DOI: 10.1111/emre.12647

RESEARCH ARTICLE

EMR European Management Review The Journal of the European Academy of Management

The paradox of research and development productivity and firm growth: Empirical evidence from publicly listed firms in the United Kingdom

Alaa Abed

Strategy, Enterprise and Sustainability Department, Manchester Metropolitan University, All Saints Campus, Manchester, UK

Correspondence
Alaa Abed, Strategy, Enterprise and Sustainability Department, Manchester Metropolitan University, All Saints Campus, Oxford Road, Manchester M15 6BH, UK.
Email: a.abed@mmu.ac.uk

Abstract
This research aims to investigate the intricate association between research and development (R&D) productivity, specifically assessed through Total Factor Productivity (TFP), and various dimensions of firm growth. Our analysis provides a comprehensive examination of different aspects of growth, including sales, productivity, and employment growth. In addition, we investigate the role of R&D investment in conjunction with R&D productivity to provide clear insights into this multifaceted relationship. Although conventional wisdom suggests a positive relationship between R&D and firm growth, our empirical exploration reveals a more intricate reality. Using 164 non-financial firms listed on the FTSE 350, our findings indicate that while R&D indeed contributes significantly to firm growth, the nature of this influence is contingent upon the specific dimension of growth under consideration and the adopted empirical models. For example, our baseline model shows a positive relationship between R&D productivity and sales and productivity growth. However, this result does not hold for employment growth. This study makes a substantial contribution to the existing body of research on R&D by illuminating the indirect intricacies of this relationship, offering practical insights for both scholars and industry professionals navigating the complex landscape of R&D-induced growth within the economic milieu.

KEYWORDS
employment growth, productivity growth, R&D investment, R&D productivity, sales growth

INTRODUCTION

Research and development (R&D) productivity is considered a firm-specific technological competence for efficiently allocating R&D resources. This encompasses aspects such as technological knowledge, R&D staff, employees, and related expenditures, which interact to yield innovative outcomes (Yoo & Lee, 2023). In the literature, the allocation of R&D resources, typically across different R&D projects, is recognized as one of the most debated strategic decisions for innovative firms (Yoo & Lee, 2023). Moreover, the determinants of R&D productivity are pivotal in R&D management and innovation-related studies. Various investigations seek to uncover firm-specific drivers, such as firm age, firm size, and knowledge production (Bloom et al., 2020; Dindaroğlu, 2018), making the drivers of R&D productivity a long-standing and engaging subject for both managers and researchers (Choi & Lee, 2022). The research frontier in this area remains open for exploration.

Therefore, it is imperative to explore the intricate relationship between R&D productivity and firm growth. Although the link between firm growth and R&D is generally perceived as "often positive," the complexity and heterogeneity of firm growth contribute to a less straightforward relationship, as pointed out by Audretsch et al. (2014, p. 745). This study illuminates the relationship between firm growth and R&D activities using a sample of listed firms in the United Kingdom. The empirical investigation begins by exploring the connection between R&D productivity and firm growth and proceeds to examine the association between R&D investment and firm growth. Furthermore, this study contributes additional insights into the R&D-growth relationship by drawing on the work of Knott & Vieregger (2019), considering various growth measures, including sales growth, productivity growth, and employment growth.

The analysis of firm growth poses challenges as firms can grow through various mechanisms, such as mergers and acquisitions, the establishment of new firms (spinouts), and innovation—introducing new products, processes, or services (Audretsch et al., 2014; Delmar et al., 2003). Scholars typically approach the examination of firm growth through either a quantitative approach (focused on "how much") involving econometric modeling or a qualitative approach (focused on "how") through case studies. This diversity in approaches, methodologies, and definitions has contributed to a conceptually complex literature with empirical findings that are often partial and occasionally confusing (Audretsch et al., 2014). Consequently, this study aims to provide further clarification on this subject within the context of publicly listed firms in the United Kingdom.

The rationale for selecting the United Kingdom as the study's setting is multifaceted. Firstly, the United Kingdom holds a preeminent position in the global economy, encompassing a wide array of industries and sectors, making it a diverse backdrop for investigating Total Factor Productivity (TFP) and firm growth. This economic diversity purportedly enhances the generalizability of research findings. Secondly, characterizing the United Kingdom as a developed and industrialized economy can arguably provide a controlled research environment, thereby minimizing potential confounding factors present in less developed economies. Finally, the study acknowledges the importance of the policy environment within the United Kingdom and its implications for academia and policymaking, especially in the context of innovation and economic growth. However, TFP and firm growth is an under-researched topic and, thus, warrants this investigation.

The various definitions and measures used in prior studies to assess firm growth, such as sales growth, employment growth, and productivity growth, have given rise to challenges in comparing and comprehending the findings and hindered generalizability (Audretsch et al., 2014; Coad et al., 2016; Coad & Grassano, 2019). Additionally, firm growth cannot be solely attributed to characteristics like firm size, firm age, or the inclusion of different industries and locations. Unobservable factors, such as employee skills and managerial capital, further complicate the analysis of firm growth. Notably, there is a lack of consensus in the literature concerning the principal factors influencing firm growth, whether they are macro-level factors (Tsuboi, 2020), firm-specific variables, or a combination of both. Furthermore, it can be argued that no single standalone theory comprehensively explains firm growth, introducing challenges in understanding the dynamics of growth from a theoretical standpoint.

Consequently, the relationship between firm growth and R&D is far from straightforward due to the complexities of both growth and R&D productivity. A critical aspect is the measurement of growth. In addressing the intricacies of defining growth, this paper employs three measures—sales growth, productivity growth, and employment growth—to investigate their relationship with R&D. From an empirical perspective, previous studies offer little consensus on the set of factors determining firm growth, whether at the macro-level or the firm-level, resulting in inconclusive results. These factors motivate this research, seeking to provide novel insights into the connection between R&D productivity and firm growth within the UK context. This endeavor advances the understanding of this relationship and makes a valuable contribution to the R&D literature. Additionally, this paper distinguishes itself by focusing on R&D productivity and firm growth, underscoring the significance of human capital in R&D productivity for enhancing firm growth. Investment in R&D activities is crucial, not only for firms but as an essential skill underpinning firm growth, when coupled with the requisite human capital, as exemplified by Knott & Vieregger (2019).

TFP stands as a pivotal metric in economic analysis, commonly employed as a proxy for assessing the efficacy of R&D. Previous studies, exemplified by Ha & Howitt (2007), Knott & Vieregger (2019), and Redding (2011), have underscored the importance of TFP in understanding the complexities of firm growth dynamics. These investigations consistently demonstrate a positive association between TFP and the potential for firm expansion, indicating that higher TFP levels associate with increased efficiency and innovation within organizations. However, it is essential to recognize the limitations of solely relying on TFP as a measure of R&D productivity. Theoretical models, while invaluable in simplifying complex economic systems, may not fully capture the multifaceted nature of growth mechanisms. Despite TFP's ability to offer a comprehensive overview of overall efficiency and productivity, it encompasses various factors contributing to growth, thereby complicating the isolation of R&D's specific impact. This limitation becomes particularly significant when considering factors beyond TFP's scope.

In this study, we acknowledge the importance of addressing these limitations and situating our analysis within the broader landscape of economic research. Our choice to focus on TFP is influenced by data constraints within our UK dataset. We note the scarcity of comprehensive patent-related information, often considered a more direct measure of R&D productivity. This limitation aligns with the findings of Knott & Vieregger (2019), who similarly faced challenges regarding patent information availability for firms engaged in R&D. While patents offer valuable insights into innovation, their applicability is hindered by variations in patent applications and disparities in economic value. Therefore, despite the limitations associated with TFP, it remains a practical metric for assessing R&D productivity, mainly in contexts where alternative measures, such as patents, may pose challenges due to data constraints and variations in applicability. Our discussion emphasizes the relationship between TFP, R&D productivity, and firm growth dynamics, with the aim of providing a comprehensive understanding of measuring R&D productivity and its implications for firm growth.

Our research, hence, contributes significantly to the existing body of knowledge on the relationship between R&D and firm growth, offering a complex insight on this interplay. First and foremost, in contrast to prior research, we rigorously examine the multifaceted link between R&D productivity and various dimensions of actual growth. This approach yields a more comprehensive understanding of the intricate relationships between R&D and different facets of firm performance. It underlines the contextual and multifaceted nature of the R&D-growth association, emphasizing that a uniform approach may not suffice when investigating these connections. Secondly, our study employs a diverse array of econometric techniques, encompassing panel data analysis and quantile regression models. By adopting this methodological diversity, we enhance the robustness of our empirical findings. Furthermore, it underscores that the nature of the R&D–firm growth relationship is contingent on several factors, including firm-specific attributes and industry contexts. We emphasize the need for researchers and practitioners to consider these nuances when assessing the impact of R&D activities on firm growth.

Thirdly, our study distinguishes itself by focusing on the intricate relationship between R&D productivity and firm growth within the context of the United Kingdom. Here, we adopt the approach proposed by Knott & Vieregger (2019), which defines R&D productivity primarily in terms of TFP. Our empirical results suggest that TFP as a metric for R&D productivity in this context yields valuable insights into how firms can harness R&D resources to enhance their growth potential. Accordingly, our study provides a solid foundation for future research, inspiring scholars to examine deeper into the multifaceted realm of R&D, firm growth, and productivity. The empirical implications we present open doors for more in-depth investigations into the specific conditions and contingencies under which R&D exerts varying influences on different facets of firm growth and overall performance. Our main models reveal a positive association between R&D activities and two facets of firm growth: sales growth and productivity growth. This shows the important role that R&D plays in enhancing a firm's capacity to increase both sales and productivity levels. Similar positive results are reported for R&D investment, affirming the notion that investing in R&D constitutes a strategic decision for firms aiming to enhance their overall growth prospects. However, our findings present inclusive results concerning productivity growth.

The remainder of this study is organized as follows. Section 2 highlights R&D and firm growth including the theoretical framework and hypothesis development. Section 3 discusses the data and research methods. Section 4 provides the empirical results, and Section 5 provides our further analyses. Finally, Section 6 concludes this study.

