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CGR Working Paper 45

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Keywords: Total Factor Productivity, Catch-Up, Effective Tax Rate, Firm-level Productivity Convergence, UK.

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Non-technical summary and policy implications

This paper argues that technological innovation is vital to enhancing firm-level productivity or efficiency growth, and thus investment in R&D can play a larger role in determining the differences in productivity across firms and help achieve productivity convergence. During periods of general economic slowdown, corporate tax policy may drive such innovation and therefore the paper examines the direct effects of corporate tax on firm productivity along with the interaction effects of tax policy and R&D activity on productivity at firm level for over 13,062 firms during 2004-2011. Our main findings are first, that there is evidence for productivity convergence and we find that there is a positive robust relationship between R&D and firm productivity, whereas tax policy has a negative distortionary effect on TFP. Second, firms with greater export orientation do not seem to achieve much improvement in productivity, whereas the favourable productivity effect in the case of R&D-based firms suggests that if there are tax incentives in place for R&D type activity, it can promote innovation and drive productivity convergence (lagging firms closing the technology gap with those at the frontier), particularly so when there is a continued decline in overall economic activity. The results also show a significant non-linear effect of tax rate on firm-level productivity, identifying an inverse U-shaped relationship with a threshold level of around 45% as the optimum productivity-enhancing effective tax rate.

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Measuring Firm-Level Productivity Convergence in the UK: The Role of Taxation and R&D Investment

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18 November 2013

Abstract

This paper argues that technological innovation is vital to enhancing firm-level productivity or efficiency growth, and thus investment in R&D can play a larger role in determining the differences in productivity across firms and help achieve productivity convergence. During periods of general economic slowdown, corporate tax policy may drive such innovation and therefore the paper examines the direct effects of corporate tax on firm productivity along with the interaction effects of tax policy and R&D activity on productivity at firm level for over 13,062 firms during 2004-2011. Our main findings are first, that there is evidence for productivity convergence and we find that there is a positive robust relationship between R&D and firm productivity, whereas tax policy has a negative distortionary effect on TFP. Second, firms with greater export orientation do not seem to achieve much improvement in productivity, whereas the favourable productivity effect in the case of R&D-based firms suggests that if there are tax incentives in place for R&D type activity, it can promote innovation and drive productivity convergence (lagging firms closing the technology gap with those at the frontier), particularly so when there is a continued decline in overall economic activity. The results also show a significant non-linear effect of tax rate on firm-level productivity, identifying an inverse U-shaped relationship with a threshold level of around 45% as the optimum productivity-enhancing effective tax rate.

Keywords: Total Factor Productivity, Catch-Up, Effective Tax Rate, Firm-level Data, UK.

JEL Classification: O3, O4.

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1. Introduction

In the light of the recent financial crisis and growth slowdown in the UK and OECD economies, it is important to understand the role of supply-side stimuli to speeding up recovery and improving productivity, especially in face of recent fiscal consolidation (see Crafts, 2013).The UK's productivity gap at the aggregate level has been lagging behind its competitor countries (see Mayhew and Neely, 2006) and hence closing this gap at the macro level requires us to understand the determinants of firm-level productivity gap with those at the technology frontier. The growth literature has identified R&D as capable of creating positive technology spillovers which tend to dominate the negative competitive effects from product market rivals(see Bloom et al., 2013).In this context, corporate tax policy may play a role in driving innovation and thereby firm productivity (see Harris et al., 2009). Meanwhile international differences in national taxation policy may adversely affect firm-level performance. In conventional growth theory, Alesina and Rodrik (1994) and Lee and Gordon (2005) have looked at whether tax policy can alter the long-run process of economic development. Developments in international trade theory (Melitz, 2003; Yeaple, 2005) meanwhile have emphasized the existence of firm heterogeneity and its importance in determining trade activity and intra-industry reallocation of resources. Another strand of that literature identifies the factors by which laggard firms can catch up to the performance levels of frontier counterparts.[5] A key policy inference from all this literature is that the broader economic policy environment can affect firm's degree of productivity catch up.

One aspect of the policy environment that has been little explored to date is how, precisely, taxation affects productivity performance at the firm level. In principle, corporate taxation might embody distortionary effects that can be easily translated into productivity losses. The negative effects of corporate tax broadly fall into two categories :(a) tax expenditure reduces corporate income by constraining the resources available for investment and market expansion and (b) taxation can impact on dynamic efficiency, absorbing resources that can be alternatively invested in

[5]Görg and Greenaway (2004) and Girma (2005) address the role of Multinationals in improving performance of domestic firms. Nicoletti and Scarpetta (2005) and Bourles et al. (2010) investigate the role of product market regulation both within and across industries in productivity performance. Griffith et al. (2009) discuss the role of geographic proximity and spillovers generated from frontier firms.

process innovation, intangible assets and technological upgrading. The latter category also includes the possibility of embodied technical change in the purchase of capital goods implying further that higher corporate taxation can induce adverse effects on capital deepening and productivity improvements by increasing the user cost of capital.

Hall and Van Reenen (2000) suggest that there is an equal and proportionate relationship between tax exemptions and R&D investment that largely determine the location of R&D activity. Similarly, Djankov et al. (2010) and Kneller et al. (2012) have found that tax policy can affect other aspects of firm productivity performance such as entry and exit decisions. So far, only Arnold et al. (2011) have studied directly the link between corporate tax and productivity showing that the growth of firms is negatively affected by taxation in more profitable industries. In this paper we set out to expand upon the limited evidence in the tax-productivity domain by studying the effects of corporate tax levels within a framework of firm productivity catch-up. The UK economy is well suited to this sort of analysis for several reasons. In recent decades, productivity levels in the UK have substantially fallen behind those of the US (Cameron et al., 2005). There also appears to be considerable firm-level heterogeneity (Davis et al., 1996; Batelsman and Doms, 2000; Disney et al., 2003) both across and within industries. To understand the technology convergence process, this heterogeneity needs to be taken into account by examining the gap between the productivity of a particular firm and the frontier firm at different points in time.

In this paper we ask, using UK firm-level data, whether firm’s corporate tax burden slows the speed of productivity convergence and, if so, through which channels this deceleration is likely to take place. For example, it may occur via a reduction in R&D activity, due to higher tax burden at a time of general economic slowdown, or by exporters being less competitive. It is now well-established that exporting firms tend to be more productive relative to non-exporters, but the evidence on the learning effect remains inconclusive for most countries, with the exception of some rapidly growing emerging markets (see, for example, Mallick and Yang, 2013). If productivity is the basis for a country's competitiveness, such productivity can be influenced by the degree of technological innovation at firm level. We therefore attempt to examine the productivity effects of taxation, exporting and R&D in the context of fiscal consolidation during a time when there has been a general decline in economic activity, and hence ask what can be done to jumpstart a recovery in firm-level productivity, and thereby achieve productivity convergence.

The remainder of the paper is organized as follows: section 2 reviews the key literature and motivation; section3 introduces a behavioral framework for looking at firm productivity convergence; section 4 illustrates data issues and econometric specification; section 5 discusses results from baseline estimates; section 6 provides some sensitivity analysis regarding the robustness of baseline estimations and section 7 concludes the paper.

2. Motivation & Empirical Strategy

This paper seeks to investigate any distortionary effects induced by corporate tax in association with the two categories namely (a) the impact of taxation on investment and market expansion and (b) the impact of taxation on dynamic efficiency represented by its interaction with R&D and exports. The main question posed is whether taxation on profits affects capital investment. Keuschnig and Ribi (2010) have developed a model that links capital investment decisions and financial constraints. We elaborate on this framework to test the hypothesis that higher levels of corporate tax decreases the amount of working capital available**.** Less working capital results in firms' inability to obtain credit required for market expansion.[6]The second key question addressed in the paper refers to the distortionary character of corporate tax with regard to dynamic efficiency. A novel aspect of our paper is to investigate whether tax liabilities are likely to affect firms with greater export orientation disproportionally.

Firm level studies have already suggested evidence of learning effects from exporting activity (Bernard and Jensen, 1999; Greenaway and Kneller, 2004; Greenaway and Yu, 2004; Crespi et al., 2008; Mallick and Yang, 2013).[7]According to this strand of literature, exporters can benefit from knowledge spillovers and contacts

[6]Gemmell et al. (2012) show that higher corporation tax affects after-tax returns to productivity-enhancing investment. This effect is proportionally higher to small firms indicating that small firms are more likely to be credit constrained due to tax liabilities and their capacity to raise credit is highly dependent on their asset size (Schaller (1993) and Aghion et al. (2007)).

