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The interrelationship between R&D, Innovation and Productivity: Evidence for micro-enterprises

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The interrelationship between R&D, Innovation and Productivity: Evidence for micro-enterprises

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DEFINITIONS

Definitions of Innovation are adopted from the Oslo Manual. The Oslo Manual was originally published by the Organisation for Economic Cooperation and Development (OECD) in 1992 and includes definitions of basic concepts, data collection guidelines and classifications for compiling innovation statistics. Definitions for product, process innovation and Research and Development are as follows:

- **Product innovation:** A good or service that is new or significantly improved. This includes significant improvements in technical specifications, components and materials, software in the product, user friendliness or other functional characteristics.

- **Process innovation:** A new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software.

- **Research and Development (R&D)**: comprises creative work undertaken on a systematic basis in order to increase the stock of human knowledge and to devise new applications based upon it. The term R&D covers three activities: basic research, applied research and experimental development. Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view. Applied research is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective. Experimental development is systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed.

- **Internal and External R&D**: Internal R&D refers to efforts on R&D that original within the control of and are used for R&D at the discretion of the reporting unit. External R&D (also referred to as extramural R&D) is R&D performed outside of the reporting unit about which information is being reported.

EXECUTIVE SUMMARY

In light of concerns about persistently weak productivity levels in UK firms, this study focuses on the relationship between investment in R&D and innovation activity and how this relates to business growth and productivity. The context for our investigation is micro-enterprises, i.e. employing up to 9 employees. These enterprises dominate the business landscape and in Northern Ireland account for almost 20 per cent of the workforce while also playing an important development role in the economy.

Drawing on survey data of nearly 10,000 micro-enterprises in 3 countries: the UK, Ireland and the US, our analysis emphasises the importance of R&D – an investment activity that is often considered not suitable for small enterprises - in supporting the relationship between innovation and productivity.

Some of our main findings include:

- Despite resource and capability constraints within micro-enterprises, that curtail their ability to undertake R&D, we find that investing in R&D has a strong and positive effect on enhancing the contribution of innovation to productivity and turnover growth. This result is consistent throughout all of our estimations, even though the actual effect might be varied across different types of industry.

- In order to explain the importance of R&D investment, we also estimate the innovation function with two innovation outcomes: product and process innovation. Our results indicate that investing in R&D activity is important not only for product/service innovation, but also for process innovation.

- R&D investment undertaken inside the enterprise is positively associated with both product innovation and process innovation, however R&D acquired externally has no significant relationship with product innovation but is positively related to process innovation.

- In line with previous studies, we identify a significantly lower level of productivity for Northern Ireland micro-enterprises.

1. INTRODUCTION

> It has been accepted wisdom for many years that Northern Ireland's private sector has been underperforming when compared to the rest of the UK … Employment levels in the private sector are well below other UK regions on a per head of population basis, while public sector employment is broadly comparable (Mac Flynn, 2016, p.4).

Several studies have examined the low productivity performance of NI firms, often with comparison to other UK regions (Brownlow 2017; Brownlow and Budd 2019). As an important source of productivity growth, what induces innovation and how it affects productivity growth are questions that are central to this literature.

However, little is known about micro-enterprises, a type of business that has been increasingly important in the development of every economy. In all countries, micro-enterprises (up to 9 employees) dominate the business landscape, accounting for 70% to 95% of all firms (OECD Report 2017). In the UK, there were 1.11 million micro-enterprises in 2017, employing around 4.09 million people (17.6% of the whole workforce) (Roper and Hart 2018). In Northern Ireland, there were around 28,500 micro-enterprises in 2017, employing around 111,000 people (19.7 per cent of the workforce). These firms generated sales of £10.4bn, 17.2 per cent of total sales of all NI firms (Hewitt-Dundas and Roper 2018).

In this report, we analyse the relationship between innovation and productivity for micro-enterprises. In particular, we address two questions:

(1) is there a relationship between micro-enterprises engaging in innovation activity and their performance, both in terms of turnover growth and productivity;

(2) how does investment in R&D activities contribute to innovation? Here we disaggregate investment in R&D into a portfolio of forms of investment – many of which are more common in micro-enterprises - rather than focusing solely on investment in 'research' efforts.

Utilising a survey-based dataset of nearly 10,000 micro-enterprises in three countries: the UK, Ireland and the US, we report several findings. First, our results indicate that the effect

of innovation on productivity is often positive, but it is significantly stronger for innovators with investment in R&D activities, either inside or outside the firm. This finding provides support to the Innovation Value Chain perspective (see, for example, Roper et al. 2008) which stresses the importance of engaging in investment activities in improving the quality of innovation and from that, strengthening the innovation-productivity relationship.

Second, we also explore the different effects of investment activities on the probability of firms reporting product and process innovation. Our results confirm that R&D inside the firm is the most important investment activity, as it has positive and significant effects on both product and process innovation, while R&D taken outside the firm or other investment only positively influence process innovation.

Third, we document a significantly lower level of productivity for NI firms.

We believe these findings are important, not only to our understanding of micro-enterprises, but also in terms of the policy implications for inducing investment and innovation in micro-enterprises, as a means of enhancing productivity performance.

The report proceeds as follows. Section 2 outlines the underpinning conceptual framework to our analysis and discusses our research hypotheses. Our empirical approach including data, model specification and methods of estimation are presented in Sections 3 and 4. Section 5 describes our main empirical results, and finally Section 6 concludes.

2. CONCEPTUAL FRAMEWORK AND HYPOTHESES

> An innovation event, such as the introduction of a new product or process, represents the end of a series of knowledge sourcing and translation activities by a firm. It also represents the beginning of a process of value creation which, subject to the firm's own attributes and market conditions, may result in an improvement in the performance of the innovating business (Roper et al. 2008)

Early work revealed that just under half of productivity growth can be attributed to growth in capital and labour. The remainder was ascribed to advanced knowledge, commercialised as innovations (Griliches 1996, 1998). Since Griliches's seminal contribution, a large number of studies have confirmed a positive relationship between innovation and productivity (Crepon et al. 1998; Loof and Heshmati 2002; Griffith et al. 2006). An extensive review of this literature can be found in Hall (2011).