R&D FOR FIRM GROWTH

The relevance of R&D for firm growth: Theoretical stand

The "R&D-centric" domain of the endogenous growth theory occupies a central position within the field of economic development research. It steadfastly underlines the empirical evidence that emphasizes the significant impact of investments in R&D on the expansion of TFP. Nevertheless, the recent decades have steered in a conundrum, notably affecting scholars, particularly within the context of OECD countries. The complex and enduring relationship between R&D and TFP has posed a significant challenge (Ha & Howitt, 2007). A perplexing paradox has surfaced, particularly evident in the United States since the early 1950s. During this period, the nation has witnessed a remarkable quintupling of its R&D workforce, predominantly comprising scientists and engineers (Ha & Howitt, 2007). Paradoxically, this substantial expansion in R&D labor has not yielded commensurate increments in per capita output or TFP growth. This discrepancy, where a substantial upswing in R&D labor does not align with TFP growth, fundamentally questions the earlier generation of R&D-based theories. These initial theories had posited a straightforward association wherein an increase in R&D labor should logically lead to an uptick in TFP growth (Ha & Howitt, 2007).

In response to this perplexing conundrum, scholars have embarked on the challenging task of devising a second generation of R&D-based theories. These new theoretical frameworks, while sharing their roots in foundational concepts, introduce intensely different long-term implications. This divergence serves to enrich the ongoing discourse on economic growth (Ha & Howitt, 2007). The first theoretical trajectory, commonly known as the "semi-endogenous" theory, as articulated by scholars like Segerstrom (1998) and Kortum (1997), introduces a central modification to the original R&D-based framework. This adaptation brings into the spotlight the concept of declining returns to the knowledge stock accumulated through R&D endeavours. It acknowledges that as technological advancements progress and become increasingly intricate, maintaining a consistent TFP growth rate necessitates ongoing growth in R&D labor. The semi-endogenous growth theory offers a straightforward and resolute long-term forecast: the pace of long-term TFP growth, and consequently, per capita income growth, is contingent on the population growth rate. In this regard, demographic dynamics tend to cast shadows over other economic determinants (Ha & Howitt, 2007).

In contrast, the second facet of second-generation R&D theory embodies the fully endogenous "Schumpeterian" models, championed by esteemed researchers such as Peretto and Smulders (2002) and Howitt (1999). These models build upon Young's (1998) foundational insights, suggesting that as an economy experiences growth, the production of different products exerts a diluting influence on the efficacy of R&D efforts aimed to improve quality. This proliferation leads to the dispersion of R&D activities across numerous sectors, thereby thinning the concentration of R&D within each sector (Ha & Howitt, 2007).

Schumpeterian theory, while acknowledging the adverse impact of mounting complexity on R&D productivity, remains rooted in the fundamental belief of constant returns to knowledge accrued through R&D activities (Ha & Howitt, 2007). Consequently, it suggests that the long-term TFP growth rate is determined by similar economic drivers as the first-generation R&D-based theories. The primary deviation within the Schumpeterian theory pertains to the negation of a positive scale effect on long-term growth stemming from the size of a country's labor force. This nuanced theoretical perspective aligns with the empirical reality where stagnant TFP growth coexists with a growing R&D labor force (Ha & Howitt, 2007). This coexistence finds its rationale in the compelling need to expand R&D labor to respond to the adverse effects of product proliferation on R&D productivity.

In addition to the Schumpeterian framework, a complex relationship emerges between innovation and entrepreneurship. Innovation emerges as the cornerstone of economic development, intrinsically intertwined with economic growth. Entrepreneurship assumes a pivotal role in facilitating the innovation process, fostering growth incentives, and nurturing economic development (Audretsch et al., 2014; Ha & Howitt, 2007). To grapple with the complexities of this field, scholars have adopted various approaches. Crafting a unified theoretical framework based solely on Schumpeter's ideas proved to be a staggering task. The complexity of the field gave rise to the evolutionary theory, rooted in the work of Nelson & Winter (1982). This theoretical stance fundamentally regards firms as dynamic social communities where knowledge forms the bedrock of comparative advantage. This perspective, as emphasized by Kogut & Zander (1993), underscores variations in productivity as the driving force behind inter-firm specialization and trade. Firms must judiciously evaluate the economic feasibility of transferring knowledge to other entities, as emphasized by Kogut & Zander (1993). This transfer hinges on the attributes of knowledge that constitute a firm's ownership advantage, encapsulating how information is encoded and actions are coordinated (Ha & Howitt, 2007).

To sum up, the second generation of R&D-based theories embarks on a nuanced journey to dissect the intricate interplay between R&D and TFP growth. These theories offer diverse insights into the role of population dynamics, the productivity of R&D investments, and the challenges posed by the ever-expanding landscape of product varieties. Consequently, these frameworks enhance our understanding of the complex relationship between R&D and economic development, reconciling empirical intricacies with robust theoretical constructs. This comprehensive examination contributes a critical dimension to the advancement of our comprehension of the factors underpinning long-term economic growth, thus enriching the broader discourse on economic development and its underpinnings.

Moving on, Romer's (1990) research explores the intricate relationship between innovative technology and growth, suggesting that knowledge acquisition is a direct outcome of R&D investments. Firms exhibit significant variance in their investments in both R&D activities and innovative technology, and it is precisely these investments that facilitate firm growth (Mairesse & Hall, 1996). R&D investments exert a direct influence on the innovation function, encompassing technological, process, and product innovation, which subsequently impacts firm growth (Mairesse & Hall, 1996).

Romer's model indicates that economic growth is fundamentally connected to R&D, with productivity in R&D playing a pivotal role. Economic theory posits that R&D productivity and investment drive growth (Knott & Vieregger, 2019). Corporations, driven by the pursuit of maximizing shareholder wealth, intensify their focus on boosting productivity (Romer, 1990). Measures of productivity capture the relationship between output and input, reflecting the intensity of resource utilization (Syverson, 2011). Knott & Vieregger (2019) accentuate the significance of R&D productivity concerning firm growth, contending that R&D investments, in and of themselves, might not be the primary drivers of firm growth. The importance of human capital is underscored, as highlighted by Bettis (1981). Knott & Vieregger (2019) conclude that not all R&D investments yield firm growth, necessitating an exploration into how productive R&D, that is, R&D productivity, stimulates firm growth. Consequently, this study delves into the impact of R&D productivity on firm growth within the UK context.

Knott & Vieregger (2019) posit that TFP represents Solow's residual for technological progress and the heterogeneity of economic growth. They argue that TFP serves as a proxy for the Solow residual, accounting for technological progress within growth calculations, while also suggesting that firms exhibiting higher TFP are more prone to expansion and growth (p. 8). However, the measurement of TFP introduces two potential concerns. Firstly, TFP, as an index of R&D productivity, has the potential to capture extraneous variables unrelated to R&D, thereby complicating the distinction between various facets of growth, such as R&D, advertising, or market expansion (Knott & Vieregger, 2019). Secondly, TFP can encompass variations in output that might not be entirely justifiable based on variations in inputs (Syverson, 2011). Nonetheless, certain trade theory literature suggests that firms with higher TFP are more inclined to grow and expand (Redding, 2011). This study estimates TFP as the residual element following the calculation of input contributions within the firm's production function (Knott & Vieregger, 2019). Given that R&D productivity is intricately linked to TFP, it is reasonable to consider the latter as a viable proxy for R&D productivity.

Hypotheses development

Coad & Rao (2008) build upon the insights of Carden (2005), contending that innovation is an imperative driver for firm growth. In a similar vein, Hay & Kamshad (1994), focusing on the context of small and medium-sized enterprises (SMEs), emphasize that investment in product innovation serves as a common strategy for these firms to achieve growth. Adopting the theoretical argument of Coad & Rao (2008), which aligns with the "semi-endogenous" and Schumpeterian theories, we attempt to merge these bold theoretical assertions regarding the centrality of innovation investments for firm growth within a quantitative empirical context.

The "semi-endogenous" theory implies that demographic dynamics, such as population growth, significantly influence the relationship between R&D investment and firm growth (Ha & Howitt, 2007). In contrast, the Schumpeterian theory implies that the relationship between R&D investment and firm growth is shaped by the adverse impact of product proliferation on R&D productivity (Ha & Howitt, 2007). Considering these theories, we expect R&D productivity will enhance firm growth.

It is pertinent to highlight that empirical studies in this domain present a heterogeneous landscape, yielding inconclusive evidence and occasionally contradictory findings concerning the relationship between R&D activities and firm growth. The complexity inherent in the phenomenon of growth contributes to this empirical diversity. For instance, Coad & Rao (2008) examined the impact of innovation (measured through R&D investment) on sales growth within high-technology industries and discerned that innovation indeed stands as a pivotal determinant of firm growth. Likewise, studies by Yasuda (2005), García-Manjón & Romero-Merino (2012), Stam & Wennberg (2009), Dachs & Peters (2014), Harrison et al. (2014), Segarra & Teruel (2014), and Cainelli et al. (2006) align with this perspective, indicating a positive relationship between R&D investment and firm growth.

Nonetheless, the empirical landscape is far from uniform. Certain studies, such as the work of Loof & Heshmati (2006), utilizing R&D investment as a proxy for innovation, deviate from this trend by reporting an absence of a significant link between innovation activities and firm growth. Moreover, researchers like Freel & Robson (2004), Ross & Zimmerman (1993), and Brouwer et al. (1993) have documented instances where R&D investment seemingly exerts a negative influence on firm growth. The spectrum of results underscores the complexity and variability inherent in the interplay between R&D and growth, leaving ample room for further exploration within specific contexts.

The question of whether R&D can indeed enhance growth remains an open avenue for investigation, particularly in distinct organizational and sectoral settings. To solve this intricate relationship, our study implements diverse statistical models, critically examining both R&D investment and R&D productivity. Furthermore, we employ various measures of firm growth to elucidate this relationship within the context of the United Kingdom.

In a manner consistent with the approach advocated by Coad et al. (2016), we posit that R&D activities stimulate growth through the generation of innovative outputs, introducing new products and services, and enhancing productivity through "technical progress." Drawing theoretical support from economic theories, such as that of Knott & Vieregger (2019), which underline the interconnection between R&D and firm growth, we postulate that R&D projects, encompassing both investment and productivity aspects, serve as potent catalysts for growth, in alignment with the findings of Dachs & Peters (2014) and Coad et al. (2016).

Our core contention is that R&D activities significantly bolster firm growth when firms effectively translate their R&D endeavors into innovative outputs, thereby introducing new and improved products and services. This heightened productivity, in turn, acts as a motivation for overall firm growth. This viewpoint resonates with Howells (2008), who asserts that R&D investments are pivotal for the success of firms, enriching them by adding value through the development of enhanced and novel products and services.

