant characteristics, a year-fixed effect δ_t to account for common macroeconomic shocks and the idiosyncratic error term ε_{ijct}. In alternative specifications, I consider industry-fixed effects and country-fixed effects instead of firm-fixed effects.

A potential problem for the empirical strategy is international profit shifting (Görg & Greenaway, 2004; Maffini & Mokkas, 2011) that could result in measurement error of the real tax burden at the firm level. To address this issue, I perform regressions that exclude observations of firms that are most likely subject to profit shifting (i.e., observations of firms with subsidiaries in tax havens).

3.2 Heterogeneity Tests

To investigate the relationships between taxation and productivity growth across different firm characteristics, I undertake a comparative analysis within sub-samples of firms categorized by firm size and multinational status. Prior studies indicate that large and multinational firms (Mallick & Yang, 2013), may exhibit a lower sensitivity to corporate tax burdens due to their stronger market power, greater access to economic resources, and a stronger use of tax-avoidance strategies. Additionally, these firms are likely to act as technological leaders within their respective industries, thereby generating positive spillover effects on the performance of less advanced firms (Melitz, 2003; McGaughey et al., 2020). Conversely, higher corporate tax burdens may exacerbate the financial and liquidity constraints faced by smaller and domestic firms, which have typically smaller economic resources and are less productive than large and multinational firms. This, in turn, can impede their capacity to catch up with leading firms and subsequently hinder their growth potential. Thus, I expect a more pronounced association of CIT rates and TPF growth for smaller and domestic firms.

In a first set of heterogeneity tests, I estimate the baseline Equation (1) for two sub-samples, namely for large firms (≥ 250 employees) and SMEs (< 250 employees) as well as for MNEs (at least one majority-owned subsidiary in another country) and domestic firms (no subsidiary in any other country). Additionally, I modify the baseline model by including additional interaction terms that account for firm heterogeneity. In Equation (2), I add a dummy variable for SMEs (< 250 employees) and interaction terms of this indicator with $lnTFPGap$, $CITR$ and the interaction of $lnTFPGap$ and $CITR$.

$$\Delta lnTFP_{ijct} = \alpha_0 + \alpha_1 \Delta lnTFP_{Fjct} + \alpha_2 lnTFPGap_{ijct-1} + \alpha_3 CITR_{ct}$$
$$+\alpha_4 lnTFPGap_{ijct-1} \times CITR_{ct} + \beta_1 SME_{ict}$$
$$+\beta_2 lnTFPGap_{ijct-1} \times SME_{ict} + \beta_3 CITR_{ct} \times SME_{ict}$$
$$+\beta_4 lnTFPGap_{ijct-1} \times CITR_{ct} \times SME_{ict} + \delta_{ct} X_{ct} + \delta_j + \delta_c + \delta_t + \varepsilon_{ijct} \quad (2)$$

Likewise, I replace the dummy variable SME in Equation (2) by the dummy variable *MNE* for multinational firms in Equation (3).

$$\Delta lnTFP_{ijct} = \alpha_0 + \alpha_1 \Delta lnTFP_{Fjct} + \alpha_2 lnTFPGap_{ijct-1} + \alpha_3 CITR_{ct}$$
$$+\alpha_4 lnTFPGap_{ijct-1} \times CITR_{ct} + \partial_1 MNE_{ict}$$
$$+\partial_2 lnTFPGap_{ijct-1} \times MNE_{ict} + \beta_3 CITR_{ct} \times MNE_{ict}$$
$$+\partial_4 lnTFPGap_{ijct-1} \times CITR_{ct} \times MNE_{ict} + \delta_{ct} X_{ct} + \delta_j + \delta_c + \delta_t + \varepsilon_{ijct} \quad (3)$$

In these extended interaction models of Equation (2) and Equation (3), I generally consider industry fixed effects and country fixed effects instead of establishment fixed effects. In doing so, I ensure that indicator variables like *MNE* and *SME* will not drop out of the regression.

4. Data Description

4.1 Data and Sample

The sample utilized in this research is from the AMADEUS database, containing financial statement and ownership information of companies across Europe. The study period spans from 2005 to 2013, with data availability expanding over time. The unit of observation is an individual entity, which may be a subsidiary of a larger group. The primary advantage of utilizing the AMADEUS database is its extensive coverage of firm-level financial accounting information, allowing for the estimation of TFP at the micro level within a cross-country context. The use of firm-level data also helps mitigate concerns related to endogeneity bias arising from reverse causality, as the statutory CIT rate is typically determined at the country level and is not influenced by firm-specific productivity. Furthermore, the AMADEUS database allows for the identification of ownership structures and international tax planning at the group level.

To prepare the dataset, I follow the approach of Gemmell et al. (2018), who also employ AMADEUS data, restricting the sample to the manufacturing and service industries[3] and excluding firms from the public sector, financial institutions, and insurance firms. Observations with incomplete or implausible information on turnover, material cost, investment, and employees are also excluded. The same holds for observations with negative calculated value-added or missing information on the lagged TFP gap.[4]

The sample incorporates external data required for the empirical analysis. This includes tax-related information, such as the statutory corporate income tax rates from KPMG's corporate tax rate tables and KPMG (2006), the top personal income tax (PIT) rate from the Eurostat Taxation Trends, the effective marginal tax rate (EMTR), and the effective average tax rate (EATR) from the Centre for Business Taxation at the University of Oxford. Country-specific data, namely GDP, GDP per capita, and unemployment rate, is obtained from the World Development and World Governance Indicators databases of the World bank, while the share of government expenditure (% of GDP) and government revenue (% of GDP) are extracted from OECD data. The EUKLEMS database is used for price deflators to determine the real value of the input and output factors.

4.2 TFP Measurement

To measure total factor productivity (TFP), I follow the literature and rely on a Cobb-Douglas production function, as follows:

$$y_{it} = \alpha_0 + \beta l_{it} + \gamma k_{it} + \rho_{it} + \varepsilon_{it}, \quad (4)$$

at which y_{it} is the logarithm of value-added output, l_{it} the logarithm of labor input and k_{it} is the logarithm of the capital stock for firm i in year t. The variable ρ_{it} stands for the technical

[3] In this analysis, I consider firms in both the manufacturing and services industries (NACE 10-96). However, I exclude the sectors of recycling (NACE 37), refuse disposal (NACE 38) and utilities (NACE 39), because of the high share of public ownership in some countries over the sample period. In addition, financial services (NACE 64-66), real estate (NACE 68) and holding companies (NACE 74) are excluded due to different reporting standards in these industries. Finally, due to the presence of many non-profit organizations in the public administration (NACE 84), education (NACE 85), health (NACE 86), gambling (NACE 92), and activities of membership organizations (NACE 94), I also exclude those industries from the sample.

[4] There is no information of material cost for observations in the UK, Croatia, and Denmark. Observations in Estonia is only available for 2005.

efficiency or transmitted total factor productivity (TFP), and ε_{it} is white noise to capture the idiosyncratic error. A significant challenge arises because productivity (ρ_{it}) is unobserved and can be correlated with input variables, leading to a simultaneity bias in standard parametric techniques like OLS (Gatto, et al., 2011). Standard approaches to endogeneity, such as fixed-effects estimators or instrumental-variables estimators, do not work well either (Griliches & Mairesse, 1999).[5]

To account for simultaneity bias, I consider the following estimation strategies. The Olley-Pakes estimator (Olley & Pakes, 1996) is one of the earliest approaches that address simultaneity bias in TFP measurement. It involves a two-step process using a firm's investment as a proxy for a firm's productivity and a low-order polynomial to approximate the control function.[6] The labor coefficient is identified in the first stage, followed by the estimation of the state variable coefficient and firm's TFP in the second stage. Levinsohn and Petrin (2003) proposed an alternative two-step procedure by incorporating intermediate inputs rather than investments in the control function. They argue that intermediates may exhibit smoother responses to productivity shocks, leading to more reliable TFP estimates. Especially, when firms face substantial adjustment costs, the investment variable becomes inappropriate. Ackerberg et al. (2007) and Ackerberg, Caves, and Frazer (2015) explore the identification issues of these two strategies, showing that the labor input may not vary independently of the function estimated using the low-order polynomial. Hence, they introduce a procedure that combines the advantages of the Olley-Pakes and the Levinsohn-Petrin methods and enables all the inputs to be identified in the second stage (the Ackerberg-Caves-Frazer estimator).

However, Wooldridge (2009) argues that the two-step methods for TFP estimation may suffer from inefficiencies due to (1) a lack of consideration for contemporaneous error correlation between the equations, and (2) inadequate handling of serial correlation. To tackle these limitations, he proposes a one-stage procedure that allows for simultaneous estimation of the input variables and the endogenous productivity responses to unobserved shocks. Numerous studies, such as Biesebroeck (2007), Van Beveren (2012), and Bournakis and Mallick (2018), have demonstrated

[5] The fixed-effects estimator may deal with the labor-productivity correlation but at the cost of imposing productivity shocks with no time variation. IV estimators are constrained by the difficulty of finding appropriate instruments.

[6] Assuming that firms make decisions to maximize the present discounted value of current and future profits in an environment in which productivity is the sole unobserved source of firm-specific uncertainty. The solution to the dynamic profit maximization problem generates a demand function for the proxy variable, that, under certain assumptions, can be inverted to define a firm's productivity as a function of observables or the control function (Olley & Pakes,1996; Levinsohn & Petrin, 2003).

the superiority of the Wooldridge estimator compared to the Olley-Pakes, Levinsohn-Petrin, and Ackerberg-Caves-Frazer estimators.

Therefore, I choose the Wooldridge (WRDG) estimator as the benchmark. In additional tests, I also use the Olley-Pakes (OP) estimator, the Levinsohn-Petrin (LP) estimator, the Ackerberg-Caves-Frazer (ACF) estimator, and the naïve Ordinary Least Squares (OLS) estimator for comparison. To achieve a feasible measurement of TFP, I adopt the internal imputation technique proposed by Gal (2013), who calculates the value-added output by the difference between turnover and material cost. I measure labor input by the logarithm of the cost of employees and capital stock by the logarithm of fixed assets. To proxy for unobserved productivity, I use the logarithm of investment and material costs. All series are deflated using appropriate deflators from the EUKLEMS dataset. To assess the robustness of my findings, I also re-estimate TFP using alternative proxies for output and input variables (Table A6 in the Appendix). Specifically, a firm's value-added output is substituted by its turnover, and its capital stock is determined by the standard Perpetual Inventory Method (PIM, see Appendix C). This approach aims to systematically investigate the sensitivity of TFP estimates to variations in input-output specifications. Through the examination of descriptive statistics and baseline results, it is evident that the empirical findings using TFP measures obtained by these techniques are consistent with one another.

4.3 Descriptive Statistics

The final dataset comprises an unbalanced panel of 137,193 firm-year observations from 16 European countries. The distribution of firms across Europe is not uniform, with France, Italy, and Sweden accounting for over 51% of the total observations. The number of observations per country, as shown in Table 2, also varies across years. Some countries exhibit a gradual increase in observations, while others experience a decline. Notably, there are instances where no observations are reported for specific years, such as the Netherlands from 2009 to 2013, or Portugal during 2011-2013.