In this strand of literature, several papers have also been dedicated to investigating the effect of innovation on productivity and growth for SMEs. Overall, results often confirm that innovation is also an important source of productivity growth for these firms (Hall et al. 2009; Price et al. 2013).

However, little has been known about the nature of this relationship in micro-enterprises. Despite their increasing importance in every economy, firms with less than 10 employees are often thought to have no, or very limited, innovative capacity. One of the main reasons proposed to explain this, is the presence of information asymmetry between micro-enterprises and external suppliers of finance, leading to credit constraints (Czarnitzki and Hottenrott 2011). A further reason comes from their lack of time and other resources to invest in training or engagement in R&D or to undertake other investment activities leading to knowledge creation (Massey 2004; Barry and Milner 2002).

So far, the only paper we are aware of that studies this issue is Baumann and Kritikos (2016). Utilising a dataset of 4,463 German micro-enterprises, they confirm that innovation is also an important source of productivity and growth for micro-enterprises. Notably, they also suggest that micro-enterprises benefit from their R&D engagement.

In this report, we go a step further to check whether having R&D investment affects the innovation-productivity relationship in micro-enterprises. Our first hypothesis is:

H1: The effect of innovation on productivity is positive and stronger for micro-enterprises *with* investment in R&D activities (either inside or outside of the enterprise).

Moreover, in the literature, results about the effect of R&D and other investment activities on different innovation outcomes are inconclusive. Even though R&D is a main source of innovation input, how much R&D investment is translated into innovation outcomes as well as economic value has been a topic of interest for economists for a long time. Indeed, the effect of this R&D investment may differ across various innovation outcomes. For example, while R&D investment is often positively linked to product innovation performance (Hurmelinna-Laukkanen et al. 2008), it is also suggested to have an effect on process innovation activity (Raymond and St-Pierre 2010). Besides, R&D undertaken outside the firm or other investment activities (such as design or investing in computer software or hardware, marketing methods, etc.) might also influence the probability of firms reporting product and process innovation.

Therefore, we explore the effects of R&D and other investment activities on two innovation outcomes: product and process innovation. We believe the results will provide greater insight on the actual effects of this range of investment activities. This suggests our second and third hypotheses:

H2: The probability of micro-enterprises reporting product innovation will be greater for enterprises investing in R&D and other activities;

H3: The probability of micro-enterprises reporting process innovation will be greater for enterprises investing in R&D and other activities.

3. DATA

Our analysis is based on an innovation survey among micro-enterprises (with one to nine employees) conducted in 3 countries: the UK, Ireland and the US. The survey closely followed the definitions and questions used in the EU Community Innovation Survey (CIS) and the UK Innovation Survey (UKIS) but adopted a different survey methodology, being conducted by telephone rather than post.

Full details of the survey and descriptive statistics are available in Hewitt-Dundas and Roper (2018, https://www.enterpriseresearch.ac.uk/wp-content/uploads/2018/11/ERC-ResReport-Understanding-micro-businesses-in-Northern-Ireland.pdf)

On average micro-enterprises in Northern Ireland have employment of 3.3 and have been operating for 28.7 years (Table 1). Around half (48.8 per cent) of all micro-enterprises in NI are home-based, a slightly smaller proportion than that in other UK regions. 78 per cent of micro-enterprises are family-owned and in four out of five the founder is still involved in the business. Typically, however the founder is not the only member of the firms' leadership team which in most regions has 1.9-2.1 members on average (Table 1).

Table 1: Profiling micro-enterprises across UK regions and comparator areas

	Employment (average)	Age of business (years)	% home based	% family owned	% founder still involved	Size of leadership team (no)
East of England	3.5	22.8	51.0	71.9	81.8	1.9
East Midlands	3.4	23.0	54.9	70.3	79.1	2.1
London	3.2	20.5	56.8	58.1	85.6	2.1
North East	3.5	21.4	52.4	66.4	82.1	1.8
North West	3.4	20.6	54.1	73.0	82.9	2.0
South East	3.4	22.8	54.7	69.6	82.6	2.0
South West	3.3	23.8	52.8	74.3	79.2	1.9
West Midlands	3.4	22.6	57.1	69.7	84.2	2.0
Yorks. & Humber	3.2	22.4	54.7	69.5	78.7	1.9
Scotland	3.2	25.4	51.0	74.0	81.0	1.9
Wales	3.3	26.5	50.1	76.2	82.4	1.9
Northern Ireland	3.3	28.7	48.8	78.1	80.2	1.9
UK	3.3	22.9	53.9	70.2	81.9	2.0
Ireland	3.1	24.7	47.3	76.6	84.9	1.8
USA	3.5	19.2	41.3	71.0	95.2	1.9

Source: Micro-business Britain Survey, observations are weighted to provide representative results for each area.

Perhaps the most noticeable contrast between micro-enterprises in Northern Ireland and those elsewhere in the UK is in terms of family ownership. In NI, 78 per cent of micro-enterprises are family-owned compared to 70 per cent in the UK as a whole and only 58 per cent in London. The profile of micro-enterprises in Northern Ireland is relatively similar to that in Ireland although compared to the US the level of family-ownership is higher and the continued involvement of the founder lower. In the US, 95 per cent of micro-enterprises still involve the founder (NI, 80 per cent).

Of nearly 10,000 respondents to our survey, more than half indicated that they had no innovation outcomes (product and/or process innovation) (Table 2). This is not unexpected as previous research has emphasized the lack of both finance and other resources as major constraints on investment activities within small firms (Czarnitzki and Hottenrott 2011; Baumann and Kritikos 2016).

Table 2: Product and process innovation

	Product innovation		Process innovation	
	Obs.	% of Total	Obs.	% of Total
UK	2086	33.35	1459	23.33
Ireland	599	39.93	416	27.73
USA	774	38.68	421	21.04
Northern Ireland	146	29.49	72	14.55

Northern Ireland records a markedly lower percentage of micro-enterprises reporting process innovation in comparison to the UK, Ireland and the US. For product innovation, the difference is slightly lower (29.49 per cent for NI, and 33.35 per cent for the UK), while the highest value is 39.93 per cent for Irish firms.