In conclusion, our research delving into the complicated dynamics between firm growth and R&D activities within the UK setting has formulated three hypotheses, each carefully designed to explore different facets of firm performance. Drawing inspiration from the seminal work of Coad & Rao (2008) and aligning with the perspectives offered by the "semi-endogenous" and Schumpeterian theories, our first hypothesis asserts a positive association between R&D activities and sales growth in the United Kingdom. This proposition is rooted in the widely recognized concept that investments in R&D, fostering innovation and the creation of novel products and services, contribute to enhancing a firm's competitiveness and positively impacting its sales performance. The theoretical foundation establishes a comprehensive understanding of how innovation, as measured through R&D activities, can serve as a catalyst for increased sales within the specific context of the United Kingdom.

Shifting our focus to the second hypothesis, we narrow in on the connection between R&D activities and employment growth. This hypothesis anticipates that various facets of R&D activities, encompassing both productivity and investment, will yield positive outcomes in terms of employment growth within the UK context. The theoretical underpinnings articulated by Coad et al. (2016) support this expectation, emphasizing the catalytic role of R&D activities in generating innovative outputs. These outputs, in turn, directly influence a firm's capacity to expand its workforce, creating employment opportunities resulting from heightened productivity and the introduction of novel products and services.

Concluding our set of hypotheses, the third proposition introduces a non-directional expectation regarding the relationship between R&D activities and productivity growth within the UK context. Recognizing the inherent complexity of productivity dynamics, this hypothesis permits an open exploration into how R&D endeavors might shape this particular facet of firm performance. The Schumpeterian theory's emphasis on the potential adverse impact of product proliferation on R&D productivity enriches our interpretation, suggesting that the relationship between R&D activities and productivity growth may be intricate, influenced by factors related to innovation and technological progress. These hypotheses, delineating positive associations with sales growth, positive employment growth, and a non-directional stance on productivity growth, collectively steer our empirical investigation. They contribute to a nuanced understanding of the role played by innovation in shaping distinct dimensions of firm growth. Thus, on the basis of the discussions grounded in both the semi-endogenous and Schumpeterian theories, we posit that under conditions of developed, innovative, multisector economies, the following holds:

> **Hypothesis 1.** (H1): There is a positive relationship between R&D productivity (and R&D investment) and sales growth.

> **Hypothesis 2.** (H2): There is a positive relationship between R&D productivity (and R&D investment) and employment growth.

> **Hypothesis 3.** (H3): There is a relationship between R&D productivity (and R&D investment) and productivity growth.

DATA AND METHODOLOGY

The sample encompasses 164 non-financial publicly listed firms on the FTSE 350 in the United Kingdom, spanning the period from 2003 to 2016. To gather the requisite data, this study utilized various sources, including the annual reports from Osiris and Eikon Thomson. The analysis accounts for industry effects (sector effects) and further controls for the impact of the financial crisis period. Employing diverse econometric techniques, the primary models consist of the IV 2SLS method, with additional analysis conducted using quantile regression methods to delve deeper into the intricate relationship between R&D and firm growth. The principal IV 2SLS time series-cross-sectional model is utilized for the primary analysis:

$$\begin{aligned}\mathrm{GRO}_{it} = {} & \beta_0 + \beta_1 \mathrm{R\&Dp}_{it-1} + \beta_2 \mathrm{firm-age}_{it} + \beta_3 \mathrm{firm} \\ & - \mathrm{size}_{it} + \beta_4\, \mathrm{Profitability}_{it} + \beta_5 \mathrm{form-debt}_{it} + \mathrm{ID} \\ & - \mathrm{dummies} + \mathrm{FC} - \mathrm{dummies} + \varepsilon_{it},\end{aligned} \tag{1}$$

where firm growth is measured as sales growth (change in the rate of firm sales to reflect the sales growth), employment growth (changes in the number of employees to reflect the growth of employment), and productivity growth (changes in the number of sales per employee to reflect the productivity growth). R&Dp represents R&D productivity which is measured as TFP. Firm age was the number of years that the firm has been in operation, and firm size was measured as the natural logarithm of total assets. ROE was the returns on equity ratio, and firm leverage was the long-term debt to assets ratio. ID-dummies represent the sector dummies from the DataStream database.

As an additional validation step, we conducted two distinct analyses: (i) a 5-year-lag model, akin to the approach employed by Knott & Vieregger (2019), with revenue as the dependent variable and employing different R&D measures as the main independent variables. (ii) A 3SLS system of equations, which investigates this association within a simultaneous equation system, thereby providing insights into the causal relationships among R&D variables. The 3SLS approach proves to be efficient due to its ability to account for correlations among unobserved disturbances in the equation system, distinguishing it from methods such as ordinary least squares (OLS) (Bakhsh et al., 2017; Ryan & Wiggins, 2002). The development of the equation system involved constructing models based on existing literature that incorporated lagged independent variables in the two equations, facilitating comprehensive analysis.

To estimate the TFP model, we employed the STATA program -xtmixed-, which is well-suited for linear mixed models, a methodology consistent with the approach followed by Knott & Vieregger (2019).

TABLE 1 Calculating R&D productivity—TFP.

Variables	LNMV
Capital	−0.00307
	(0.00764)
Labour	0.836***
	(0.0116)
Constant	6.662***
	(0.141)
Observations	1987
Industry dummies	Yes

Abbreviations: R&D, research and development; TFP, Total Factor Productivity.
***$p < 0.01$.

Utilizing the STATA command -predict-, we derived the best linear unbiased estimates for TFP, computed as the residual component of the production function in the panel data analysis. In alignment with the methodologies outlined in the works of Bloom et al. (2013) and Knott & Vieregger (2019), the employment of a fixed effects model is shown to yield more accurate results for TFP estimation. Given the panel data nature of this study, we chose fixed effects estimation to calculate TFP. The model used for TFP calculation is represented as follows:

$$\ln MV_{it} = (\gamma_0 + \gamma_{0i}) + (\gamma_1 + \gamma_{1i}) \ln \text{Capital}_{it} + (\gamma_2 + \gamma_{2i}) \ln \text{Labour}_{it} + \varepsilon_{it}. \quad (2)$$

Table 1 shows the output of the linear mixed model LNMV is the natural logarithm of firm market value that was measured as the number of shares outstanding multiplied by the market price. Capital was measured as the natural logarithm of property, plant, and equipment, and labor was measured as the natural logarithm of the number of employees. The estimated residuals were then obtained using the predict command. The model reported in Table 1 is statistically significant (based on the *F* value); therefore, the residuals were estimated to form the TFP (the R&D productivity).[1]

Table 2, panel A, presents the descriptive statistics that show that the average TFP is 3.1% and the average R&D investment ratio is 2.7%. In addition, we reported the average of the growth measures. The sales growth average is around 0.69%, and productivity growth and employment growth are 0.77% and 5.7%, respectively. On average, profitability is around 22%, and firms rely on averages of around 20% for debt. The correlation matrix reported in Table 2 panel B shows that there are no high correlations; therefore, multicollinearity is not a problem in this study.

[1]This model is used only to calculate its residuals (if the model is fit and significant based on its *F* value).

R&D and firm growth within our sample

Because our focus is on R&D, Graph 1 illustrates the average trend of Ln(R&D) within various industries throughout the sample period from 2003 to 2016. In general, all industries underwent a positive shift during this period, albeit with some fluctuations. The health industry exhibited the highest average Ln(R&D) at 11.21, followed by the telecommunication industry with 10.1. The technology industry registered an average of 7.1, and the lowest average for Ln(R&D), 0.92, pertained to the consumer goods industry.

Graph 2 represents the trend of average of Ln(R&D) within the sample period. It is noticeable that there is a positive trend, and firms in our sample have increased their average spending during the year, with the highest average investment in R&D is in 2015. Average R&D investment dropped slightly in 2009 if compared with 2008, and this is likely be a reflection of the financial crisis at that year.

In Graph 3, we show the average growth of firms in our sample during the sample period. Three types of growth are reported: sales growth, employment growth, and productivity growth. There is a clear drop in sales and employment growth in 2009 that might reflect the starting effect of the financial crisis on the sampled firms, but the graph shows the recovery over (2014–2016) in sales and employment growth. Productivity growth fluctuated in the period (2008–2011) with a clear drop in 2014 (similar to sales and employment growth).

Accordingly, there is an interesting shift in firms' growth in our sample and R&D changes within the industries, and hence, we control for these industries in our regression models.

EMPIRICAL RESULTS

We now delve into the empirical findings derived from the models employed to investigate the impact of R&D productivity, TFP, and R&D investment on actual firm growth, encompassing measures such as sales growth, productivity growth, and employment growth. Our discussion is structured in three parts: firstly, we explore the relationship with R&D productivity, followed by R&D investment; secondly, we scrutinize the connection between R&D productivity and actual firm growth; and finally, we examine the association between R&D investment and actual firm growth.

R&D productivity and R&D investment

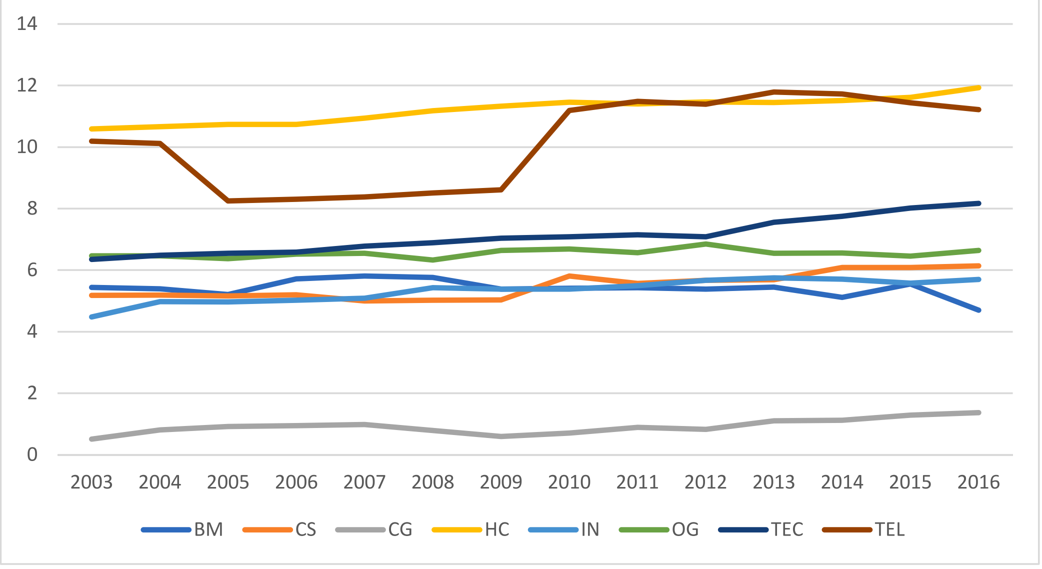
In our pursuit of understanding the potential relationship between R&D productivity and R&D investment, we have visually represented these two variables in Graph 4. A conspicuous positive correlation emerges, particularly

TABLE 2 Descriptive statistics and correlation matrix.