Table 2 - Number of Observations by Year and Country

Country	2006	2007	2008	2009	Year 2010	2011	2012	2013	Total
Austria	2	1	1	77	159	206	219	231	896
Belgium	1,086	1,151	1,120	1,069	1,149	1,323	1,342	1,328	9,568
Czech Republic	1,518	1,748	1,462	1,424	1,858	1,979	1,924	1,682	13,595
Germany	645	1,075	1,255	1,334	1,545	1,843	1,932	1,727	11,356
Finland	1,104	1,258	1,095	929	980	1,106	1,233	1,262	8,967
France	3,862	3,698	3,203	2,570	2,780	2,873	1,975	2,011	22,972
Hungary	16	50	174	175	231	233	239	293	1,411
Italy	2,661	3,742	3,647	3,490	3,283	3,863	5,484	5,500	31,670
Luxembourg	0	1	14	15	24	32	20	24	130
Latvia	0	5	1	1	5	9	10	9	40
Netherlands	14	20	10	0	0	0	0	0	44
Poland	687	870	885	1,012	888	650	356	229	5,577
Portugal	0	1,271	1,291	1,274	15	0	0	0	3,851
Sweden	2,075	2,383	2,397	2,404	2,677	2,897	2,840	2,784	20,457
Slovenia	234	264	255	211	214	315	314	314	2,121
Slovakia	374	490	506	479	636	687	692	674	4,538
Total	14,278	18,027	17,316	16,464	16,444	18,016	18,580	18,068	137,193

Table 3 presents descriptive statistics for the whole sample,[7] where each observation corresponds to a single firm in a given year. The average value-added output is approximately 227 Mio. US$ On average, each firm employs 115 employees with associated employee costs amounting to about $65 Mio. US$ per annum. The average total assets and fixed assets are roughly $387 Mio. US$ and $160.5 Mio. US$, respectively. Regarding industry-specific and macro-level information, the industry profitability stands at approximately 0.345, indicating that the industry, on average, generates a profit of 34.5% of its value-added output. The GDP of the countries included in the sample amounts to 1.425 trillion US$ per year, with government revenues averaging 46.9% of GDP, and government expenses averaging 49.4% of GDP. The average statutory corporate income tax rate is 28.5%, while the EMTR and EATR are lower at 12.5% and 24.4%, respectively. Multinational enterprises (MNEs) constitute 57.2% of the entire sample.

[7] The descriptive statistics for each sub-sample is available in Table A4-Appendix D.

Table 3 - Descriptive Statistics of Firm Characteristics

Total sample	N	Mean	Median	SD
Value added ($1000s)	137,193	226.938	43.992	1361.059
Cost of employees ($1000s)	137,193	64.861	13.657	373.135
Number of employees	137,193	114.541	27.000	529.805
Total assets ($1000s)	137,193	386.866	61.156	3,267.141
Fixed assets ($1000s)	137,193	160.526	10.650	1,917.682
Industrial profitability	137,193	0.345	0.324	0.132
GDP ($1000,000,000s)	137,193	1,425.588	578.742	1,181.633
Government revenue (%)	137,193	0.469	0.476	0.046
Government expense (%)	137,193	0.494	0.500	0.045
Statutory corporate tax rates	137,193	0.285	0.295	0.055
EMTR	137,153	0.125	0.153	0.074
EATR	137,153	0.244	0.247	0.046
MNEs	137,193	0.572	1	0.495

This table presents descriptive statistics for observations in the main analysis. The variable 'value-added' represents the difference between turnover and material costs, adjusted by appropriate price deflators from the EUKLEMS dataset. The industrial profitability ratio for each industry is calculated as gross operating surplus divided by value added, derived from the 2007 U.S. Benchmark Input–Output Database. The statutory corporate income tax rates, inclusive of average local taxes and surtaxes, are obtained from KMPG (2006) and the KPMG corporate tax tables. The effective marginal tax rate (EMTR) and effective average tax rate (EATR) have been derived from the Centre for Business Taxation at the University of Oxford. Government revenue and government expenditure are represented as ratios of total government revenue and government expenditure, respectively, to GDP. 'Tax-haven MNEs' is a dummy variable that indicates the presence of subsidiaries in tax-haven jurisdictions for firms in the analysis.

Table 4 presents the TFP estimates using the described methodologies, whereas statistics of TFP based on alternative choices of input and output proxies are documented in Table A5 in Appendix D. The results indicate that the WRDG and LP methods produce similar estimates of TFP for both firm and frontier levels (see also Van Beveren, 2012; Kané, 2022). The OP and ACF method produce slightly lower TFP values, while the OLS estimator produces remarkably lower TFP levels. Regarding the TFP gap, all five methods yield a similar disparity in productivity level between lagging firms and the frontier. Note that the TFP gap is calculated based on the ratio of the TFP level of the frontier divided by the TFP level of each individual firm. Thus, the TFP gap estimated by WRDG method as 0.996 implies that the level of TFP of the frontier is approximately $e^{0.996} \approx 2.612$ times as high as the level of TFP of the average firm. TFP growth rates do not differ significantly for different TFP measurement methods. On average, TFP at firms increases by 6% per annum, which is faster than the frontier's growth rate of 0.5% annually. Comparing to the study of Gemmell et al., (2008) on the Amadeus database during 1995-2005, the average TFP growth rate has increased (from 2.7 to 6 percent), while the growth rate at the frontier remains stable.

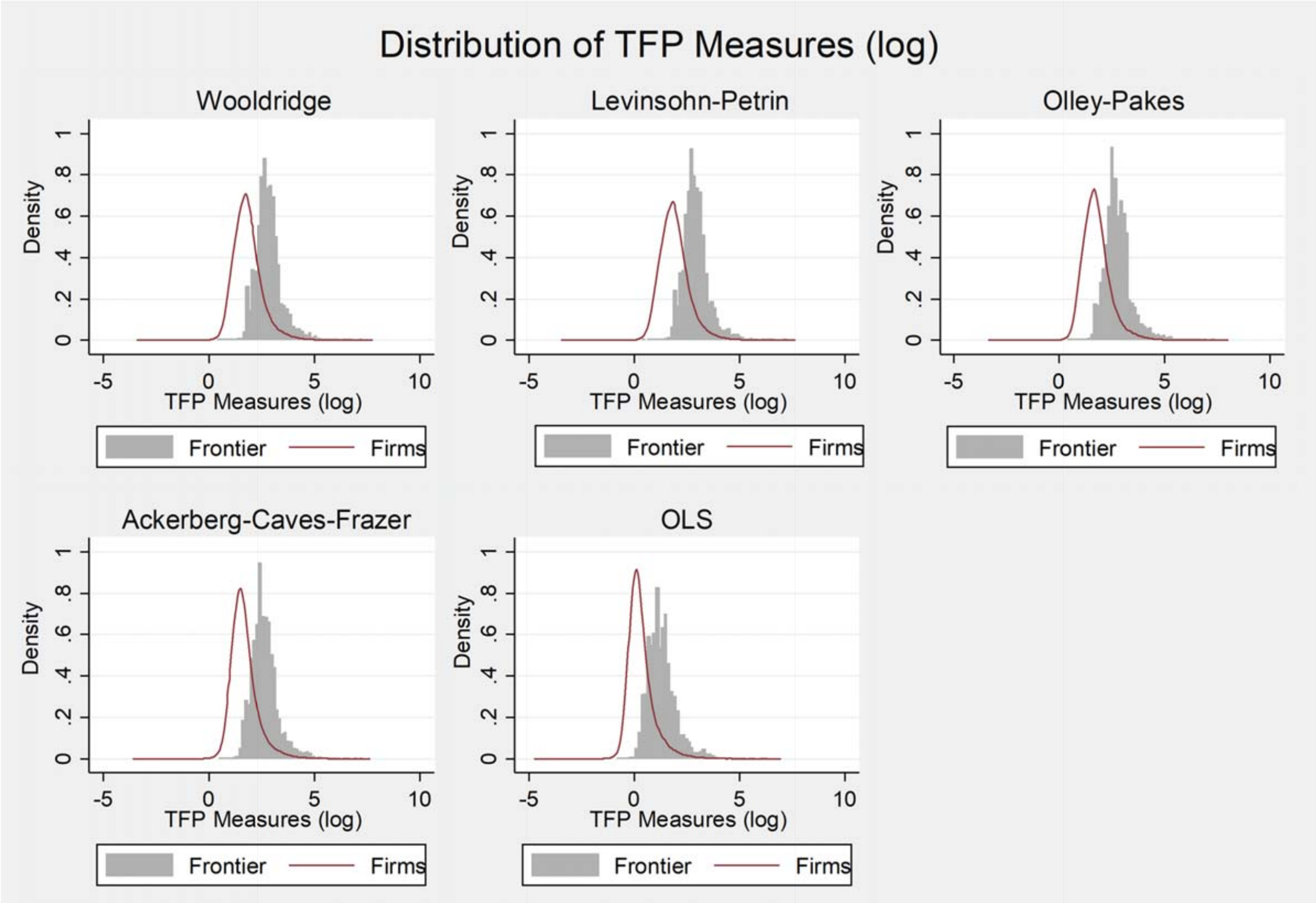
Table 4 - Descriptive Statistics of TFP Measures

Number of observations: 137,193	Mean (SD)				
	WRDG	LP	OP	ACF	OLS
Firms' TFP estimates (log)	1.825 (0.676)	1.896 (0.692)	1.773 (0.671)	1.656 (0.632)	0.305 (0.622)
Frontiers' TFP estimates (log)	2.826 (0.610)	2.909 (0.596)	2.775 (0.627)	2.628 (0.617)	1.298 (0.658)
TFP gap of frontier to firm (log)	0.996 (0.702)	1.011 (0.704)	0.995 (0.707)	0.961 (0.687)	0.978 (0.705)
Firms' TFP growth (%)	0.064 (1.043)	0.064 (0.934)	0.065 (1.195)	0.060 (1.093)	0.061 (1.506)
Frontiers' TFP growth (%)	0.004 (0.225)	0.004 (0.208)	0.005 (0.258)	0.005 (0.348)	0.006 (0.333)

This table presents the statistics of Total factor productivity (TFP) of firm and frontier measured by using the equation $y_{it} = \alpha_0 + \beta l_{it} + \gamma k_{it} + \delta_{it} + \varepsilon_{it}$, at which y_{it} is the (log) value-added output, l_{it} is (log) cost of employees and k_{it} is (log) total assets for firm *i* in year *t*, δ_{it} represents for TFP, and ε_{it} is white noise. WRDG, LP, OP, ACF, and OLS stands for the Wooldridge, Levinsohn-Petrin, Olley-Pakes, Ackerberg-Caves-Frazer, and Ordinary Least Squares estimator, respectively. The frontier is defined as firms that lie above the 95th percentile of the TFP distribution in each country–industry time period. The TFP gap is calculated based on the ratio of the TFP level of the frontier divided by the TFP level of each individual firm.

Figure 1 visualizes the distribution of TFP measures (log) at both firm and frontier levels used in the main analysis. The figure illustrates that while techniques yield slightly different TFP estimates (OLS estimates are remarkably lower than the others), the overall firm-frontier patterns exhibit stability. Notably, the similar distributions at both firms' and frontier's productivity across advanced TFP estimators (WRDG, OP, LP, and ACF) aligns with Syverson's (2011) argument on limited sensitivity to productivity measurement choices. Additionally, an alternative TFP measure based on a distinct input-output set (see Figure A1 in Appendix D) also exhibits a similar productivity distribution across measurement techniques.

Figure 1 - Distribution of (log) TFP of Firms and Frontier



Source: Author's own Illustrations

5. Empirical Findings

5.1 CITR and Productivity Growth

Table 5 documents the baseline regression results of Equation (1). The first column examines the direct association between CITR and productivity growth without controls. Columns 2 and 3 present results for the baseline econometric specification without and with controls. To assess the initial robustness of the estimations, the last four columns consider additional aspects such as profit-shifting opportunities, sampling bias, and alternative specifications. Further validation checks are provided in Subsection 5.4.