[7] The evidence of learning-by-exporting within a UK context cannot be viewed as conclusive. There are studies (Girma et al. (2004), Harris and Li (2009)) that found evidence only for the one side of the causality that more productive firms self-select to export. Therefore, the debate is still open and thus it remains of interest to explore whether taxation can hinder the exploitation of learning-by-exporting effects.

with international best practices while purely domestic firms cannot. Consequently, exporting firms can grow faster and close quicker the technology gap with the frontier. Hence, a follow-up question is whether tax policy restricts export activity, hampering technology transfer and thus lowering productivity growth. Similarly, we evaluate the effect of corporate tax on firms with different innovation status. In productivity catch-up models, the role of R&D is well-established (Griffith et al., 2003/2004, Cameron, 2006).[8] The crucial issue here is whether differences in tax policy can generate incentives (or disincentives) for more (less) R&D investment. If R&D activity is risky, it is more likely to be undertaken by highly profitable firms. This indicates that a progressive corporate tax system might affect adversely firms with high levels of innovation. We can test this by looking at the interaction between R&D and the tax rate. If both private and social returns to innovation are important for productivity convergence, both at firm and industry level, then any negative impact of corporate tax on R&D can be crucial both for individual and aggregate productivity**.** Our paper seeks to investigate whether firms with different innovative status respond differently to changes in tax policy.

A series of testable hypotheses regarding the effects of corporate tax on firm's productivity are investigated, with particular reference to distance from the productivity frontier and the associated speed of catch up process. We use the FAME data base for UK manufacturing firms over the period 2004-2011. The data are mainly derived from firms' balance sheets and profit and loss accounts. The behavioral framework used is a convergence model, building upon existing work in the macroeconomic convergence literature (Bernard and Jones (1996a, 1996b)). Within this set up, taxation has an autonomous effect on productivity growth while also interacting with the catch–up process towards the frontier counterpart.

The implementation of a convergence framework requires a well-specified and unbiased measure of total factor productivity (TFP) at the firm level. The appropriate estimation technique for TFP depends on the fulfillment of two key criteria. First, estimation should address the issue of simultaneity bias between inputs and various productivity shocks. Standard parametric techniques that use OLS estimators in Cobb-Douglas production functions clearly fail to mitigate this problem (Higon (2004,

[8] In the productivity convergence literature, R&D has a dual role: first stimulates the rate of innovation and second improves the absorptive capacity of the laggard firm. The second role implies that higher R&D investment is necessary even if it does not generate direct productivity gains as it contributes to a more efficient imitation of the technological advancements of the frontier.

2007), Blundell and Bond (2000)). Second, selection bias is likely to exist infirm level studies. In a frictionless market environment the least productive firms exit the market while new more productive firms enter. TFP estimation should control for the correlation between productivity shocks and exit probability.[9] We use a semi-parametric methodology developed by Olley and Pakes (OP, hereafter)[10] (1996) to account for simultaneity and selection bias. This should yield consistent and unbiased TFP estimates[11] in the presence of unobserved productivity shocks. We also apply Levinsohn-Petrin (LP) (2003) non-parametric technique for estimating TFP as a robustness check in Section 6.

3. A Model of Firm-level Productivity Convergence

This section explains the formulation of a productivity catch-up model that can be used as a benchmark for the derivation of an empirically testable model. The starting point isamacroeconomicmodel of productivity convergence (see among others, Bernard and Jones, 1996a and 1996b; Cameron et al., 2005) that specifies a generic production function:

$$Y_{i,t} = A_{i,t} f\left(\mathrm{X}_{i,t}\right) \qquad [3.1]$$

Where i denotes firm and t represents time. Y measures value added and X indicates a set of production inputs. Parameter A captures unobserved technological shifts over time that vary across firms and time. The quantitative equivalent of parameter A is an index of Total Factor Productivity (TFP). At any point in time, productivity is evolved by the following Autoregressive Distribute Lag ADL (1,1) process:

$$\ln A_{i,t} = \gamma_{i,t} + a_1 \ln A_{i,t-1} + a_2 \ln A_{F,t} + a_3 \ln A_{F,t-1} + u_{i,t} \qquad [3.2]$$

[9] The correlation here exists between capital input and the probability to exit. Firms with higher level of capital stock are likely to generate more future profits and thus the probability to exit after a negative productivity shock is smaller.

[10] We have also experimented with Levinsohn and Petrin (2003) (Table 4 Section 6) estimation framework of TFP with no significant differences in results.

[11] Unobserved productivity shock is not the only source of bias in TFP estimates. In our tests of robustness, we instrument TFP variable to account for additional measurement errors.

Assuming long–run homogeneity $\frac{a_2 + a_3}{1 - a_1} = 1$ implies that productivity growth depends on relative rather than on absolute convergence. Expression [3.2] can be viewed as an Error Correction Model (ECM) that is transformed into:

$$\Delta \ln A_{i,t} = a_2 \Delta \ln A_{F,t} + \gamma_{i,t} + \lambda \ln\left(\frac{A_{F,t-1}}{A_{i,t-1}}\right) + u_{i,t} \qquad [3.3]$$

where $\lambda = 1 - a_1$. Equation [3.3] describes productivity growth in the non-frontier firm as a function of autonomous productivity growth in the frontier, a term for technology transfer and technological capabilities γ in firm *i*. A reduced form of [3.3] assumes $a_2 = 0$ and thus the productivity convergence model is written as:

$$\Delta \ln A_{i,t} = \gamma_{i,t} + \lambda \ln\left(\frac{A_{F,t-1}}{A_{i,t-1}}\right) + u_{i,t} \qquad [3.4]$$

Equations [3.3] and [3.4] can be used as benchmark econometric specifications for estimating the drivers of productivity convergence. Parameter γ refers to standardtechnological drivers of firm *i*, and also captures the autonomous role of corporate taxation on productivity. Parameter λ represents the speed of productivity convergence between firm *i* and its frontier counterpart F, and u is a stochastic error term. Corporate taxation is measured by effective tax rate (ETR) and the current specification seeks to reveal whether the effect of ETR varies according to the position of firm *i* relative to the frontier. To test this hypothesis, we augment equation [3.3] with the following term:

$$\Delta \ln A_{i,t} = a_2 \Delta \ln A_{F,t} + \gamma_{i,t} + \lambda \ln\left(\frac{A_{F,t-1}}{A_{i,t-1}}\right) + \underbrace{\mu \gamma_{i,t} \times \ln\left(\frac{A_{F,t-1}}{A_{i,t-1}}\right)}_{\text{absorptive capacity}} + u_{i,t} \qquad [3.5]$$

Intuitively, parameter μ measures whether taxation induces distortionary effects that alter resources away from Efficiency Enhancement Activities (EEA) hampering firm *i*'s absorptive capacity and thus decelerating productivity growth.

The definition of the frontier firm (*F*) is rather important in the implementation of [3.4] and [3.5] as it will capture the distance from the productivity leader as well as the potential for catch-up for each individual firm *i*. Our benchmark definition for F is the firm with the highest productivity in industry j at year t (i.e. $\max A_j$).In our sensitivity analysis, we replicate the benchmark specifications with two alternative definitions for the frontier. We take the firm with the highest productivity in the whole sample (i.e. $\max A_t$) at year t and the 5% of firms with the highest productivity in industry j in year t.

To obtain the distance that firm i lies behind the frontier in the long-run steady state one needs to solve the reduced form expression [3.4] to obtain the following condition:

$$\ln\left(\frac{\bar{A}_i}{\bar{A}_{F,j}}\right) = \frac{\gamma_i - \gamma_F}{\lambda} : \textbf{Distance from the Industry Frontier} \qquad [3.6]$$

4. Empirical Implementation

4.1. Dataset Description

For the empirical estimation of the TFP growth equation we use data from FAME, which provides access to balance sheet and income statement items for both private and public companies in the UK. The time span of the data used in this paper covers the period from 2004 to 2011. The rationale for considering three years before the recent crisis period is to examine the slowdown in firm productivity during the crisis years. This would also allow us to gauge whether the frontier firm's productivity has declined from its peak level during 2004-06.The sectoral coverage of the firms is restricted to manufacturing which is defined according to the NACE Rev.2 classification and include firms that fall within the industrial classification between 1011-3299. The initial firm population refers to 14,222 firms annually. For the calculation of TFP, we merge FAME data with various deflators at the industry level obtained by Office of National Statistics (ONS). After this merging, the number of firms reduces to a balanced panel of 13062 firms. Nevertheless, there have been firms with data missing in variables needed to construct TFP and other core variables of the analysis. Regarding the calculation of TFP, we define value added as the difference of total sales adjusted for inventories with costs in materials. Sales and inventories are expressed in constant 2005 prices using an output price deflator at the four-digit industry level while cost expenditures are deflated using an industry invariant material price index.