Panel A: Descriptive statistics				
Variable	**Mean**	**St. Dev**	**Min**	**Max**
R&D	0.0271	0.1082	0	0.998
TFP	0.0315	0.808	−1.8365	2.916
Sales growth	0.00695	0.026544	−0.15238	0.630121
Productivity growth	0.00768	0.0315706	−0.093369	0.141675
Employment growth	0.057363	0.192638	−0.42112	1.1019
Firm age	71.16626	59.14857	0	271
Firm size	14.48264	1.71695	10.241	18.807
Profitability	0.226922	0.256844	−0.6522	0.99
LEV	0.203593	0.17211	0	0.866919

Panel B: Correlation matrix						
	R&D	**Firm age**	**Firm size**	**Profitability**	**LEV**	**TFP**
R&D	1					
Firm age	−0.1565	1				
Firm size	−0.1514	0.0525	1			
Profitability	−0.03	−0.0478	0.0182	1		
LEV	−0.163	−0.0393	0.1301	−0.0828	1	
TFP	−0.1083	0.0602	0.5656	0.0442	−0.0884	1

Note: Where firm growth is measured as sales growth (change in the rate of firm sales to reflect the sales growth), employment growth (changes in the number of employees to reflect the growth of employment), and productivity growth (changes in the number of sales per employee to reflect the productivity growth). R&D is used to refer to the R&D to sales ratio (R&D investment), and R&D productivity is measured as TFP. Firm age is the number of years that the firm has been in operation, and firm size is measured as the natural logarithm of total assets. ROE is the returns on equity ratio, while firm leverage (LEV) is the long-term debt to assets ratio. Abbreviations: R&D, research and development; TFP, Total Factor Productivity.

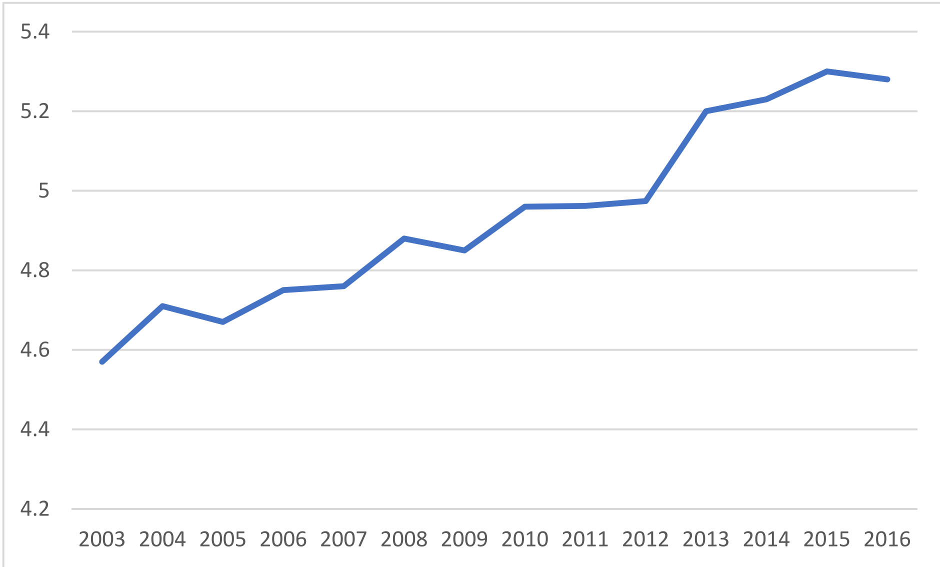


GRAPH 1 Trend of R&D per industry.

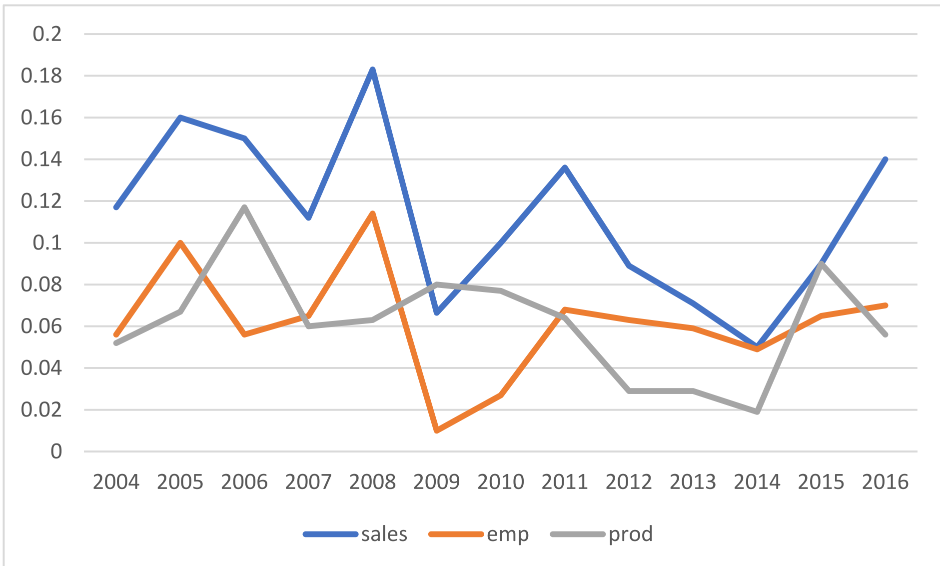
among firms actively involved in these activities. This is worth investigating empirically using the regression models. We have showed the full representation of data below, including when there were non-zero values.

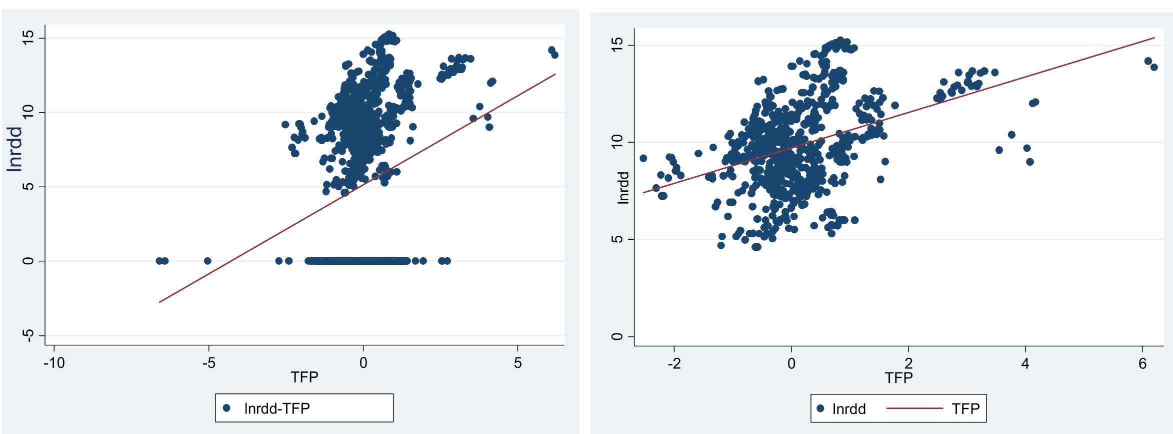
In addition, we followed Knott & Vieregger (2019) approach and examined whether R&D productivity is associated with R&D investment. We estimated the model using the natural logarithm of R&D investment (LNRD) as the dependent variable and capital (LNPPE), labor (LNEMPLOY), and R&D productivity (TFP) as the independent variables. Industry and financial crisis dummies were also controlled for in the models. Knott &

GRAPH 2 Research and development (R&D) trend.



GRAPH 3 Growth per year.





GRAPH 4 Research and development (R&D) investment and R&D productivity.

TABLE 3 R&D investment and R&D productivity.

Variables	(1)	(2)	(3)	(4)
	LNRDD	LNRDD	LNRDD-FE	LNRDD-FE
LNPPE	0.0813	0.0366	0.00438	0.00438
	(0.106)	(0.128)	(0.0232)	(0.0232)
LNEMPLOY	0.625***	0.457*	0.490***	0.488***
	(0.188)	(0.251)	(0.0686)	(0.0687)
TFP	0.779**	1.132***	0.500***	0.494***
	(0.375)	(0.366)	(0.0821)	(0.0830)
Constant	−1.400	0.577	0.688	0.689
	(2.122)	(2.643)	(0.658)	(0.660)
Observations	1480	1480	1480	1480
R-squared	0.333	0.065	0.051	0.053
Industry dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Number of firms (id)			164	164

Note: Where the natural logarithm of R&D investment (LNRD) as a dependent variable, capital (LNPPE), labour (LNEMPLOY), and R&D productivity (TFP) as independent variables. Standard errors in parentheses.

Abbreviation: R&D, research and development.

***$p < 0.01$.

**$p < 0.05$.

*$p < 0.1$.

Vieregger (2019) argued that there should be a positive association between R&D productivity and R&D investment. We reported the results in Table 3, which shows that there is strong evidence of a positive relationship between R&D productivity and R&D investment, indicating that the more productive R&D is where the more firms are more engaged in long-term projects. This result is consistent with the findings of Knott & Vieregger (2019), therefore suggests the importance of R&D productivity in the overall R&D investment decision.

R&D productivity and firm growth

We present the baseline models, IV 2SLS, which explore the relationships between growth and R&D productivity and investment. These findings are reported in Table 4 and are instrumental in addressing potential endogeneity issues between growth and R&D productivity. The 2SLS method is widely employed in the literature to mitigate endogeneity concerns through the use of instrumental variables. In our analysis, we meticulously selected instrumental variables that are directly associated with various critical aspects of firm performance, encompassing growth opportunities, liquidity, and capital expenditure ratios. These variables were chosen to provide a robust framework for investigating the impact of R&D activities on firm growth. The validity of our instrumental variables was rigorously assessed and confirmed through the Sargan test, which yielded non-significant results, affirming the appropriateness of our instruments.

