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Exploring the links between design investment, innovation and productivity

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Stephen Roper
Enterprise Research Centre and Warwick Business School
stephen.roper@wbs.ac.uk

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About ERC
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KEY FINDINGS

Here, we use data from the UK Innovation Survey to undertake a causal analysis of the links between design, innovation of different types and productivity. Our analysis draws on data from around 15,000 UK companies which responded to two consecutive waves of the UK Innovation Survey.

The starting point for our analysis is the UK Innovation Survey indicator of whether or not each firm 'engages in … design activities, including strategic, for the development or implementation of new or improved goods, services and processes'. Are firms which are engaging with design more likely to be innovating? The second stage of our analysis explores the extent to which each of the three types of innovation results in improvements in firms' productivity.

We adopt a value chain perspective suggesting that design may influence innovation in the short-term but that any productivity benefits may take some time to emerge. We consider the extent to which firms' engagement with design drives (a) product/service innovation; (b) process innovation; and, (c) organisational innovation. Organisational innovation is broadly defined and covers changes to firms' strategy, work organisation and marketing activities.

We find a consistently positive and significant causal effect of design engagement on the probability of product/service and process innovation. This effect is largest among manufacturing firms and where firms are also undertaking in-house R&D.

Process and organisational innovation have positive and significant causal effects on productivity. Indeed, organisational innovation has a positive and significant effect for all firms, SMEs, R&D performers and non-performers and non-manufacturing firms. Similarly, process innovation has a positive effect for all firm, non-R&D performers and non-manufacturing firms. Product/service innovation has a consistently negative effect where it is significant, perhaps suggesting a disruption effect when new innovative products are first introduced.

In summary, design engagement increases the probability that firms will undertake both product/service and process innovation. This effect is consistent across most groups of firms but is slightly larger in manufacturing firms and where firms are

undertaking in-house R&D. As process innovation is positively related to subsequent productivity, the effect of design engagement on process change leads to productivity increases. The design effect through product/service innovation is offsetting as product/service innovation is linked negatively to productivity, at least in the short-term.

CONTENTS

1. INTRODUCTION

The case studies and design survey undertaken for the "Design Economy 2018" have suggested the different mechanisms through which design and designers can contribute to firms' innovation and performance. Here, we use data from the UK Innovation Survey to undertake a causal analysis of the links between design, innovation of different types and productivity. Our analysis draws on data from around 15,000 UK companies which responded to two consecutive waves of the UK Innovation Survey.

The starting point for our analysis is the UK Innovation Survey indicator of whether or not each firm 'engages in … design activities, including strategic, for the development or implementation of new or improved goods, services and processes'. Are firms which are engaging with design more likely to be innovating? More specifically, we explore whether firms which are engaging with design are more likely to be engaging in product or service innovation, process innovation and organisational innovation. The second stage of our analysis explores the extent to which each of the three types of innovation results in improvements in firms' productivity.

The UK Innovation Survey has a number of advantages for this type of causal analysis. First, it is a large-scale survey and this means both national estimates and sub-sample estimates can be made. Here, we focus on firms of different sizes, whether or not firms are R&D performers and the contrast between manufacturing and services firms. Second, the survey provides details of both design investment, innovation and a productivity indicator (sales per employee) for consistent reporting units. Third, the survey provides a number of variables which can be used as control factors to help identify more precisely the design effect.

The survey is not without its disadvantages, however. Central to this is the focus in the survey on technological innovation. To count as product or service innovation in the UK Innovation Survey a product/service must be 'new or significantly improved [and] Excludes … changes of a solely aesthetic nature'. One aspect of design clearly addresses exactly this aesthetic element of product/service change and this will not be captured in our analysis and means our analysis may under-estimate the contribution of design to innovation and productivity. Second, the UK Innovation Survey provides little information on how design or designers are engaged with any change process.

Again, this limits our analysis and in particular the nature of any lessons which we might draw for the implementation of design as part of firms' innovation activity.

Our evidence points to a strong and consistently positive relationship between design investment and innovation. The relationship between innovation and productivity seems more complex with some evidence of both positive (process and organisational) effects and some evidence of negative (product/service) effects. Overall, design engagement increases the probability of innovating by around a third or around 8 pp.

