Economics of Innovation and New Technology

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/gein20

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To cite this article: Marc Cowling, Tim Vorley, Weixi Liu & Syahirah Abdul Rahman (17 Dec 2024): Are product and process innovations supermodular? Complementary returns to product and process innovations, Economics of Innovation and New Technology, DOI: 10.1080/10438599.2024.2436961

To link to this article: https://doi.org/10.1080/10438599.2024.2436961

ECONOMICS OF INNOVATION AND NEW TECHNOLOGY
https://doi.org/10.1080/10438599.2024.2436961

Routledge
Taylor & Francis Group

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Are product and process innovations supermodular? Complementary returns to product and process innovations

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ABSTRACT

Most firms do not undertake innovation despite clear evidence that innovation is associated with performance. Of the firms that do innovate, the common forms of innovation are in products and services, suggesting a preference for outward market-facing innovation. Fewer firms engage in process innovations that may drive costs of production down. In this paper, we use the classic literature on strategic fit and complementarities and explicitly question whether conducting product and process innovations simultaneously allows firms to generate higher returns than conducting either in isolation. Using a longitudinal UK SME data set from 2015 to 2020, we find that product and process innovations are complements and that engaging in both at the same time increases employment growth by more than simply 'adding-up' the returns to doing innovative things in isolation. We then reflect on why only 5% of UK SMEs do both in parallel thus ignoring their supermodular properties.

ARTICLE HISTORY
Received 9 September 2024
Accepted 27 November 2024

KEYWORDS
Product innovation; process innovation; complementarities; strategic fit; firm performance; jobs; sales

1. Introduction

Innovation is associated with greater economic efficiency and faster growth irrespective of the unit of analysis (Audretsch, Coad, and Segarra 2014) whether it be the firm (Talay 2005), the industry (Audretsch 1995), or any spatial unit from cities (Johnson 2008), to regions (Crescenzi and Rodríguez-Pose 2011), to nations (Bilbao-Osorio and Rodríguez-Pose 2004). However, innovation can take many forms and can impact on the firm's internal processes and productive efficiency or have a more outward, market facing, focus where the generation of new products and services creates more consumer choice and the potential for entirely new markets in the case of radical innovation. Whilst many studies have used a single measure of innovation (Coad and Guenther 2014; Hervas-Oliver, Sempere-Ripoll, and Boronat-Moll 2014), or multiple measures individually (Coad and Rao 2011; Guarascio and Tamagni 2019; Bhojraj and Sengupta, 2003), there is a gap in our knowledge about the effects of conducting different types of innovation simultaneously and in a complementary way and this is where the focus of our study lies. Of the 14 empirical studies investigating innovation and complementarities, 11 focus exclusively on manufacturing, only two include a UK sample, the majority use samples from the 2000s, and only two do not use Community Innovation Survey data. This highlights that our study adds significantly knowledge in respect of the UK *per se*, with a full size and industry scope, and for a more recent time period.

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This paper aims to test and validate the complementary effects on firm performance of two innovation-related activities, product innovation and process innovation. We draw on the theory of complementarity and strategic fit developed by Milgrom and Roberts (1995), and the broader concept of Edgeworth (1925) who considered that activities are complementary if doing more of one increased the returns to doing more of the other. The specific lens we use is innovation as it is generally associated with superior outcomes at the firm (Hall, Mairesse, and Mohnen 2010; Sood and Tellis 2009) and societal level (Jones and Summers 2020). Here we identify an outward market-facing innovation around the development of new or improved products and services, and an inward-facing innovation around the improvement of internal firm processes. The former we might expect would increase sales revenues and the latter lowers the average production costs of the firm. We use as our reference point the absolute majority of firms that do neither innovation activity.

We focus on SMEs as they are most likely to face constraints on innovation activities (De Massis et al. 2018; Lee, Sameen, and Cowling 2015), but are also a great contributor to the innovation system in many countries due to their entrepreneurial dynamic (Acs and Audretsch 1988; Malerba and McKelvey 2020; Saunila 2020). From the standard theory of markets and competition, it follows that any small firm that differentiates its offer through innovation should strengthen its market position and generate higher returns. Equally, any small firm that improves its internal production processes should lower its average cost base and be more cost competitive (Cowling and Nadeem 2020).

To test if product and process innovations are complements, we use the UK Longitudinal Small Business Survey from 2015 to 2020. The firm performance measures we use are (real) sales growth and job growth. Our core data shows that 76.7% of SMEs do not engage in any product or process activities at all. Product innovation is evident amongst 15.4% of firms and process innovation 12.8%. However, only 5.0% of SMEs engage in product and process innovation simultaneously. From our econometric analysis, we find that engaging in both at the same time increases employment growth by more than simply 'adding-up' the individual returns to doing innovative things in isolation. Our key finding is that complementary innovation has a much more consistent impact on jobs than sales. Further, dropping out of external capital markets and trying to self-fund new activities reduces growth.

The rest of the paper is organised as follows. In Section 2, we review the literature on complementarities and strategic fit, innovation in small firms, and the wider literature on firm growth and innovation. We then introduce our data and present the descriptive statistics and modelling strategy in Section 3. We report on our econometric results in Section 4 where we estimate firm performance models for real sales growth and job growth. We conclude in Section 5 and consider the potential consequences for firms that do not engage in innovation activities by choice and those that face significant barriers.

2. Theoretical framework

We present our review of the relevant literature and our underlying theoretical framework in four sections that cover complementarities and strategic fit, innovation in small firms, financing innovation, and the wider literature on firm growth and innovation. The former describes the theoretical foundations for understanding complementarity. The second section develops our understanding of how small firms engage in innovation and the barriers that many firms face that inhibit their innovation activities and potential. The third section discusses how small firms finance innovation and the barriers they face in accessing external funds. The final section provides an empirical context for understanding the body of empirical work that has formally tested for relationships between innovation and growth.

2.1. Complementarities and strategic fit

The concept of complementarity as framed initially by Edgeworth (1925) is very clear and simply states that activities are complementary if doing (any) more of one activity increases the returns to another activity. More formally, the mixed-partial derivatives of a pay-off function are such that the marginal returns to one variable are increasing in the level of another variable. Milgrom and Roberts (1995) provide a perfect mathematical derivation of this using the examples of product innovations and process improvements. They state that a firm's profit, π, depends upon three core variables. The actual quantity of output they produce and sell, denoted q, the frequency of product innovation, r, and the frequency of process improvements, i. Thus, $\pi r = \pi r$ (q, r, i). In this respect, π (profit) is supermodular in all three variables, product and process innovation and output. Put simply, marginal sales revenue increases when a firm is a product innovator and marginal costs reduce when a firm process innovates. Process improvements impact on the cost side of the firm's profit function as $C = f$ (q,i), output and process innovation. Here, supermodularity refers to the gains from increasing all components are greater than the gains to an individual component increase. The sum of the whole is greater than the sum of the parts. For us, as sales revenue growth is a performance variable, we assume that if product innovation increases sales and process innovation reduces costs then profit will increase as average costs decline per unit of output and sales increase. Product innovation may also be associated with a shift from a perfectly competitive market structure where firms face an exogenously determined price and a horizontal demand and marginal revenue curve, to a monopolistically competitive market with a slightly differentiated product offering and some price setting discretion. Audretsch, Prince, and Thurik (1999) argue that this is a particularly rational strategy for smaller firms as it offers increased protection against large firms.

We also identified 14 papers that have empirically examined aspects of complementarities between different forms of innovation (see Table in the Appendix). Of those 14 papers, only two do not use the Community Innovation Survey. These include the Kamutando and Tregenna (2023) single cross-sectional survey for 2019 amongst a sample of manufacturing SMEs in Johannesburg, South Africa, and Miravete and Pernias (2006), who used the DIRNOVA Spanish database to examine firms in the ceramics industry a longitudinal panel for the 1980s. Further, only Carboni and Russo (2018) and Ballot et al. (2015) studies considered the UK, the former along with six other European countries and the latter with France. It is also the case that 11 of the 14 studies only covered manufacturing industries and the majority used samples from the 2000s.