Across all columns, I find a positive association between a firm's productivity growth and the TFP growth of the technological frontier ($\Delta lnTFP_F$), as well as a positive coefficient for the productivity gap ($lnTFPGap$) suggesting that productivity catch-up becomes harder for firms being closer to the technological frontier.

These findings provide evidence for spillover effects of productivity growth at the frontier as well as productivity catch-up and align with previous research (Singh, 2016; Hartmann et al., 2021). Furthermore, the estimated coefficients of spillover effects and TFP catch-up in my paper compare favorably with those reported by Gemmell et al. (2018).

In line with Hypothesis H1b, I obtain a positive and statistically significant coefficient of $CITR$ in model 1 (0.160), implying that higher CIT rates are positively associated with TFP growth. Therefore, on the sample average, factors supporting a positive association between corporate taxation and TFP growth (investment quality, squeeze-out of low productivity firms and spillover effects of public investments to agglomeration economies) seem to outweigh negative effects of corporate taxation on TFP growth (higher user costs of capital and liquidity constraints).

Table 5 - Baseline Results

Dependent variable: $\Delta\ln TFP_i$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\Delta\ln TFP_F$	0.269***	0.269***	0.268***	0.275***	0.332***	0.100***	0.103***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnTFPGap	0.468***	0.540***	0.581***	0.597***	0.846***	0.144***	0.174***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CITR	0.160***	0.409***	0.389***	0.474***	0.345	0.682***	0.743***
	(0.007)	(0.000)	(0.000)	(0.000)	(0.415)	(0.000)	(0.000)
lnTFPGap ×CITR		-0.267***	-0.260***	-0.277***	-0.472**	-0.204***	-0.277***
		(0.003)	(0.004)	(0.009)	(0.032)	(0.000)	(0.000)
I_{jt}			0.085*	0.081	0.297	0.050**	0.055**
			(0.054)	(0.106)	(0.203)	(0.035)	(0.030)
lnTFPGap × I_{jt}			-0.116***	-0.109**	-0.260***	-0.002	-0.002
			(0.003)	(0.013)	(0.001)	(0.883)	(0.898)
GE			0.167*	0.201**	0.562	-0.062	-0.061
			(0.056)	(0.041)	(0.256)	(0.329)	(0.326)
GR			-0.589***	-0.631***	-0.584	-0.470***	-0.487***
			(0.000)	(0.000)	(0.349)	(0.000)	(0.000)
Observations	140,431	140,431	137,193	113,312	123,468	137,193	137,193
R-squared	0.500	0.501	0.500	0.508	0.693	0.072	0.084
Establishment FE	YES	YES	YES	YES	YES	NO	NO
Year FE	YES	YES	YES	YES	YES	YES	YES
Country FE	NO	NO	NO	NO	NO	YES	NO
Industry FE	NO	NO	NO	NO	NO	YES	NO
Industry-Country FE	NO	NO	NO	NO	NO	NO	YES

This table presents coefficient estimates and t-statistics (in brackets) of Equation (1) at which TFP is measured by the benchmark (WRDG) method. The dependent variable is the rate of productivity growth in firm *i* in year *t*. The frontier *F* is defined as the 95th percentile of the TFP distribution in each country-industry-year combination. The TFP gap is measured as the log ratio of TFP of the frontier *F* over TFP of firm *i* in industry *j*, country *c* in year *t*. I_{jt} is the industrial profitability, GE and GR stand for the total government expenditure and total government revenue, respectively. Appendix B provides detailed variable definitions. All regressions use the whole sample, except regression 4 that uses only observations from non-tax haven firms. Regression 5 includes probability weights, while regressions 6 and 7 replace firm fixed effect by country- and industry-, and country-industry fixed effects, respectively. *, **, and *** indicate statistical significance at the levels of 10, 5, and 1 percent, respectively. Standard errors are clustered at the firm level and reported in parentheses.

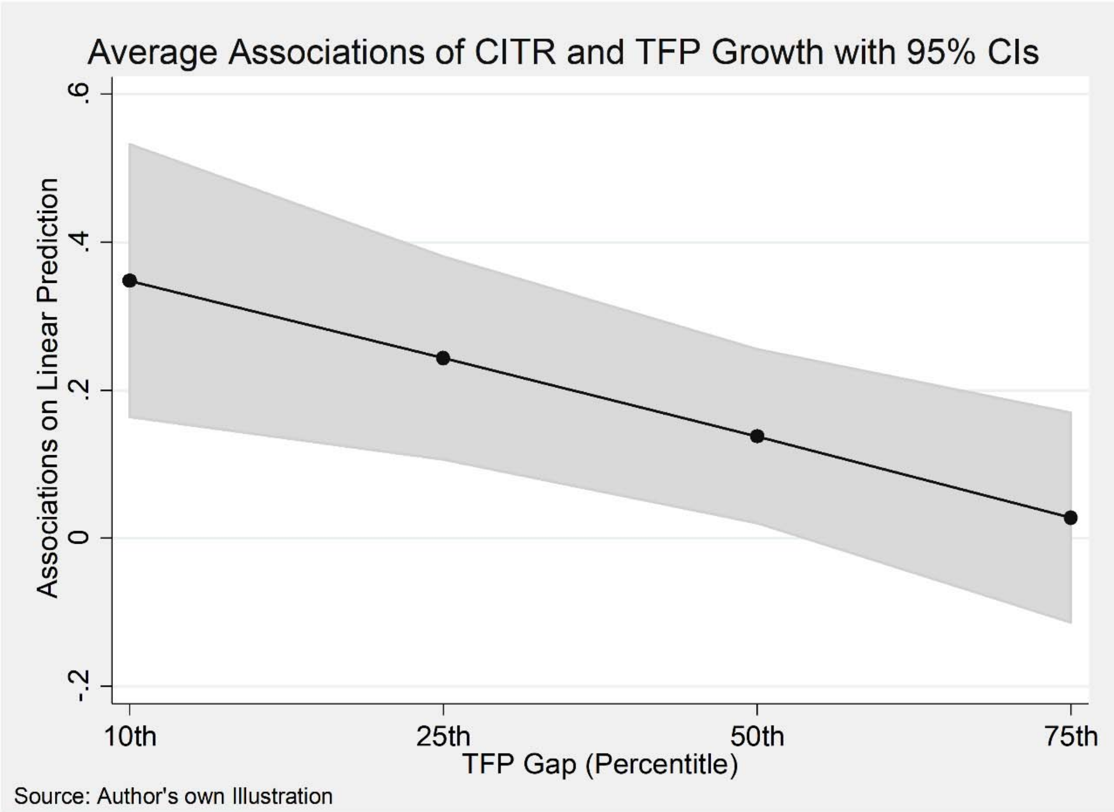
Notably, the results of models 2 and 3 reveal a nonlinear relationship between corporate taxation and productivity growth. In particular, adding the interaction term of *CITR* and productivity catch-up, as expressed in Equation (1), provides evidence for a negative and statistically significant association of *CITR* and productivity catch-up (supporting Hypothesis 2) as already shown by the literature (e.g., Gemmell et al., 2018). Meanwhile, the aforementioned direct association of *CITR* and productivity growth (Hypothesis 1b) seems to become stronger and remains positive and statistically significant. Indeed, compared to model 1 (coefficient 0.160), I observe a much larger positive regression coefficients for *CITR* in models 2 (0.409) and 3 (0.389). This suggests that the negative association with the productivity catch-up process biases the *CITR* coefficient in model 1 downwards.

Based coefficients estimated from Regression 3, I find that a 1 percentage point higher CIT rate is associated with an increase in TFP growth of 0.389% for the frontier firm (*lnTFPGap* of zero). For the firm with the average TFP gap, I still find a positive but very small increase in TFP growth of 0.13%. For the firm with the maximum TFP gap, I find that a 1 percentage point higher CIT rate is association with reduction in TFP growth of 0.747%.[8] This describes the non-linear relationship between CIT rates and TFP growth. Additionally, I document the average association of CITR with a firm's TFP growth across varying firm-frontier distances[9] in Figure 2, further demonstrate that the positive relationship between CITR and firm's TFP growth is deteriorated by the TFP gap existing between lagging firms and the frontier. Consequently, the findings imply a moderating role of the TFP gap between frontier and non-frontier firms in shaping the relationship of taxation and productivity growth.

[8] The association of TFP growth and the CITR rate is described by $\Delta lnTFP = 0.389 - 0.26\ lnTFPGap$. For a TFP gap of 1 (no gap), ln TFP Gap becomes zero and I obtain a semi-elasticity of 0.389. For the sample average of *lnTFPGap* of 0.996, I obtain a semi-elasticity of 0.13 (= 0.389 – 0.26 × 0.996). For the maximum value of *lnTFPGap* of 4.369, I obtain a negative semi-elasticity of -0.747 (= 0.389 – 0.26 × 4.369).

[9] The average associations are measured when the TFP Gap is set to its values at the 10th, 25th, 50th, and 75th percentiles, holding all other independent variables at their means.

Figure 2 - Average Associations of CITR and TFP Growth



Moving to the initial sensitivity checks, model 4 excludes firms operating in tax-haven jurisdictions. The estimated results remain qualitatively and quantitatively unchanged, implying that the baseline findings are robust to the presence of observations in tax havens. In model 5, I address the under-representation of small and medium-sized firms in the database by using the probability weight approach of Devereux and Griffith (2003) [10]. While the nonlinear relationship between *CITR* and productivity growth remains significant, the corresponding coefficients are significantly higher than those estimated in the baseline model, suggesting stronger taxation-productivity associations for smaller firms compared to the larger firms (see also Table 7). In the last two columns, I show that the results remain robust if I replace firm-fixed effects either by country-fixed effects and industry-fixed effects (column 6) or by country-industry-fixed effects (column 7). It is also worth noting that the variation in coefficients for different specifications of

[10] I use information on the distribution of firms by size class and industry from Eurostat Structural Business Statistics to determine the weights for each size-industry pair relative to the total number of firms in each country in the sample. The use of probability weights in regression 5 helps to ensure that the estimated sample is more representative of the true population of firms in all industries for each country, and thus provides additional evidence that the baseline findings are robust.

fixed effects suggests that macro-level factors, firm-specific traits, and industrial contexts may influence the relationship between the variables to some extent (Syverson, 2011).

Overall, Table 5 provides robust empirical evidence on a nonlinear relationship between *CITR* and TFP growth at the firm level. Although higher *CITR* are positively associated with firms' TFP growth on average (Hypothesis 1b), a negative relationship emerges between *CITR* and the productivity catch-up for firms lagging behind (Hypothesis 2). Thus, the CITR-productivity growth relationship is moderated by the distance existing between the industrial frontier and the laggards, suggesting that firms positioned further away from the top tier encounter a competitive disadvantage due to higher CIT rates. Notably, these main findings retain significant even when employing alternative TFP metrics derived from diverse input-output proxies (see Table A6 in Appendix E).

5.2 Baseline Results with Different TFP Measures

In this section, I replicate the baseline analysis using alternative TFP estimators proposed by Levinsohn and Petrin (2003), Olley and Pakes (1996), Ackerberg et al. (2015), as well as naive conventional OLS estimates. The findings in Table 6 consistently demonstrate the statistical significance of the positive coefficient of *CITR* and the negative coefficient of *TFP gap* × *CITR* across different TFP measures. These results confirm the existence of a nonlinear relationship between *CITR* and productivity growth at the micro level. Additionally, results remain not only qualitatively but also quantitatively robust for different TFP measures as well as for specifications without potentially endogenous control variables (see Table A7 in Appendix E). Overall, Table 6 suggests that TFP measurement issues do not play an important role regarding the association of corporate tax rates and TFP growth.