Figure 1 shows a clear negative correlation between productivity performance (TFP in this case) and effective tax rate (ETR). The latter is computed as the share of corporate tax over gross profits. This preliminary evidence supports our initial argument that higher tax rates decrease working capital and thus impede market expansion and investment. Figure 2 is an initial indication regarding returns to R&D. The positive correlation illustrated in the graph is clear and shows that there are positive private returns to R&D as the evidence is at company level (not industry). Our empirical evidence enriches this point with the regressions later in the paper emphasising the importance of R&D in productivity growth. In this line of argument, Figure 3 supports the idea that R&D active firms as well as exporting firms tend to be closer to the frontier. For example, the number 0.72 for R&D active firms indicate that on average an R&D active firm's TFP is equal to 72% TFP of the frontier's while for the R&D inactive firm the distance is bigger, currently 67%. One could argue that the difference in the *GAP* between R&D and non-R&D firms (or exporting and non-exporting firms) is not large enough. Because the time span is relatively small, the dynamics of convergence process cannot be fully captured. Given that time series in firm level data are always shorter, 5 percentage points distance from the frontier between R&D and non-R&D active firms is still a considerable difference.

Figure 1: TFP versus Effective Tax Rate (Corporate Tax over Profits)

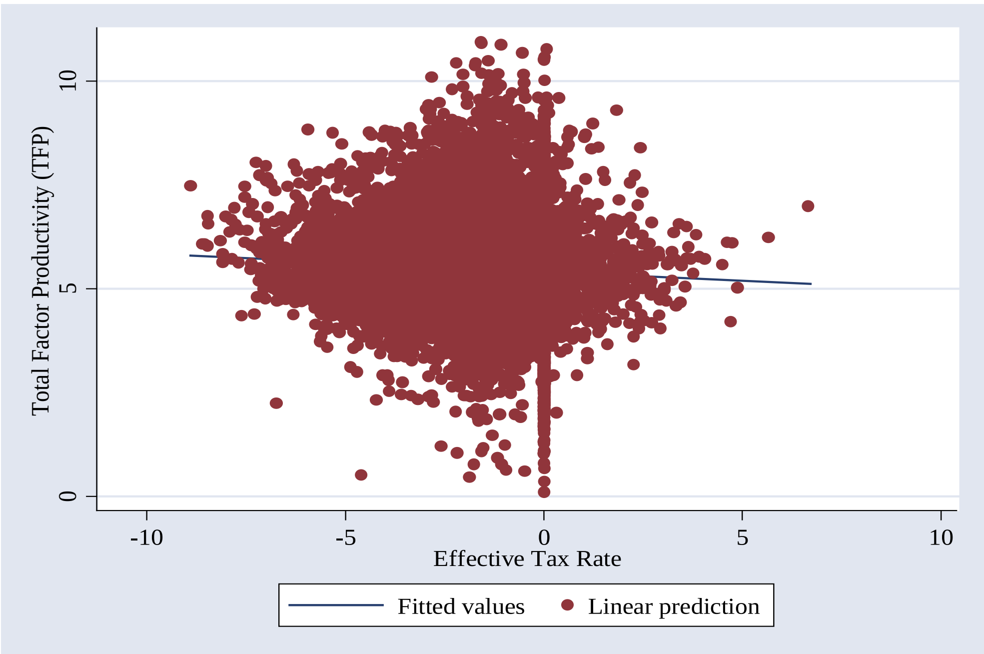


Figure 2: TFP Growth versus R&D Intensity

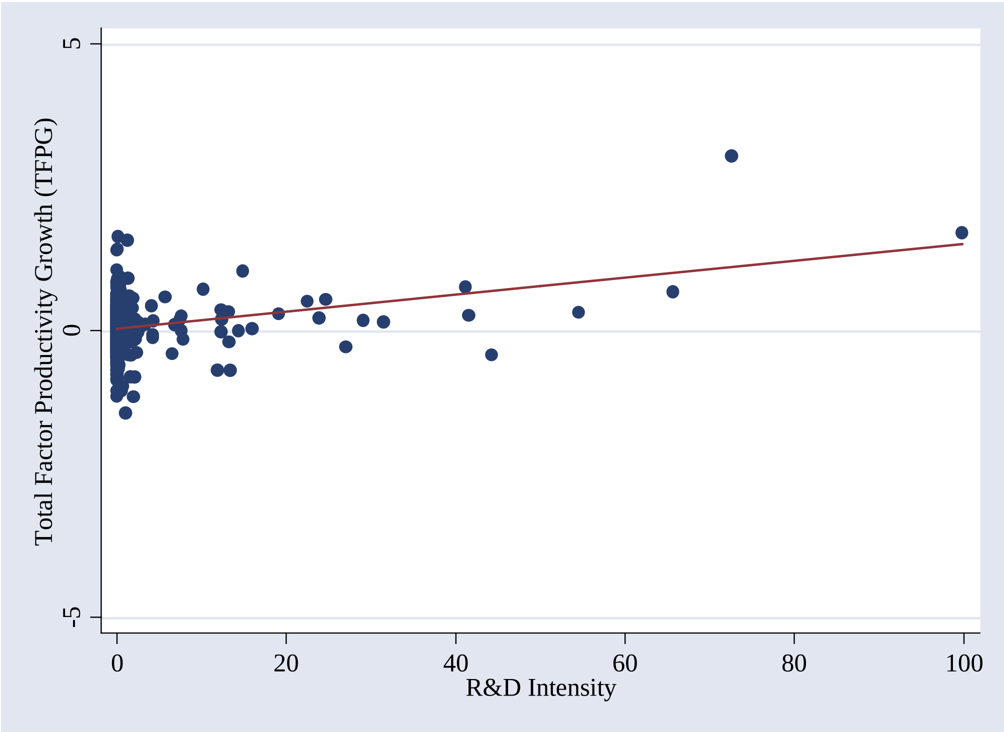
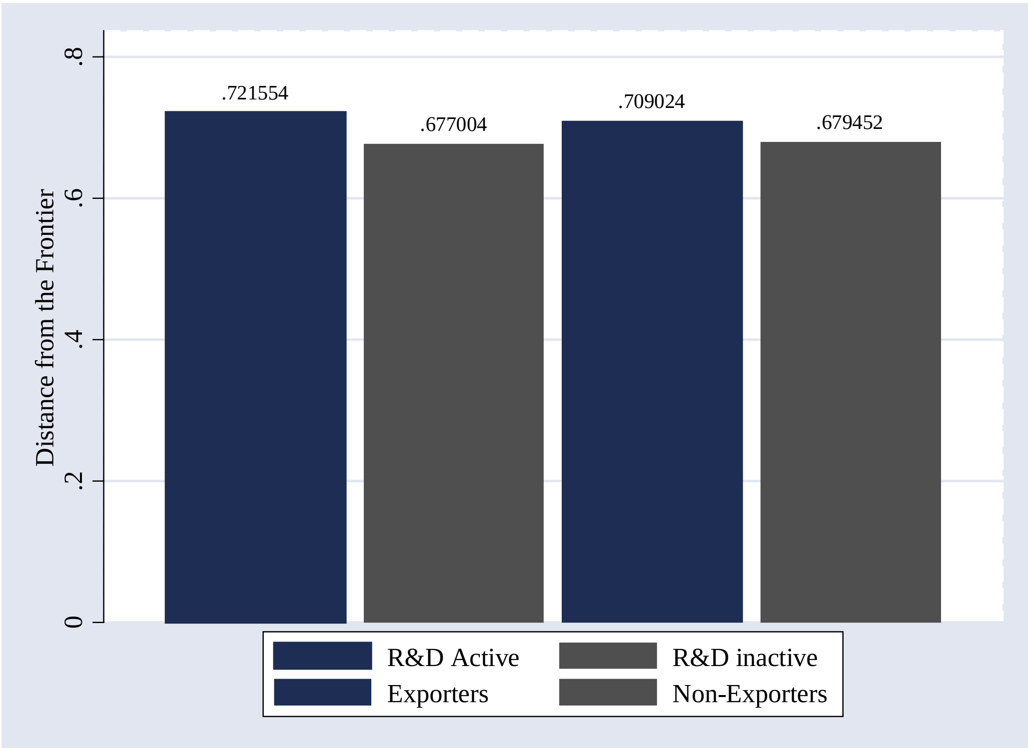


Figure 3: Distance from the Frontier for Different Groups



Note: Distance is calculated as the exponential value of *GAP*. See the text for more details about the interpretation of these figures.

Appendix A1 outlines the behavioral framework of Olley and Pakes (1996). Regarding the key state variable of OP, capital stock, it is approximated by the value of fixed assets as reported in FAME. We use capital price index at the four-digit level to convert capital related variables into 2005 constant prices. Investment is derived from the following perpetual inventory method: $I_{i,t} = k_{i,t} - (1-\delta)k_{i,t+1}$, where k is the value of capital stock. The raw measure of tax used in the paper refers to corporate tax figures as reported in FAME database. To reflect the actual tax paid by firms in the sample and unlike much of the literature (Arnold et al. (2011), Gemmell et al. (2012))[12] on the issue, we adopt the definition of the effective tax rate introduced by Djankov et al. (2010). This measure reflects the tax that firms pay if they comply with the country's laws and is defined as the actual corporate income tax over the pre-tax profits. In order to take into account the time value of money we discount this measure with a typical value of 4% as a representative discounting factor. By this we introduce the final measure of actual tax paid which we call discounted effective tax rate (*DETR*). Finally, we define as exporters all the firms which report positive values of exports for all the years in the sample and as research-active all the firms which report a positive value in the R&D account of the balance sheet for all eight years examined here. This definition can be regarded as too strict firms but given the short time span of our panel we prefer excluding from the sample the export and R&D active firms – those that sporadically devote resources to these activities. Table A2 provides a short description of all variables taken from FAME.