Disaggregating innovation activity further for NI micro-enterprises indicates some significant contrasts (Table 3). Specifically, larger micro-enterprises (5-9 employees) are more likely to be undertaking product or process innovation. Further, a higher proportion of micro-enterprises in the service sector are undertaking product/service as well as process innovation, than those in the manufacturing sector. In addition, non-family firms are more likely to be product and/or process innovators, however the difference is small and insignificant.

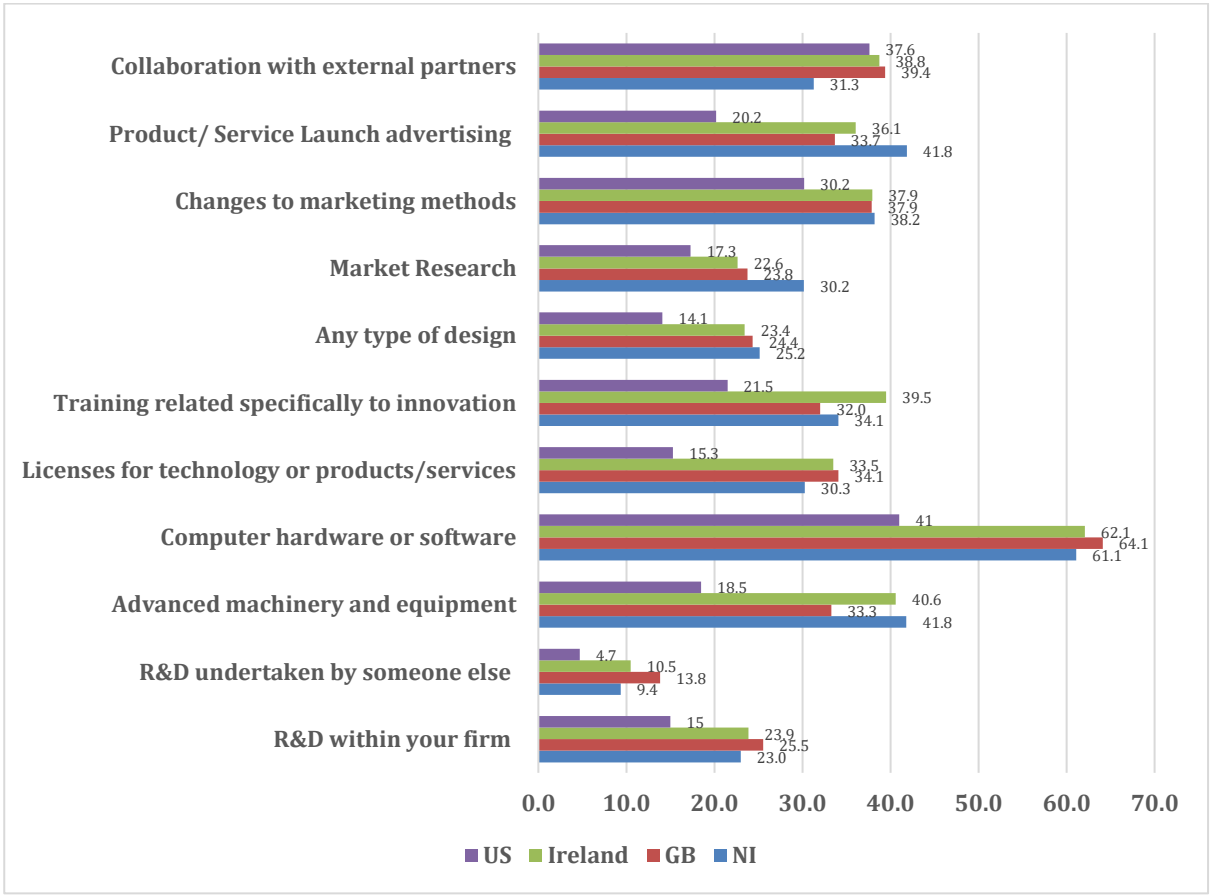
Table 3: Innovation by type of micro-enterprise: Northern Ireland

	Product or service innovators (% firms)	Process innovators (% firms)
A. By firm sizeband		
1-4 employees	24.4	10.5
5-9 employees	35.6	19.4
B. By broad sector		
Manufacturing	17.1	7.3
Service	32.3	15.3
C. By ownership		
Non-family	28.0	15.8
Family	26.4	11.5

Focusing on those micro-enterprises reporting innovation activity, only around a quarter of these innovating firms were undertaking in-house R&D. This suggests that the majority of innovating firms were undertaking innovation without any in-house R&D capability.

Figure 1 below shows the comparison between UK, Ireland, US and Northern Ireland micro-businesses with regards to their investment activities and collaboration. It can be seen that for all regions, the percentage of enterprises reporting R&D inside is significantly higher than that of R&D outside. For NI micro-enterprises this equates to 23.0% of innovating firms undertaking in-house R&D as compared to 9.4% undertaking R&D externally. Notably, more than 60% of micro-enterprises in all regions, except the US, report that they had invested in computer hardware or software.

Figure 1: Investment activity for Innovating Micro-enterprises (Percentage)



Turning to rates of productivity and growth, similar to previous studies, we consider turnover per employee (in natural logarithm form) as our measure of productivity and for growth we simply take turnover growth (turnover of last year in comparison with that of the year before).

Table 4: Productivity – Growth measures

	Productivity		Turnover growth	
	Obs.	Mean	Obs.	Mean
UK	5040	11.26	5476	0.032
Ireland	1116	11.27	1373	0.048
USA	1835	10.54	1991	0.032
Northern Ireland	375	11.16	436	0.033

Table 4 indicates that US firms seem to have lowest level of productivity, while the highest level of both productivity and growth is recorded for Irish firms. Surprisingly, in contrast to what has been discussed in the recent literature (Mac Flynn, 2015; 2016), the average values for productivity (turnover per employee) and turnover growth, do not indicate lower performance by NI firms.