Table 6 - Baseline Results with Alternative TFP using Different Techniques

Dependent variable: $\Delta lnTFP_i$	LP (1)	OP (2)	ACF (3)	OLS (4)
$\Delta lnTFP_F$	0.273***	0.261***	0.265***	0.251***
	(0.000)	(0.000)	(0.000)	(0.000)
lnTFPGap	0.589***	0.569***	0.581***	0.555***
	(0.000)	(0.000)	(0.000)	(0.000)
CITR	0.402***	0.389***	0.441***	0.428***
	(0.000)	(0.000)	(0.000)	(0.000)
lnTFPGap × CITR	-0.268***	-0.240***	-0.265***	-0.228***
	(0.003)	(0.009)	(0.003)	(0.010)
Observations	137,193	137,193	137,193	137,193
R-squared	0.502	0.497	0.496	0.489
Establishment FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Controls	YES	YES	YES	YES

This table presents coefficient estimates and t-statistics (in brackets) for Equation (1), with TFP measured by different methodologies: regression 1: Levinsohn-Petrin (LP) estimator; regression 2: Olley- Pakes (OP) estimator; regression 3: Ackerberg et al., (ACF) estimator and regression 4: OLS estimator. The dependent variable is the rate of productivity growth of firm *i* in year *t*. The frontier *F* is defined as the 95th percentile of the TFP distribution in each country-industry-year cell. The TFP gap is measured as the log of the ratio of TFP at the frontier F over TFP of firm *i* in industry *j*, country *c* and year *t*. Appendix B provides detailed variable definitions. All regressions include control variables, firm- and year-fixed effects. Controls include industry profitability interacted with TFP gap, total government expenditure, and total government revenues (ratio to GDP). *, **, and *** indicate statistical significance at the levels of 10, 5, and 1 percent, respectively. Standard errors are clustered at the firm level and are reported in parentheses.

5.3 Heterogeneity Effects

5.3.1 Firm Size

Table 7 presents the estimation results for various subsamples with regard to firm size. The first two columns report the estimation of Equation (1) for sub-samples of large firms (≥ 250 employees) and SMEs (< 250 employees), respectively. To account for profit shifting opportunities in tax-haven subsidiaries, I perform the analysis on non-haven subsamples in regression 3 (non-haven large firms) and 4 (non-haven SMEs). Additionally, I investigate three sub-samples of SMEs, namely micro firms (< 10 employees), small firms (10 to 49 employees) and medium-sized firms (50 to 249 employees) in the models 5, 6, and 7. In the last two columns, I consider an alternative specification outlined in Equation (2) that accounts for an SME dummy variable and interaction terms of *SME* and main variables of interest.

All models once again demonstrate a positive and significant relationship between firms' TFP growth and both the growth of technological leaders and the TFP gap. These positive associations are more pronounced for smaller firms, indicating a stronger spillover and catch-up effect for SMEs, in line with Griffith et al. (2009) and Gemmell et al. (2018). The coefficient estimates for the main variables of interest *CITR* and the interaction term *lnTFPGap* × *CITR* are both insignificant for large firms but statistically significant for all subsamples of SMEs. This suggests that the relationship between CIT rates and TFP growth is more profound for SMEs than for large firms. This confirms previous studies (Gemmell et al., 2018; Romero-Jordán et al., 2020). These results remain qualitatively and quantitatively robust even when analyzing non-haven sub-samples or when not including (potentially endogenous) control variables (see Table A8 in Appendix E).

The models 5 to 7 show statistically significant results for all types of SMEs (medium, small and micro). While this is not tested statistically, the coefficient sizes suggest stronger associations of CIT rates and TFP growth for the smaller size classes (i.e., micro and small). That holds for the direct association with *CITR* as well as for the interaction term *lnTFPGap* × *CITR*.

The estimates of Equation (2) yield noteworthy results. The coefficient estimates for SME in both columns 8 (-0.205) and 9 (-0.215) indicate a weaker average TFP growth for SMEs. The positive and significant coefficients of the interaction term *SME* × *lnTFPGap* provide empirical support for a stronger productivity catch-up of SMEs. More importantly, the coefficient estimates for the interaction terms *SME* × *CITR* and *SME* × *lnTFPGap* × *CITR* are both statistically significant confirming that the productivity growth and catch-up of SMEs are more sensitive to corporate taxation compared to large firms. The findings also remain robust after excluding all tax-haven subsidiaries.[11] Thus, findings do not seem to be driven by profit shifting.

[11] Although the significance of the coefficient β_4 for the interaction term *SME* × *lnTFPGap* × *CITR* diminishes in the non-haven sample, its magnitude and other coefficients remain consistent. Thus, the overall relationship might still be robust and the lack of significance of β_4 could be due to the reduced sample size.

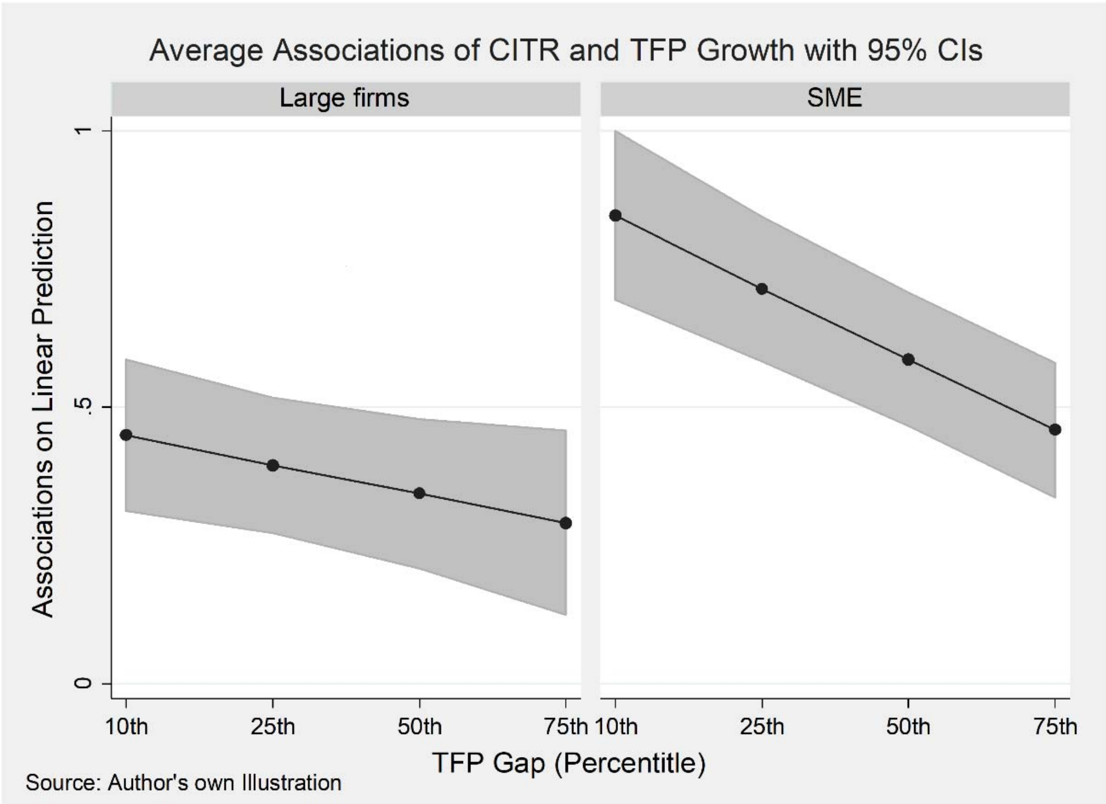
Table 7 - Heterogeneity – Firm Size

Dependent variable: $\Delta \ln TFP_i$	Large	SME	Non-haven Large	Non-haven SME	Medium	Small	Micro	Whole sample (no Medium)	Non-haven sample (no Medium)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\Delta \ln TFP_F$	0.196***	0.274***	0.198***	0.280***	0.189***	0.257***	0.371***	0.115***	0.117***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnTFPGap	0.426***	0.602***	0.471***	0.618***	0.425***	0.631***	0.894***	0.102***	0.131***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CITR	0.140	0.485***	0.300	0.566***	0.370***	0.895***	0.864*	0.472***	0.509***
	(0.375)	(0.000)	(0.104)	(0.000)	(0.007)	(0.000)	(0.052)	(0.000)	(0.000)
lnTFPGap × CITR	-0.188	-0.285***	-0.303	-0.308***	-0.256*	-0.395**	-0.606**	-0.124*	-0.203**
	(0.270)	(0.005)	(0.148)	(0.008)	(0.064)	(0.018)	(0.039)	(0.076)	(0.039)
SME								-0.205***	-0.215***
								(0.000)	(0.000)
SME × lnTFPGap								0.093***	0.083**
								(0.000)	(0.013)
SME × CITR								0.429***	0.455***
								(0.000)	(0.000)
SME × lnTFPGap × CITR								-0.179**	-0.137
								(0.031)	(0.219)
Observations	12,369	124,824	7,869	105,443	27,583	45,645	32,215	101,135	85,729
R-squared	0.416	0.508	0.415	0.515	0.441	0.521	0.622	0.078	0.082
Establishment FE	YES	YES	YES	YES	YES	YES	YES	NO	NO
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Country FE	NO	NO	NO	NO	NO	NO	NO	YES	YES
Industry FE	NO	NO	NO	NO	NO	NO	NO	YES	YES

This table presents the results of tests comparing large firms and SMEs. The dependent variable is the rate of productivity growth in firm i in year t. SME is a dummy variable for firms fewer 250 employees. Regressions 1-7 reports the results for Equation (1) with firm- and year fixed effects for specific sub-sample by firm size. Regressions 1 and 3: large firms (at least 250 employees), regressions 2 and 4: SMEs (fewer than 250 employees), regression 5: medium firms (50 to 249 employees), regression 6: small firms (10 to 49 employees), regression 7: micro firms (less than 10 employees). Regressions 8 and 9 report the results for Equation (2) with county-, industry-, and year fixed effects for whole sample excluding medium-sized firms. In regressions 3, 4, and 9, I exclude all firms operating in tax-havens jurisdictions. Appendix B provides detailed variable definitions. *, **, and *** indicate statistical significance at the levels of 10, 5, and 1 percent, respectively. Standard errors are clustered at the firm level and are reported in parentheses.

Figure 3 documents the average associations of CITR and TFP growth for both SMEs and large firms. It highlights a) a stronger positive average association for SMEs as well as a steeper negative association for the TFP gap reducing the positive association between CITR and TFP growth for lagging-behind SME firms.

Figure 3 – Average Associations between CITR and TFP Growth by Firm Sizes



5.3.2 Multinational Status

In Table 8, I re-estimate Equation (1) for different subsamples with regard to MNE status. Regression 1, 2 and 3 document the estimates for MNEs, non-haven MNEs (i.e. MNEs without any subsidiary or shareholding in a tax-haven country as documented by Table A2 in Appendix A), and domestic firms, respectively. The models 4 and 5 describe the results of the whole sample and the non-haven sample using Equation (3), where a categorical variable *MNE* with a value of one for MNEs is introduced along with its interactions with main explanatory variables.