Moving to the core findings, our examination of R&D productivity brings to light a compelling narrative of its influence on firm performance. Mainly, we observed a consistently positive relationship between R&D activities and two facets of firm growth: sales growth and productivity growth; this is in line with H1 and H3. This significant relationship supports the significance role that R&D plays in enhancing a firm's ability to expand its sales and optimize its productivity levels. Furthermore, we extended our analysis to include R&D investment, and the results showed a similar relationship between R&D investment and firm growth. This supports the notion that investing in R&D is a key strategic decision for firms seeking to improve their overall growth prospects.

These empirical findings not only are aligned to our initial expectations but also resonate with our expectations. Furthermore, they are in line with previous research in the field, providing additional empirical support to the existing body of knowledge. As a result of these findings, we have laid evidence that supports our expectations. The implications of these results are substantial, showing the key role of R&D in enhancing firm growth, thus contributing significantly to the extant literature on this subject.

Additional analysis

To gain additional insights into the relationship between firm growth and R&D productivity, we employ quantile regression analysis. This approach has been previously

TABLE 4 IV regressions.

Variables	R&D investment			R&D productivity		
	(1) Sales growth	(2) Productivity growth	(3) Employment growth	(4) Sales growth	(5) Productivity growth	(6) Employment growth
L.R&D	0.0299**	0.0371**	−0.0315			
	(0.0116)	(0.0164)	(0.0950)			
L.TFP				0.00600*	0.0128*	−0.0331
				(0.00347)	(0.00740)	(0.0423)
Control variables						
Firm age	−0.0004***	−0.00005**	−0.00025**	−0.0002***	−0.00058	−0.0003***
	(0.000128)	(0.000179)	(0.000104)	(0.000794)	(0.000170)	(0.000969)
Firm size	−0.00150***	−0.00205***	−0.0036	−0.002***	−0.0041**	−0.000781
	(0.000521)	(0.000751)	(0.00436)	(0.000828)	(0.00175)	(0.0100)
Profitability	0.0002	−0.0041	0.00095	−0.00244	−0.00658*	0.0110
	(0.00244)	(0.00339)	(0.0197)	(0.00180)	(0.00384)	(0.0220)
Leverage	−0.0042	0.00129	−0.0517	−0.00662	0.00322	−0.107*
	(0.00546)	(0.00766)	(0.0445)	(0.00460)	(0.00974)	(0.0555)
Constant	0.0189***	0.0306***	0.114**	0.0464***	0.0786***	0.0810
	(0.00659)	(0.00925)	(0.0538)	(0.0118)	(0.0252)	(0.144)
Observations	1469	1446	1447	1356	1348	1349
R-squared			0.041			0.020
Sargan test	3.973	0.648	4.080	4.523	0.554	4.764

Note: Where firm growth is measured as sales growth (change in the rate of firm sales to reflect the sales growth), employment growth (changes in the number of employees to reflect the growth of employment), and productivity growth (changes in the number of sales per employee to reflect the productivity growth). R&D is used to refer to the R&D to sales ratio (R&D investment), and R&D productivity is measured as TFP. Firm age is the number of years that the firm has been in operation, and firm size is measured as the natural logarithm of total assets. ROE is the returns on equity ratio, and firm leverage (LEV) is the long-term debt to assets ratio; standard errors in parentheses.

Abbreviation: R&D, research and development.

***$p < 0.01$.

**$p < 0.05$.

*$p < 0.1$.

employed by different studies (e.g., Coad et al., 2016). This regression provides a detailed check of the relationship and facilitates the gaining of additional results to compare with the main results. The quantile regression models for R&D productivity are reported in Table 5. The results show that there is strong evidence of a positive association between R&D productivity and sales growth from the 20th quantile to the 60th quantile. The results acquired from our analysis, congruent with our initial expectations and H1, carry significant implications for comprehending the intricate relationship between R&D productivity and diverse dimensions of firm growth. This observation underscores that firms making substantial investments in R&D activities tend to experience heightened rates of sales growth, thus underscoring the substantial influence of R&D endeavors on a firm's market performance.

Additionally, the outcomes concerning employment growth correspond with our foreseen results, manifesting positive and statistically significant trends spanning from the 20th quantile to the 60th quantile. This pattern indicates that firms deeply engrossed in R&D pursuits tend to exhibit more proactive workforce expansion, thereby reinforcing the notion that investments in R&D activities yield a beneficial ripple effect on employment generation. These findings bear substantial practical implications by underscoring the potential of R&D not only to stimulate economic growth but also to contribute to employment opportunities within the firm itself and the broader economy. This finding hence is in line with H2.

Our study showed the impact of R&D activities on key dimensions of firm growth, particularly sales growth and employment expansion, reaffirming the key role of R&D in enhancing a firm's competitiveness and market expansion capabilities. Firms actively engaged in R&D activities experience a substantial increase in sales, and a positive relationship extends to employment growth, revealing expanded job opportunities associated with increased R&D investments. However, exploring the models for productivity growth reveals an unexpected inverse relationship between R&D productivity and productivity growth. This unanticipated outcome prompts a thorough examination of potential impediments that may hinder productivity growth despite positive impacts on

TABLE 5 Quantile regression models—R&D productivity and firm growth.

Variables	(1) 20	(2) 40	(3) 60	(4) 80	(5) 90
Dependant variable: sales growth					
L.TFP	0.000613*	0.00105***	0.000809**	0.000560	−0.000631
	(0.000336)	(0.000293)	(0.000350)	(0.000555)	(0.00127)
Control variables					
Firm age	−0.0001**	−0.0001***	−0.0002***	−0.0002***	−0.0003**
	(0.0004)	(0.0003)	(0.0004)	(0.0006)	(0.0001)
Firm size	−0.000918***	−0.00130***	−0.00165***	−0.00257***	−0.00366***
	(0.000173)	(0.000151)	(0.000180)	(0.000285)	(0.000652)
Profitability	0.000415	−0.000196	−0.000531	0.000235	0.00110
	(0.000905)	(0.000789)	(0.000943)	(0.00149)	(0.00342)
LEV	−0.00244**	−0.00200*	−0.00341***	−0.00503**	−0.00718
	(0.00122)	(0.00106)	(0.00127)	(0.00202)	(0.00461)
Constant	0.00888***	0.0211***	0.0339***	0.0593***	0.0907***
	(0.00273)	(0.00238)	(0.00284)	(0.00450)	(0.0103)
Observations	1546	1546	1546	1546	1546
Dependant variable: productivity growth					
L.TFP	−0.00254*	−0.00251***	−0.00335***	−0.00871***	−0.0151***
	(0.00139)	(0.000911)	(0.000915)	(0.00164)	(0.00260)
Firm age	0.000257	0.000496	−0.000103	−0.000297	−0.000455
	(0.000165)	(0.000108)	(0.000109)	(0.000195)	(0.000308)
Firm size	0.00111*	0.000127	−0.000276	−0.000995	−0.00274**
	(0.000660)	(0.000433)	(0.000435)	(0.000780)	(0.00123)
Profitability	−0.00710**	−0.00179	−0.00228	0.00217	0.00825
	(0.00349)	(0.00229)	(0.00230)	(0.00413)	(0.00653)
LEV	−0.0108**	−0.00883**	−0.00746**	−0.00870	−0.0125
	(0.00551)	(0.00361)	(0.00363)	(0.00651)	(0.0103)
Constant	−0.0340***	0.00179	0.0291***	0.0740***	0.130***
	(0.0104)	(0.00681)	(0.00684)	(0.0123)	(0.0194)
Observations	1526	1526	1526	1526	1526
Dependant variable: employment growth					
L.TFP	0.0102**	0.00772*	0.0120**	0.00842	−0.00282
	(0.00518)	(0.00400)	(0.00520)	(0.00888)	(0.0227)
Firm age	−0.000197***	−0.000253***	−0.000341***	−0.000413***	−0.000568**
	(0.000615)	(0.000475)	(0.000617)	(0.000105)	(0.000269)
Firm size	−0.00350	−0.0116***	−0.0182***	−0.0248***	−0.0323***
	(0.00246)	(0.00190)	(0.00247)	(0.00422)	(0.0108)
Profitability	−0.00619	0.00387	0.00623	0.0478**	−0.0163
	(0.0130)	(0.0101)	(0.0131)	(0.0223)	(0.0571)
LEV	−0.0346*	−0.0419***	−0.0620***	−0.0736**	−0.125
	(0.0206)	(0.0159)	(0.0206)	(0.0352)	(0.0899)
Constant	−0.00443	0.178***	0.333***	0.490***	0.743***
	(0.0388)	(0.0299)	(0.0389)	(0.0665)	(0.170)
Observations	1527	1527	1527	1527	1527

Note: Where firm growth is measured as sales growth (change in the rate of firm sales to reflect the sales growth), employment growth (changes in the number of employees to reflect the growth of employment), and productivity growth (changes in the number of sales per employee to reflect the productivity growth). R&D is used to refer to the R&D to sales ratio (R&D investment), and R&D productivity is measured as TFP. Firm age is the number of years that the firm has been in operation, and firm size is measured as the natural logarithm of total assets. ROE is the returns on equity ratio, and firm leverage (LEV) is the long-term debt to assets ratio; standard errors in parentheses.

Abbreviation: R&D, research and development.

***$p < 0.01$.

**$p < 0.05$.

*$p < 0.1$.

TABLE 6 Quantile regression models—R&D investment and firm growth.