4.2. Econometric Specification

The econometric model is derived from equation [3.5] and treats TFP growth as a function of *DETR,* a vector $\boldsymbol{\gamma}_i$ of individual characteristics and a term for productivity catch-up. The specification is written as:

$$\Delta \ln TFP_{i,t} = a_2 \Delta \ln TFP_{F,t} + \beta_1 DETR_{i,t-1} + \boldsymbol{\beta}_2 \boldsymbol{\gamma}_{i,t-1} + \lambda GAP_{t-1} + \delta \Upsilon_t + \eta S_j + u_{i,t} \quad [4.1]$$

[12] These studies use an exogenous measure of tax which essentially captures the level of statutory tax directly associated with changes happening at the macroeconomic policy environment

For the ease of exposition, the term $GAP_{i,t-1}$, refers to the relative TFP between firm *i* and frontier firm *F*. As discussed in the previous section, the benchmark definition of *F* is $\frac{TFP_{i,t-1}}{TFP_{F,t-1}}$, with $TFP_{F,t-1} = \max TFP_{j,t-1}$, where *j* denotes industry. Appendix Tables A4 and A5 show summary statistics of *GAP* for different definitions of *F*. For example, figures presented in the first column of Table A4 indicate that average firm's TFP is 68.6% of the frontier's TFP; in other words, the distance from the frontier is 32% (1-0.68=0.32). The distance from the national frontier is bigger as shown in column 2 while the distance from the 5% more productive firms in the industry is relatively smaller. Section 6 explores whether taking alternative definitions of the frontier can drive our econometric results.

The estimated coefficient of the *GAP* term is expected to have a negative sign indicating that as firms fall behind the frontier they tend to grow faster. Parameter β_1 captures the distortionary effect of corporate tax on TFP growth and $\boldsymbol{\beta}_2$ is a vector of parameters to be estimated and mainly referring to firm *i*'s export and R&D activities. We have also augmented the econometric model with a set of year (Υ) and four-digit NACE sector (S) dummies to capture common macroeconomic effects as well as fixed idiosyncrasies at the industry level. The above benchmark specification is augmented with an interaction term of *GAP* and *DETR* to assess whether the corporate tax affects the speed of technology transfer. This effect is captured by parameter β_3 in specification [4.2]:

$$\begin{aligned}\Delta \ln TFP_{i,t} = a_2 \Delta \ln TFP_{F,t} + \beta_1 DETR_{i,t-1} + \boldsymbol{\beta}_2 \boldsymbol{\gamma}_{i,t-1} + \lambda GAP_{t-1} + \\ + \beta_3 GAP_{t-1} \times DETR_{i,t-1} + \delta \Upsilon_t + \eta S_j + u_{i,t} \qquad [4.2]\end{aligned}$$

If the hypothesis that corporate tax is heavily distortionary is valid then the estimated coefficient of the autonomous *DETR* variable is expected to be negative while the sign of the interaction term must be positive.

5. Results Baseline Specifications

5.1 Pooled OLS Results

Table 1 illustrates results from specifications [4.1] and [4.2]. Columns (1) and (2) show estimations from the whole sample where vector $\boldsymbol{\gamma}$ control for export and R&D activity by using binary variables to indicate whether firm *i* is export active and R&D

active. The *GAP* term is negative and highly significant confirming the convergence hypothesis. Likewise, firms that are export and R&D active tend to experience faster rates of TFP growth although the coefficient of the export dummy is insignificant in conventional statistical terms. Turning to the key variable of interest, both columns reveal a negative estimate of *DETR* and highly statistically significant while the interaction term ($GAP_{t-1} \times DETR_{i,t-1}$) is positive and significant. This baseline result is consistent with the fundamental hypothesis tested in the paper that high corporate tax slows down the rate of TFP growth. Given that the *DETR* measure is weighted by profitability this result confirms the hypothesis that, as tax liabilities increase relative to profits, then firms lack the resources required for capital investment. This effect is more likely to come about by a decrease in working capital which is necessary for obtaining external funding as pointed out in Arnold et al. (2011) and Gemmell et al. (2012).This negative effect is greater, the greater is the distance of firm *i* from the technological frontier.

In column (3), we control for the intensity of export and R&D activity rather than status. We use exports to total sales ratio and R&D as a share of value added. The results confirm the importance of R&D in stimulating innovation rates as well as the existence of learning by exporting gains. Column (3) also provides evidence for the hypothesis of absorptive capacity (see Griffiths et al. (2004)) that higher levels of export and research intensity contribute to more effective imitations of the technological advancements of the frontier. As in firm level studies the estimated coefficient of R&D intensity can be interpreted as the private return to innovation (Jones and Williams, 1998), the current value is 0.048, broadly consistent with what is documented in the literature (Grilliches, 1992).[13]Columns (4) and (5) test whether corporate tax affects the speed of convergence by extracting resources from efficiency enhancement activities damaging the degree of absorptive capacity. To do so, we use two interaction terms ($GAP_{t-1} \times DETR_{i,t-1} \times ES_{t-1}$ and $GAP_{t-1} \times DETR_{i,t-1} \times RDS_{t-1}$). The estimates of these interaction terms in columns (4) and (5) are positive but insignificant.

[13] The private rate of R&D return is smaller than the social one. Cameron et al. (2005) reveals a rate of R&D return for the UK Manufacturing in the interval of 0.40 to 0.60 but this magnitude refers to social return that already captures the possibility of positive R&D related spillovers generated from inter-firm linkages.

Table 1: Pooled OLS Regressions of TFP growth- UK Firms 2004-2011

	M1	**M2**	**M3**	**M4**	**M5**	**M6**
Constant	0.188***	0.176***	0.260***	0.259***	0.260***	0.276***
	(10.44)	(8.31)	(4.44)	(3.85)	(3.87)	(4.09)
GAP_{t-1}	-0.187***	-0.128***	-0.257***	-0.259***	-0.257***	-0.252***
	(-9.41)	(-5.69)	(-3.60)	(-3.39)	(-3.35)	(-3.26)
Exporter	0.003	0.002				
	(1.17)	(0.82)				
R&D Active	0.011***	0.010***				
	(3.56)	(3.10)				
ES_{t-1}			0.015**	0.015**	0.015**	0.012**
			(2.46)	(2.55)	(2.53)	(2.25)
RDS_{t-1}			0.030**	0.029**	0.029**	0.030**
			(2.43)	(2.26)	(2.25)	(2.27)
$DETR_{t-1}$	-0.005***	-0.006***	-0.011***	-0.010***	-0.010***	0.004
	(-4.38)	(-3.84)	(-5.65)	(-5.10)	(-5.43)	(0.88)
Interaction Terms						
$GAP_{t-1} \times DETR_{t-1}$		0.005***		-0.002		
		(2.81)		(-0.86)		
$GAP_{t-1} \times ES_{t-1}$			-0.020**	-0.020**	-0.018**	-0.018**
			(-2.45)	(-2.51)	(-2.29)	(-2.39)
$GAP_{t-1} \times RDS_{t-1}$			-0.032*	-0.032*	-0.032*	-0.028
			(-1.96)	(-1.81)	(-1.80)	(-1.55)
$GAP_{t-1} \times DETR_{t-1} \times ES_{t-1}$					0.001	
					(1.06)	
$GAP_{t-1} \times DETR_{t-1} \times RDS_{t-1}$						0.005***
						(3.51)
Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Diagnostic Tests						
Observations	2 3770	16877	3913	3913	3913	3821
F-statistic	545.93	26.81	55.08	306.20	131.31	186.79
p-value	0.000	0.000	0.000	0.000	0.000	0.000
RESET	134.42	6.98	14.09	14.15	16.21	23.97
p-value	0.000	0.0001	0.000	0.000	0.000	0.000

Notes: *GAP* stands for the distance of productivity for a given firm from the industry frontier. *Exporter* is a dummy variable taking the value one if a firm is exporter for all the years of the sample and zero otherwise. *R&D active* is a dummy variable taking the value one if a firm is research active and zero otherwise. *ES* stands for the export share and *RDS* stands for the research share. *DETR* stands for discounted effective tax rate. RESET test refers to the hypothesis that the model has no omitted variables. Coefficients with t-statistics in parentheses are consistent for robust standard errors clustered by firm and *indicates p< 0.10, **indicates p< 0.05, ***indicates p< 0.01.