As shown in the first three columns, the coefficients of *CITR* and the interaction term *lnTFPGap* × *CITR* are both insignificant for MNEs, including non-haven MNEs. However, they are statistically significant for domestic firms, indicating that corporate taxes are more relevant for TFP growth of domestic entities. In regression 2, where all MNEs with subsidiaries in tax havens are excluded, the positive coefficient of *CITR* is (weakly) significant and its magnitude increases from 0.19 to 0.275. This can be taken as (weak) evidence that profit-shifting opportunities of MNEs are responsible for a lower average relevance of corporate taxation for the TFP growth of MNEs.

The last two columns present results for Equation (3). The positive and significant coefficients of *MNE* indicate a higher average TFP growth for multinational firms. This is consistent with prior research indicating that high-performing firms engage in international business (Bernard & Jensen, 1999; Greenaway & Yu, 2004; Yeaple, 2005). In regression 4, the significance of the coefficient estimates of *MNE* × *CITR*, *MNE* × *lnTFPGap*, and *MNE* × *CITR*× *lnTFPGap* reflect the discrepancy in the tax-productivity relationship between MNE and domestic firms.

Notably, those coefficients lose their statistical significance, when I exclude tax-haven MNEs (regression 5). This confirms the results of column (2) and suggests that profit-shifting opportunities of MNEs are one reason for the lower relevance of CITR for the TFP growth of MNEs. Furthermore, the findings remain robust for specifications without control variables (see Table A9 in Appendix E).

Overall, I find evidence for stronger associations of *CITR* with productivity growth for SMEs and for domestic firms that both have typically lower resources for productivity-enhancing investments and have lower average TFP growth. With regard of the MNE firms, part of the lower relevance of corporate taxation for productivity growth seems to be driven by tax avoidance activities (i.e., profit shifting to low tax locations) of these firms.

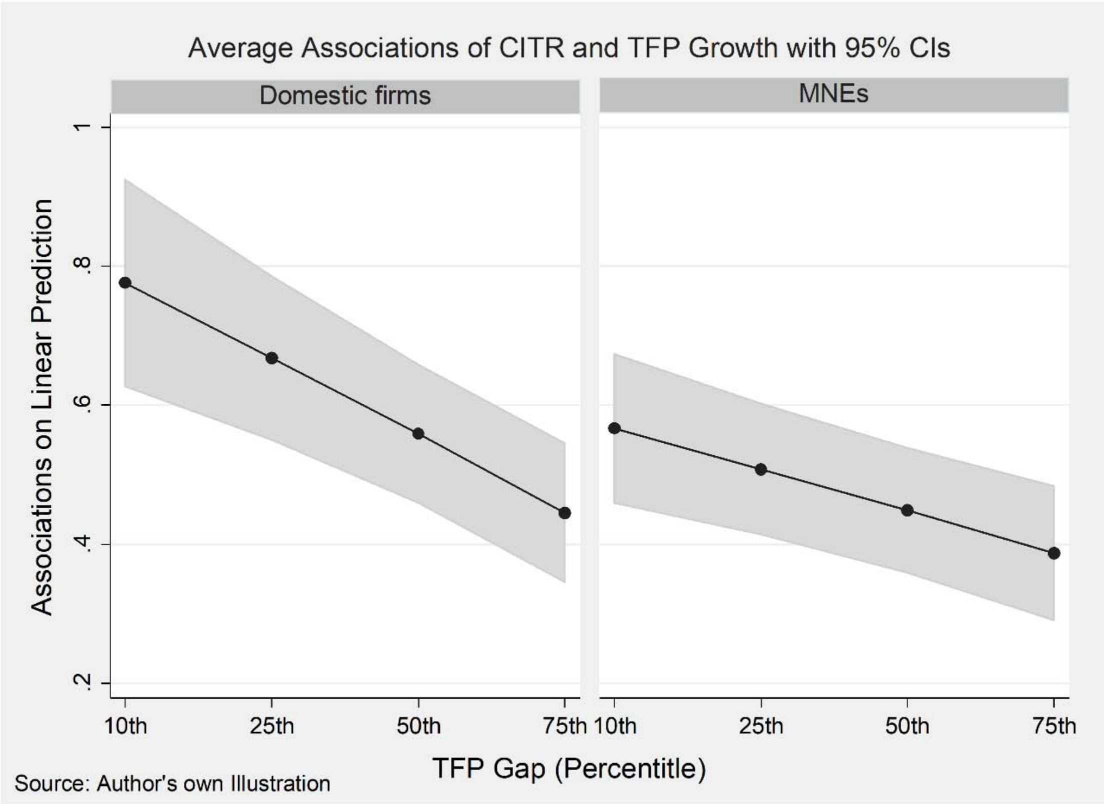
Table 8 - Heterogeneity – Multinational Status

Dependent variables: $\Delta \ln TFP_i$	MNE (1)	Non-haven MNE (2)	Domestic (3)	Full sample (4)	Non-haven sample (5)
$\Delta \ln TFP_F$	0.255***	0.265***	0.283***	0.103***	0.106***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnTFPGap	0.538***	0.559***	0.635***	0.185***	0.187***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CITR	0.190	0.275*	0.731***	0.819***	0.837***
	(0.142)	(0.097)	(0.000)	(0.000)	(0.000)
lnTFPGap × CITR	-0.170	-0.196	-0.361**	-0.269***	-0.270***
	(0.166)	(0.216)	(0.013)	(0.000)	(0.000)
MNE				0.124***	0.093***
				(0.000)	(0.001)
MNE × lnTFPGap				-0.061***	-0.032
				(0.002)	(0.165)
MNE × CITR				-0.229***	-0.158*
				(0.006)	(0.085)
MNE × lnTFPGap × CITR				0.123*	0.046
				(0.071)	(0.552)
Observations	78,412	54,531	58,781	137,193	113,312
R-squared	0.472	0.479	0.529	0.076	0.079
Establishment FE	YES	YES	YES	NO	NO
Year FE	YES	YES	YES	YES	YES
Country FE	NO	NO	NO	YES	YES
Industry FE	NO	NO	NO	YES	YES
Controls	YES	YES	YES	YES	YES

This table presents coefficient estimates and t-statistics (in brackets) for Equation (1) and Equation (3). The dependent variable the log of TFP growth of firm *i* in year *t*. MNE is a dummy variable for multinational firms. Regressions 1-3 report the results of Equation (1) with firm- and year fixed effects for specific sub-samples. Regressions 1 and 2: MNEs and non-haven MNEs, regressions 3: domestic firms. Regressions 4 and 5 report the results of Equation (3) with county-, industry-, and year fixed effects for the whole sample and the non-haven sample, respectively. Appendix B provides detailed variable definitions. *, **, and *** indicate statistical significance at the levels of 10, 5, and 1 percent, respectively. Standard errors are clustered at the firm level and are reported in parentheses.

Figure 4 documents the average associations of CITR and TFP growth for both domestic and MNE firms. It highlights a) a stronger positive average association for domestic firms as well as a steeper negative association for the TFP gap reducing the positive association between CITR and TFP growth for lagging-behind domestic firms.

Figure 4 - Average Associations of CITR and TFP Growth by Multinational Status



5.4 Robustness tests

In the final section, I present additional tests to validate the robustness of the findings, involving an investigation on different tax measures and alternative technological frontiers. I illustrate results in tables 9 and 10. The study acknowledges that relying on statutory corporate tax rates will not capture the association of the personal income tax with TFP growth (Mertens et al., 2013). Moreover, previous research has indicated that the statutory tax rate may overlook various elements of the corporate tax system, such as amortization, investment deductions, tax loss compensation, and deductibility of financial costs (Vartia, 2008; Romero- Jordán et al., 2020). To address these issues, I include the top personal income tax rate (PITR) in Equation (1), and then conduct a sensitivity analysis replacing the statutory corporate income tax rate (CITR), either by the effective marginal tax rate (EMTR) or by the effective average tax rate (EATR). In both cases, results remain robust if I do not consider potentially endogenous control variables in the regressions (see Table A10 and Table A11 in Appendix E).

Table 9 - Robustness Test: Alternative Tax Measures

Dependent variable: $\Delta \ln TFP_i$	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln TFP_F$	0.267***	0.274***	0.267***	0.274***	0.267***	0.274***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnTFPGap	0.585***	0.603***	0.515***	0.525***	0.569***	0.581***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
PITR	0.200***	0.222***				
	(0.000)	(0.000)				
lnTFPGap x PITR	0.077	0.060				
	(1.415)	(0.980)				
CITR	0.433***	0.498***				
	(0.000)	(0.000)				
lnTFPGap x CITR	-0.386***	-0.387***				
	(0.000)	(0.000)				
EMTR			0.042	0.013		
			(0.283)	(0.772)		
lnTFPGap x EMTR			-0.035	-0.019		
			(0.287)	(0.625)		
EATR					0.557***	0.585***
					(0.000)	(0.000)
lnTFPGap x EATR					-0.255**	-0.256**
					(0.018)	(0.039)
Observations	137,153	113,296	137,153	113,296	137,153	113,296
R-squared	0.501	0.508	0.500	0.507	0.500	0.508
Establishment FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES	YES

This table presents the results of further tests regarding additional or alternative tax measures. The dependent variable is the log of the TFP growth of firm *i* in year *t*. Models 1 and 2 add the top personal income tax rate (PITR). Regressions 3 and 4 use the effective marginal tax rate (EMTR) and regressions 5 and 6 the effective average tax rate (EATR) as alternative tax measures. All regressions include controls that consist of industry profitability interacted with TFP gap, total government expenditure, and total government revenues (ratio to GDP), firm- and year-fixed effects. Regressions 1, 3, 5 are estimated for the whole sample, while regression 2, 4, 6 are limited to the non-haven sample. Appendix B provides detailed variable definitions. *, **, and *** indicate statistical significance at the levels of 10, 5, and 1 percent, respectively. Standard errors are clustered at the firm level and are reported in parentheses.

The first two columns in Table 9 reveal a positive relationship between the top PITR and productivity growth, but no significant relationship with the catch-up process. Additionally, the coefficients for *CITR* and the interaction term *TFP gap* $\times$ *CITR* remain significant, indicating the robustness of the nonlinear relationship between the *CITR* and productivity growth when accounting for association with the PITR. Regarding alternative corporate tax measures, the models

3 to 6 indicate that the relationship between corporate taxation and productivity growth is only statistically significant for the EATR but not for the EMTR.

A comparison with prior research also indicates that the findings of Gemmell et al. (2018) based on the statutory rate have a stronger and more robust association with productivity growth than the results of Devereux and Griffith (2003) who analyze the EMTR. Notably, R&D and innovative activities often involve long-term investment horizons, and their decision-making is influenced by the overall tax treatment of income, as captured by the EATR, rather than the marginal tax rate.

The contrasting results for the EATR and the EMTR underscore the relevance of the overall tax burden and not only the marginal tax rate for TFP growth. This highlights the significance of considering the average tax liability across all income levels in analyzing the tax-productivity association. The results are not sensitive to subsidiaries being located in tax-haven jurisdictions, as demonstrated in regression 5 and 6.

In Table 10, I assess whether the findings derived from Equation (1) are sensitive to the definition of technological competition and the frontier at the industry level. In the baseline model, I follow Gemmell et al. (2018) and define the frontier at the country-industry-year level as 95th percentile. In Table 10, I employ an alternative definition of the productivity frontier, including the maximum TFP value and the TFP level of firms positioned at the 99th percentile. Additionally, I account for technological transfer across borders and the economic integration of the EU single market by establishing frontiers based on the 95th percentile at the industry-year level for the full EU sample. These new frontiers are used to replicate the analysis of Equation (1).

Additional robustness tests in the Appendix E reveal that the results are also robust to alternative input and output proxies for the calculation of TFP values (Table A6 in Appendix E). Furthermore, results of my various models and specifications are robust to the exclusion of potentially endogeneous control variables (tables A7 to A11).