	(1)	(2)	(3)	(4)	(5)
Variables	**20**	**40**	**60**	**80**	**90**
Dependant variable: sales growth					
L.R&D	0.00219	0.0144***	0.0231***	0.0278***	0.0232***
	(0.00224)	(0.00184)	(0.00215)	(0.00358)	(0.00656)
Firm age	−0.0001***	−0.0002***	−0.0002***	−0.0003***	−0.0005***
	(0.0004)	(0.0003)	(0.0004)	(0.0007)	(0.0001)
Firm size	−0.000630***	−0.000830***	−0.00109***	−0.00176***	−0.00307***
	(0.000176)	(0.000144)	(0.000168)	(0.000281)	(0.000514)
Profitability	0.0003	−0.000304	−0.000514	−0.000298	−0.000779
	(0.00106)	(0.000865)	(0.00101)	(0.00169)	(0.00309)
LEV	−0.00245*	−0.00311***	−0.00409***	−0.00554**	−0.00849**
	(0.00138)	(0.00113)	(0.00132)	(0.00221)	(0.00404)
Constant	0.00631**	0.0155***	0.0259***	0.0472***	0.0781***
	(0.00287)	(0.00235)	(0.00275)	(0.00458)	(0.00838)
Observations	1644	1644	1644	1644	1644
Dependant variable: productivity growth					
L.R&D	0.0232***	0.0295***	0.0365***	0.0462***	0.0328**
	(0.00769)	(0.00439)	(0.00456)	(0.00754)	(0.0130)
Firm age	0.000585	−0.000529	−0.000167*	−0.000108	−0.000161
	(0.000166)	(0.000947)	(0.000983)	(0.000162)	(0.000280)
Firm size	0.000698	−0.000143	−0.000559	−0.00138**	−0.00314***
	(0.000619)	(0.000354)	(0.000367)	(0.000607)	(0.00104)
Profitability	−0.00737**	−0.00343	−0.00359	−0.00300	−0.00721
	(0.00371)	(0.00212)	(0.00220)	(0.00364)	(0.00626)
LEV	−0.00401	−0.00160	−0.00223	−0.00108	−0.0137
	(0.00569)	(0.00325)	(0.00338)	(0.00558)	(0.00960)
Constant	−0.0254**	0.00318	0.0279***	0.0600***	0.110***
	(0.00999)	(0.00571)	(0.00593)	(0.00979)	(0.0168)
Observations	1603	1603	1603	1603	1603
Dependant variable: employment growth					
L.R&D	0.00354	−0.0153	0.0150	0.0338	0.0423
	(0.0273)	(0.0207)	(0.0264)	(0.0425)	(0.109)
Firm age	−0.000134**	−0.000253***	−0.000343***	−0.000423***	−0.000522**
	(0.000587)	(0.000446)	(0.000569)	(0.000916)	(0.000235)
Firm Size	0.00150	−0.00671***	−0.0105***	−0.0162***	−0.0240***
	(0.00219)	(0.00167)	(0.00213)	(0.00342)	(0.00879)
Profitability	−0.00323	0.00585	0.00476	0.0166	−0.0113
	(0.0132)	(0.00998)	(0.0127)	(0.0205)	(0.0527)
LEV	−0.0525***	−0.0600***	−0.0835***	−0.0983***	−0.102
	(0.0202)	(0.0153)	(0.0196)	(0.0315)	(0.0809)
Constant	−0.0690*	0.126***	0.227***	0.388***	0.590***
	(0.0354)	(0.0269)	(0.0343)	(0.0552)	(0.142)
Observations	1604	1604	1604	1604	1604

Note: Where firm growth is measured as sales growth (change in the rate of firm sales to reflect the sales growth), employment growth (changes in the number of employees to reflect the growth of employment), and productivity growth (changes in the number of sales per employee to reflect the productivity growth). R&D is used to refer to the R&D to sales ratio (R&D investment), and R&D productivity is measured as TFP. Firm age is the number of years that the firm has been in operation, and firm size is measured as the natural logarithm of total assets. ROE is the returns on equity ratio, and firm leverage (LEV) is the long-term debt to assets ratio; standard errors in parentheses.

Abbreviation: R&D, research and development.

***$p < 0.01$.

**$p < 0.05$.

*$p < 0.1$.

sales and employment. High-risk R&D projects, while contributing positively to sales and employment figures, may encounter complex challenges. For instance, unforeseen technical challenges, such as difficulties in implementing cutting-edge technologies or adapting to rapidly evolving industry standards, can pose significant obstacles. Market uncertainties, including unpredictable shifts in consumer preferences or unexpected competitive disruptions, further complicate the landscape. Financial considerations also play a role, as the substantial investment required for ambitious R&D initiatives may lead to financial strain, especially if anticipated returns are delayed or uncertain.

Moreover, regulatory hurdles and compliance complexities introduce additional layers of difficulty. Navigating a regulatory landscape that may not align seamlessly with innovative endeavors can impede progress. For example, industries with stringent regulations or evolving compliance standards may face delays in product launches or encounter obstacles in scaling innovative solutions. These impediments collectively contribute to a complex interplay between R&D intensity and its impact on productivity growth. By examining into these challenges, our study shows the need for firms and policymakers to adopt strategic approaches when navigating the intricate landscape of R&D. Addressing these impediments requires a holistic understanding of the potential roadblocks associated with high-intensity R&D activities and emphasizes the importance of proactive strategies to mitigate such challenges for sustained productivity growth.

These findings show the multifaceted nature of the relationship between R&D activities and firm growth. While the positive outcomes in sales growth and employment expansion affirm the strategic importance of R&D investments, the inclusive results in productivity growth highlight the need for a clearer understanding of how different facets of innovation may influence distinct dimensions of firm performance. Our results, therefore, contribute valuable insights for firms aiming to navigate the complex landscape of innovation-driven growth strategies. The implications of our results extend to the realm of strategic decision-making, as firms strive to strike a balance between the prospective rewards of R&D productivity and the related risks. This nuanced perspective imparts fresh insights into the complexities of R&D activities and their influence on firm growth, thereby providing valuable contributions to the academic and practical domains in this field.

In Table 6, we report the results between R&D investment and firm growth that we show strong evidence of a positive association between R&D investment and sales growth starting from the 40th quantile until the 90th quantile. The models for productivity growth show strong evidence of a positive association between R&D investment and productivity growth starting from the 20th quantile until the 90th quantile. Regarding employment growth, we report no association between R&D investment and employment growth for all of the investigated quantiles. Hence, our results show the importance of R&D investment and firm growth, which is consistent with our main findings and H1.

TABLE 7 Ln (Sales) models.

Variables	(1) LNSALES	(2) LNSALES	(3) LNSALESFE	(4) LNSALESFE	(5) LNSALES-RDINT	(6) LNSALES-RDINT	(7) LNSALES-RDINT-FE	(8) LNSALES-RDINT-FE
L5.lnsales	0.817***	0.830***	0.0312	−0.111***	0.855***	0.859***	0.0731**	0.248***
	(0.0459)	(0.0395)	(0.0378)	(0.0427)	(0.0337)	(0.0291)	(0.0305)	(0.0261)
L5.lnrdd	0.00759	0.00619	−0.000835	−0.00295	0.00224	0.000527	−0.000711	0.00399
	(0.00719)	(0.00562)	(0.0100)	(0.00979)	(0.00626)	(0.00505)	(0.00853)	(0.00887)
L5.TFP	0.0173	0.0228	0.354***	0.330***				
	(0.0379)	(0.0378)	(0.0327)	(0.0321)				
L5.rdint					0.204	0.213*	−0.0464	0.000601
					(0.125)	(0.112)	(0.141)	(0.147)
Constant	2.985***	2.782***	14.07***	16.18***	2.510***	2.370***	13.53***	10.94***
	(0.693)	(0.572)	(0.528)	(0.606)	(0.507)	(0.418)	(0.433)	(0.361)
Observations	889	889	889	889	1272	1272	1272	1272
R-squared	0.878	0.875	0.182	0.229	0.886	0.884	0.161	0.083
Industry dummies	Yes	No	No	No	Yes	No	No	No

Note: Where LN Sales is the natural logarithm of sales; LNRDD is the natural logarithm of R&D; standard errors in parentheses.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

In summary, our results from the quantile regression models provide intriguing evidence that the relationship between firm growth and R&D is contingent upon how firm growth is defined. Regarding R&D productivity, these models reveal compelling evidence of a positive association between firm growth (specifically, sales growth and employment growth) and R&D productivity. However, an unexpected inverse relationship is observed in the case of productivity growth. Furthermore, we report favorable evidence indicating a positive link between R&D investment and both sales growth and productivity growth. These findings collectively underscore the intricate and multifaceted nature of firm growth.

FURTHER CHECKS AND ANALYSES

We also adopted the 5-year lag model (presented in Table 7), as utilized by Knott & Vieregger (2019), with revenue as the dependent variable, and various measures of R&D (R&D intensity, R&D productivity, and R&D investment) as independent variables. The findings reveal that R&D (measured as LN R&D) lacks statistical significance, and there is discernible evidence of a positive association between R&D productivity and firm growth. Additionally, there is limited evidence of a positive effect stemming from R&D investment (as indicated in Model 6) on firm growth. These results show empirical evidence

TABLE 8 System for the equation modeling (3SLS)—TFP and firm growth.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	**GRS–TFP**	**TFP–GRS**	**GRP–TFP**	**TFP–GRP**	**Gremp–TFP**	**TFP–Gremp**
L.TFP	−0.0053***		−0.0204***		0.0472***	
	(0.000737)		(0.00152)		(0.00935)	
L.GRS	0.164***	1.001				
	(0.0198)	(0.827)				
L.GRP			0.0151	1.782***		
			(0.0296)	(0.588)		
L.Gremploy					0.168***	−0.160
					(0.0294)	(0.0972)
R&D		−0.623***		−0.666***		−0.522**
		(0.208)		(0.200)		(0.206)
Control variables						
Liquidity		0.0133		0.00478		−0.00234
		(0.0152)		(0.0148)		(0.0153)
Firm age	−0.000***	0.000660*	−0.00005	0.00075**	−0.0003***	0.000658*
	(0.000006)	(0.000374)	(0.000005)	(0.000368)	(0.000111)	(0.000370)
Firm size	0.000323	0.248***	0.00352***	0.245***	−0.019***	0.240***
	(0.000359)	(0.0130)	(0.000744)	(0.0129)	(0.00447)	(0.0129)
Profitability	−0.00202	0.0373	−0.00401	0.0467	0.00531	0.0391
	(0.00180)	(0.0752)	(0.00375)	(0.0746)	(0.0224)	(0.0747)
LEV	−0.013***	−0.731***	−0.0243***	−0.762***	−0.0255	−0.791***
	(0.00290)	(0.122)	(0.00600)	(0.120)	(0.0360)	(0.120)
Financial crisis dummies	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.00404	−3.518***	−0.0279**	−3.513***	0.308***	−3.395***
	(0.00574)	(0.226)	(0.0120)	(0.223)	(0.0713)	(0.224)
Observations	1034	1034	1023	1023	1024	1024
R-squared	0.122	0.408	0.011	0.415	0.077	0.411

Note: Where firm growth is measured as sales growth (change in the rate of firm sales to reflect the sales growth), employment growth (changes in the number of employees to reflect the growth of employment), and productivity growth (changes in the number of sales per employee to reflect the productivity growth). R&D is used to refer to the R&D to sales ratio (R&D investment), and R&D productivity is measured as TFP. Firm age is the number of years that the firm has been in operation, and firm size is measured as the natural logarithm of total assets. ROE is the returns on equity ratio, and firm leverage (LEV) is the long-term debt to assets ratio; standard errors in parentheses.
Abbreviation: TFP, Total Factor Productivity.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

of the relationship between firm growth and R&D. The statistically significant findings offer further insights into this relationship within the sample of listed firms in the United Kingdom, thereby complementing the work of Knott & Vieregger (2019) in the United States, which emphasizes the importance of R&D productivity in relation to firm growth and overall performance.