In general, 12 of the 14 studies find at least some evidence of complementarities, and the Chinese study of Zhang (2022) and the French – UK study of Ballot et al. (2015) found no complementarity or weak effects. Others found that complementarities exist, but were dependent upon the specific phase of the firm's innovation (Mohnen and Roller, 2005), and Galia and Legros (2004), in their French study, identified an important distinction between postponed and abandoned innovation projects. Further, Miravete and Pernias (2006) found that firm size class was an area of importance in distinguishing between product and process innovation.

2.2. Small firms and innovation

The work of Joseph Schumpeter (1934) made a case that smaller firms were uniquely placed to engage in creative destruction due to their entrepreneurial dynamic and speed of strategic decision-making. These factors meant that innovation opportunities were more likely to be identified, and they were also more likely to be acted upon by small, entrepreneurial, firms. In this respect, their agility and dynamism allowed them to challenge inefficient, incumbent, firms and that productive resources would be re-allocated from static large firms towards more efficient, new entrepreneurial entrants. Innovation was fundamental to this dynamic process (Kotha, Zheng, and George 2011).

The theory of dynamic capabilities is also relevant as entrepreneurs create value through their ability to create, define, identify and exploit new opportunities, in essence be innovative. There is an important distinction between 'ordinary' capability, that captures a firm's ability to generate a desired output, and a dynamic capability, that encompasses a higher-order ability to manipulate their 'ordinary' capabilities (Zahra, Sapienza, and Davidsson 2006). The essence of the Resource Based View (RBV) is its emphasis on resources and capabilities as the basis of competitive advantage. As resources are heterogeneously distributed across competing firms, and are not perfectly mobile, firms that have superior resources tend to sustain their advantage over time. Clearly, this advantage is beneficial, but in a dynamic trading environment firms need to have access to distinctive capabilities to manage their resources dynamic capabilities encapsulate the evolutionary nature of resources and capabilities (Wang and Ahmed 2007).

Firms then differ in their ability to develop and apply dynamic capabilities defined by the skills of the entrepreneur in reconfiguring the firm's resources and procedural routines to exploit a new opportunity (Penrose 1959). To sum up, the theory of dynamic capabilities places great emphasis on the dynamics and dynamism of capability itself, rather than the external environment. Here, the entrepreneurs' role as a key decision maker is front and centre. This is evidenced by Cowling and Liu (2022), who study the identification of new opportunities to invest in ICT, the decision to invest or not, and the cash investment. They found that ICT opportunities, investments, and scale of investment were increasing in firm size but negatively related to firm age. This firm size effect suggests that resource and capability munificence are important in all three links in the causal chain. The age effect suggests that dynamic young entrepreneurial firms led by founding entrepreneurs are more capable of identifying new opportunities for technology investments, and more willing to press the go button when an opportunity arises. However, other studies have emphasised the key role of complementary managerial skills outside of the founding entrepreneurial team (Siepel, Cowling, and Coad 2017).

In contrast, Malerba and McKelvey (2020) take the view that firms' actions in relation to innovation are strongly influenced by national innovation systems that define the pool of innovation opportunities available to firms. The national innovation system (NIS) is characterised and defined by public institutions, the education system, public policy and formal regulatory environments. It is the national innovation system that directly impacts the generation and diffusion of knowledge. This, in turn, affects the dynamics of innovative entrepreneurial activity. As our study is for a single country, the UK, we are more interested in lower spatial levels and other forms of innovation systems. Innovation systems have also been identified, and studied, at the regional, local and cluster levels (Cooke and Piccaluga 2004). Further, industry specific innovation systems have also been identified as being important to understanding how opportunities for innovative activity exist for smaller firms (Carlsson 2012). Taken together, these bodies of research highlight the importance of geography and industry in creating the opportunity for innovation.

2.3. Financing innovation in small firms

In contrast to the debate about whether the main driver for innovation in smaller firms is more inward-or-outward looking, there is a strong consensus that smaller innovative firms face significant constraints when seeking to access finance from capital markets (Lee, Sameen, and Cowling 2015). These problems are due to the high level of uncertainty in the outcomes of innovation projects (Hall and Lerner 2010; Jalonen 2012) that adds another layer of concern to financiers that exacerbate the more common problem of informationally opaque small firms (Stiglitz and Weiss 1981). The higher incidence of credit rationing for small and innovation driven firms is well-established in empirical work (Lee, Sameen, and Cowling 2015), and even if firms are able to access capital they face inferior contracts including a greater requirement for collateral, and higher interest rates. This feature of debt contracts is termed 'the innovation debt penalty' by Cowling, Ughetto, and Lee (2018). In addition, Ughetto (2008) and Himmelberg and Petersen (1994) find that small innovative firms respond to these external capital market constraints by seeking to finance their innovative activities from internal cash. This actually gives larger firms a comparative advantage as their cash flows are more certain, and this means that firms can retain the desired level of internal funds more easily in order to support future investment needs (Hall and Lerner 2010).

External equity providers, venture capitalists and business angels, face similar problems of asymmetric information to debt providers in their dealings with small, innovative firms seeking funding. However, the role of VCs as very highly specialised financial intermediaries can mitigate these agency problems through intensive due diligence *ex ante* and intense monitoring *ex post*. Typically, equity investment contracts of this type are structured such that payments are staged subject to achieving a desired performance level (Wang and Zhou 2004). However, it remains the case that external equity is a minority source of funding, even for innovation-led firms. This is due to a strong preference for internal funds, and then debt products (Cowling, Liu, and Zhang 2021a) and these features of small firms led Hall and Lerner (2010) to conclude that there are limits to venture capital as a solution to the funding gap. To summarise our discussion of the financing of innovation in small firms, it is apparent that considerable barriers and constraints exist in debt and equity markets and that these problems may lead to an under-investment problem. It follows that the ability to self-fund or raise external capital should be associated with innovation in small firms.

2.4. Innovation and firm growth

It is a widely accepted view that innovation is positively associated with growth regardless of the unit of analysis and spatial context. This view dates back to the pioneering work of Schumpeter (1934) who argued that (a) innovation is central to economic development, and, (b) innovation is dependent on entrepreneurs. Nelson and Winter (1982) and Dosi (1982) built on this framework and advanced the theory of creative destruction using an evolutionary economics approach. Crucially, innovation raises productivity, and it is productivity growth that raises economic growth, and, ultimately, aggregate wealth in an economy. This evolutionary approach, with innovation at its core, fed into the endogenous growth models of Lucas Jr (1993) and Romer (1994) as it is knowledge, and knowledge spill-over's, that drive economic growth through creating the conditions for new entrepreneurial activity.

The empirical study of the association between innovation and firm growth has created a large, and diverse, body of literature. This literature can be set against a broader base of work that fundamentally challenges whether growth is simply a random process with equal probabilities of growth, stability, or decline (Coad et al. 2013). On balance, the innovation-growth evidence base shows a positive effect of innovation on firm growth, although this differs substantially between types of firm, markets, and geography (Audretsch, Coad, and Segarra 2014; Coad 2009). For example, Coad and Rao (2008) find that the innovation – firm growth relationship only holds for the fastest growing firms. Other studies have identified a positive innovation – growth relationship for sales and productivity, but not for employment as innovation can often mean that less labour is required. More nuanced definitions of innovation, separating out product and process innovations, has helped provide a more detailed picture. Product innovation increases demand in external markets and this can raise employment. On the contrary, process innovation may increase the technology and automation available to the firm and result in job losses (Coad and Rao 2011).

Other studies have focused on differences by firm size, and Demirel and Mazzucato (2012: Page 87), in their study of R&D in pharmaceutical industries find some important results that led them to conclude that, 'it can be very misleading to assume that R&D will always translate into growth'. Specifically, they find that small firms are able to generate higher rates of growth from increasing their R&D, conditional on patenting. However, large firms were not able to realise any growth and, in some cases, R&D was associated with a decline in growth. They rationalise their findings by pointing out that small and large firms conduct different types of R&D, with small firms focusing on niche areas and radical innovation and large firms on process innovations in mature markets. They also note that small firm R&D commitments are less frequent and persistent compared to large firms.