Table 10 - Robustness Test: Alternative Frontiers

Dependent variables: $\Delta\ln\text{TFP}_i$	Highest TFP level		99^{th} percentile		95^{th} percentile (EU Single Market)	
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta\ln\text{TFP}_\text{F}$	0.058***	0.026***	0.105***	0.036***	0.351***	0.130***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnTFPGap	0.235***	0.077***	0.345***	0.078***	0.818***	0.200***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CITR	1.150***	0.719***	1.196***	0.689***	0.706***	0.715***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnTFPGap x CITR	-0.418***	-0.098***	-0.466***	-0.082***	-0.623***	-0.226***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	133,474	133,474	132,842	132,842	129,829	129,829
R-squared	0.388	0.046	0.418	0.048	0.552	0.059
Firm FE	YES	NO	YES	NO	YES	NO
Year FE	YES	YES	YES	YES	YES	YES
Country FE	NO	YES	NO	YES	NO	YES
Industry FE	NO	YES	NO	YES	NO	YES

This table presents the results of further tests using alternative frontiers. The dependent variable is the log of the rate of TFP growth of firm *i* in year *t*. In regressions 1 and 2, the frontier is the maximum TFP level in each country-industry-year cell. In regressions 3 and 4, the frontier is the 99^{th} percentile of the TFP distribution in each country-industry-year cell. In regressions 5 and 6, the frontier is the 95^{th} percentile of the TFP distribution in each industry-year cell. Controls include industry profitability interacted with TFP gap, total government expenditure, and total government revenues (ratio to GDP). Regression 1, 3, and 5 include firm and year fixed effects, while regression 2, 4, 6 include year, country, and industry fixed effects. Appendix B provides detailed variable definitions. *, **, and *** indicate statistical significance at the levels of 10, 5, and 1 percent, respectively. Standard errors are clustered at the firm level and are reported in parentheses.

6. Conclusion

This research provides an empirical investigation of the relationship between corporate income tax rates and firms' productivity growth, utilizing AMADEUS data of European firms enriched by tax and country information. The study uncovers a nonlinear relationship between CIT rates and total factor productivity (TFP) growth at the firm level. While the direct association between the CIT rate and TFP growth is positive, I also find a negative association of the CIT rate with the TFP catch-up of lagging firms with lower TFP levels. Moreover, the study examines the heterogeneity in the tax-productivity relationship across different firm types by performing comparisons between large and small firms, as well as between multinational and domestic firms. The results indicate that this nonlinear relationship is more profound for domestic and SME firms that are typically also less productive. This heterogeneity underscores the significance of considering firm size and multinational status when analyzing the association of CIT rates with TFP growth.

I confirm the robustness of my findings by sensitivity tests regarding : a) specifications with and without control variables; b) alternative fixed effects specifications (firm fixed effects, year fixed effects, country fixed effects, industry fixed effects, industry-country fixed effects); c) various TFP measures (OLS; Olley & Pakes, 1996; Levinsohn & Petrin, 2003; Ackerberg et al., 2015); d) the use of alternative input-output proxies in TFP measurement; e) the exclusion of firms with higher profit-shifting opportunities; and f) alternative definitions of the technological frontier. Regarding alternative tax burden measures replacing the statutory corporate income tax rates (CITR) in the baseline setting, I find robust evidence for effective average tax rates (EATR) but not for effective marginal tax rates (EMTR).

Despite the primary results remaining robust in the presence of tax-haven affiliates, a noteworthy difference is observed in the results of MNEs resident in tax and non-tax haven jurisdictions. This discrepancy suggests that international profit-shifting activities with the target of tax avoidance may influence the tax-productivity relationship for multinationals. As a result, future research should delve into these profit-shifting practices in more detail to better comprehend their effects on the tax-productivity nexus for MNEs. Furthermore, the study highlights potential avenues for further exploration. For instance, incorporating TFP estimates at the producer-level input or utilizing more comprehensive information on employees and firm survival could enhance the accuracy of productivity measures and ensure that unobserved shocks are not underestimated. Such improvements in measurement could contribute to a better understanding of the underlying dynamics of the tax-productivity relationship.

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Appendix

Appendix A: Tax rate and Tax haven

Table A1 - Tax rate per country and year

Country	2005	2006	2007	2008	2009	2010	2011	2012	2013
Austria	25%	25%	25%	25%	25%	25%	25%	25%	25%
Belgium	34%	34%	34%	34%	34%	34%	34%	34%	34%
Czech Republic	26%	24%	24%	21%	20%	19%	19%	19%	19%
Finland	26%	26%	26%	26%	26%	26%	26%	25%	25%
France	34%	33%	33%	33%	33%	33%	33%	33%	33%
Germany	38%	38%	38%	30%	29%	29%	29%	29%	30%
Italy	37%	37%	37%	31%	31%	31%	31%	31%	31%
Latvia	15%	15%	15%	15%	15%	15%	15%	15%	15%
Luxembourg	30%	30%	30%	30%	29%	29%	29%	29%	29%
Netherlands	32%	30%	26%	26%	26%	26%	25%	25%	25%
Portugal	28%	28%	25%	25%	25%	25%	25%	25%	25%
Romania	16%	16%	16%	16%	16%	16%	16%	16%	16%
Slovakia	19%	19%	19%	19%	19%	19%	19%	19%	23%
Slovenia	25%	25%	23%	22%	21%	20%	20%	18%	17%
Spain	35%	35%	33%	30%	30%	30%	30%	30%	30%
Sweden	28%	28%	28%	28%	26%	26%	26%	26%	22%

Table reports the statutory corporate income tax rate including the federal rates and average local tax rate and the surtaxes by country and year. Tax rates derived from KMPG (2006) and the KPMG corporate tax tables.

Table A2 - List of Tax haven jurisdictions

In a report issued in 2009, the OECD identified the following jurisdictions as tax haven:

Andorra
Anguilla
Antigua and Barbuda
Aruba
Bahamas
Bahrain
Belize
Bermuda
British Virgin Islands
Cayman Islands
Cook Islands
Dominica
Gibraltar
Grenada
Liberia
Liechtenstein
Marshall Islands
Monaco
Montserrat
Nauru
Netherlands
Antilles
Niue
Panama
St Kitts and Nevis
St Lucia
St Vincent & Grenadines
Samoa
San Marino
Turks and Caicos Islands
Vanuatu

Appendix B: Variable Description

Table A3 - Variable Definitions

Variable	Definition	Data Source
Productivity Variables		
$\Delta lnTFP_{ijct}$	The change in the natural logarithm of TFP for firm *i* of industry j, in country c, in year t calculated by the change in natural logarithmic difference of TFP for given firm i $(lnTFP_{ijct} - lnTFP_{ijct-1})$, at which TFP is the total factor productivity level estimated by WRDG estimator on the Cobb-Douglas value-added production function $y_{it} = \alpha_0 + \beta l_{it} + \gamma k_{it} + \delta_{it} + \varepsilon_{it}$. y_{it} is the log real value-added output, l_{it} is log real cost of employees and k_{it} is log of capital stock measured by fixed assets.	Amadeus /EUKLEMS
$\Delta lnTFP_{Fjct}$	The change in the natural logarithm of TFP at the technological frontier F of industry j, in country c, at time t calculated by the logarithmic difference $(lnTFP_{Fjct} - lnTF_{Fjct-1})$, at which the productivity frontier in each country–industry time period is approximated by the productivity of firms that lie above the 95th percentile of the TFP distribution.	Amadeus /EUKLEMS
$lnTFPGap_{ijct-1}$	Lagged natural logarithm of the TFP gap between firm *i* and the technological frontier F in year t calculated as the ratio of the level of TFP of the relevant country-industry frontier to the TFP level of each firm at time *t-1* or $\frac{TFP_{Fjct-1}}{TFP_{ijt}-1}$.	Amadeus /EUKLEMS
Tax Variables		
CIT_{ct}	The statutory corporate income tax rate of country *c,* at time t	KMPG
$EMTR_{ct}$	The effective marginal tax rate of country *c,* at time *t*	Centre for Business Taxation
$EATR_{ct}$	The effective average tax rate of country *c,* at time *t*	Centre for Business Taxation
PTR_{ct}	The top personal income tax rate of country *c,* at time *t*	KMPG
Firm Indicators		
MNE_{ict}	Dummy variable that defines the ownership of firm *i* (1= multi-enterprise, 0= domestic firms).	Amadeus
SME_{ict}	Dummy variable that defines the size of firm i (1= small and medium firms with fewer 250 employees, 0= large firms with at least 250 employees)	Amadeus
Control Variables		
I_{jt}	Profitability ratio of industry j at time t in the U.S. calculated as gross operating surplus divided by value added, and then applied to the 2005–2013 period.	2007 U.S. Benchmark Input–Output Data
GR_{ct},	Ratio of country *c*'s government revenue to GDP	OECD
GE_{ct},	Ratio of country *c*'s government expenditure to GDP	OECD

Appendix C: Estimating Capital Stock at Firm Level

In adherence to the Perpetual Inventory Method (PIM), the level of real capital stock k_{it} in firm i at time t is determined by the level of real capital stock at the immediately preceding time period (k_{it-1}), depreciation rate (σ_{it}), and real investment (I_{it}). This relationship is formally articulated as follows:

$$k_{it} = k_{it-1} \times (1 - \sigma_{it}) + I_{it} \qquad \text{(A.1)}$$

where real investments are estimated as the disparity between the current and lagged book value of fixed tangible asset, k_{it}^{BV} *and* k_{it-1}^{BV}, plus depreciation, deflated by the country and industry specific deflators

$$I_{it} = (k_{it}^{BV} - k_{it-1}^{BV} + DP_{it}^{BV})/PI_t \qquad \text{(A.2)}$$

PI_t is the annual investment price deflator of each country at the 2-digit industry level derived from the Eurostat Database. The depreciation rate is defined as $\sigma_{it} = DP_{it}^{BV}/k_{it-1}^{BV}$

For the first observed year of each firm (t=0), the capital stock is the observed booked value of fixed tangible assets deflated by the price deflators:

$$k_{i0} = k_{i0}^{BV}/PI_0 \qquad \text{(A.3)}$$

Appendix D: Additional Descriptive Statistics

Table A4 - Descriptive Statistics for Sub-Samples

	Observations	Mean	Median	SD
Large firms				
Value added ($1000s)	12,369	1,548.245	652.681	4,188.602
Cost of employees ($1000s)	12,369	463.669	249.744	1,163.685
Number of employees	12,369	827.561	443.000	1,589.664
Total asset ($1000s)	12,369	2,591.771	818.784	9,606.339
Fixed asset ($1000s)	12,369	1,176.157	245.787	4,908.931
TFP level of firm	12,369	11.909	9.353	17.036
TFP level of frontier	12,369	22.937	16.095	29.776
TFP gap	12,369	2.298	1.624	2.844
CIT	12,369	0.281	0.295	0.060
EMTR	12,358	0.134	0.151	0.057
EATR	12,358	0.243	0.263	0.050
Tax-Haven MNE	12,369	0.364	0	0.481
SMEs				
Value added ($1000s)	124,824	96.007	36.207	327.918
Cost of employees ($1000s)	124,824	25.343	11.242	39.090
Number of employees	124,824	43.887	22.000	52.425
Total asset ($1000s)	124,824	168.379	50.226	1,434.847
Fixed asset ($1000s)	124,824	59.886	8.301	1,241.725
TFP level of firm	124,824	8.408	5.474	24.315
TFP level of frontier	124,824	21.638	15.578	29.263
TFP gap	124,824	3.810	2.748	7.987
CIT	124,824	0.285	0.295	0.054
EMTR	124,795	0.124	0.157	0.075
EATR	124,795	0.244	0.247	0.045
Tax-Haven MNE	124,824	0.155	0	0.362
Domestic firms				
Value added ($1000s)	58,781	58.132	19.275	205.567
Cost of employees ($1000s)	58,781	19.842	6.492	66.258
Number of employees	58,781	44.428	14.000	135.699
Total asset ($1000s)	58,781	85.986	25.917	281.623
Fixed asset ($1000s)	58,781	33.576	5.803	189.171
TFP level of firm	58,781	6.787	4.435	26.933
TFP level of frontier	58,781	19.733	14.173	26.759
TFP gap	58,781	4.220	3.024	9.867
CIT	58,781	0.279	0.280	0.051
EMTR	58,777	0.127	0.157	0.075
EATR	58,777	0.240	0.240	0.043