Finally, we examined the relationship between R&D and growth in a system used as part of a system of equations. Ryan & Wiggins (2002) argue that investigating R&D as part of a system of equations will provide more accurate inferences related to the causality within the associations related to R&D. This study acknowledges this view for the two main themes (R&D and firm growth). This method might be able to provide accurate insights into the impact of R&D on firm growth. From a statistical perspective, the system of equations has the potential to provide accurate estimates if the relations between the investigated variables are endogenous compared to the single equation model. The endogenous variables were firm growth (sales growth, productivity growth, and employment growth) and R&D (R&D investment and R&D productivity), and we have reported the results in Tables 8 and 9. Our equations were as follows:

TABLE 9 System for the equation modeling (3SLS)—R&D investment and firm growth.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	GRS–R&D	R&D–GRS	GRP–R&D	R&D–GRP	Gremp–R&D	R&D–Gremp
L.R&D	0.0193***		0.0430***		0.00891	
	(0.00634)		(0.00857)		(0.0511)	
L.GRS	0.206***	0.290**				
	(0.0301)	(0.119)				
L.GRP			−0.0228	0.278***		
			(0.0293)	(0.0868)		
L.Gremploy					0.158***	0.00170
					(0.0287)	(0.0143)
TFP			−0.0113***		−0.0130***	−0.012***
			(0.00439)		(0.00455)	(0.00456)
Control variables						
Liquidity		0.0067***		0.0072***		0.0075***
		(0.00221)		(0.00226)		(0.00227)
Firm age	−0.00014	−0.0001**	−0.00015	−0.0001**	−0.0002**	−0.0001**
	(0.0005)	(0.00006)	(0.00007)	(0. 0005)	(0.000107)	(0.00005)
Firm size	−0.000551	−0.00140	−0.00114*	−0.000985	−0.00638*	−0.00163
	(0.000460)	(0.00216)	(0.000625)	(0.00219)	(0.00375)	(0.00218)
Profitability	−0.00175	−0.029***	−0.00550	−0.0265**	0.00822	−0.0279**
	(0.00271)	(0.0107)	(0.00367)	(0.0109)	(0.0220)	(0.0109)
LEV	−0.00836*	−0.073***	−0.00650	−0.072***	−0.0573	−0.075***
	(0.00430)	(0.0175)	(0.00583)	(0.0178)	(0.0350)	(0.0179)
Years dummies	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.0145*	0.0465	0.0366***	0.0357	0.114*	0.0493
	(0.00762)	(0.0358)	(0.0103)	(0.0363)	(0.0617)	(0.0361)
Observations	1075	1075	1052	1052	1053	1053
R-squared	0.085	0.313	0.050	0.322	0.081	0.316

Note: Where firm growth is measured as sales growth (change in the rate of firm sales to reflect the sales growth), employment growth (changes in the number of employees to reflect the growth of employment), and productivity growth (changes in the number of sales per employee to reflect the productivity growth). R&D is used to refer to the R&D to sales ratio (R&D investment), and R&D productivity is measured as TFP. Firm age is the number of years that the firm has been in operation, and firm size is measured as the natural logarithm of total assets. ROE is the returns on equity ratio, and firm leverage (LEV) is the long-term debt to assets ratio; standard errors in parentheses.

Abbreviation: R&D, research and development.

***$p < 0.01$.

**$p < 0.05$.

*$p < 0.1$.

$$\mathrm{GRO}_{\mathrm{it}} = \pi_0 + \pi_1\,\mathrm{GROi}_{\mathrm{t}-1} + \pi_2\,\mathrm{R\&D}_{\mathrm{it}-1} + \pi_3\mathrm{firm} - \mathrm{age}_{\mathrm{it}} + \pi_4\mathrm{firm} - \mathrm{size}_{\mathrm{it}} + \pi_5\mathrm{Profitability}_{\mathrm{it}} + \pi_6\mathrm{form} - \mathrm{debt}_{\mathrm{it}} + \mathrm{ID} - \mathrm{dummies} + \varepsilon_{\mathrm{it}}. \quad (3)$$

$$\mathrm{R\&D}_{\mathrm{it}=}\, \pi_7 + \pi_8\,\mathrm{GROi}_{\mathrm{t}-1} + \pi_9\,\mathrm{TFP}_{\mathrm{it}} + \pi_{10}\,\mathrm{firm} - \mathrm{liquidity}_{\mathrm{it}+}\,\pi_{11}\mathrm{firm} - \mathrm{age}_{\mathrm{it}} + \pi_{12}\,\mathrm{firm} - \mathrm{size} + \pi_{13}\mathrm{firm} - \mathrm{debt}_{\mathrm{it}} + \pi_{14}\,\mathrm{Profitability}_{\mathrm{it}} + \mathrm{ID} - \mathrm{dummies} + \varepsilon_{\mathrm{it}}. \quad (4)$$

In Table 8, we outline the system of equations employed to model the relationship between R&D productivity and firm growth. In the case of productivity growth, the results reaffirm the presence of a positive relationship between R&D productivity and employability growth. Interestingly, results in Table 8 yield conflicting evidence compared to our previous findings. Shifting our focus to R&D investment (Table 9), we find evidence supporting a positive association between R&D and firm growth. These results might be seen as evidence to support our main expectations as well as it adds an important aspect that such relationship is subject to changes based on the employed models.

Hence, our empirical models reveal that the relationship between R&D and firm growth is far from straightforward and is contingent upon the specific measures of growth employed. Furthermore, we observed that distinct econometric modeling approaches produce varying results, albeit the single equation models and the system equation analysis yielded congruent outcomes.

In summary, our empirical findings, derived from a sample of publicly listed UK firms, show compelling evidence substantiating the positive impact of R&D on firm growth. This paper, therefore, contributes fresh insights to the R&D literature by offering robust support for the positive relationship between R&D and firm growth in the UK context. Equally significant, our findings underscore the intricacies of firm growth, indicating that the outcome hinges not only on the measurement of firm growth but also on the choice of econometric methodology employed. Thus, our study emphasizes the imperative of meticulously investigating the interplay between R&D (productivity and investment) and firm growth, recognizing that the generalization of previous findings should be understood within the specific contextual framework of each study.

DISCUSSION AND CONCLUSION

This study investigates the intricate relationship between R&D productivity, measured as TFP (Knott & Vieregger, 2019), and firm growth within the context of the UK's listed firms. Whereas past research has yielded varying results (Brouwer et al., 1993; Dachs & Peters, 2014; Freel & Robson, 2004; García-Manjón & Romero-Merino, 2012; Harrison et al., 2014; Ross & Zimmerman, 1993; Yasuda, 2005), and the anticipated positive link between R&D and growth remains subject to complexity and multifaceted dynamics (Audretsch et al., 2014), our investigation brings fresh insights and contributions to the forefront. Our approach significantly enriches the existing literature. Firstly, by distinguishing between R&D investment and R&D productivity, we provide a more critical understanding of how these dimensions influence a firm's actual growth. This methodological distinction sheds light on the intricate web of factors that determine growth, emphasizing the multifaceted nature of the R&D–growth relationship.

Furthermore, our exploration encompasses three distinct types of growth—sales growth, productivity growth, and employment growth (Audretsch et al., 2014; Coad et al., 2016; Coad & Grassano, 2019). This multi-faceted approach to assessing growth allows for a comprehensive understanding of how R&D impacts different dimensions of firm performance, reinforcing the notion that the R&D-growth connection is indeed complex and context-specific. By adopting a dual perspective, merging the business and economic viewpoints through the application of the Cobb–Douglas equation, we bridge the gap between managerial and economic traits. This approach underscores the multi-dimensional nature of the R&D-firm growth nexus and its relevance in both realms. The findings from our main models underscore the positive link between R&D investment and actual growth, lending strong support our expectations. These results underscore the significance of this relationship and emphasize the importance of R&D investments in driving firm growth. Nonetheless, we acknowledge that the results concerning R&D productivity remain inconclusive, further underlining the complexity of R&D's impact on growth. These findings reinforce the call for a more nuanced exploration of these relationships, and the imperative to consider R&D productivity alongside investment.

This study, hence, contributes to the literature by offering additional empirical evidence regarding the significance of R&D productivity, particularly measured through TFP, and R&D investment within the context of the UK's listed firms. These findings hold even after addressing potential endogeneity issues. The findings of this study hold essential implications for both researchers and practitioners. Researchers are encouraged to delve into diverse dimensions and measures of firm growth when investigating the R&D–growth relationship, particularly focusing on the influence of R&D productivity as a key dimension. The quest for more comprehensive insights into the strategic allocation of resources and their impact on growth remains paramount. For managers, this study underscores the importance of assessing the productivity of R&D projects, highlighting the significance of human capital and TFP in driving firm growth.

A clear understanding R&D investments effectiveness is of significance for making informed strategic decisions.

Nonetheless, our study is not without limitations. It is important to recognize that TFP may not capture the intricate dynamics of R&D activities fully (Knott & Vieregger, 2019; Syverson, 2011). By aggregating various inputs and outputs, TFP may overlook specific nuances related to the nature and impact of innovation. The complexity of R&D activities, particularly in high-risk projects, may not be entirely encapsulated by TFP, and therefore, the study might not fully capture the nuances of how different R&D strategies influence productivity growth. While acknowledging these limitations, our study maintains a critical perspective, recognizing the importance of future research that explore other dimensions of R&D productivity. Encouraging the inclusion of variables such as patents, innovation indices, or specific product development metrics would contribute to the understanding of the diverse factors influencing firm growth and provide a broader context for interpreting the relationship between R&D and firm performance.