4. METHODOLOGY

Our analysis is based on the concept of the innovation production function, which relates micro-enterprises' innovation outputs to their productivity and growth. Our dependent variable in equation (1) is productivity, calculated as turnover per employee. An essentially similar model is run for turnover growth. However, equation (1) is conducted based on a strict assumption that the effect of innovation on productivity is similar between innovative firms with and without R&D investment. In order to test whether engaging in R&D activities improves the quality of innovation outcomes and hence strengthens the effect it has on productivity, an idea that has been suggested by the Innovation Value Chain perspective (Roper et al. 2008), we allow for the separation between these innovators with and without R&D investment. It is reflected in two binary variables *Innov_w_RD* and *Innov_wt_RD* in equation (2). The former takes the value of 1 if a firm has innovation outcomes and reports that it also engages in either R&D investment inside or outside, while the latter equals 1 if a firm has innovation outcomes but does not report any R&D investment.

As our measures of productivity and growth are in continuous form, we apply the simple OLS regression. Then, to test the effects of innovation on productivity between innovators with or without R&D investment, we use the Wald test for the difference between the estimated coefficients β_{21} and β_{22} in equation (2) below.

$$prod_i = \beta_{11} innov + \gamma_{1,n} X_i + u_{1i} \quad (1)$$

$$prod_i = \beta_{21} innov\_w\_RD + \beta_{22} innov\_wt\_RD + \gamma_{2,n} X_i + u_{2i} \quad (2)$$

The productivity model is then run on different sub-samples of high-technology/knowledge-intensive and low-technology/less knowledge-intensive firms; or manufacturing and service firms[1].

[1] Following Cowling et al. (2018), we apply the European Commission classification for high-tech/knowledge-intensive firms versus low-tech/less knowledge-intensive firms. Details can be found in: http://ec.europa.eu/eurostat/cache/metadata/Annexes/htec_esms_an3.pdf. For manufacturing and service sectors, we rely on SIC 2007 section classification. Details can be found in Table A2 in the Appendix.

In order to test the next two hypotheses, H2 and H3, we apply the innovation function. Our dependent variables here are two binary variables reflecting whether a firm reports product/process innovation or not. More specifically, product innovation defines whether a firm introduced a new or significantly improved good or service in the last 3 years, while process innovation reflects any new or significantly improved methods for the production or supply of goods and services.

$$pd_i = \beta_{31} RD\_in + \beta_{32} RD\_out + \beta_{33} other\_inv + \gamma_{3,n} X_i + u_{3i} \quad (3)$$

$$pz_i = \beta_{41} RD\_in + \beta_{42} RD\_out + \beta_{43} other\_inv + \gamma_{4,n} X_i + u_{4i} \quad (4)$$

Where the product and process innovation indicators are represented by pd_i and pz_i, respectively. Whether a firm invests in different activities are reflected by three variables: R&D inside, R&D outside, and other investment (if a firm has any of the following investment activities: advanced machinery and equipment, computer software or hardware, tech license, training specifically for new product/service, any type of design, market research, changing in marketing methods, or product/service launch advertising)[2].

As these two dependent variables - pd_i and pz_i - are binary, we apply the bivariate probit regression. However, similar to Cowling (2016), our results indicate that these two models are unrelated (LR test P-value = 0.493) and thus can be estimated as single equations. Therefore, we estimate separately two probit regressions for product and process innovation.

We follow previous studies to control for the other factors that might influence the innovation-productivity relationship:

- Firm size – measured by the natural logarithm of total employment – is included to reflect the scale of a firm's resources.

- Skilled labour level – or the strength of firms' human resources – impact upon innovation (Leiponen 2005; Hewitt-Dundas 2006) and are measured using the proportion of a firm's employees that hold a degree or equivalent qualification. Firms

[2] We test also for the effects of innovation on productivity between innovators with or without each of these investment activities, but the difference is small and insignificant. Results are not reported here, but are available upon request.

with a highly skilled workforce may be better able to harness the performance benefits of innovation and better incorporate R&D into the innovation process.

- Firm age is another factor that might influence innovation strategy of micro-firms (Baumann and Kritikos 2016; Classen et al. 2014). Therefore, we control for it by adding the natural logarithm of firm age in our model.

- Exporting and innovative activity has been linked through both competition and learning effects (Love and Roper 2015). A binary (0/1) variable is included indicating whether or not the firm exported during the three-year period.

- Family-owned and home-based factors: The significant effect of family related issue on innovative activities of SMEs is documented in several studies (De Massis et al. 2013; Classen et al. 2014). Hence, 2 binary variables are added to reflect whether a firm is family-owned or home-based.

- Founder still runs business and leadership team's size: Innovation is often considered as high-risk activity, which might depend heavily on the managerial incentive and preference. Therefore, we control for the leadership effect by two other variables, a binary variable which reflects whether the founder still runs their business, and a ratio between leadership team and total employment.

- The extent of a firm's interactive knowledge search has been used extensively in studies of the determinants of innovation (for example, Laursen and Salter 2006; Becker et al. 2016) and is measured by a variable indicating the extent or breadth of the firm's innovation co-operation. In our survey, micro-businesses are asked specifically about co-operation which may have taken place with seven particular co-operation partners (for example, competitors or other businesses within the industry, universities or other higher education institutions and government or public research institutes). Following Laursen and Salter (2006) and Becker et al. (2016), firms' binary (0/1) responses for each of the seven co-operation partners are summed to create a count indicator having a minimum value of 0 and a maximum value of 7. This count indicator is included in the model to represent firms' breadth of innovation co-operation.

- External finance: Finally, we use another binary variable to indicate whether a firm is using external finance.

We also control for country and industry fixed effects in our models.

5. RESULTS AND DISCUSSION

Results of equation (1) and (2) are presented in Table 5. Columns 1 and 2 displays the results for the general effect of innovation on productivity and growth, while columns 3 and 4 allow for the separation of these innovating firms with and without R&D investment.