	Observations	Mean	Median	SD
MNEs				
Value added ($1000s)	78,412	353.482	85.030	1,781.051
Cost of employees ($1000s)	78,412	98.610	25.461	487.498
Number of employees	78,412	167.101	45.000	686.195
Total asset	78,412	612.419	112.653	4,300.926
Fixed asset	78,412	255.693	18.700	2,527.131
TFP level of firm	78,412	10.175	6.864	20.977
TFP level of frontier	78,412	23.271	16.942	31.002
TFP gap	78,412	3.264	2.357	5.457
CIT	78,412	0.289	0.314	0.057
EMTR	78,376	0.124	0.141	0.073
EATR	78,376	0.247	0.267	0.047
Tax-Haven MNE	78,412	0.305	0	0.460
Non-tax haven MNEs				
Value added ($1000s)	54,531	225.314	71.944	652.111
Cost of employees ($1000s)	54,531	68.435	22.233	188.580
Number of employees	54,531	127.838	40.000	389.910
Total asset ($1000s)	54,531	361.570	99.400	1,281.708
Fixed asset ($1000s)	54,531	140.184	17.538	765.816
TFP level of firm	54,531	9.364	6.526	20.429
TFP level of frontier	54,531	22.376	16.281	29.540
TFP gap	54,531	3.329	2.436	5.907
CIT	54,531	0.286	0.314	0.057
EMTR	54,519	0.122	0.141	0.074
EATR	54,519	0.244	0.263	0.047
Tax- Haven MNEs				
Value added ($1000s)	23,881	646.146	127.778	3,053.137
Cost of employees ($1000s)	23,881	167.513	36.820	832.054
Number of employees	23,881	256.756	60.000	1,089.671
Total asset ($1000s)	23,881	1,185.220	155.916	7,517.697
Fixed asset ($1000s)	23,881	519.453	22.575	4,419.359
TFP level of firm	23,881	12.028	7.721	22.064
TFP level of frontier	23,881	25.315	18.096	34.017
TFP gap	23,881	3.116	2.162	4.250
CIT	23,881	0.295	0.314	0.057
EMTR	23,857	0.128	0.151	0.070
EATR	23,857	0.253	0.267	0.047

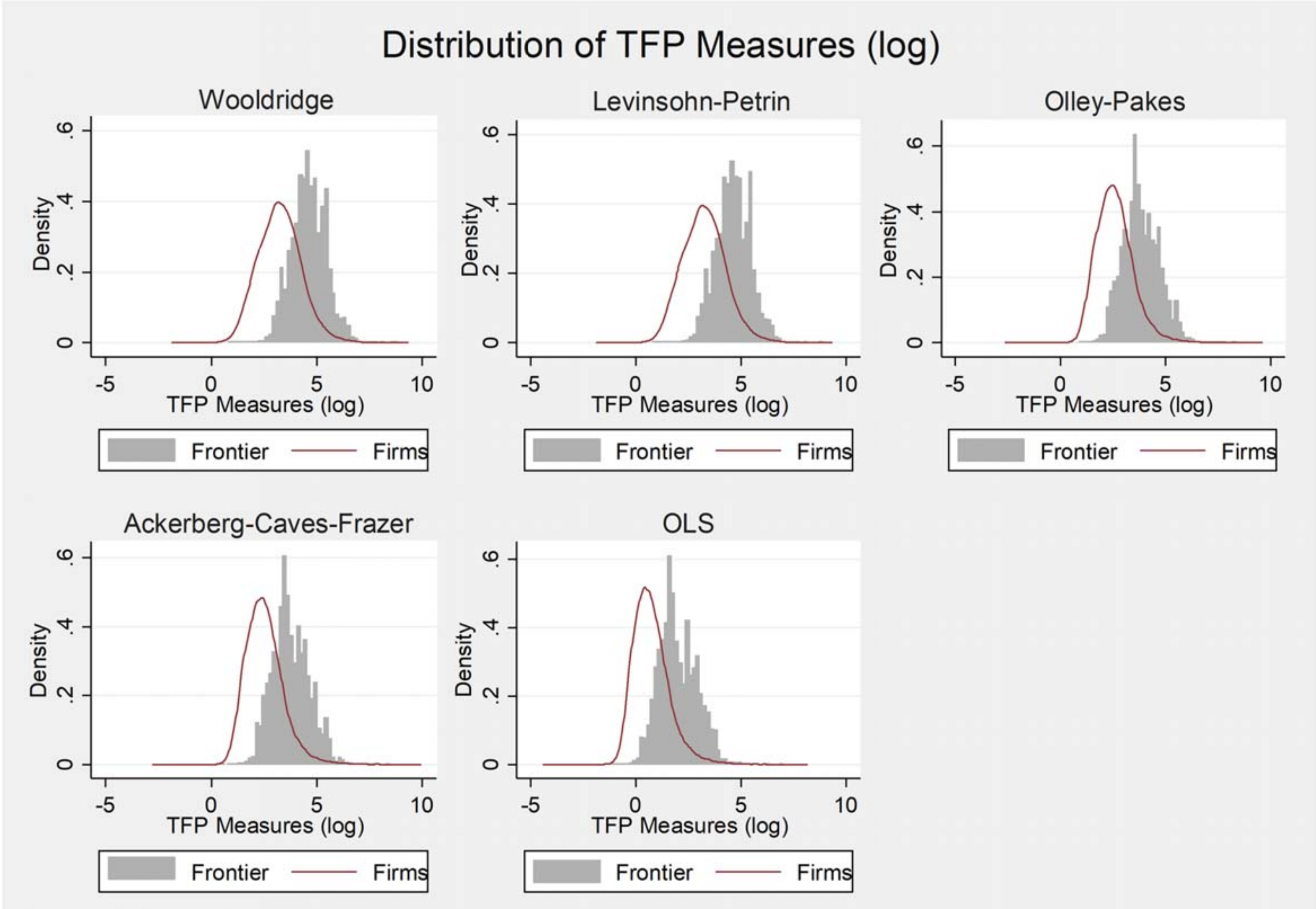
This table presents descriptive statistics for observations of each sub-sample. The variable 'value-added' represents the difference between turnovers and material costs, adjusted by appropriate price deflators from the EUKLEMS dataset. The industrial profitability ratio for each industry is calculated as gross operating surplus divided by value added, derived from the 2007 U.S. Benchmark Input–Output Database. The statutory corporate tax rates, inclusive of average local taxes and surtaxes, obtained from KMPG. The effective marginal tax rate (EMTR) and effective average tax rate (EATR) have been directly derived from the Centre for Business Taxation at the University of Oxford. The TFP growth rate has been calculated by taking the difference between the current value and the first lag of the variable, divided by the first lag, and expressed as a percentage. Government revenue and government expenditure are represented as ratios of total government revenue and government expenditure, respectively, to GDP. 'Tax-haven MNEs' is a dummy variable that indicates the presence of subsidiaries in tax-haven jurisdictions for firms in the analysis

Table A5 - Additional TFP Measures with Alternative Input-Output Proxies

Number of observations: 92,081	Mean (SD)				
	WRDG	LP	OP	ACF	OLS
Firms' TFP estimates (log)	3.225 (1.031)	3.232 (1.035)	2.593 (0.883)	2.500 (0.880)	0.728 (0.851)
Frontiers' TFP estimates (log)	4.609 (0.806)	4.619 (0.807)	3.844 (0.857)	3.758 (0.878)	1.992 (0.889)
TFP gap of frontier to firm (log)	1.405 (0.949)	1.409 (0.952)	1.255 (0.885)	1.259 (0.894)	1.260 (0.891)
Firms' TFP growth (%)	0.064 (0.666)	0.064 (0.669)	0.054 (3.152)	0.058 (4.656)	0.053 (4.620)
Frontiers' TFP growth (%)	0.006 (0.421)	0.004 (0.217)	0.005 (0.223)	0.006 (0.364)	0.006 (0.228)

This table presents the growth of the total factor productivity (TFP) of firm and frontier measured by using the equation $y_{it} = \alpha_0 + \beta l_{it} + \gamma k_{it} + \delta_{it} + \varepsilon_{it}$, at which y_{it} is the (log) turnover, l_{it} is (log) cost of employees and k_{it} is (log) capital stock for firm i in year t, δ_{it} represents for TFP, and ε_{it} is white noise- WRDG, LP, OP, ACF, and OLS stands for the Wooldridge, Levinsohn-Petrin, Olley-Pakes, Ackerberg-Caves-Frazer, and Ordinary Least Squares estimator, respectively. The frontier is defined as firms that lie above the 95th percentile of the TFP distribution in each country–industry time period. The TFP gap is calculated based on the ratio of the TFP level of the frontier divided by the TFP level of each individual firm.

Figure A1 - Distribution of (log) TFP of Firm and Frontier with Alternative Input-Output Proxies



Source: Author's own Illustrations

Appendix E: Additional Regression Results

Table A6 - Baseline Results with Alternative Input-Output Proxies

Dependent variable: $\Delta lnTFP_i$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\Delta lnTFP_F$	0.202***	0.203***	0.198***	0.199***	0.304***	0.056***	0.055***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnTFPGap	0.354***	0.435***	0.473***	0.494***	0.642***	0.057***	0.067***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CITR	0.092	0.520***	0.603***	0.773***	0.413	0.530***	0.576***
	(0.215)	(0.000)	(0.000)	(0.000)	(0.529)	(0.000)	(0.000)
lnTFPGap × CITR		-0.311***	-0.335***	-0.399***	-0.497*	-0.109***	-0.150***
		(0.000)	(0.000)	(0.000)	(0.073)	(0.000)	(0.000)
I_{jt}			0.175**	0.173**	-0.275	0.061**	0.043
			(0.015)	(0.045)	(0.536)	(0.032)	(0.150)
lnTFPGap × I_{jt}			-0.080*	-0.068	0.150	0.027***	0.037***
			(0.090)	(0.215)	(0.412)	(0.008)	(0.001)
GE			-0.208*	-0.267*	-0.724	-0.020	-0.037
			(0.093)	(0.054)	(0.313)	(0.812)	(0.650)
GR			0.033	0.034	0.785	-0.529***	-0.530***
			(0.828)	(0.838)	(0.373)	(0.000)	(0.000)
Observations	100,279	100,279	92,081	76,770	88,543	92,081	92,081
R-squared	0.515	0.516	0.515	0.519	0.691	0.071	0.079
Establishment FE	YES	YES	YES	YES	YES	NO	NO
Year FE	YES	YES	YES	YES	YES	YES	YES
Country FE	NO	NO	NO	NO	NO	YES	NO
Industry FE	NO	NO	NO	NO	NO	YES	NO
Industry-Country FE	NO	NO	NO	NO	NO	NO	YES

This table presents the baseline results of Equation (1) at which TFP is measured by the benchmark (WRDG) method but uses alternative input and output proxies. Specifically, a firm's value-added output is substituted by its turnover, and its capital stock is determined by the standard Perpetual Inventory Method. The dependent variable is the log of TFP growth of firm i in year t. The frontier F is defined as the 95th percentile of the TFP distribution in each country-industry-year cell. The TFP gap is measured as the log of the ratio of TFP at the frontier F over TFP of firm i in industry j, country c in year t. I_{jt} is the industrial profitability. GE and GR stand for the total government expenditure and total government revenue, respectively. Appendix B provides detailed variable definitions. All regressions use whole sample, except regression 4 that uses only observations from non-tax haven firms. Regression 5 includes probabiliy weights, while regressions 6 and 7 replace the firm fixed effect by country- and industry-, and country-industry fixed effects, respectively. *, **, and *** indicate statistical significance at the levels of 10, 5, and 1 percent, respectively. Standard errors are clustered at the firm level and are reported in parentheses.