3. Methodology

The data available for our analysis is the UK Longitudinal Small Business Survey (LSBS). The LSBS survey is administered by a private survey company and it is sponsored by the UK Department for Business, Energy & Industrial Strategy (BEIS). The longitudinal aspect of the LSBS allows us to explore the dynamics of innovation related activity and how this feeds through into future job and sales growth. The LSBS is a detailed nationally representative survey of the UK SMEs. The LSBS is a telephone-based survey of the UK small business owners and managers constructed using a stratified sample of owner-managers of SMEs with less than 250 employees across the four constituent parts of the UK (England, Northern Ireland, Scotland and Wales). The survey collects detailed information relating the financial and non-financial activities of SMEs, and includes; the nature of any innovative activities, export activities, barriers to growth, attitudes towards accessing external finance, and finance market interactions.

The LSBS is a longitudinal panel data set that began in 2015, and the latest wave available is for 2020. It contains 27,921 firm units and 89,814 observations in total spread across six survey waves from 2015, 2016, 2017, 2018, 2019, and 2020. In this sense, the large sample size and the panel structure of the data enables us to explore the evolution of firms' innovating behaviours and the consequences for future firm growth.

The Inter Departmental Business Register (IDBR) was the sample source for registered businesses. Dun & Bradstreet's database was the sample source for unregistered businesses with no employees. Contacts are excluded from the sample frame if they either had employees on their payroll, or paid VAT. The IDBR is a record of all UK enterprises that pay VAT or PAYE, containing around 2.7 million unique entries for enterprises. The BEIS Business Population Estimates (BPE) publication estimates around 5.7 million enterprises in the UK in total. The difference in the figures is due to unregistered enterprises that do not pay VAT or PAYE.

A 336-cell sample stratification matrix was devised, the targets within each cell informed by the BPE. These cells were combinations from the:

- 14 'one-digit' SIC 2007 categories (ABDE, C, F, G, H, I, J, KL, M, N, P, Q, R, S)
- six size categories (unregistered zero employees, registered zero employees, 1–4 employees, 5–9 employees, 10–49 employees, 50–249 employees)
- four nations (England, Scotland, Wales, Northern Ireland)

The first variables we consider relate to innovation. Innovation is defined in two ways in the survey; process innovation, and product innovation. Table 1 shows that across all survey waves from 2015 to 2020 on average 76.71% of firms do not innovate at all. For firms that do engage in innovative activity, product innovation is more prevalent than process innovation as 15.43% of firms engage in product innovation and only 12.84% in process innovation. Only 4.99% of firms engage in product and process innovation. This latter group of dual innovators are central to testing the theory of complementarity and fit outlined in Section 2.1.

We then consider the time-series evolution of the firm's innovation behaviour and engagement between 2015 and 2021. Figure 1 highlights some interesting and important dynamics, most notably the fact that the general long-trend is that fewer firms are engaging in innovation activity. The decline in innovation activity, from 28.47% to 22.16%, is of sufficient magnitude to be of general

Table 1. Process and product innovation.

	Process innovator		
Product innovator	No	Yes	Total
No	76.71	7.85	84.57
Yes	10.44	4.99	15.43
Total	87.16	12.84	

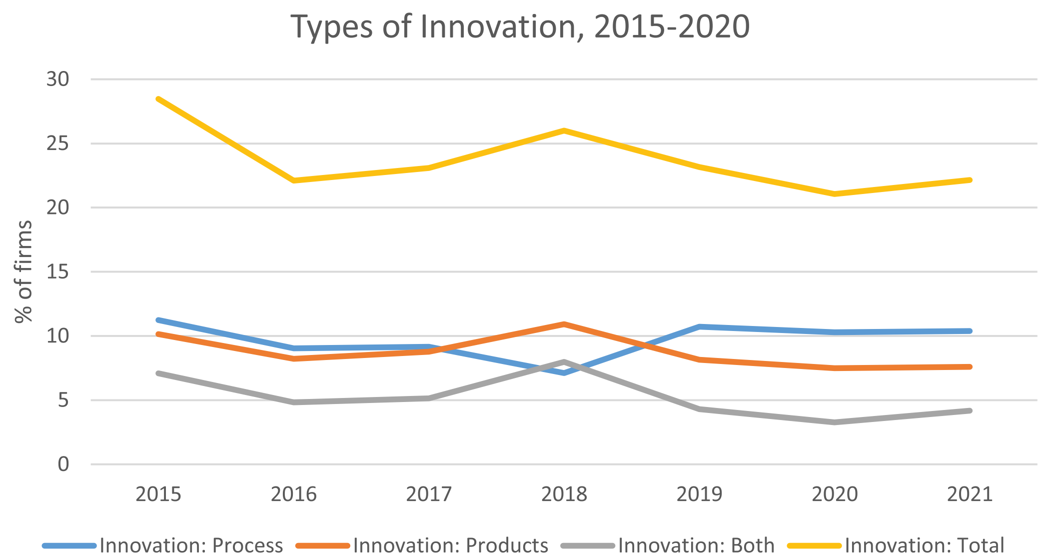

Figure 1. The dynamics of different types of Innovation, 2015–2021.

concern if indeed we ultimately find that current innovation activity is causally related to future firm growth. Of the two types of innovation activity, process innovation is more stable over time than process innovation. Product innovation declined from 10.84% in 2015 to 7.59% in 2021. This significant decline in process innovation activity led to a fairly proportional decline in dual innovation activity over the same period, from 7.09% to 4.18%. This suggests one of two things; that firms are constrained in their innovation activity, or they do not believe that process and product innovations are complements, and view them as separate strategic decisions.

We now discuss the core, firm level, demographics across the four innovation classes (no innovation, process innovation, product innovation, and dual innovation). The basic statistics by innovation status are reported in Table 2. The first point is that we adjust all variables denominated in nominal cash terms by the UK GDP deflator. From this point, all cash figures are expressed in real (inflation adjusted) 2020 terms. We observe that the average (real) sales of dual innovators is highest at £681,429 per annum and lowest for non-innovators at £333,104 per annum. Process innovators have larger sales than product innovators. Average employment (including self-employed) mirrors the general pattern for sales with the average for dual innovators being 4.26 employees. If we exclude the zero self-employed, we see that average employment for dual innovators is 11.10 and for non-innovators 7.33. All innovators have higher employment than non-innovators. There are few differences by firm age, although process innovators and dual innovators are the youngest on average at 15.4 and 15.7 years since foundation respectively.

Dynamic capabilities have been notoriously difficult to operationalise in empirical studies, so we proxy the ability to reconfigure and manage firm resources in an efficient way by two variables. The first is a firm providing management training to develop the skills and capabilities of its management team, and the second is a firm that engages in exporting. We feel that each measure tells us something important about the firms' ability to coordinate resources internally (to upgrade their dynamic capabilities) and externally (to support and coordinate trading in international markets). In relation to management training, we find that 18.02% of dual innovators provided management training and 16.09% of process innovators. This compares to only 9.31% of product innovators and 6.03% of non-innovators. In relation to exporting, we find that 20.20% of dual innovators operate in international markets compared to only 8.30% of non-innovators. Product innovators had a 14.95% prevalence rate in international export markets and process innovators a 14.93% incidence. Across our two

Table 2. Sample descriptive statistics by innovation type.