To explore further the possibility that the distortionary effect of corporate tax varies between exporting and (non-exporting) firms as well as between R&D active and R&D inactive firms, we split our initial sample into two sub-samples according to export and R&D status. We then replicate the estimation of column (1) from Table 1. This specification can be informative to whether firms that are not engaged in export and research activity tend to catch-up more slowly making the distortionary effect of taxation even higher. Estimates from this specification are shown in Table 2. The autonomous effect of *DETR* is negative and statistically significant in both groups whereby the interaction term $GAP_{i,t-1} \times DETR_{i,t-1}$ is insignificant in the group of exporting and research active firms. This result can be viewed as evidence that research active and exporting firms manage to compensate more easily the losses from higher taxation and thus the speed of convergence is not affected significantly. This effect is more likely attributed to the fact that exporting and research active firms are naturally closer to the frontier and thus any taxation-induced effect harms less compared to domestically oriented firms as well as those that are not R&D active.

Table 2: Pooled OLS Regressions of TFP growth. Exporters-Non Exporters and R&D- Non R&D active firms

	M1	**M2**	**M3**	**M4**
	Exporters	**Non-Exporters**	**Research Active**	**Non-Research Active**
Constant	0.110^{***}	0.137^{***}	0.120^{***}	0.131^{***}
	(4.83)	(4.95)	(6.26)	(5.12)
GAP_{t-1}	-0.111^{***}	-0.139^{***}	-0.064^{***}	-0.142^{***}
	(-4.44)	(-4.59)	(-2.89)	(-5.09)
$DETR_{t-1}$	-0.006^{**}	-0.006^{***}	-0.004^{*}	-0.007^{***}
	(-2.27)	(-3.29)	(-1.93)	(-3.73)
$GAP_{t-1} \times DETR_{t-1}$	0.005	0.005^{**}	0.004	0.005^{**}
	(1.44)	(2.36)	(1.62)	(2.25)
Industry Dummies	Yes	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes	Yes
Diagnostic Tests				
Observations	3346	13531	3913	12964
F-statistic	18.65	31.31	9.27	36.62
p-value	0.0000	0.0000	0.0000	0.0000
RESET	6.27	14.76	17.62	7.66
p-value	0.000	0.000	0.000	0.000

Notes: Definition of variables is identical to Table 1. As exporters are defined firms that report sales to international markets for all years of the sample 2004-2011. Similarly, R&D active firms are defined as those that report R&D spending in all years of the sample. RESET test refers to the hypothesis that the model has no omitted variables. Coefficients with t-statistics in parentheses are consistent for robust standard errors clustered by firm and *indicates p< 0.10, **indicates p< 0.05, ***indicates p< 0.01.

Table 3: Pooled OLS Regressions of TFP growth: Identifying Non-Linearities

	M1	M2	M3	M4	M5	M6
Constant	0.243***	0.259***	0.144***	0.145***	0.142***	0.145***
	(13.54)	(13.62)	(5.12)	(3.62)	(3.56)	(3.62)
GAP_{t-1}	-0.244***	-0.268***	-0.135***	-0.150***	-0.140**	-0.150***
	(-14.51)	(-13.69)	(-4.62)	(-2.67)	(-2.50)	(-2.68)
Exporter	-0.002	-0.002				
	(-0.81)	(-0.83)				
R&D Active	0.018***	0.018***				
	(7.04)	(7.01)				
ES_{t-1}			0.006	-0.046	-0.038	-0.046
			(0.62)	(-0.83)	(-0.69)	(-0.85)
RDS_{t-1}			0.004	0.116***	0.116***	0.105**
			(0.43)	(3.92)	(3.92)	(2.14)
$DETR_{t-1}$	0.073***	-0.071	0.102***	0.118	0.117	0.124
	(5.34)	(-1.26)	(2.86)	(1.20)	(1.15)	(1.26)
$(DETR_{t-1})^2$	-0.066***	-0.070***	-0.109**	-0.119**	-0.113**	-0.120**
	(-2.90)	(-3.04)	(-2.07)	(-2.33)	(-2.20)	(-2.36)
Interaction Terms						
$GAP_{t-1} \times DETR_{t-1}$		0.214***		-0.012	-0.080	-0.016
		(2.65)		(-0.10)	(-0.65)	(-0.13)
$GAP_{t-1} \times ES_{t-1}$				0.074	0.048	0.075
				(0.98)	(0.62)	(0.98)
$GAP_{t-1} \times RDS_{t-1}$				-0.219***	-0.219***	-0.191
				(-4.20)	(-4.20)	(-1.65)
$GAP_{t-1} \times DETR_{t-1} \times ES_{t-1}$					0.141**	
					(2.12)	
$GAP_{t-1} \times DETR_{t-1} \times RDS_{t-1}$						-0.054
						(-0.26)
Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Diagnostic Tests						
Observations	38033	38033	3738	3738	3738	3738
F- statistic	1820	411.78	228.43	7900	1357.54	38.96
p-value	0.000	0.000	0.000	0.000	0.000	0.000
RESET	74.98	13.15	37.86	25.37	16.33	17.30
p-value	0.000	0.000	0.000	0.000	0.000	0.000

Notes: **Notes:** *GAP* stands for the distance of productivity for a given firm from the industry frontier. *Exporter* is a dummy variable taking the value one if a firm is exporter for all the years of the sample and zero otherwise. *R&D active* is a dummy variable taking the value one if a firm is research active and zero otherwise. *ES* stands for the export share and *RDS* stands for the research share. *DETR* stands for discounted effective tax rate. RESET test refers to the hypothesis that the model has no omitted variables. Coefficients with t-statistics in parentheses are consistent for robust standard errors clustered by firm and *indicates p< 0.10, **indicates p< 0.05, ***indicates p< 0.01.

5.2 The identification of non-linear effects between TFP and Taxation

Estimations in Tables 1 and 2 implicitly assume that taxation causes productivity distortions at any levels. In other words, the TFP-taxation nexus is linear over all levels of effective tax rate. Nevertheless, the plot illustrated in Figure 1 indicates that this relationship could be non-linear. A quadratic prediction plot between Total Factor Productivity Growth and *DETR* shown in Figure 4 reveals an inverted U-shaped relationship. This means that at low levels of corporate tax, productivity growth co-moves with tax share while there is a critical threshold beyond which further increases in corporate tax slow down productivity growth. To assess the empirical validity of such hypothesis, we introduce a quadratic term of *DETR* in the $\Delta \ln TFP$ equation. Results from these specifications are illustrated in Table 3.

The quadratic term is always negative and statistically significant at the 5% level while the linear term is positive and mainly insignificant. These findings are supportive of a non-linear relationship and allow us to derive from the estimated equations the critical value of DETR beyond which the deceleration of TFP growth occurs. We take the specification in column (3) where continuous measures of export and R&D activity are included and both DETR terms are statistically significant. The estimated equations are written as:

$$\begin{aligned} \Delta TFP = {} & 0.144 - 0.135 GAP_{t-1} + 0.102 DETR_{t-1} - 0.109 (DETR_{t-1})^2 \\ & + 0{,}006 ES_{t-1} + 0.004 RDS_{t-1} \end{aligned}$$

From this equation, we can figure out that the turning point is equal to 46.7%.[14]This share indicates that any corporate tax paid above this threshold causes effectively deceleration in firm's Total Factor Productivity Growth. The headline corporate statutory tax rate has declined over time in the UK (to 23% in 2013 from 33% in 1996).The effective corporate tax rates however could differ by firm size and industry. Smaller firms could experience a higher effective corporate tax rate relative to larger

[14]The reader can find summary statistics for Discounted Effective Tax Rate for different percentiles in Table A6 in the Appendix. As it is shown in Table A6, for the 5% of firms the effective amount of corporate tax paid is around 40% while for the 1% the amount paid is above 70%. These figures indicate substantial differences in the amount of corporate tax paid, which also indicate that the actual tax burden for each firm varies significantly from the statutory policy tax set by fiscal authorities.

firms, and thereby could end up with a negative productivity growth when the rate exceeds the critical threshold level.

Figure 4: Non-Linear Prediction for the TFP Growth- Tax Rate Relationship

6. Some Sensitivity Tests

An issue of potential endogeneity bias emerges in equations [4.1] and [4.2] between the rate of TFP growth and the gap term due to the presence of TFP level in both sides of the equation. Additionally, TFP can be subject to measurement errors that are unobserved from the econometrician and can potentially produce spurious econometric results. The OP framework applied for the calculation of TFP accounts for endogeneity bias between the selection of inputs and output, although a series of other issues remain unresolved. For example, capital might not always be under full utilization introducing short term rigidities that can cause efficiency losses without necessarily reflecting technical changes. Similarly, OP methodology does not address cases in which firms experience monopolistic power that might lead to economies of scale and can be mistakenly attributed to technological progress. To address these sources of endogeneity and measurement bias we use an Instrumental Variables (IV) estimation framework to test the robustness of benchmark results presented in Table 1.