Table A7 - Baseline Results with Different Measure Techniques (without Control Variables)

Dependent variable: $\Delta \ln TFP_i$	LP (1)	OP (2)	ACF (3)	OLS (4)
$\Delta \ln TFP_F$	0.274***	0.263***	0.267***	0.252***
	(0.000)	(0.000)	(0.000)	(0.000)
lnTFPGap	0.549***	0.522***	0.539***	0.504***
	(0.000)	(0.000)	(0.000)	(0.000)
CITR	0.413***	0.404***	0.458***	0.442***
	(0.000)	(0.000)	(0.000)	(0.000)
lnTFPGap × CITR	-0.274***	-0.244***	-0.277***	-0.243***
	(-3.034)	(0.007)	(0.002)	(0.005)
Observations	140,431	140,431	140,431	140,431
R-squared	0.503	0.497	0.496	0.489
Establishment FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Controls	NO	NO	NO	NO

This table presents coefficient estimates and t-statistics (in brackets) for Equation (1), with TFP measured by different methodologies: regression 1: Levinsohn-Petrin (LP) estimator; regression 2: Olley- Pakes (OP) estimator; regression 3: Ackerberg et al., (ACF) estimator and regression 4: OLS estimator. The dependent variable is the rate of productivity growth of firm *i* in year *t*. The frontier *F* is defined as the 95th percentile of the TFP distribution in each country-industry-year cell. The TFP gap is measured as the log of the ratio of TFP at the frontier F over TFP of firm *i* in industry *j*, country *c* and year *t*. Appendix B provides detailed variable definitions. All regressions include control variables, firm- and year-fixed effects. *, **, and *** indicate statistical significance at the levels of 10, 5, and 1 percent, respectively. Standard errors are clustered at the firm level and are reported in parentheses.

Table A8 - Heterogeneity – Firm Size (without Control Variables)

Dependent variable: $\Delta lnTFP_i$	Large	SME	Non-haven Large	Non-haven SME	Medium	Small	Micro	Whole sample (no Medium)	Non-haven sample (no Medium)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\Delta lnTFP_F$	0.195***	0.276***	0.195***	0.282***	0.190***	0.260***	0.374***	0.115***	0.117***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnTFPGap	0.362***	0.560***	0.392***	0.579***	0.402***	0.558***	0.821***	0.090***	0.116***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CITR	0.157	0.491***	0.345*	0.569***	0.369***	0.889***	0.826*	0.417***	0.452***
	(0.331)	(0.000)	(0.074)	(0.000)	(0.007)	(0.000)	(0.056)	(0.000)	(0.000)
lnTFPGap × CITR	-0.197	-0.290***	-0.306	-0.311***	-0.247*	-0.387**	-0.605**	-0.107	-0.184*
	(0.253)	(0.004)	(0.150)	(0.007)	(0.072)	(0.020)	(0.037)	(0.119)	(0.055)
SME								-0.204***	-0.214***
								(0.000)	(0.000)
SME × lnTFPGap								0.096***	0.087***
								(0.000)	(0.000)
SME × CITR								0.422***	0.448***
								(0.000)	(0.000)
SME × lnTFPGap × CITR								-0.189**	-0.149
								(0.021)	(0.174)
Observations	12,639	127,792	8,058	108,055	27,963	46,673	33,419	103,908	88,150
R-squared	0.413	0.509	0.411	0.516	0.442	0.520	0.623	0.078	0.081
Establishment FE	YES	YES	YES	YES	YES	YES	YES	NO	NO
Controls	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year FE	NO	NO	NO	NO	NO	NO	NO	YES	YES
Country FE	NO	NO	NO	NO	NO	NO	NO	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES	YES	YES	YES

table presents the results of tests comparing large firms and SMEs. The dependent variable is the rate of productivity growth in firm i in year t. SME is a dummy variable for firms fewer 250 employees. Regressions 1-7 reports the results for Equation (1) with firm- and year fixed effects for specific sub-sample by firm size. Regressions 1 and 3: large firms (at least 250 employees), regressions 2 and 4: SMEs (fewer than 250 employees), regression 5: medium firms (50 to 249 employees), regression 6: small firms (10 to 49 employees), regression 7: micro firms (less than 10 employees). Regressions 8 and 9 report the results for Equation (2) with county-, industry-, and year fixed effects for whole sample excluding medium-sized firms. In regressions 3, 4, and 9, I exclude all firms operating in tax-havens jurisdictions. Appendix B provides detailed variable definitions. *, **, and *** indicate statistical significance at the levels of 10, 5, and 1 percent, respectively. Standard errors are clustered at the firm level and are reported in parentheses.

Table A9 - Heterogeneity – MNE Status (without Control Variables)

Dependent variables: $\Delta lnTFP_i$	MNE (1)	Non-haven MNE (2)	Domestic (3)	Full sample (4)	Non-haven sample (5)
$\Delta lnTFP_F$	0.257***	0.266***	0.284***	0.103***	0.106***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnTFPGap	0.485***	0.509***	0.602***	0.179***	0.181***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CITR	0.215*	0.296*	0.742***	0.771***	0.787***
	(0.090)	(0.069)	(0.000)	(0.000)	(0.000)
lnTFPGap × CITR	-0.174	-0.198	-0.365**	-0.262***	-0.264***
	(0.149)	(0.207)	(0.011)	(0.000)	(0.000)
MNE				0.121***	0.090***
				(0.000)	(0.001)
MNE × lnTFPGap				-0.061***	-0.032
				(0.002)	(0.156)
MNE × CITR				-0.217***	-0.144
				(0.008)	(0.113)
MNE × lnTFPGap × CITR				0.120*	0.045
				(0.074)	(0.558)
Observations	79,792	55,474	60,639	140,431	116,113
R-squared	0.472	0.479	0.530	0.075	0.078
Establishment FE	YES	YES	YES	NO	NO
Year FE	YES	YES	YES	YES	YES
Country FE	NO	NO	NO	YES	YES
Industry FE	NO	NO	NO	YES	YES
Controls	NO	NO	NO	NO	NO

This table presents coefficient estimates and t-statistics (in brackets) for Equation (1) and Equation (3). The dependent variable the log of TFP growth of firm *i* in year *t*. MNE is a dummy variable for multinational firms. Regressions 1-3 report the results of Equation (1) with firm- and year fixed effects for specific sub-samples. Regressions 1 and 2: MNEs and non-haven MNEs, regressions 3: domestic firms. Regressions 4 and 5 report the results of Equation (3) with county-, industry-, and year fixed effects for the whole sample and the non-haven sample, respectively. Appendix B provides detailed variable definitions. *, **, and *** indicate statistical significance at the levels of 10, 5, and 1 percent, respectively. Standard errors are clustered at the firm level and are reported in parentheses.

Table A10 - Robustness Test: Alternative Tax Measures (without Control Variables)

Dependent variables: ΔlnTFP$_i$	(1)	(2)	(3)	(4)	(5)	(6)
ΔlnTFP$_F$	0.269***	0.276***	0.269***	0.276***	0.269***	0.276***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnTFPGap	0.541***	0.561***	0.472***	0.485***	0.526***	0.540***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
PITR	0.165**	0.186**				
	(0.012)	(0.016)				
lnTFPGap x PITR	0.076	0.062				
	(0.155)	(0.306)				
CITR	0.445***	0.510***				
	(0.000)	(0.000)				
lnTFPGap x CITR	-0.387***	-0.390***				
	(0.000)	(0.000)				
EMTR			0.059	0.033		
			(0.155)	(0.306)		
lnTFPGap x EMTR			-0.030	-0.013		
			(-0.912)	(-0.348)		
EATR					0.564***	0.589***
					(0.000)	(0.000)
lnTFPGap x EATR					-0.255**	-0.254**
					(0.017)	(0.040)
Observations	140,391	116,097	140,391	116,097	140,391	116,097
R-squared	0.501	0.509	0.500	0.508	0.501	0.508
Establishment FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Controls	NO	NO	NO	NO	NO	NO

This table presents the results of further tests regarding additional or alternative tax measures. The dependent variable is the log of the TFP growth of firm *i* in year *t*. Models 1 and 2 add the top personal income tax rate (PITR). Regressions 3 and 4 use the effective marginal tax rate (EMTR) and regressions 5 and 6 the effective average tax rate (EATR) as alternative tax measures. All regressions include controls that consist of industry profitability interacted with TFP gap, total government expenditure, and total government revenues (ratio to GDP), firm- and year-fixed effects. Regressions 1, 3, 5 are estimated for the whole sample, while regression 2, 4, 6 are limited to the non-haven sample. Appendix B provides detailed variable definitions. *, **, and *** indicate statistical significance at the levels of 10, 5, and 1 percent, respectively. Standard errors are clustered at the firm level and are reported in parentheses.

Table A11 - Robustness Test: Alternative Frontiers (without Control Variables)

Dependent variables: $\Delta lnTFP_i$	Highest TFP level		99th percentile		95th percentile (EU Single Market)	
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta lnTFP_F$	0.057***	0.026***	0.117***	0.044***	0.351***	0.131***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnTFPGap	0.236***	0.073***	0.365***	0.109***	0.829***	0.204***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CITR	1.172***	0.688***	1.194***	0.645***	0.734***	0.671***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnTFPGap x CITR	-0.428***	-0.098***	-0.467***	-0.081***	-0.676***	-0.235***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	136,645	136,645	136,007	136,007	132,909	132,909
R-squared	0.388	0.045	0.417	0.047	0.552	0.058
Firm FE	YES	NO	YES	NO	YES	NO
Year FE	YES	YES	YES	YES	YES	YES
Controls	NO	NO	NO	NO	NO	NO

This table presents the results of further tests using alternative frontiers. The dependent variable is the log of the rate of TFP growth of firm *i* in year *t*. In regressions 1 and 2, the frontier is the maximum TFP level in each country-industry-year cell. In regressions 3 and 4, the frontier is the 99th percentile of the TFP distribution in each country-industry-year cell. In regressions 5 and 6, the frontier is the 95th percentile of the TFP distribution in each industry-year cell. Controls include industry profitability interacted with TFP gap, total government expenditure, and total government revenues (ratio to GDP). Regression 1, 3, and 5 include firm and year fixed effects, while regression 2, 4, 6 include year, country, and industry fixed effects. Appendix B provides detailed variable definitions. *, **, and *** indicate statistical significance at the levels of 10, 5, and 1 percent, respectively. Standard errors are clustered at the firm level and are reported in parentheses.

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