	No innovation		Process innovation		Product innovation		Product and process innovation		
	Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev	Significance
Real Sales £s	333,104	1,905,732	556,478	2,862,727	429,637	2,169,657	681,429	2,776,584	***
Firm_Age	18.502	14.479	15.396	12.778	17.398	14.186	15.739	13.611	***
Management Training [0,1]	6.028	23.802	16.086	36.744	9.309	29.059	18.021	38.441	***
Export [0,1]	8.304	27.595	14.932	35.644	14.952	35.663	20.200	40.155	***
Region									
East Midlands	7.950		6.170		8.240		7.790		
East of England	10.650		10.180		10.310		10.590		
London	9.970		11.810		7.740		12.410		
North East	2.480		2.940		2.660		1.940		
North West	9.310		9.390		9.110		8.860		
South East	18.520		18.370		17.990		17.940		
South West	13.730		13.510		15.080		14.910		
West Midlands	8.230		8.960		8.350		7.430		
Yorkshire & Humber	7.250		7.700		7.800		6.230		
Scotland	6.050		6.710		6.300		6.710		
Wales	3.800		2.790		4.320		3.990		
Northern Ireland	2.070		1.470		2.100		2.000		
Total within class %	100.000		100.000		100.000		100.000		***
Industry									
ABDE – Primary	3.590		5.240		4.070		3.410		
C – Manufacturing	4.350		6.110		8.650		10.600		
F – Construction	18.490		14.500		8.350		10.600		
G – Wholesale/ Retail	9.460		7.890		13.960		11.100		
H – Transport/ Storage	6.960		2.810		1.840		1.090		
I – Accommodation/ Food	3.320		2.460		4.040		2.070		
J – Information / Communication	5.690		7.420		11.170		14.740		
KL – Financial/ Real Estate	3.930		3.610		1.840		2.480		
M – Professional/ Scientific	15.450		19.090		16.520		21.930		
N – Administrative/ Support	8.990		12.530		8.210		7.840		
P – Education	4.540		5.370		4.960		4.190		
Q – Health/ Social Work	5.450		5.700		5.840		5.680		
R – Arts/ Entertainment	4.290		2.960		7.520		4.680		
S – Other service	5.500		4.330		3.030		4.800		
Total within class %	100.000		100.000		100.000		100.000		***
Finance									
Equity	0.053	2.305	0.170	4.121	0.134	3.661	0.317	5.622	***
Debt	6.940	25.413	11.425	31.814	10.489	30.644	16.500	37.124	***
Growth Rates Annual									
Real Sales	−7.540	54.569	1.923	47.249	−6.648	56.911	−8.619	61.794	***
Employment	−6.997	42.877	−8.729	50.037	−8.282	43.128	−7.178	52.655	***
Number Observations	34,163		3496		4651		2223		

proxy measures for dynamic capabilities, there is a degree of consistency as dual innovators are most likely to provide management training, and engage in exporting. Non-innovators are the least likely to do both. Process innovators are more likely to provide management training but marginally less likely to operate in international markets. This suggests that dynamic capabilities might be more relevant to superior internal coordination and process-driven change.

In relation to the industry sector, we find relatively high shares of dual innovator firms in manufacturing (10.60% compared to 4.35% of non-innovators), information & communications (14.74% compared to 5.69%), and professional and scientific services (21.93% compared to 15.45%). In contrast, low relative shares of non-innovators were found in construction (18.49%) and transport & storage (6.96%), where the dual innovator share was only 1.09%. Process innovation rates were relatively high in primary industries (5.24% compared to 3.59%), professional and scientific services (19.09% compared to 15.45%), administrative services (12.53% compared to 8.99%), and education (5.37% compared to 4.54%). Product innovators were more represented in wholesale & retail (13.96% compared to 9.46%), and arts & entertainment (7.52% compared to 4.29%). This is generally supportive of the work of Carlsson (2012) who argued that the state of a specific industry in terms of its scale and maturity, and specifically the maturity of its internal innovation system, defines the type of innovation opportunities available and whether the type of innovation is radical or incremental.

The NIS literature and its lower order spatial counterparts emphasises the importance of different layers of geography in shaping the innovation environment. As we are studying a single country, the UK, we focus on geographic regions within it. Non-innovation rates are relatively high in North East England (2.48% compared to 1.94% of dual innovators) and Yorkshire & Humberside (7.25% compared to 6.23% of dual innovators). London has relatively high shares of process (11.81% compared to 9.97% of non-innovators) and dual innovators (12.41% compared to 9.97%). South West England has relatively high shares of product innovators (15.08% compared to 13.73%). On balance, regional differences were less evident than industry differences, with the notable exception of the capital city London which had relatively high shares of process and dual innovators.

On financing, we observe that dual innovators were the most likely to seek external debt finance and non-innovators the least likely at 16.50% and 6.94% respectively. Debt was the dominant form of finance sought and only 0.32% of dual innovators and 0.05% of non-innovators used equity funding. All single innovation classes of firms were more likely to use debt and equity. This highlights the importance of external funding for innovation (Lee, Sameen, and Cowling 2015).

We now turn our attention to our outcome measures of firm growth. We have two measures available to us that have been widely used in previous growth studies, employment growth and (real) sales growth. The period under investigation was unique in UK history as we had the Brexit vote in June 2016, the subsequent period of transition out of the European Union until 2021, and the onset of Covid-19 in 2020. The average rate of job growth between 2015 and 2020 was negative for all innovation states, but lowest at – 7.00% for non-innovators and highest for product innovators at – 8.73%. In respect to real sales growth, we find that process innovators had a positive growth rate of 1.92% and dual innovators the lowest real sales growth at – 8.62%. If we exclude the Covid-19 year of 2020, then process innovators actually improved their relative and absolute growth rates. These findings might suggest that process innovation that makes internal operations more efficient and reduces the average costs of production appear to have more impact on sales than product innovations. Process innovation does appear to have a negative effect on jobs as discussed by Audretsch, Coad, and Segarra (2014).

We have panel data for 14,969 firms over the period 2015–2020. Our aim is to estimate how different innovation states affect future jobs and (real) sales growth at the firm level. However, the first step in our analysis before we estimate our growth models for jobs and sales is to estimate a set of models to understand more about what types of firms choose to innovate, and, if so, what form does that innovation take. Here, we draw upon our literature review that relates a firms' innovation status to dynamic capabilities, finance, geography and industry. We estimate each innovative state (process innovator only, product innovator only, and dual process and product innovator) separately against our non-innovator state. As we have panel data, we estimate a series of dynamic probit models that fit the maximum likelihood random effects model $\Pr(y_{it} \neq 0 \mid x_{it}) = \Phi(x_{it}\beta + v_i)$ for $i = 1, \ldots, n$ panels, where $t = 1, \ldots, n_i$, v_i are i.i.d., $N(0, \sigma2\ v)$, and Φ is the standard normal cumulative distribution function. Underlying this model is the variance components model $y_{it} \neq 0 \Longleftrightarrow x_{it}\beta + v_i + \varepsilon_{it} > 0$ where ε_{it} are i.i.d. Gaussian distributed with mean zero and variance $\sigma_\varepsilon^2 = 1$, independently of v_i.

As we predict that firm capabilities and finance might influence their innovation status, we might also consider that the same capabilities also influence growth. In this sense, there may be a direct effect of capabilities on growth and an indirect effect. The indirect effect is mediated through firms' innovation status. To address these potential issues, we adopt two strategies. First, we use an instrumental variables approach using the experimental average treatment effect. This effect calculates the predicted probability of being in a particular innovation state (compared to a state of non-innovation). These predicted probabilities then enter the growth models. Secondly, we use the control function approach (Heckman, 1979) and calculate the inverse mills ratio for each innovation state. Again, these ratios enter the growth equations.

For the growth models, we apply the first differencing to remove unobserved heterogeneity and include the lag of the dependent variables in order to model the partial adjustment process. This gives us a model specification:

$$\Delta y_{it} = \Delta y_{it} - 1\gamma + \Delta x_{it}\beta + \Delta\varepsilon_{it} \quad (1)$$

where the lag of the dependent variable is included on the right-hand-side of the model and our core explanatory variables relating to innovation status (plus firm demographics) are in X_{it}.

4. Results

We present our results in two stages. Firstly, we focus on innovation states and compare each of the three innovation states individually against our state of non-innovation. Then we estimate a set of growth models for (real) sales and employment.

4.1. Innovation status

The first important finding is that for all types of innovation state there is evidence of persistence as being innovative last year increases the probability that a firm is innovative this year. The highest degree of persistence was in product innovation and the lowest degree in process innovation. Equally, non-innovation also has persistence and this reduces the share of the firm population engaging with innovation over time. The findings also suggest that innovation has a degree of persistence and longevity that may be less dependent upon the economic and business cycle.