A crucial issue when a lagged dependent variable (i.e. $TFP_{i,t-1}$) appears on the right hand–side of the equation is to identify the degree of bias.[15]The latter is associated with the panel structure of the data. As Kiviet (1995) and Judson and Owen (1999)have shown when the number of firms (N) is sufficiently greater than the number of years (T) (the case in the current paper) a GMM estimator produces a lower Root Mean Square Error (RMSE) and thus it is more efficient. In the absence of any exogenous instruments with the desired properties which are to be correlated with the endogenous variable (*GAP*) but uncorrelated with the error term (u) in equations [4.1] and [4.2] we consider the case of a "restricted" GMM[16] that uses as instruments a sub-set of higher order lags of the endogenous variables. Before proceeding with this estimation, we first examine for the presence of serial correlation in our estimations by applying the Arellano-Bond (1991) test of autocorrelation. As presented in Table 4, the null hypothesis of no autocorrelation is not rejected for third and fourth lags of the endogenous variable. Thus, we instrument *GAP* and its associated terms with their third and fourth order lags. At the bottom of Table 4, we report Sargan-Hansen statistic values that test the validity of instruments. Under the null, the instruments included are uncorrelated with the error term, thus they are valid. Sargan-Hansen test follows the Chi-squared distribution with (L-K) degrees of freedom.[17]Another test of robustness implemented is to re-estimate some of our baseline specifications using the Levinsohn-Petrin (LP) (2003) non-parametric technique for estimating TFP. The key difference between OP and LP is that the latter uses intermediate inputs as a proxy for unobservable productivity shocks. The rationale behind this is that intermediate inputs perform better than investment in external shocks hence using them can provide more consistent TFP estimates. In our

[15]Nickell (1981) has shown that in panels with long time series cross section dimension the endogeneity bias is of order 1/T, where T is the number of years. Therefore, the bias tends to zero and thus a standard Least Square Dummy Variable (LSDV) can be both efficient and unbiased. Nonetheless, Judson and Owen (1999) have determined as a rule of thumb that the number of years needs to be close to 30 in order for the bias to tend to∞. In cases with smaller T the degree of bias can still be as high as equal to 20% in the coefficient of interest. The time and cross- section dimension of our panel is a typical microeconomic one and based on the Monte Carlo experiments of Kiviet (1995) and Judson and Owen (1999), GMM is the best option.

[16] A "restricted" GMM increases computational efficiency without detracting from its effectiveness. A necessary condition that makes plausible the use of lagged endogenous variables as instruments is the absence of serial correlation in the residuals.

[17]L is the number of instruments and K is the number of regressors.

case, an insight about the differences between the two approaches can be taken in Figure A3 (Appendix). The fit between the two is very similar with a correlation score equal to 0.70 although OP tends to be slightly upward biased. Table 5 shows POLS estimates from LP TFP. The main results however remain robust with regard to the distortionary tax effect and the private return to R&D. Interestingly Table 5 shows a negative and statistically significant interaction term between *DETR* and R&D share that indicates how corporate tax increases can harm a firm's absorptive capacity.

Table 4: GMM Regressions of TFP growth

	M1	M2	M3	M4	M5	M6
Constant	0.069***	0.063**	0.156**	0.170***	0.182***	0.207***
	(5.87)	(2.54)	(2.35)	(2.59)	(2.75)	(2.94)
GAP_{t-1}	-0.068***	-0.054	-0.196**	-0.210**	-0.234**	-0.343***
	(-4.51)	(-1.28)	(-2.08)	(-2.24)	(-2.39)	(-2.86)
Exporter	-0.003	-0.002				
	(-1.11)	(-0.40)				
R&D Active	0.006*	-0.002				
	(1.90)	(-0.12)				
ES_{t-1}			-0.000	-0.044	-0.0001	-0.0001
			(-0.06)	(-0.87)	(-0.01)	(-0.2)
RDS_{t-1}			0.018	0.018***	0.018***	0.018***
			(3.01)	(3.05)	(3.03)	(3.07)
$DETR_{t-1}$	-0.002	-0.000	-0.01***	-0.01***	-0.01***	-0.009***
	(-1.52)	(-0.03)	(-3.30)	(-3.08)	(-3.15)	(-3.01)
Interaction Terms						
$GAP_{t-1} \times DETR_{t-1}$		-0.016				
		(-0.98)				
$GAP_{t-1} \times ES_{t-1}$			0.002	0.059	0.020	0.014
			(0.14)	(0.86)	(0.25)	(0.19)
$GAP_{t-1} \times RDS_{t-1}$			-0.041	-0.067**	-0.061*	-0.089**
			(-1.46)	(-2.01)	(-1.88)	(-2.41)
$GAP_{t-1} \times DETR_{t-1} \times ES_{t-1}$					-0.005	
					(-0.50)	
$GAP_{t-1} \times DETR_{t-1} \times RDS_{t-1}$						0.023*
						(1.95)
Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Diagnostic Tests						
Observations	10824	4533	1508	1573	1573	1573
Wald Test	23.76	1.77	18.85	22.07	23.37	20.35
p-value	0.0001	0.8800	0.0044	0.0025	0.0029	0.0091
Sargan-Hansen test	0.043	3.079	3.990	3.220	5.168	5.897
p-value	0.8352	0.2145	0.2626	0.5216	0.3957	0.3164
Arrelano Bond test for autocorrelation						
Lag(3)	2.26	0.96	0.38	0.36	0.37	0.44
	[0.023]	[0.33]	[0.703]	[0.721]	[0.715]	[0.663]
Lag(4)	0.41	0.96	0.24	0.25	0.22	0.30
	[0.681]	[0.33]	[0.80]	[0.802]	[0.824]	[0.763]

Notes: Endogenous variables are considered GAP_{t-1} and its associated terms and as instruments used GAP_{t-3} , GAP_{t-4} and their associated interaction terms with, *ES*, *RDS* and *DETR*. Wald test refers to the joint significance of all second stage regressors and Sargan-Hansen test refers to the identification of instruments, under the null hypothesis the instrument used are valid (see the text for further information). First stage estimates reported for the exogenous variables (*Exporter*, *R&D Active*, *ES*, *RDS*, and *DETR*). Coefficients with t-statistics in parentheses are consistent for robust standard errors clustered by firm and *indicates p< 0.10, **indicates p< 0.05, ***indicates p< 0.01.

Finally, we pose the question whether our benchmark results are sensitive to the definition of the frontier. We investigate this by applying two alternative definitions for the frontier firm. First, *GAP* is calculated as the distance of the focal firm from the national frontier, $\max \mathrm{TFP}_t$ (i.e. the firm with the highest TFP level in the whole sample at a given year) and second *GAP* is calculated as the distance from the 5% percentile of the firms with the highest TFP level in the industry at a given year. We replicate benchmark specifications for these alternative definitions and results are reported in Tables 6 and 7, respectively.

The pattern of estimates from these sensitivity tests does not change significantly our baseline results. The *GAP* term remains negative and significant throughout all columns in Table 4 implying that any potential endogeneity bias has not driven our initial findings. Similarly, the negative impact of *DETR* on TFP growth remains confirming once again the distortionary character of taxation for productivity performance. This result suggests that lower corporate tax rate can improve firm productivity which corroborates the finding in the tax structure literature that substantial welfare gains can be obtained from tax reforms that decrease the capital tax rate relative to the labour/consumption tax rates (see Angelopoulos et al., 2012). Some alterations exist only in the interaction terms of GAP with *DETR* and Export activity (*ES*) that are now statistically insignificant at conventional levels. Using LP algorithm to calculate TFP, the *GAP* term appears insignificant in two of the specifications indicating a weaker convergence process but the results concerning R&D and *DETR* remain robust.

Turning to the specifications with a different definition for the frontier unit, the pattern of the estimated coefficients does not change substantially. The only notable difference in comparison to baseline estimates shown in Table 1 is that Tables 6 and 7 could not reveal direct export gains as the coefficient of export intensity is insignificant. Nevertheless, both tables indicate clearly that the greater is firm *i*'s export orientation the better the absorptive capacity, a result that one can interpret as an indirect productivity benefit derived from exports.