It can be seen clearly from columns 1 and 2 that innovation has positive effects on both productivity level and growth of micro-businesses, even though it is only statistically significant in column 2 where turnover growth is our dependent variable. Micro-enterprises undertaking innovation - product and/or process innovation - increases the productivity and growth level by around 2%. However, when we differentiate between innovators with or without investment in R&D activity, the findings are even more interesting (columns 3 and 4). It is clear that the effects of innovation on productivity and growth are stronger and more significant for enterprises with R&D investment. In fact, if an enterprise is undertaking innovation without engaging in R&D investment, the effect of its innovation on productivity is very small and statistically insignificant. In contrast, innovating enterprises that are also investing in R&D achieve a significantly higher level of productivity up to more than 10%. The Wald test p-value (0.027 in column 3 of Table 5, which is smaller than 5 percent level of significance) statistically confirms this difference between the effect of innovation on productivity between innovating enterprises with and without R&D investment. These results stress the importance of investing in R&D activities for micro-enterprises. Even though the difference is smaller with regards to turnover growth (column 4), it remains greater for those innovating micro-enterprises with R&D investment.

Our control variables largely take the anticipated signs. Similar to previous studies (Belderbos et al. 2004; Griffith et al. 2006; Mansury and Love 2008), we find that older enterprises have a higher level of productivity and lower level of growth, while both are higher when a firm's size is larger. With regards to family-owned issue, in line with Classen et al. (2014), we find that family micro-enterprises demonstrate a lower level of productivity than non-family ones. Similar negative results are reported for firms in which founders still run their day to day business. One notable exception of our results comes from firm's collaboration, as we find that widening the breadth of the firm's innovation co-operation only affects growth significantly, while its effect on productivity level is small and statistically insignificant. For other variables, home-based enterprises or enterprises with more skilled employees report higher level of productivity, while similar to the larger leadership team size, exporting positively influences both productivity and growth. Finally, we find that

having access to external finance does not improve either productivity or growth significantly for the micro-enterprises in our sample.

After controlling for all these factors, in line with the recent discussion of productivity crisis in Northern Ireland (Mac Flynn, 2015, 2016), our results document a significantly lower level of productivity for NI micro-enterprises, in comparison with firms in England (our reference group). As these small-sized firms are increasingly important in the development of the economy, how to improve their productivity and growth is, we believe, an essential policy priority.

Table 5: Results of productivity and growth models

	1 Productivity	2 Growth	3 Productivity	4 Growth
Innovation	0.020	0.021**		
	(0.035)	(0.008)		
Innovation (without R&D)			-0.001	0.019**
			(0.036)	(0.008)
Innovation (with R&D)			**0.104****	**0.029****
			(0.050)	**(0.014)**
Firm size (ln_size)	0.156***	0.042***	0.154***	0.042***
	(0.032)	(0.008)	(0.032)	(0.008)
Skilled labour	0.181***	0.010	0.175***	0.010
	(0.046)	(0.011)	(0.046)	(0.011)
Firm age (ln_age)	0.124***	-0.033***	0.125***	-0.033***
	(0.025)	(0.008)	(0.025)	(0.008)
Exporting	0.098***	0.029**	0.093***	0.029**
	(0.033)	(0.012)	(0.032)	(0.012)
Collaboration (=0 – 7)	0.015	0.010**	0.007	0.009**
	(0.014)	(0.004)	(0.014)	(0.004)
Family owned	-0.092***	-0.002	-0.091***	-0.001
	(0.033)	(0.010)	(0.033)	(0.010)
Home based	0.330***	0.001	0.330***	0.001
	(0.031)	(0.008)	(0.031)	(0.008)
Founder still run business	-0.127***	-0.002	-0.128***	-0.002
	(0.045)	(0.011)	(0.045)	(0.011)
Leadership team (Ratio)	0.469***	0.024***	0.469***	0.024***
	(0.039)	(0.009)	(0.039)	(0.009)
External finance	0.016	-0.007	0.015	-0.007
	(0.032)	(0.007)	(0.032)	(0.007)
Industry1_Primary	0.653***	-0.008	0.646***	-0.009
	(0.092)	(0.016)	(0.092)	(0.016)
Industry2_Manufacturing	0.547***	0.006	0.539***	0.005
	(0.061)	(0.009)	(0.062)	(0.009)
Industry3_Construction	0.895***	0.031	0.893***	0.031
	(0.062)	(0.020)	(0.062)	(0.020)
Industry4_Retail_Wholesale	0.624***	0.004	0.625***	0.004
	(0.056)	(0.009)	(0.056)	(0.009)
Industry5_Transp._Accom_Food	0.126**	-0.010	0.125**	-0.010
	(0.064)	(0.010)	(0.064)	(0.010)
Industry6_Info._Finance_RE	0.597***	0.012	0.591***	0.012
	(0.061)	(0.010)	(0.061)	(0.010)
Industry7_Prof._Scientific	0.454***	0.005	0.451***	0.005
	(0.053)	(0.010)	(0.053)	(0.010)
Industry8_Admin._Services	0.675***	0.035**	0.674***	0.035**
	(0.069)	(0.016)	(0.068)	(0.016)
Scotland	-0.126**	-0.010	-0.124**	-0.010
	(0.061)	(0.010)	(0.061)	(0.010)
Wales	-0.159**	-0.004	-0.157**	-0.004
	(0.064)	(0.010)	(0.064)	(0.010)
Northern Ireland	-0.164**	0.013	-0.163**	0.014
	(0.065)	(0.011)	(0.065)	(0.011)
Ireland	-0.061	0.011	-0.057	0.011
	(0.045)	(0.008)	(0.045)	(0.008)
USA	-0.771***	-0.004	-0.764***	-0.004
	(0.042)	(0.009)	(0.042)	(0.009)
Constant	9.796***	0.033	9.801***	0.034
	(0.119)	(0.032)	(0.119)	(0.032)
Obs.	7738	8506	7738	8506
R-squared	0.186	0.0266	0.187	0.0267
Wald test P-value			0.027	0.425

Note: standard errors are in parentheses. ***, **, and * indicate the level of significance at 1%, 5%, and 10% respectively.