Firm characteristics were also important in the determination of innovation status. For example, firm size (lagged one year) relates, in a positive way, to all innovation states. The largest effects were for process and dual process and product innovation. This clearly suggests that large (small) firms innovate more (less). Firm age effects were also apparent and we find that younger firms are associated with a higher incidence of product innovation and also dual process and product innovation. This was not the case for process innovation and the age of the firm. Taken together, the age effects, where present, are of greater magnitude than the size effects and this suggests that young firms are key for innovation before routines set in and firms become established in secure markets (Table 3).

We have two measures intended to capture the firm's dynamic capabilities. The first, that relates to the provision of management training, is positively associated with all types of innovation and is particularly influential for process innovation and dual process and product innovation. This is consistent with dynamic capabilities allowing for better internal configurations of resources to support innovation. The outward facing measure of capabilities is the ability to operate in export markets. Here again we find that it is positively associated with all forms of innovation and in particular

Table 3. Innovation types: panel probit models.

	[1] Process innovation				[2] Product innovation				[3] Product and process innovation			
Innovation type lags	Coefficient	S.E	z	Pr > z	Coefficient	S.E	z	Pr > z	Coefficient	S.E	z	Pr > z
I_ Process												
L1.	0.6428	0.0402	15.98	0.000								
I_ Product												
L1.					0.8666	0.0326	26.61	0.000				
I_ Product and Process												
L1.									0.7376	0.0605	12.19	0.000
ln Real Sales												
L1.	0.0671	0.0117	5.71	0.000	0.0459	0.0099	4.63	0.000	0.0693	0.0155	4.47	0.000
Ln Firm Age	−0.0251	0.0278	−0.90	0.367	−0.0827	0.0238	−3.47	0.001	−0.1027	0.0377	−2.72	0.006
Management Training												
L1.	0.1490	0.0410	3.64	0.000	0.1137	0.0358	3.18	0.001	0.1400	0.0539	2.60	0.009
Export												
L1.	0.1414	0.0478	2.95	0.003	0.1992	0.0420	4.75	0.000	0.1876	0.0606	3.10	0.002
Region												
East Midlands												
East of England	−0.1335	0.0846	−1.58	0.115	−0.1280	0.0741	−1.73	0.084	−0.2297	0.1086	−2.12	0.034
London	−0.1636	0.0866	−1.89	0.059	−0.1920	0.0763	−2.52	0.012	−0.2227	0.1102	−2.02	0.043
North East	−0.1643	0.1323	−1.24	0.214	−0.1117	0.1128	−0.99	0.322	−0.3015	0.1782	−1.69	0.091
North West	−0.0275	0.0875	−0.31	0.753	−0.0461	0.0769	−0.60	0.549	−0.1838	0.1144	−1.61	0.108
South East	−0.1636	0.0789	−2.07	0.038	−0.0961	0.0686	−1.40	0.162	−0.2542	0.1013	−2.51	0.012
South West	−0.0471	0.0811	−0.58	0.562	−0.0288	0.0708	−0.41	0.684	−0.1457	0.1037	−1.41	0.160
West Midlands	−0.0469	0.0881	−0.53	0.594	−0.1008	0.0776	−1.30	0.194	−0.2004	0.1153	−1.74	0.082
Yorkshire & Humber	−0.0590	0.0948	−0.62	0.534	0.0831	0.0810	1.03	0.305	−0.1386	0.1212	−1.14	0.253
Scotland	−0.1077	0.0847	−1.27	0.204	−0.0661	0.0740	−0.89	0.372	−0.1738	0.1064	−1.63	0.102
Wales	−0.0480	0.1127	−0.43	0.671	−0.0658	0.0974	−0.68	0.500	−0.0377	0.1398	−0.27	0.787
Northern Ireland	−0.1808	0.1056	−1.71	0.087	−0.2196	0.0932	−2.36	0.019	−0.3053	0.1350	−2.26	0.024
Industry												
ABDE – Primary												
C – Manufacturing	0.1262	0.1005	1.26	0.209	0.2602	0.0842	3.09	0.002	0.2184	0.1263	1.73	0.084
F – Construction	−0.1414	0.1094	−1.29	0.196	−0.4568	0.0959	−4.77	0.000	−0.3327	0.1495	−2.23	0.026
G – Wholesale/ Retail	−0.1633	0.1006	−1.62	0.105	−0.0972	0.0828	−1.17	0.240	−0.1551	0.1291	−1.20	0.230
H – Transport/ Storage	−0.2978	0.1403	−2.12	0.034	−0.4848	0.1199	−4.04	0.000	−0.6612	0.2252	−2.94	0.003
I – Accommodation/ Food	−0.2513	0.1202	−2.09	0.037	−0.2513	0.0970	−2.59	0.010	−0.2456	0.1559	−1.58	0.115
J – Information / Communication	0.2635	0.1088	2.42	0.015	0.2221	0.0917	2.42	0.015	0.2694	0.1363	1.98	0.048
KL – Financial/ Real Estate	−0.1835	0.1270	−1.44	0.149	−0.4554	0.1132	−4.02	0.000	−0.3415	0.1759	−1.94	0.052
M – Professional/ Scientific	0.1460	0.0977	1.49	0.135	−0.1588	0.0831	−1.91	0.056	0.0814	0.1249	0.65	0.515
N – Administrative/ Support	0.0781	0.1060	0.74	0.462	−0.2331	0.0920	−2.53	0.011	−0.0241	0.1371	−0.18	0.860
P – Education	0.0655	0.1354	0.48	0.628	−0.1523	0.1177	−1.29	0.196	−0.1704	0.1892	−0.90	0.368

(*Continued*)

Table 3. Continued.

	[1] Process innovation				[2] Product innovation				[3] Product and process innovation			
Innovation type lags	Coefficient	S.E	*z*	Pr > z	Coefficient	S.E	*z*	Pr > z	Coefficient	S.E	*z*	Pr > *z*
Q – Health/ Social Work	0.0325	0.1097	0.30	0.767	−0.1917	0.0949	−2.02	0.043	−0.1198	0.1447	−0.83	0.408
R – Arts/ Entertainment	−0.2649	0.1533	−1.73	0.084	−0.0401	0.1156	−0.35	0.729	−0.3396	0.2100	−1.62	0.106
S – Other service	−0.2340	0.1443	−1.62	0.105	−0.1916	0.1138	−1.68	0.092	−0.2724	0.1930	−1.41	0.158
Finance												
Equity	0.5308	0.2157	2.46	0.014	0.6214	0.2078	2.99	0.003	0.7024	0.2321	3.03	0.002
Debt	0.1061	0.0477	2.22	0.026	0.1330	0.0415	3.20	0.001	0.1536	0.0608	2.53	0.011
Constant	−2.3817	0.1981	−12.02	0.000	−1.6452	0.1602	−10.27	0.000	−2.5876	0.2648	−9.77	0.000
No. Observations	10,862				10,862				10,862			
Pr>χ2	0.00001				0.00001				0.00001			

product innovation and dual process and product innovation. This link to product-related innovation is consistent with outward facing dynamic capabilities.

There are also some geographically important effects, and these are more prevalent for dual class innovators and less prevalent for process innovators. Process innovation is lowest in the South East of England and product innovation is least prevalent in London and Northern Ireland. In terms of dual class innovation status, large swathes of the wealthiest regions of the UK (London, South East, and East of England) had low probabilities of being dual class innovators along with Northern Ireland. This evidence is weakly supportive of regional innovation systems and in the UK the strongest regional innovation systems appear to lie outside of the core wealthy regions of the South and East of England.

Industry sector has clear linkages with innovation and has strong empirical support from a large body of research. Our findings confirm this and the Information & Communications is the sector most widely associated with all innovation states. Manufacturing was also associated with a higher probability of product innovation. In contrast, the construction industry and transport & storage sectors were associated with lower innovation probabilities. In terms of sector variation across innovation states, there was more variation in respect of product innovation than process innovation. This is consistent with outward, market facing, conditions influencing the need for firms in particular industries to be more innovative, or be left – behind. Process innovation is less sector dependent as all firms should seek to become more efficient and produce their output at the lowest cost possible.