The remainder of this section is organised as follows:

- Section 2 describes our conceptual approach linking design, innovation and productivity.
- Section 3 deals with the link between design and innovation controlling for a range of other firm-level factors.
- Section 4 focuses on the relationship between innovation and design and productivity as measured by turnover per employee.
- Section 5 summarises the key findings and considers the implications for policy and practice.

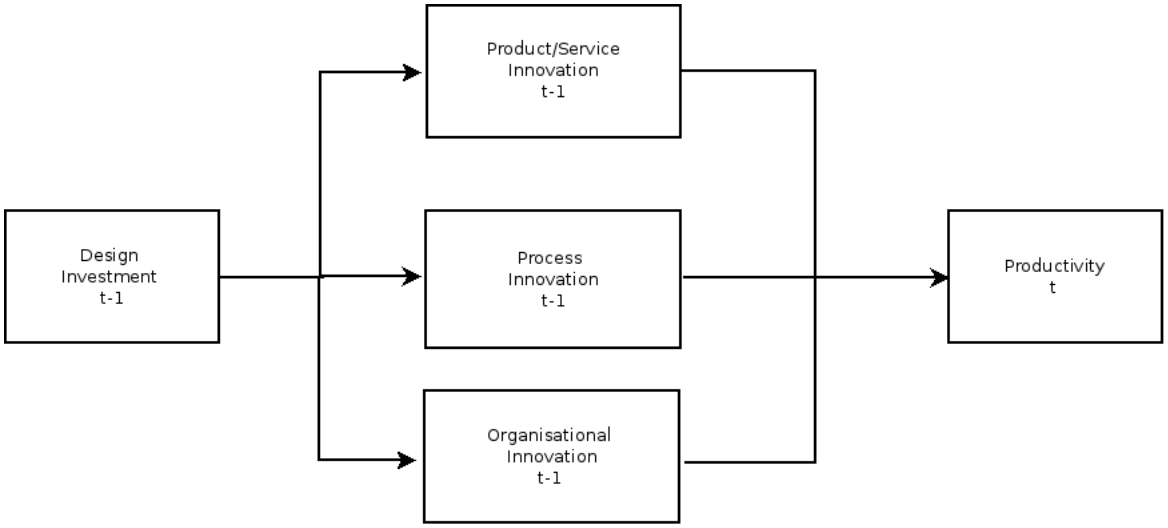
An annex provides details of the more technical aspects of our analysis including estimation methods.

2. CONCEPTUAL OVERVIEW

We adopt a value chain perspective suggesting that design may influence innovation in the short-term but that any productivity benefits may take some time to emerge[1]. Figure 1 depicts the causal links we consider reflecting the extent to which firms' engagement with design drives (a) product/service innovation; (b) process innovation; and, (c) organisational innovation. Organisational innovation is broadly defined and covers changes to firms' strategy, work organisation and marketing activities.

[1] Roper, S., Du, J., & Love, J. H. (2008). Modelling the Innovation Value Chain. *Research Policy, 37*(6-7), 961-977.

Figure 1: Causal links – from design investment to productivity



We then consider how each type of innovation is related to productivity in the subsequent survey period. Because of the structure of the UK Innovation Survey this means there is a two-year lag between the dates at which design engagement and innovation and productivity are measured[2]. In considering the relationship between design and innovation and innovation and productivity we allow for a range of other factors which may influence firm performance. These are:

- Firm size – measured by employment. The argument here is that larger firms may have stronger internal design and innovation resources which may drive productivity.
- Skills – firms with a more highly skilled workforce may be better able to harness the productivity benefits of innovation and better incorporate design resources into the innovation process.
- R&D – has benefits both in terms of knowledge creation (discovery) and absorptive capacity, and may help firms to translate innovation into productivity benefits.
- Exporting – may facilitate learning-by-exporting processes enhancing both innovation and productivity.

[2] Note that this is due to the innovation survey being conducted every two years. The survey itself relates to design engagement and innovation activity for the three years prior to the survey date.

- Innovation partnering – or open innovation has been shown to be an important element of firms' innovation strategy and may complement knowledge generated from R&D or elements of design.
- Knowledge investments- related to market information or technical know-how may also drive innovation and performance.