In order to test for different sources of heterogeneity at industry-level, we estimate our productivity model on different sub-samples of (i) high-tech or knowledge-intensive versus low-tech sectors, and (ii) manufacturing versus service sectors, following the 2007 Standard Industry Classification. Results are displayed in Table 6[3].

Table 6: Relationship between Productivity and Innovation activity by sector

	(1) High-tech	(2) Low-tech	(3) Manufacturing	(4) Service
Innov (without R&D)	-0.068	0.010	0.014	-0.035
	(0.057)	(0.046)	(0.101)	(0.039)
Innov (with R&D)	-0.024	**0.202*** **	**0.259** **	0.075
	(0.072)	**(0.069)**	**(0.119)**	(0.058)
Firm size (ln_size)	0.080	0.197***	0.189*	0.140***
	(0.051)	(0.041)	(0.098)	(0.036)
Skilled labour	0.189***	0.161**	-0.312*	0.193***
	(0.058)	(0.065)	(0.160)	(0.044)
Firm age (ln_age)	0.071*	0.188***	0.205***	0.139***
	(0.041)	(0.031)	(0.070)	(0.026)
Exporting	0.124**	0.035	-0.092	0.148***
	(0.049)	(0.042)	(0.090)	(0.036)
Collaboration (=0 – 7)	0.002	0.024	0.029	0.025
	(0.020)	(0.021)	(0.056)	(0.016)
Family owned	-0.100**	-0.048	-0.221**	-0.058
	(0.049)	(0.046)	(0.091)	(0.037)
Home based	0.385***	0.284***	0.231***	0.368***
	(0.051)	(0.039)	(0.086)	(0.035)
Founder still run business	-0.088	-0.063	-0.013	-0.099*
	(0.087)	(0.054)	(0.113)	(0.051)
Leadership team (Ratio)	0.449***	0.505***	0.484***	0.449***
	(0.065)	(0.049)	(0.149)	(0.044)
External finance	-0.035	0.035	0.018	-0.060*
	(0.049)	(0.041)	(0.082)	(0.035)
Scotland	-0.062	-0.181**	-0.029	-0.119*
	(0.092)	(0.076)	(0.158)	(0.068)
Wales	-0.066	-0.226***	-0.017	-0.163**
	(0.092)	(0.081)	(0.154)	(0.075)
Northern Ireland	-0.076	-0.190**	-0.050	-0.129
	(0.091)	(0.079)	(0.184)	(0.079)
Ireland	-0.075	-0.152**	0.109	-0.121**
	(0.071)	(0.059)	(0.114)	(0.052)
USA	-0.742***	-0.803***	-0.530***	-0.736***
	(0.062)	(0.056)	(0.131)	(0.045)
Constant	10.478***	10.038***	10.175***	10.158***
	(0.198)	(0.142)	(0.310)	(0.123)
Obs.	2562	5176	793	5760
R-squared	0.147	0.146	0.112	0.136
Wald test P-value	0.515	0.004	0.037	0.040

Note: standard errors are in parentheses. ***, **, and * indicate the level of significance at 1%, 5%, and 10% respectively.

[3] Results of our growth model for these sub-samples are presented in Table A3 in the Appendix. Overall, all results are consistent with that of productivity model, except that the higher effect of innovation on growth for innovating firms with R&D investment than without R&D investment is less significant than in the case of productivity.

Overall, the results in Table 6 confirm that the effect of innovation on productivity is always higher and more significant when an innovating firm reports that it has R&D investment. The only case where this innovation-productivity relationship is negative is in column 1 for high-tech or knowledge-intensive sectors. It might be attributable to the fact that in these sectors, often a small number of large enterprises dominate the innovative process. Therefore, innovation might not have much influence on the productivity level for these micro-enterprises.

With regards to low-tech or manufacturing sectors, again, our results confirm the importance of having R&D investment, either inside or outside the enterprise, on the innovation-productivity relationship. Innovative micro-enterprises with R&D investment have significantly higher productivity levels than those without R&D investment. For low tech and manufacturing micro-enterprises, undertaking innovation in the absence of R&D investment has a relatively small and statistically insignificant effect on productivity.

For micro-enterprises in the service sector, even though the effect of innovation on productivity is insignificant, the Wald test's result also confirms that the effect of innovation on productivity, is statistically higher for innovative firms with R&D investment than for those innovative firms without R&D.

Given this general finding that undertaking R&D enhances the effect of innovation on productivity we explore this relationship further in relation to the association between R&D investment activities and the two main innovation outcome measures: product/service innovation and process innovation. Results are presented in Table 7.

Table 7: R&D investments and Innovation outcomes

	(1) Product innovation	(2) Process innovation
R&D and other investments		
R&D inside	**0.077*** **	**0.122*** **
	(0.027)	**(0.030)**
R&D outside	0.013	**0.124*** **
	(0.027)	**(0.032)**
Other investment	-0.019	**0.138*** **
	(0.024)	**(0.027)**
Control variables		
Firm size (ln_size)	-0.044***	0.098***
	(0.015)	(0.018)
Skilled labour	0.038*	0.014
	(0.021)	(0.025)
Firm age (ln_age)	-0.014	-0.030**
	(0.012)	(0.014)
Exporting	0.027*	-0.046**
	(0.016)	(0.018)
Collaboration (=0 – 7)	0.011**	0.033***
	(0.006)	(0.006)
Family owned	0.015	-0.010
	(0.016)	(0.019)
Home based	-0.015	0.049***
	(0.015)	(0.018)
Founder still run business	0.071***	-0.074***
	(0.022)	(0.027)
Leadership team (Ratio)	-0.056***	0.077***
	(0.019)	(0.024)
External finance	0.010	0.021
	(0.015)	(0.018)
Industry1_Primary	-0.145***	0.061
	(0.048)	(0.057)
Industry2_Manufacturing	-0.043	0.017
	(0.033)	(0.037)
Industry3_Construction	-0.143***	0.054
	(0.034)	(0.041)
Industry4_Retail_Wholesale	-0.017	-0.030
	(0.029)	(0.033)
Industry5_Transport_Accom_Food	-0.073**	0.037
	(0.035)	(0.039)
Industry6_Information_Finance_RE	-0.173***	0.135***
	(0.030)	(0.035)
Industry7_Professional_Scientific	-0.175***	0.068**
	(0.029)	(0.035)
Industry8_Administrative_Services	-0.133***	0.072*
	(0.034)	(0.039)
Scotland	0.004	-0.069*
	(0.032)	(0.038)
Wales	0.008	-0.026
	(0.035)	(0.040)
Northern Ireland	0.076**	-0.112**
	(0.037)	(0.043)
Ireland	0.030	-0.022
	(0.022)	(0.026)
USA	0.100***	-0.064***
	(0.021)	(0.023)
Obs.	4333	4324
Chi-squared	168.4	216.7
Pseudo R^2	0.0502	0.0507

Note: Marginal effects are reported. Standard errors are in parentheses. ***, **, and * indicate the level of significance at 1%, 5%, and 10% respectively.