Finally, we observe that the ability of firms to access external capital is key in understanding innovation. Across all innovation states, accessing external capital raises the probability of being innovative. However, the coefficient sizes for equity finance are much larger than the respective coefficient sizes for debt finance. This clearly suggests that most firms cannot fully fund innovation activities from internal funds. The concern is that a substantial minority of firms, particularly those who are small and young, face significant problems when seeking to raise outside capital. This implies that a key role in supporting innovation in the business sector requires direct public sector interventions, or the hybrid debt and equity provision that is favoured by UK policy-makers.

4.2. Sales and job growth

The first finding, that is consistent across sales and job growth models, is that there is a negative relationship between lagged growth rates and current growth rates. This suggests that growth is not persistent between years. We also find that real firm size has no significant relationship with current sales growth but a negative relationship with current jobs growth. On jobs, smaller firms, on average, have higher job growth rates. In contrast, firm age had no impact on sales or job growth, a feature that is often associated with young firms in previous studies. Industry sector was found to be an important source of variation in sales growth in particular, and, to a lesser degree, job growth. Industry sectors with the lowest sales growth rates included hospitality, professional and scientific services, administration services, arts and cultural activities, and other services. In contrast, transport and health were industry sectors that achieved above average growth in jobs (Table 4).

The four-way innovation classification that uses not innovating as its reference category was found to be significant, and our dual innovators class acted in a positive way on growth in sales and jobs in the base models. The magnitude of the respective coefficients shows a slightly larger effect on jobs than sales growth. Dual-class innovator firms were consistently identified as having superior job growth rates. This evidence is consistent with Milgrom and Roberts (1995) theory of complementarity and strategic fit in the context of process and product innovation. In fact, our results are even stronger and suggest that doing one only has no effect on firm growth. Importantly, there is little evidence of selection between firms that choose to innovate in particular ways and growth in either our CF models, or the experimental average – treatment effect models.

Table 4. Employment growth models.

	[1] Employment growth: Base model				[2] Employment growth: CF model				[3] Employment growth: Mills selection model			
Innovation type lags	Coefficient	S.E	*z*	Pr > z	Coefficient	S.E	*z*	Pr > z	Coefficient	S.E	*z*	Pr > z
I_ Process												
L1.	0.0077	0.0188	0.41	0.682	−0.0038	0.0206	−0.19	0.852				
I_ Product												
L1.	0.0193	0.0139	1.39	0.164	0.0149	0.0153	0.97	0.332				
I_ Product and Process												
L1.	0.0708	0.0194	3.64	0.000	0.0718	0.0215	3.35	0.001				
Predicted Innovation Type												
Process					0.0316	0.0254	1.24	0.213				
Product					−0.0002	0.0165	−0.01	0.989				
Product and Process					0.0786	0.0327	2.40	0.016				
Mills Selection of Innovation Type												
Process									−0.0473	0.0326	−1.45	0.147
Product									−0.0085	0.0220	−0.39	0.699
Product and Process									−0.0831	0.0407	−2.04	0.041
Independent Variables												
L1. Growth	−0.3204	0.0102	−31.43	0.000	−0.3340	0.0114	−29.20	0.000	−0.3333	0.0113	−29.49	0.000
L1. Level	−0.0515	0.0045	−11.57	0.000	−0.0559	0.0050	−11.20	0.000	−0.0576	0.0052	−11.08	0.000
Ln Firm Age	0.0001	0.0086	0.01	0.992	0.0115	0.0098	1.17	0.241	0.0103	0.0099	1.05	0.295
Management Training												
L1.	0.0288	0.0118	2.44	0.015	0.0017	0.0104	0.16	0.872	0.0028	0.0138	0.20	0.840
Export												
L1.	0.0270	0.0148	1.82	0.069	0.0104	0.0150	0.69	0.487	0.0039	0.0168	0.23	0.816
Industry												
ABDE – Primary												
C – Manufacturing	0.0160	0.0304	0.53	0.600	−0.0090	0.0338	−0.27	0.790	−0.0036	0.0341	−0.10	0.917
F – Construction	−0.0229	0.0312	−0.74	0.462	0.0196	0.0355	0.55	0.582	0.0216	0.0358	0.60	0.546
G – Wholesale/ Retail	0.0018	0.0288	0.06	0.950	0.0227	0.0321	0.71	0.479	0.0237	0.0320	0.74	0.460
H – Transport/ Storage	0.0281	0.0387	0.73	0.467	0.1276	0.0457	2.79	0.005	0.1229	0.0467	2.63	0.008
I – Accommodation/ Food	0.0060	0.0337	0.18	0.859	0.0418	0.0379	1.10	0.270	0.0462	0.0379	1.22	0.223
J – Information / Communication	−0.0156	0.0332	−0.47	0.639	−0.0462	0.0367	−1.26	0.208	−0.0423	0.0370	−1.14	0.253
KL – Financial/ Real Estate	−0.0227	0.0353	−0.64	0.519	0.0157	0.0397	0.40	0.692	0.0144	0.0401	0.36	0.719
M – Professional/ Scientific	−0.0468	0.0283	−1.65	0.099	−0.0429	0.0313	−1.37	0.171	−0.0412	0.0316	−1.30	0.192
N – Administrative/ Support	0.0056	0.0318	0.18	0.861	0.0204	0.0354	0.58	0.565	0.0225	0.0355	0.63	0.526
P – Education	0.0256	0.0392	0.65	0.514	0.0515	0.0443	1.16	0.245	0.0515	0.0446	1.15	0.249
Q – Health/ Social Work	0.0667	0.0320	2.08	0.037	0.1042	0.0361	2.89	0.004	0.1040	0.0362	2.87	0.004
R – Arts/ Entertainment	−0.0444	0.0416	−1.07	0.286	0.0096	0.0469	0.20	0.838	0.0073	0.0470	0.16	0.876
S – Other service	−0.0408	0.0386	−1.06	0.291	0.0076	0.0433	0.18	0.861	0.0073	0.0435	0.17	0.867

Finance												
L1. Equity	0.1226	0.0704	1.74	0.082	0.0473	0.0522	0.91	0.365	0.0534	0.0759	0.70	0.482
L1. Debt	0.0519	0.0149	3.48	0.001	0.0168	0.0123	1.36	0.173	0.0410	0.0166	2.47	0.013
L1. Scarred Borrower	−0.0484	0.0171	−2.84	0.005	−0.0337	0.0141	−2.39	0.017	−0.0583	0.0186	−3.14	0.002
L1. Fully Credit Rationed	−0.0176	0.0331	−0.53	0.595	−0.0208	0.0256	−0.82	0.415	−0.0194	0.0353	−0.55	0.582
Constant	0.0127	0.0378	0.34	0.737	0.2084	0.0585	3.56	0.000	0.3129	0.0785	3.99	0.000
No. Observations	8130				6780				6780			
Pr>χ2	0.0000				0.0000				0.0000			

Table 5. Real sales growth models.