Table 1: Sample descriptives: Pooled data from UK Innovation Surveys 4 -9

Label	Variable definition	Obs.	Mean	Std. Dev.
Productivity	Turnover per employee at the end of the survey period	59,837	123.469	134.802
Product/service innovator	Proportion of firms introducing either new or improved product or service	78,237	0.242	0.428
Process innovator	Proportion of firms introducing new or improved processes	64,024	0.150	0.357
Organisational innovator	Proportion of firms introducing innovations in strategy, marketing or work organisation	78,242	0.369	0.482
Design engaged	Proportion of firms investing in design	69,708	0.174	0.380
Employment (log)	Employment at the end of the survey period	67,483	3.778	1.790
Science Graduates	Proportion of the workforce which are science or engineering graduates	56,801	7.019	16.740
Other Graduates	Proportion of the workforce which are other graduates	58,977	9.971	19.462
Exporting firm	Proportion of firms which are exporting	77,935	0.311	0.463
Innovation partners	Number of types of innovation partners (zero for non-innovating firms)	78,237	0.641	1.503
In-house R&D	Proportion of firms undertaking in-house R&D	77,933	0.247	0.432
External R&D	Proportion of firms undertaking external R&D	77,929	0.089	0.285
Training	Proportion of firms investing in training related to innovation	76,303	0.247	0.431
External knowledge acquisition	Proportion of firms investing in external knowledge acquisition related to innovation	77,928	0.087	0.282
Market intelligence acquisition	Proportion of firms investing in acquiring market intelligence related to innovation	77,928	0.264	0.441
Machinery acquisition	Proportion of firms investing in machinery acquisition related to innovation	77,935	0.404	0.491

Notes: Data is pooled from waves 4-9 of the UK Innovation Survey. Observations are weighted to give representative results. Observation numbers differ due to non-response to specific survey questions. For Productivity outliers with turnover per employee greater than £1m pa (c. 2 per cent of all observations) are excluded.

Table 1 provides summary statistics and variable definitions for each of the variables used in our analysis. In all estimation we also control for the survey wave and the sector in which the firm is operating.

3. FROM DESIGN ENGAGEMENT TO INNOVATION

We consider here how design engagement changes the probability that firms will be a product or service innovator, a process innovator and/or an organisational innovator. Table 2 reports estimates for all firms across waves 4 to 9 of the UK Innovation Survey. The coefficients in the table are marginal values, meaning that on average firms engaged in design are 8.1 per cent more likely to be a product/service innovator than those with no design engagement (Table 2). There is a smaller process innovation effect from design engagement (+3.5 per cent) and no significant link between design engagement and the probability that a firm engages in organisational innovation (Table 2).

Table 2: Modelling the effects of design engagement on the probability of innovation: all firms

	Product/service innovator	Process innovator	Organisational innovator
	b/se	b/se	b/se
Design engaged	0.081***	0.035***	-0.003
	(0.011)	(0.006)	(0.012)
Employment (log)	0.001	0.006***	0.041***
	(0.002)	(0.001)	(0.003)
Science Graduates	0.001***	0	0.001***
	(0.000)	(0.000)	(0.000)
Other Graduates	0	0	0.002***
	(0.000)	(0.000)	(0.000)
Exporting firm	0.051***	0.006	0
	(0.008)	(0.005)	(0.009)
Innovation partners	0.134***	0.073***	0.115***
	(0.007)	(0.004)	(0.009)
Innovation partners - squared	-0.015***	-0.008***	-0.012***
	(0.001)	(0.001)	(0.001)
In-house R&D	0.184***	0.062***	0.080***
	(0.015)	(0.006)	(0.014)
External R&D	-0.007	-0.007	-0.001
	(0.011)	(0.006)	(0.015)
Training	0.073***	0.058***	0.099***
	(0.013)	(0.006)	(0.012)
External knowledge acquisition	0.024**	0.014**	0.034**
	(0.011)	(0.006)	(0.014)
Market intelligence acquisition	0.191***	0.039***	0.282***
	(0.010)	(0.005)	(0.010)
Machinery acquisition	0.066***	0.088***	0.246***
	(0.009)	(0.005)	(0.009)
Number of observations	51586	44466	51586
chi^2	7203.15	4945.119	6366.339
Rho	0	0	0
Pseudo R^2	0.332	0.27	0.283
BIC	41006.626	28686.541	50954.794

Notes: Data is pooled from waves 4-9 of the UK Innovation Survey. Observations are weighted to give representative results.