Table 5: TFP Growth Estimates with Levinsohn and Petrin (2003) Approach

	M1	M2	M3	M4
Constant	-0.037***	-0.038***	-0.086**	-0.100**
	(-3.52)	(-3.53)	(-1.97)	(-2.21)
GAP_{t-1}	-0.248***	-0.252***	-0.338***	-0.330***
	(-8.69)	(-8.44)	(-2.80)	(-2.60)
Exporter	0.004*	0.004*		
	(1.96)	(1.89)		
R&D Active				
ES_{t-1}			0.086*	0.095*
			(1.73)	(1.86)
RDS_{t-1}			-0.026*	-0.026*
			(-1.94)	(-1.93)
$DETR_{t-1}$	-0.017***	-0.009*	-0.023**	-0.008*
	(-2.89)	(-1.92)	(-2.44)	(-1.81)
Interaction Terms				
$GAP_{t-1} \times DETR_{t-1}$		0.054*		0.108
		(1.83)		(1.47)
$GAP_{t-1} \times ES_{t-1}$			0.250	0.285*
			(1.54)	(1.70)
$GAP_{t-1} \times RDS_{t-1}$			-0.077***	-0.079***
			(-3.44)	(-3.38)
Industry Dummies	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes
Diagnostic Tests				
Observations	29371	29371	2911	2911
F-statistic	27.07	24.91	8.21	5.08
p-value	0.000	0.000	0.000	0.000
RESET	105.52	105.17	65.63	58.25
p-value	0.000	0.000	0.000	0.000

Notes: TFP is calculated using the Levinsohn-Petrin (2003) non-parametric technique. All estimates are from Pooled OLS regressions.*GAP* stands for the distance of productivity for a given firm from the industry frontier. *Exporter* is a dummy variable taking the value one if a firm is exporter for all the years of the sample and zero otherwise. *R&D active* is a dummy variable taking the value one if a firm is research active and zero otherwise. *ES* stands for the export share and *RDS* stands for the research share. *DETR* stands for discounted effective tax rate. RESET test refers to the hypothesis that the model has no omitted variables. Coefficients with t-statistics in parentheses are consistent for robust standard errors clustered by firm and *indicates p< 0.10, **indicates p< 0.05, ***indicates p< 0.01.

Table 6: Pooled OLS Regressions of TFP growth with National Frontier

	M1	M2	M3	M4	M5	M6
Constant	0.187***	0.179***	2.288***	2.290***	2.293***	2.28***
	(10.93)	(8.86)	(12.67)	(12.63)	(12.66)	(12.63)
GAP_{t-1}	-0.254***	-0.179***	-4.011***	-4.015***	-4.021***	-4.014***
	(10.09)	(-6.34)	(-12.67)	(-12.63)	(-12.67)	(-12.63)
Exporter	0.003	0.002				
	(1.17)	(0.84)				
R&D Active	0.012**	0.011***				
	(3.76)	(3.29)				
ES_{t-1}			0.010	0.010	0.010	0.010
			(1.16)	(1.14)	(1.07)	(1.14)
RDS_{t-1}			0.041	0.041	0.042	0.041
			(1.47)	(1.47)	(1.47)	(1.47)
$DETR_{t-1}$	-0.005**	-0.006***	-0.005***	-0.005***	-0.005***	-0.005***
	(-4.36)	(-3.90)	(-2.88)	(-2.87)	(-2.87)	(-2.87)
Interaction Terms						
$GAP_{t-1} \times DETR_{t-1}$		0.007***				
		(2.98)				
$GAP_{t-1} \times ES_{t-1}$			-0.033***	-0.033***	-0.030**	-0.032**
			(-2.65)	(-2.62)	(-2.23)	(-2.62)
$GAP_{t-1} \times RDS_{t-1}$			-0.046	-0.046	-0.047	-0.045
			(-0.99)	(-0.98)	(-1.00)	(-0.98)
$GAP_{t-1} \times DETR_{t-1} \times ES_{t-1}$					0.003	
					(1.41)	
$GAP_{t-1} \times DETR_{t-1} \times RDS_{t-1}$						0.0006
						(0.71)
Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Diagnostic Tests						
Observations	23770	16877	3913	3913	3913	3913
F-statistic	225.75	99.48	35.51	30.38	30.97	30.30
p-value	0.000	0.000	0.000	0.000	0.000	0.000
RESET	127.02	5.23	17.38	17.51	18.71	25.68
p-value	0.000	0.001	0.000	0.000	0.000	0.000

Notes: The specification of this table is identical to the one presented in Table 1 with the exception that here frontier firm (*F*) is set the one with the highest TFP level in the whole sample (national frontier) at year *t*.

Table 7: Pooled OLS Regressions of TFP growth with Frontier the 5% Percentile of Highest TFP in the Industry

	M1	M2	M3	M4	M5	M6
Constant	0.174***	0.169***	1.527***	1.527***	1.528***	1.526***
	(10.62)	(8.67)	(10.76)	(10.75)	(10.76)	(10.75)
GAP_{t-1}	-0.164***	-0.115***	-1.631***	-1.631***	-1.633***	-1.631***
	(-9.76)	(-6.07)	(-9.70)	(-9.70)	(-9.71)	(-9.70)
Exporter	0.003	0.002				
	(1.13)	(0.81)				
R&D Active	0.011***	0.011***				
	(3.64)	(3.23)				
ES_{t-1}			0.013	0.013	0.013	0.013
			(1.37)	(1.37)	(1.33)	(1.37)
RDS_{t-1}			0.092***	0.092***	0.093***	0.092***
			(3.13)	(3.13)	(3.14)	(3.13)
$DETR_{t-1}$	-0.005***	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***
	(-4.32)	(-3.92)	(-2.82)	(-2.82)	(-2.82)	(-2.82)
Interaction Terms						
$GAP_{t-1} \times DETR_{t-1}$		0.005***				
		(3.07)				
$GAP_{t-1} \times ES_{t-1}$			-0.024**	-0.024**	-0.022**	-0.023**
			(-2.29)	(-2.29)	(-2.11)	(-2.29)
$GAP_{t-1} \times RDS_{t-1}$			-0.069*	-0.069*	-0.069**	-0.069**
			(-1.96)	(-1.96)	(-1.97)	(-1.96)
$GAP_{t-1} \times DETR_{t-1} \times ES_{t-1}$					0.001	
					(0.63)	
$GAP_{t-1} \times DETR_{t-1} \times RDS_{t-1}$						0.001
						(0.08)
Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Diagnostic Tests						
Observations	23770	16877	3913	3913	3913	3913
F-statistic	172.48	75.70	28.798	24.780	24.856	24.660
p-value	0.0000	0.0000	0.000	0.000	0.000	0.000
RESET	143.88	8.96	19.26	19.61	21.33	25.75
p-value	0.000	0.000	0.000	0.000	0.000	0.000

Notes: The specification of this table is identical to the one presented in Table 1 with the exception that here frontier firm (*F*) is defined as the a hypothetical firm with TFP at year *t* the average TFP level of the 5% most productive firms of the industry.

7. Conclusions

This paper looks at how corporate taxation affects productivity performance at the firm level. In principle, corporate taxation might embody distortionary effects that can be passed on into productivity losses. Our aim in this paper has been to add to the limited body of evidence in the tax-productivity domain by studying the effects of corporate tax levels within an international framework of firm productivity catch-up. By attempting to include the existence of firm-level heterogeneity, both across and within industries, we hope to add to a better understanding of the convergence process in productivity levels between countries.

Using UK firm-level data, we looked at whether the firm's corporate tax burden slows the speed of productivity convergence and, if so, through which channels this deceleration is likely to take place. The main question posed being whether the taxation of profits affects capital investment. Our results suggest that higher rates of corporate taxation slow the rate of TFP growth. Our explanation for this is that increased tax liabilities, relative to profits, may reduce firm's resources for capital investment. This effect is likely to come about via a decrease in working capital, necessary for obtaining external funding. In addition, we find that firms that are export and R&D active tend to experience faster rates of TFP growth. We interpret this result as an indirect productivity benefit that can be derived from exporting.

Finally, a key policy inference from our results may be that the broader economic environment, and in particular national fiscal policy, can affect firm's ability to catch up with prevailing international productivity norms. From a policy perspective it would appear that the greater a firm's export orientation, the better its absorptive capacity for productivity enhancing ideas. If the negative distortionary effect of corporate tax, as uncovered in the paper, is the key channel through which firm productivity can recover or converge to the frontier, tax incentives for R&D related activities can have a positive effect on productivity in relatively open economies such as the UK after a deep economic slump.

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Appendices

A1. Olley and Pakes Methodology

Taking the logarithmic form of a standard Cobb-Douglas production function for firm *i*:

$$y_{i,t} = a_0 + \alpha k_{i,t} + \beta l_{i,t} + \gamma m_{i,t} + \omega_{i,t} + \varepsilon_{i,t} \qquad \text{[A.1]}$$

where ω and ε are i.i.d idiosyncratic error terms. It is assumes that ω affects firm *i*'s individual decisions while ε is a common shock to all firms (i.e. common changes in input prices, other macroeconomic shocks etc.). Estimating parameters α, β and γ with OLS is problematic mainly due to the underlying selection bias between unobserved productivity shocks $\omega_{i,t}$ and inputs in period *t*. Every period firm *i* decides whether to "exit" or "stay" in the market. In the conditional "stay" decision the firm also decides the amount of its inputs such as: investment (*I*), labour and material. Capital stock is accumulated over time by: $k_{i,t} = (1-\delta)k_{i,t} + I_{i,t-1}$. The investment function depends on two state variables, capital stock (k) and productivity (ω), $I = I(\omega_{i,t}, k_{i,t})$ .the inverse investment is monotonic (Pakes (1994)) and thus productivity is a function of capital and investment:

$$\omega = h(k_{i,t}, I_{i,t}) \qquad \text{[A.2]}$$

By substituting equation (A.2) into (A.1) we get the following production function:

$$y_{i,t} = \beta l_{i,t} + \gamma m_{i,t} + f(k_{i,t}, I_{i,t}) + \varepsilon_{i,t} \qquad \text{[A.3]}$$

where, $f(k_{i,t}, I_{i,t}) = a_0 + \alpha k_{i,t} + h(k_{i,t}, I_{i,t})$.