	[1] Real sales growth: base model				[2] Real sales growth: CF model				[3] Real sales growth: Mills selection model			
Innovation type lags	Coefficient	S.E	z	Pr > z	Coefficient	S.E	z	Pr > z	Coefficient	S.E	z	Pr > z
I_ Process												
L1.	0.0323	0.0251	1.29	0.198	0.0262	0.0254	1.03	0.301				
I_ Product												
L1.	−0.0101	0.0184	−0.55	0.583	−0.0128	0.0188	−0.68	0.494				
I_ Product and Process												
L1.	0.0529	0.0253	2.09	0.036	0.0415	0.0264	1.57	0.116				
Predicted Innovation Type												
Process					0.0069	0.0315	0.22	0.826				
Product					−0.0077	0.0193	−0.40	0.691				
Product and Process					0.0226	0.0300	0.75	0.452				
Mills Selection of Innovation Type												
Process									−0.0174	0.0403	−0.43	0.665
Product									0.0114	0.0251	0.45	0.650
Product and Process									−0.0282	0.0363	−0.78	0.437
In Dependent Variable												
L1. Growth	−0.2225	0.0157	−14.20	0.000	−0.2225	0.0157	−14.20	0.000	−0.2222	0.0157	−14.18	0.000
L1. Level	0.0003	0.0040	0.08	0.932	−0.0019	0.0043	−0.44	0.662	−0.0020	0.0043	−0.47	0.637
Ln Firm Age	−0.0121	0.0109	−1.10	0.269	−0.0104	0.0111	−0.94	0.349	−0.0107	0.0111	−0.96	0.335
Management Training												
L1.	0.0105	0.0129	0.81	0.417	0.0083	0.0130	0.64	0.524	0.0074	0.0130	0.57	0.571
Export												
L1.	0.0343	0.0188	1.83	0.067	0.0324	0.0189	1.72	0.086	0.0323	0.0188	1.71	0.087
Industry												
ABDE – Primary												
C – Manufacturing	−0.0188	0.0373	−0.50	0.614	−0.0230	0.0377	−0.61	0.541	−0.0232	0.0377	−0.61	0.539
F – Construction	−0.0127	0.0391	−0.33	0.745	−0.0084	0.0399	−0.21	0.834	−0.0071	0.0401	−0.18	0.860
G – Wholesale/ Retail	−0.0419	0.0359	−1.17	0.243	−0.0385	0.0360	−1.07	0.284	−0.0382	0.0360	−1.06	0.288
H – Transport/ Storage	−0.0169	0.0491	−0.34	0.731	−0.0052	0.0502	−0.10	0.917	−0.0038	0.0503	−0.08	0.939
I – Accommodation/ Food	−0.2309	0.0422	−5.47	0.000	−0.2270	0.0424	−5.35	0.000	−0.2256	0.0424	−5.32	0.000
J – Information / Communication	−0.0497	0.0403	−1.23	0.218	−0.0574	0.0409	−1.40	0.160	−0.0577	0.0408	−1.41	0.158
KL – Financial/ Real Estate	−0.0364	0.0439	−0.83	0.408	−0.0331	0.0447	−0.74	0.459	−0.0310	0.0448	−0.69	0.490
M – Professional/ Scientific	−0.0744	0.0349	−2.13	0.033	−0.0801	0.0353	−2.27	0.023	−0.0803	0.0353	−2.28	0.023
N – Administrative/ Support	−0.0799	0.0397	−2.01	0.044	−0.0826	0.0401	−2.06	0.039	−0.0828	0.0402	−2.06	0.039
P – Education	−0.0661	0.0504	−1.31	0.190	−0.0652	0.0510	−1.28	0.201	−0.0659	0.0510	−1.29	0.197
Q – Health/ Social Work	−0.0065	0.0392	−0.17	0.869	−0.0070	0.0397	−0.18	0.861	−0.0072	0.0397	−0.18	0.856
R – Arts/ Entertainment	−0.2269	0.0514	−4.41	0.000	−0.2181	0.0516	−4.22	0.000	−0.2180	0.0516	−4.22	0.000
S – Other service	−0.1186	0.0482	−2.46	0.014	−0.1126	0.0483	−2.33	0.020	−0.1116	0.0483	−2.31	0.021

Finance												
L1. Equity	−0.0043	0.0926	−0.05	0.963	−0.0879	0.0694	−1.27	0.205	−0.0932	0.0695	−1.34	0.180
L1. Debt	0.0042	0.0156	0.27	0.788	0.0011	0.0156	0.07	0.944	−0.0013	0.0157	−0.08	0.936
L1. Scarred Borrower	−0.0202	0.0180	−1.12	0.262	−0.0210	0.0180	−1.17	0.244	−0.0214	0.0180	−1.18	0.236
L1. Fully Credit Rationed	0.0034	0.0321	0.11	0.915	0.0059	0.0321	0.18	0.855	0.0062	0.0321	0.19	0.848
Constant	0.0670	0.0638	1.05	0.294	0.1309	0.0735	1.78	0.075	0.1701	0.0813	2.09	0.036
No. Observations	6780				5686				5686			
Pr>χ2	0.0000				0.0000				0.0000			

Changes in firms' ability to access external debt and equity did impact on firm employment growth rates, and this effect was stronger for debt than equity. Changes in management training provision, through a human capital effect was found to increase employment growth. A change in a firm's export status was associated with increased sales growth although only at the 10% level of significance. However, we did find that self-exclusion from external capital markets, and seeking to fund all activities from internal reserves due to a recent negative experience of capital markets, was associated with lower growth rates. This suggests that firms are struggling to meet their cash-flow and investment requirements, and that self-exclusion may be negatively impacting their ability to create new employment (Table 5).

4.3. Results summary

To summarise, there is persistence in innovation, but not firm growth. Further, young firms innovate more, but do not grow faster. Dynamic capabilities can be seen as innovation enabling, and job enhancing. There are very large industry differences in terms of engaging in innovation and the precise form of innovation. Industry differences are also important in understanding firm growth. However, the industry sectors that innovate more do not map well into the industry sectors that have superior growth rates. Finance is important for innovation, but financial behaviours are more important in understanding growth. On the former, raising external debt and equity support more innovation, with equity having the greatest impact. On the latter, firms choosing to self-exclude from capital markets due to a previous bad experience, are doing themselves self-harm if we are concerned about job creation. Firms that do access debt also grow their employment faster, but not their sales.

5. Discussion

We set out to test if there was evidence that engaging in process and product innovation simultaneously generated more benefits in terms of firm growth than doing either form of innovation in isolation. We also sought to understand more about smaller firms, innovation, and growth and the potential finance and capabilities barriers they might face. Using panel data for the period 2015–2020, we find that the smallest firms engage less with innovation than their medium-sized counterparts and only 5.0% conduct process and product innovation simultaneously. In contrast, younger firms engage with innovation more than their more established peers. Dynamic capabilities are important in understanding innovation in smaller firms and management training is at the heart of this. Finance is also important for innovation, and particularly equity finance. This finding suggests that the current UK support for hybrid equity funds for innovative smaller and younger firms is well-targeted, although we should not ignore the role of debt finance. In this sense, support interventions that combine management development training and improve access to finance might be expected to achieve superior innovation outcomes.

The role of regional and industry innovation systems in supporting or discouraging innovation in smaller firms cannot be overstated. Both can increase or reduce firms' engagement with innovation. The importance of peripheral, and Northern, regions, in the UK's innovation system is not appreciated by policy-makers, and we also find that the wealthy Southern regions around the capital make a much smaller contribution than previously assumed. Further, innovation activity is hugely industry dependent and manufacturing and information and communications sectors are at the forefront of small firm innovation. The construction industry, in contrast, has a much lower level of innovation.

Finance is critical to innovation and, in particular, the ability to raise debt and equity from capital markets. This has been a problematic issue for many innovative small and young firms and this is not just a UK problem. This finance issue extends to growth but mainly in a behavioural context as firms that have moved into a state of what is termed by Cowling, Liu, and Calabrese (2021b) 'scarred borrowers' due to a recent negative experience with capital markets grow at a slower rate. Put another way, firms that seek to self-fund their day-to-day operations, innovation and investment do not seem able to fund their activities at a rate that maximises their job growth. Further research into this issue and the incidences under which firms' transition from active capital market seekers to scarred borrowers will shed more light on what the potential public policy solution might be.

We also asked the basic question: Does innovation generate more growth? Our evidence suggests that it does, but only if firms engage in process and product innovation simultaneously as they are strong complements as predicted by Milgrom and Roberts (1995). This suggests that to generate superior growth, firms must create innovative new products and services that differentiate themselves from their competitors whilst also becoming more internally efficient and producing output at lower cost. Doing either may of course generate higher profits even with constant sales but our data did not allow us to explore this. It was also true that our evidence is stronger for the impact of innovation on jobs growth than sales growth and the magnitude of the effects were larger. However, we find little supporting evidence that there is some magical unobserved mechanism that means that innovating firms are on average, and systematically, more likely to grow faster. Rather, growth is shaped by the industry a firm operates in, whether it engages in dual innovation, and continues to top up its own funds with external debt and equity when needed.