Finally, the dataset used might be relatively small and limited to publicly traded firms in the United Kingdom. Furthermore, our dataset, due to the significant individual effort involved, is constrained in the number of variables it incorporates. The inclusion of additional variables like patents for measuring R&D productivity could have added further depth to our analysis. A more extended period would allow for the exploration of the R&D–growth relationship from additional dynamic perspectives, shedding light on how these relationships evolve over time. These aspects are areas of exploration left for future research endeavors, as the quest for a more comprehensive understanding of the intricacies governing the R&D–firm growth relationship continues, with a particular focus on the role of TFP and R&D productivity.

CONFLICT OF INTEREST STATEMENT

I declare that there is no conflict of interest regarding the publication of this paper. I declare that the information given in this disclosure is true and complete to the best of my knowledge and belief.

DATA AVAILABILITY STATEMENT

Data are available upon request.

ETHICS STATEMENT

This research has been conducted with a commitment to uphold the highest standards of ethical integrity. Given the nature of our study, due to use of secondary data analysis, there is no ethical consideration, and no ethical approval was required for this study.

ORCID

Alaa Abed https://orcid.org/0000-0002-1918-3017

REFERENCES

Audretsch, D.B., Segarra, A. & Teruel, M. (2014) Why not all young firms invest in R&D. *Small Business Economics*, 43(4), 751–766. Available from: https://doi.org/10.1007/s11187-014-9561-9

Bakhsh, K., Rose, S., Ali, M.F., Ahmad, N. & Shahbaz, M. (2017) Economic growth, CO2 emissions, renewable waste and FDI relation in Pakistan: new evidences from 3SLS. *Journal of Environmental Management*, 196, 627–632. Available from: https://doi.org/10.1016/j.jenvman.2017.03.029

Bettis, R.A. (1981) Performance differences in related and unrelated diversified firms. *Strategic Management Journal*, 2(4), 379–393. Available from: https://doi.org/10.1002/smj.4250020406

Bloom, N., Jones, C.I., Reenen, J.V. & Webb, M. (2020) Are ideas getting harder to find? *American Economic Review*, 110(4), 1104–1144. Available from: https://doi.org/10.1257/aer.20180338

Bloom, N., Schankerman, M. & Van Reenen, J. (2013) Identifying technology spillovers and product market rivalry. *Econometrica*, 81(4), 347–1393.

Brouwer, E., Kleinknecht, A. & Reijnen, J.O.N. (1993) Employment growth and innovation at the firm level. *Evolutionary Economics*, 3(2), 153–159. Available from: https://doi.org/10.1007/BF01213832

Cainelli, G., Evangelista, R. & Savona, M. (2006) Innovation and economic performance in services: a firm-level analysis. *Journal of Economics*, 30(3), 435–458. Available from: https://doi.org/10.1093/cje/bei067

Carden, S.D. (2005) What global executives think about growth and risk. *McKinsey Quarterly*, 2, 16–25.

Choi, J.U. & Lee, C.Y. (2022) The differential effects of basic research on firm R&D productivity: the conditioning role of technological diversification. *Technovation*, 118, 102559. Available from: https://doi.org/10.1016/j.technovation.2022.102559

Coad, A. & Grassano, N. (2019) Firm growth and R&D investment: SVAR evidence from the world's top R&D investors. *Industry and Innovation*, 26(5), 508–533. Available from: https://doi.org/10.1080/13662716.2018.1459295

Coad, A. & Rao, R. (2008) Innovation and firm growth in high-tech sectors: a quintile regression approach. *Research Policy*, 37(4), 633–648. Available from: https://doi.org/10.1016/j.respol.2008.01.003

Coad, A., Segarra, A. & Teruel, M. (2016) Innovation and firm growth: does firm age play a role? *Research Policy*, 45(2), 387–400. Available from: https://doi.org/10.1016/j.respol.2015.10.015

Dachs, B. & Peters, B. (2014) Innovation employment growth and foreign ownership of firms: a European perspective. *Research Policy*, 43(1), 214–232. Available from: https://doi.org/10.1016/j.respol.2013.08.001

Delmar, F., Davidsson, P. & Gartner, W.B. (2003) Arriving at the high-growth firm. *Journal of Business Venturing*, 18(2), 189–216. Available from: https://doi.org/10.1016/S0883-9026(02)00080-0

Dindaroğlu, B. (2018) Determinants of patent quality in U.S. manufacturing: technological diversity, appropriability, and firm size. *The Journal of Technology Transfer*, 43(4), 1083–1106. Available from: https://doi.org/10.1007/s10961-017-9587-7

Freel, M.S. & Robson, P.J. (2004) Small firm innovation, growth and performance: evidence from Scotland and Northern England. *International Small Business Journal*, 22(6), 561–575. Available from: https://doi.org/10.1177/0266242604047410

García-Manjón, J.V. & Romero-Merino, M.E. (2012) Research, development, and firm growth. Empirical evidence from European top R&D spending firms. *Research Policy*, 41(6), 1084–1092. Available from: https://doi.org/10.1016/j.respol.2012.03.017

Ha, J. & Howitt, P. (2007) Accounting for trends in productivity and R&D: a Schumpeterian critique of semi-endogenous growth theory. *Journal of Money, Credit and Banking*, 39(4), 733–774. Available from: https://doi.org/10.1111/j.1538-4616.2007.00045.x

Harrison, R., Jaumandreu, J., Mairesse, J. & Peters, B. (2014) Does innovation stimulate employment? A firm level analysis using comparable micro-data from four European countries. *International Journal of Industrial Organization*, 35, 29–43. Available from: https://doi.org/10.1016/j.ijindorg.2014.06.001

Hay, M. & Kamshad, K. (1994) Small firm growth: intentions, implementation and impediments. *Business Strategy Review*, 5(3), 49–68. Available from: https://doi.org/10.1111/j.1467-8616.1994.tb00166.x

Howells, J. (2008) New directions in R&D: current and prospective challenges. *R&D Management*, 38(3), 241–252. Available from: https://doi.org/10.1111/j.1467-9310.2008.00519.x

Howitt, P. (1999) Steady endogenous growth with population and R&D inputs growing. *Journal of Political Economy*, 107(4), 715–730. Available from: https://doi.org/10.1086/250076

Knott, A. & Vieregger, C. (2019). Does R&D drive growth? Available at SSRN 2382885.

Kogut, B. & Zander, U. (1993) Knowledge of the firm and the evolutionary theory of the multinational corporation. *Journal of International Business Studies*, 24(4), 625–645. Available from: https://doi.org/10.1057/palgrave.jibs.8490248

Kortum, S. (1997) Research, patenting, and technological change. *Econometrica*, 65(6), 1389–1419. Available from: https://doi.org/10.2307/2171741

Loof, H. & Heshmati, A. (2006) On the relationship between innovation and performance: a sensitivity analysis. *Economics of Innovation and New Technology*, 4(5), 317–344. Available from: https://doi.org/10.1080/10438590500512810

Mairesse, J., & Hall, B. H. (1996). Estimating the productivity of research and development: an exploration of GMM methods using data on French & United States manufacturing firms. NBER working paper, (w5501).

Nelson, R.R. & Winter, S.G. (1982) *An evolutionary theory of economic change*. Cambridge, Mass: Harvard University Press.

Peretto, P. & Smulders, S. (2002) Technological distance, growth and scale effects. *The Economic Journal*, 112(481), 603–624.

Redding, S.J. (2011) Theories of heterogeneous firms and trade. *Annu. Rev. Econ.*, 3(1), 77–105. Available from: https://doi.org/10.1146/annurev-economics-111809-125118

Romer, P.M. (1990) Endogenous technological change. *Journal of Political Economy*, 98(5, Part 2), S71–S102. Available from: https://doi.org/10.1086/261725

Ross, D.R. & Zimmerman, K. (1993) Evaluating reported determinants of labour demand. *Labour Economics*, 1(1), 71–84. Available from: https://doi.org/10.1016/0927-5371(93)90006-4

Ryan, H.E., Jr. & Wiggins, R.A., III. (2002) The interactions between R&D investment decisions and compensation policy. *Financial Management*, 31(1), 5–29. Available from: https://doi.org/10.2307/3666319

Segarra, A. & Teruel, M. (2014) High-growth firms and innovation: an empirical analysis for Spanish firms. *Small Business Economics*, 43(4), 805–821. Available from: https://doi.org/10.1007/s11187-014-9563-7

Segerstrom, P.S. (1998) Endogenous growth without scale effects. *American Economic Review*, 88(5), 1290–1310.

Stam, E. & Wennberg, K. (2009) The roles of R&D in new firm growth. *Small Business Economics*, 33(1), 77–89. Available from: https://doi.org/10.1007/s11187-009-9183-9

Syverson, C. (2011) What determines productivity? *Journal of Economic Literature*, 49(2), 326–365. Available from: https://doi.org/10.1257/jel.49.2.326

Tsuboi, M. (2020) Growth, R&D, and uncertainty. *Economic Modelling*, 87, 394–400. Available from: https://doi.org/10.1016/j.econmod.2019.08.012

Yasuda, T. (2005) Firm growth, size, age and behaviour in Japanese manufacturing. *Small Business Economics*, 24(1), 1–15. Available from: https://doi.org/10.1007/s11187-005-7568-y

Yoo, S.H. & Lee, C.Y. (2023) Technological diversification, technology portfolio properties, and R&D productivity. *The Journal of Technology Transfer*, 48(6), 2074–2105.

Young, A. (1998) Growth without scale effects. *Journal of Political Economy*, 106(1), 41–63. Available from: https://doi.org/10.1086/250002

AUTHOR BIOGRAPHY

Alaa Abed is a lecturer in Innovation and Sustainability within the Strategy, Enterprise, and Sustainability Department at Manchester Metropolitan University. Her primary research interests encompass the domains of sustainability and innovation, with a particular specialization in research and development (R&D). Her research is primarily dedicated to exploring the intricate interplay between R&D investment, corporate governance, growth opportunities, and firm growth. She actively engages in research endeavors spanning sustainability, circular economy, environmental performance, and strategic business, employing advanced quantitative management methodologies to further advance the field.

How to cite this article: Abed, A. (2024) The paradox of research and development productivity and firm growth: Empirical evidence from publicly listed firms in the United Kingdom. *European Management Review*, 1–19. https://doi.org/10.1111/emre.12647