Table 7 provides explanation to the extent of why undertaking R&D investment either inside or outside, significantly affects the innovation-productivity relationship. The most important investment activity is confirmed to be R&D inside the enterprise, as it has positive and highly significant effects on the probability of reporting product and also process innovation. The alternative investment options for micro-enterprises, such as hiring other(s) to do R&D activity for them (outside the enterprise), or performing other investments such as training, design, improving marketing methods etc. all seem to only induce more process innovation.

With regards to our control variables, results in Table 7 confirm the importance of controlling for these factors in our innovation model. It shows that larger enterprises tend to focus more on process innovation, while the older a firm is, the less likely it is to report any innovation outcome. Notably, our results indicate that exporting only increases the probability of micro-enterprises reporting product innovation. This may be attributable to the fact that they might have to focus their investment on tailoring their products to make them suitable to export markets. In addition, similar to previous studies (Hewitt-Dundas 2006; Nieto and Santamaría 2010), we find that having collaboration induces enterprises to report more innovation outcomes, both in product or process innovation.

Family-ownership has no significant effect on the likelihood of micro-enterprises reporting innovation outcomes (either product/service or process). What is interesting however, is where the founder is still involved in running the enterprise. Here we find that where the founder is still involved, then the probability of product/service innovation is significantly higher, while the probability of undertaking process innovation is significantly lower.

Extending this analysis on the governance structure to include the leadership team, we find that a larger leadership team (relative to total employees) significantly reduces the probability of undertaking product/service innovation while increasing the probability of process innovation. Further, having a micro-enterprise located at an individual's (most likely the founder's) home reduces the probability of undertaking product innovation (albeit insignificantly) while increasing the probability of undertaking process innovation.

Surprisingly, we find that a micro-enterprise accessing external finance has no significant effect on the probability of undertaking either product/service or process innovation. A lack of finance is one of the main problems suggested in the literature for micro-enterprises or even SMEs not engaging in R&D and other investment activities. Yet, here, our results

show that micro-enterprises accessing external finance do not have a higher probability of reporting either product or process innovation.

With regards to NI firms, results from Table 7 suggest significantly lower probability of undertaking process innovation, even though their probability of reporting product innovation is higher than that of micro-enterprises in England (our reference group). A similar tendency to focus more on product innovation for NI SMEs can be found back in Cooke et al. (2003) and may suggest that greater policy may benefit from focusing more on process innovation activities of micro-enterprises.

6. CONCLUSIONS AND RECOMMENDATIONS

In this study we analyse the question of whether having R&D investment strengthens the innovation-productivity relationship for micro-enterprises. Utilizing a rich dataset of nearly 10,000 micro-enterprises from 3 countries: the UK, Ireland and the US, we report several findings.

Conscious of the fact that small and micro-enterprises are known to have resource and capability constraints (Hewitt-Dundas 2006) that restrict their engagement in R&D activities, our findings emphasise how important R&D investment is, in strengthening the innovation-productivity/growth relationship. When comparing the effects of innovation on productivity and growth between innovating firms with and without R&D investment, either inside or outside the firm, our results demonstrate clearly that the positive effects of innovation are stronger and more significant, when an innovating firm reports that they are also investing in R&D.

> ***Recommendation 1:*** Productivity and growth are both greater, where micro-enterprises undertake innovation. The effect of innovation remains small in the absence of R&D but is substantial where R&D is present. This suggests that policy efforts may be warranted in encouraging micro-enterprises to undertake innovation and that investing in R&D should be integral to this innovation. This will result in significantly higher productivity and turnover growth performance.

However, replicating the productivity estimation on different sub-samples shows that this result is varied by sectors. More specifically, micro-enterprises in low-tech or manufacturing sectors report the strongest effects of innovation on productivity if they engage in R&D investment, while for high-tech sectors this effect is negative, albeit statistically insignificant. For service sectors there is also a significantly higher effect of innovation on productivity for firms with R&D investment, however, the effect is not as strong as it is for low-tech or manufacturing enterprises.

> ***Recommendation 2:*** Promoting innovation and specifically, innovation with R&D, will have a greater effect on productivity performance for micro-enterprises in low-tech and manufacturing sectors.

We also show that it is important to disaggregate R&D investments and innovation activity as the relationships vary. For example, R&D activity undertaken inside an enterprise is confirmed to be the most important investment activity, as it is positively and significantly associated with a greater probability of both product/service and process innovation. However, it is not the only type of investment that can increase the probability of firms reporting innovation outcomes. Micro-enterprises can choose also to acquire R&D from outside the firm, or other investments such as design or investing in computer software or hardware, marketing methods etc. with both of these approaches having a positive effect on the probability of undertaking process innovation.

> ***Recommendation 3:*** While it could be argued that due to resource constraints (human, financial, managerial etc.), micro-enterprises should try to acquire R&D from outside their own firm, in reality, introducing product innovations is heavily dependent on the enterprise conducting R&D internally. For process innovation this is less important, with R&D conducted internally and externally both important. Policy efforts to stimulate R&D and innovation activity in micro-enterprises should therefore account for whether the desired outcome is product or process innovation and ensure that this is supported by appropriate R&D efforts.