Finally, growth, at least in the short-term, is not continuous, or persistent, and this suggests that policy-makers and indeed investors who try to pick winners will generally fail. This is consistent with the 'gambler's ruin' theory put forward by Coad et al. (2013) that most growth paths occur with equal probability and follow a random walk. However, the actual time-period under examination was a unique one in UK history. In June 2016, the UK population voted to exit from the European Union and began the slow exit transition. This led to a huge decline in new investment by UK businesses and as we observed within the data a drop-off in innovation rates. At the end of this uncertain EU exit transition, the Covid-19 pandemic arrived in the UK. Currently, we have Covid-19, and the economy is feeling the effects of the Russian war in Ukraine. At some point in the future, it would be immensely valuable to repeat this analysis and answer the question about the uniqueness of the time-period under investigation and ask the question if under business as usual conditions, there is a stronger direct and indirect effect of individual and dual innovation on firm growth.

6. Limitations and further research

We have tested the effects of innovation on firm growth at a unique time in UK history and our findings may be shaped by a heightened level of uncertainty in the economy that has been prevalent since 2016 and is still present. Future research could replicate this work using the same UK data with an extended time-series and this would allow for a test of the uniqueness of our time window. Given that our core innovation variables are present in other large innovation surveys, this would also facilitate a broader set of analyses covering other single countries, or indeed multiple countries simultaneously. Research could also explore how the innovation – growth relationships gets stronger or weaker in different institutional and macroeconomic environments.

Acknowledgements

The authors would like to thank the UK Economic and Social Research Council (ESRC) for funding this research under award number ES/W010259/1.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Economic and Social Research Council [Grant Number ES/W010259/1].

Data availability statement

The data is available for academic researchers who register with the UK Data Service (https://ukdataservice.ac.uk/).

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Appendix: Empirical studies of complementarities between different forms of innovation (product, process and organisational)

Paper	Data	Countries	Structure of Data	Industries	Key Findings
Kamutando and Tregenna (2023)	Single Survey	Johannesburg, South Africa	Cross-section, 2019	Manufacturing SMEs (including micro and informal)	• Small and micro-firms benefit from synergistic effects of innovation complementarity on performance. • Innovation complementarity enhances performance only for formal firms. • Innovation complementarity impacts performance more for foreign-owned and micro-firms than domestic-owned and small firms.
Zhang (2022)	CIS	China	2011–2013	Manufacturing SMEs	• For Chinese SMEs, there is no interplay or complementarity between product, quality (process), and organisational

(*Continued*)

Continued.

Paper	Data	Countries	Structure of Data	Industries	Key Findings
					innovation, unlike evidence from developed countries. • This lack of complementarity may be due to weaker capabilities of Chinese SMEs to transfer knowledge and leverage synergies across innovation types. • Substitutability is found between efficiency and flexibility innovation for Chinese SMEs pursuing a low-cost strategy. • Organisational innovation enables complementarity between efficiency and flexibility innovation by reconciling contradictory knowledge processes.
Wang, Xiao, and Savin (2021)	CIS	Germany	2002–2004 and 2005–2007	Manufacturing and business related services	• Certain contextual variables like appropriability conditions, cooperation, market information, human capital, public funding, and firm size are found to stimulate firms to prefer the combination strategy of internal R&D and external technology acquisition. • For product innovations, the combination strategy leads to better radical innovation performance in science-based (SB industries and better incremental innovation performance in supplier-dominated (SI) industries compared to using only one knowledge source. • For process innovations, the combination strategy allows higher quality improvements in SB industries and significant cost reductions in both SB and SI industries. • The results are consistent with the existence of complementarity between internal and external innovation activities, requiring tight integration within the firm's innovation process
Guisado-González, Wright, and Guisado-Tato (2017)	CIS	Spain	2009–2012	Manufacturing	• Product and process innovation exhibit an unconditional complementary relationship. • No unique relationship exists between product and organisational innovation. • For firms not performing product innovation, process and organisational innovation exhibit a substitutive relationship. • No universal complementarity

(*Continued*)

Continued.

Paper	Data	Countries	Structure of Data	Industries	Key Findings
					applies to all pairs of the three innovation types.
Carboni and Russu (2017)	CIS	Italy, Austria, France, Germany, Hungary, Spain and UK	2007–2009	Manufacturing	• Strong evidence of interdependence and complementarity between product, process, and organisational innovation decisions • Firms likely to engage in all three innovation modes simultaneously • Particularly high complementarity between process and organisational innovations • Complementarities imply need for aligned, multi-pronged innovation strategies by R&D managers
Krzeminska and Eckert (2016)	CIS	Germany	2001–2009	Manufacturing	• Strong evidence for complementarity between internal and external R&D is found for product innovations. • The study cannot confirm any complementarity between internal and external R&D for process innovations. • This suggests that for process innovations, the benefits of knowledge creation from combining external and internal R&D may not outweigh the risks of knowledge transfer, unlike for product innovations. • This lack of complementarity for process innovations is attributed to the tacit and systemic nature of knowledge involved, as opposed to the more explicit and autonomous knowledge in product innovations
Ballot et al. (2015)	CIS	France and UK	2002–2004	Manufacturing only	• The simultaneous introduction of product, process, and/or organisational innovation does not always associate with improved performance. • There is no single 'winning strategy' regarding the complementarities of different innovations.
Doran (2012)	CIS	Ireland	2004–2006	Not specified	• Three of the six analysed pairwise relationships exhibit complementarity, while none exhibit substitutability. • Each innovation form complements at least one other form. • Organisational innovation, a non-technical form, exhibits a strong complementary relationship with technological innovation.

(*Continued*)

Continued.

Paper	Data	Countries	Structure of Data	Industries	Key Findings
Polder, Leeuwen Mohnen and Raymond (2010)	CIS	Netherlands	2002–2006	Manufacturing and services	• In manufacturing, R&D drives product innovation output and positively affects process and organizational innovation. • No evidence of R&D impacting any innovation type in the service sector. • Organisational and product innovations are substitutes, product and process innovations are complements, and organisational and process innovations are complements. • Without organisational innovation, product and process innovations lack positive effects. • In both manufacturing and services, ICT investment and application importantly drive organisational innovation.
Martínez-Ros and Labeaga (2009)	CIS	Spain	1990–1999	Manufacturing	• Strong persistence effects in product/process innovation predict continued innovation • Complementarities between product and process innovation are key determinants of innovation probabilities • For future process innovation success, persistence in product innovation matters more than process persistence itself • Findings suggest product and process innovations are interdependent activities exhibiting complementarities
Cassiman and Veugelers (2006)	CIS	Belgium	1993	Manufacturing	• Evidence shows complementarity exists between internal and external innovation activities when tightly integrated in the firm's process. • The degree of reliance on basic R&D affects the strength of this complementarity between activities – complementarity is context-specific. • Innovation success depends on combining activities and creating the right organisational context through careful innovation process management.
Miravete and Pernias (2006)	DIRNOVA, a database of Spanish firms	Spain	Panel, 1980s	Ceramic tiles	• Product and process innovations exhibit significant complementarity, driven largely by unobserved firm heterogeneity (e.g. organisational factors, managerial ability) • Smaller firms are more inclined towards product innovations due to technology

(*Continued*)

Continued.

Paper	Data	Countries	Structure of Data	Industries	Key Findings
					complementarities • Organisational factors play a bigger role in driving process innovations across firm sizes
Mohnen & Roller (2007)	CIS	Denmark, Germany, Ireland, and Italy	1992	Manufacturing	• Evidence on innovation policy complementarities varies based on the innovation phase (propensity vs. intensity) and the specific policy pair • For innovation propensity, complementary policy relationships are more common • For innovation intensity, substitutability between policies is more prevalent, contrasting with propensity phase
Galia and Legros (2004)	CIS	France	1994–1996	Manufacturing	• Distinguishes between obstacles in postponed innovation projects vs abandoned projects • For postponed projects, complementarities exist between obstacles related to: Risk, costs, finance; Organisational attitudes; Skills/information gaps; Institutional environment, customer responsiveness • For abandoned projects, complementarities only between obstacles related to risk, costs, finance, organisation, skills, technology information • Suggests need for coherent policy packages targeting complementary obstacles for postponed projects

Note: CIS is the Community Innovation Survey.

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