The OP algorithm is implemented in three stages: First stage, a partial linear estimation is used to obtain values for β and γ . Second stage of the estimation refers to the exit decision of the firm and it is disentangled by endogeneity bias as the estimation of $\hat{h}$ in the first stage takes into account any unobserved shock ε. It is assumed that ω follows a first order Markov process: $\omega_{i,t} = E\left[\omega_{i,t} \mid \omega_{i,t-1}\right] + \nu_{i,t} = \theta(\omega_{i,t-1}) + \nu_{i,t}$ .Plugging the Markov-process in the production function:

$$y_{i,t} = a_0 + \alpha k_{i,t} + \beta l_{i,t} + \gamma m_{i,t} + \theta(\omega_{i,t-1}) + \nu_{i,t} + \varepsilon_{i,t} \qquad \text{[A.4]}$$

Production function can be written in a conditional form as follows:

$$\mathrm{E}[y_{i,t} \mid w_{i,t-1}, x=1] = a_0 + ak_{i,t} + bl_{i,t} + gm_{i,t} + q(w_{i,t-1}, w_{i,t}) + n_{i,t} + e_{i,t}$$

$$= a_0 + ak_{i,t} + bl_{i,t} + gm_{i,t} + q(w_{i,t-1}, \hat{h}(k_{i,t}, I_{i,t})) + n_{i,t} + e_{i,t} \qquad \text{[A.5]}$$

Where x equals to 1 if the firm has survived in the market till the end of period *t*. For the estimation of the survival probability on the second stage we approximate the unobserved productivity parameter $w_{i,t}$ by the estimate of the inverse function obtained from the first stage. Equation [A.5] is estimated by a linear probit and the probability of surviving in period *t* is called P_t. Third stage, the coefficient of capital stock (state variable) is estimated fitting anon-linear least squares equation:

$$y_{i,t} - \hat{b}l_{i,t} - \hat{g}m_{i,t} = a_0 + ak_{i,t} + q(\hat{f}_{t-1} - ak_{i,t-1}, \hat{P}_{i,t}) + n_{i,t} + e_{i,t} \qquad \text{[A.6]}$$

A2. **Description of FAME Variables**

Name	Definition
Output	Deflated Total Sales by PPI adjusted for firm inventories
Capital	Fixed Assets in current GBP deflated by capital price index
Materials	Cost of Sales
Labour	Number of Employees
Wages	Wages and Salaries in GBP
Age	The number of years since the establishment of a corporation.
Tax rate	Corporation Tax over Profit (Loss) before Tax
Total Sales	Total Turnover in GBP
Exports	Overseas Turnover in GBP

Notes: All values are recorded annually

Figure A3: Correlation between TFP Measures

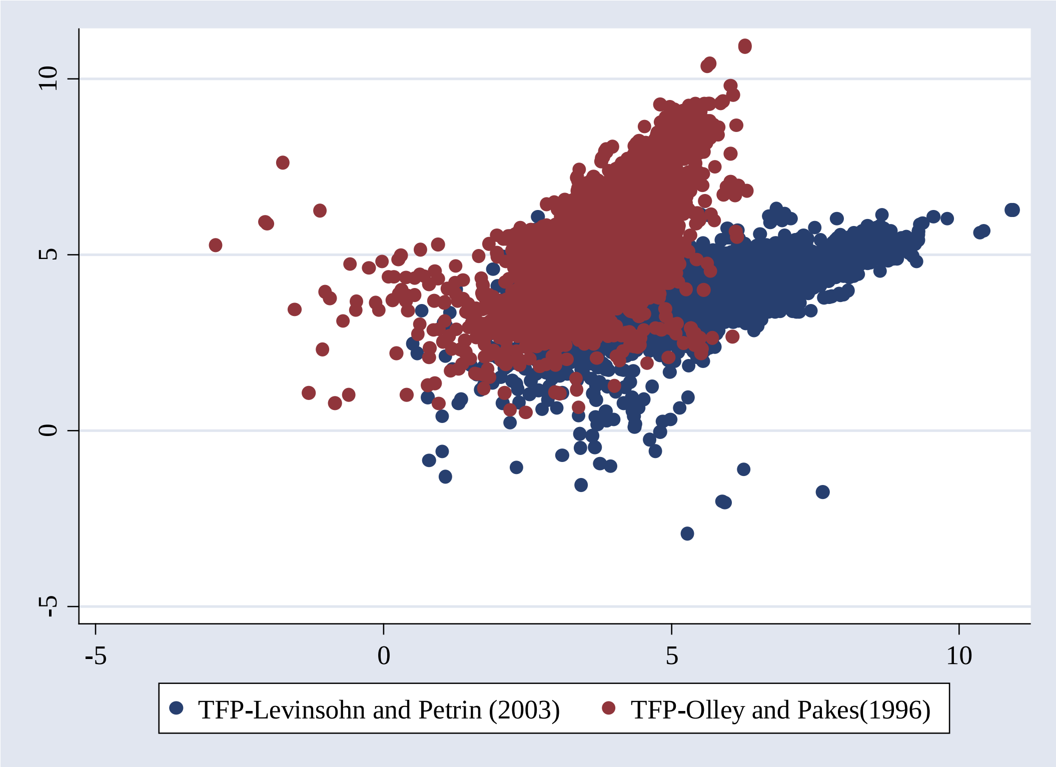

Table A4: Descriptive statistics for TFP growth (Olley-Pakes (1996))

Year	Mean	SD	MIN	P25	P50	P75	MAX
2005	4.33%	20.21%	-3.81	-0.02	0.04	0.10	2.60
2006	5.42%	18.64%	-2.59	-0.01	0.05	0.11	3.00
2007	5.87%	18.93%	-3.05	-0.01	0.05	0.11	3.23
2008	2.29%	21.09%	-4.53	-0.04	0.02	0.08	3.04
2009	-0.78%	22.65%	-2.34	-0.09	0.00	0.07	4.86
2010	4.94%	17.13%	-2.39	-0.02	0.05	0.12	1.85
2011	5.56%	16.97%	-3.26	0.00	0.05	0.11	1.99
Average	**3.95%**	**19.37%**	**-3.14**	**-0.03**	**0.04**	**0.10**	**2.94**

Table A5: GAP Industry and GAP National Frontier Values

Year	GAPIndustry	GAPNational	GAP 95% Percentile
2004	69.04%	51.17%	77.85%
2005	68.92%	51.50%	77.95%
2006	69.00%	51.49%	78.10%
2007	68.93%	51.25%	78.31%
2008	68.92%	50.89%	78.45%
2009	68.38%	49.78%	79.22%
2010	68.18%	49.99%	79.36%
2011	68.28%	50.26%	79.52%
Average	**68.65%**	**50.68%**	**78.70%**

Notes: *GAP* Industry takes as frontier the firm with the highest TFP in the industry in year *t*, *GAP* National takes as frontier the firm with the highest TFP in the whole sample in year *t* and *GAP* 95% percentile takes as frontier a hypothetical firm with the average TFP of the five more productive firms in the industry in year *t*.

Table A6: Discounted Effective Tax Rate (DETR) of UK Firms for Different Percentiles

Year	Mean	SD	P50	P75	P90	P95	P99
2004	13.55%	16.36%	9.29%	22.97%	32.79%	42.62%	73.66%
2005	13.10%	16.21%	7.63%	22.82%	32.09%	41.02%	73.81%
2006	13.24%	16.22%	7.76%	23.08%	32.67%	41.64%	71.10%
2007	13.27%	15.68%	8.76%	23.40%	31.89%	40.34%	67.39%
2008	12.96%	16.47%	6.04%	23.31%	31.88%	40.91%	73.31%
2009	12.68%	16.86%	3.16%	23.09%	32.77%	43.90%	75.00%
2010	12.90%	16.21%	6.89%	23.21%	31.57%	41.20%	73.23%
2011	11.89%	14.93%	6.38%	21.25%	28.90%	36.46%	69.54%
Average	**12.91%**	**16.11%**	**6.99%**	**22.81%**	**31.82%**	**40.98%**	**72%**

Table A7: Export and R&D shares

Year	Export share (ES)	R&D Share (RDS)
2004	0.163	0.034
2005	0.169	0.032
2006	0.172	0.026
2007	0.179	0.025
2008	0.180	0.025
2009	0.176	0.022
2010	0.175	0.021
2011	0.180	0.021
Average	**0.175**	**0.024**

Notes: Export share is defined as exports over total sales and R&D share is defined as R&D expenditure over total cost.