Although it is frequently argued that a lack of available and accessible finance prevents the growth and productivity of micro-enterprises, this is not supported in the analysis.

> ***Recommendation 4:*** Policy efforts directed towards building capability (specifically R&D capability) are likely to be more impactful on growth and productivity than efforts to increase access to finance.

To conclude, our data confirms that not only are NI micro-enterprises significantly less likely to be undertaking process innovation, but they also report lower productivity levels compared to other micro-enterprises in Ireland and the rest of the UK. At the same time, where micro-enterprises are encouraged to undertake R&D activity this not only significantly increases the probability of conducting innovation, but in turn, also significantly enhances growth and productivity performance. This suggests that policy efforts to promote R&D and innovation in micro-enterprises, that account for almost 20 per cent of the workforce and sales in NI, is likely to lead to significant economic benefits.

Limitations:

While our study provides some new insights into micro-enterprise innovation, it has two main limitations. First, it is based on a cross-sectional survey without real investment data or the investment information for non-innovators, which prevent us from applying the traditional Crépon, Duguet and Mairesse (CDM)[4] model to study the endogenous effect of R&D and other investment activities on innovation and productivity. Second, the nature of our cross-sectional data prevents us from establishing the causal effect of innovation on productivity. Future work will no doubt benefit from richer data which tracks investment activities through time.

[4] The CDM model has been used extensively in empirical analyses of innovation and productivity. The CDM model is a structural model that explains productivity by innovation output, and innovation output by research investment. An advantage of the CDM model is its method of correcting for selectivity and endogeneity inherent in the model. An excellent critique and review of the CDM methodology is available in Economics of Innovation and Technology, 2017, Vol. 26, Issue 1-2: CDM 20 Years After. https://doi.org/10.1080/10438599.2016.1202522

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APPENDIX

Table A1: Variable definitions

Name	Description
Productivity and growth measures	
Productivity	Current turnover (sales) per employee
Growth	Percentage of growth of turnover (sales)
Innovation measures	
Innovation	Firms report at least one of the two: product and process innovation
Innov_w_RD	Firms report at least 1 of the two: product and process innovation, and also an engagement in R&D investment, either inside or outside
Innov_wt_RD	Firms report at least 1 of the two: product and process innovation, but do not have any engagement in R&D investment, either inside or outside
Product innovation	Whether there is any new or significantly improved products or services
Process innovation	Whether there is any new or significantly improved forms of organisation, business structures or processes
R&D and other investment activities	
R&D inside	R&D within your firm
R&D outside	R&D undertaken by someone else
Other investment	Firms with at least 1 investment activity except from R&D
Control Variables	
Size	Natural log of current total employment
Skilled labour	Number of employees having a degree / Total number of employees
Age	Natural log of firm age (till 2019)
Exporting	Dummy: = 1 if a firm has international sales
Collaboration	Number of collaborations a firm has (0-7)
Family owned business	Dummy: = 1 if a firm is owned by a family
Home-based business	Dummy: = 1 if a firm is located at home
Founders still run business	Dummy: = 1 if founders still run business
Leadership team ratio	Leadership team / Total number of employees
External finance	Dummy: = 1 if a firm uses external finance

Table A2: Manufacturing and service sectors

Type	Category
Manufacturing	C - Manufacturing
Services	G – Retail, wholesale
	HI – Transport, accommodation, food
	JKL – Information, finance, real estate
	M – Professional, scientific
	N – Administrative services
	PQRS – Other services

Table A3: Results with growth model for sub-samples

	(1) High-tech	(2) Low-tech	(3) Manufacturing	(4) Service
Innov (without R&D)	0.036***	0.015	0.004	0.024
	(0.012)	(0.010)	(0.015)	(0.018)
Innov (with R&D)	0.050**	0.019	0.027	0.064**
	(0.025)	(0.015)	(0.019)	(0.028)
Firm size (ln_size)	0.023	0.049***	0.033**	0.030***
	(0.014)	(0.010)	(0.016)	(0.007)
Skilled labour	0.002	0.016	0.009	0.011
	(0.014)	(0.017)	(0.022)	(0.011)
Firm age (ln_age)	-0.026***	-0.036***	-0.058***	-0.024***
	(0.008)	(0.009)	(0.012)	(0.005)
Exporting	0.021**	0.028**	0.017	0.024***
	(0.011)	(0.014)	(0.013)	(0.009)
Collaboration (=0 – 7)	0.009*	0.008	0.023**	0.012***
	(0.005)	(0.006)	(0.010)	(0.004)
Family owned	-0.002	-0.002	0.010	0.002
	(0.013)	(0.013)	(0.015)	(0.007)
Home based	0.011	-0.003	0.007	0.006
	(0.012)	(0.011)	(0.012)	(0.008)
Founder still run business	-0.005	0.003	-0.005	-0.001
	(0.015)	(0.013)	(0.015)	(0.014)
Leadership team (Ratio)	-0.002	0.034***	0.003	0.015
	(0.017)	(0.011)	(0.031)	(0.010)
External finance	-0.002	-0.012	0.001	-0.004
	(0.011)	(0.009)	(0.014)	(0.007)
Scotland	-0.002	-0.017	0.028	-0.023**
	(0.021)	(0.012)	(0.027)	(0.012)
Wales	0.032	-0.018	0.008	-0.005
	(0.020)	(0.012)	(0.023)	(0.011)
Northern Ireland	0.050	0.001	0.014	0.007
	(0.033)	(0.011)	(0.033)	(0.013)
Ireland	0.032***	-0.002	0.059***	0.012
	(0.012)	(0.011)	(0.015)	(0.007)
USA	0.008	-0.017	0.024	0.003
	(0.012)	(0.013)	(0.021)	(0.008)
Constant	0.046	0.044	0.117**	0.025
	(0.040)	(0.041)	(0.059)	(0.026)
Obs.	2828	5678	829	6417
R-squared	0.0339	0.0232	0.114	0.0246
Wald test P-value	0.553	0.716	0.256	0.180

Note: standard errors are in parentheses. ***, **, and * indicate the level of significance at 1%, 5%, and 10% respectively.

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