A range of other factors also prove important in shaping the probability that a firm is engaged in innovation: partnering, R&D, and investment in external knowledge acquisition, training and machinery all have consistently positive and strong effects. Interestingly, the effect of design engagement on the probability of innovating is around

half that of engaging with internal R&D (Table 2).

It is possible to also consider how design engagement influences innovation for various sub-groups of firms within the UK Innovation Survey. Detailed results are included in Annex 2 and Table 3 provides a summary of the key results

Table 3: Design impacts on the probability of innovation: sample sub-groups

Sample	Product/service innovator	Process innovator	Organisational innovator
All firms	0.081***	0.035***	-0.003
SMEs	0.081***	0.034***	0.011
Larger firms	0.041	0.079***	0.023
R&D performers	0.099***	0.079***	0.018
R&D non-performers	0.066***	0.021***	0.025
Manufacturing	0.117***	0.034***	-0.003
Non-manufacturing	0.070***	0.036***	0.006

Notes: Models are reported in full in Annex 2. Marginal effects in the table represent the impact of design engagement on the probability of innovation.

For SMEs we find very similar results to the aggregate picture: design engagement has a positive and significant increase on the probability of product/service and process innovation (Table 3). For larger firms the benefits of design engagement operate more specifically through process innovation, with no significant effect on the probability of product/service or organisational innovation. For both R&D and non-R&D performing firms design engagement also has a significant and positive effect on product/service innovation and process innovation. In each case, however, the effect is stronger for R&D performing firms, suggesting some complementarity between design investment and that in R&D. A rather similar picture emerges when we distinguish between manufacturing and non-manufacturing firms. Design engagement again has positive and significant effects on product/service innovation and process innovation, with the product/service innovation effect strongest for manufacturing firms (Table 3).

In summary, we find a consistently positive and significant effect of design engagement on the probability of product/service and process innovation. This effect is largest among manufacturing firms and where firms are also undertaking in-house R&D.

4. FROM INNOVATION TO PRODUCTIVITY

As Figure 1 suggests, design engagement is linked to productivity through innovation. Modelling this whole process is relatively complex involving two stages: the link between design and innovation and then the link between innovation and productivity. Here, we use a lag of both design engagement and innovation to ensure a causal forward link to productivity. Table 4 reports the full models, with:

- Part A of the table is the model of (log) productivity which includes the instrumented (and lagged) product/service innovation, process innovation and organisational innovation terms;
- Parts B, C and D of Table 4 relate to the determinants of the three different types of innovation and in particular include design engagement along with a set of other controls.

Table 4: Modelling the link between Design engaged, innovation and productivity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	All firms	SMEs	Larger firms	R&D Performers	Non-R&D Performers	Manufact-uring	Non-manuf-acturing
A. Productivity (log) model							
Productivity (log, lag)	0.585***	0.544***	0.419***	0.592***	0.575***	0.646***	0.573***
	(0.025)	(0.027)	(0.042)	(0.041)	(0.030)	(0.035)	(0.028)
Employment (log)	-0.091***	-0.077***	-0.072***	-0.03	-0.118***	0.024**	-0.116***
	(0.033)	(0.014)	(0.021)	(0.019)	(0.040)	(0.011)	(0.037)
Science Graduates	0.001*	0.001	0.004***	0	0.002	0.002***	0.001
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Other Graduates	0.002***	0.001**	0.006***	0.001	0.002***	0.001	0.002***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Exporting firm	0.162***	0.156***	0.326***	0.080***	0.191***	0.079***	0.174***
	(0.020)	(0.022)	(0.044)	(0.030)	(0.025)	(0.018)	(0.026)
Product/service innovator (lag)	-0.388***	0.141	0.003	-0.277*	-0.408**	0.03	-0.452***
	(0.139)	(0.198)	(0.101)	(0.143)	(0.163)	(0.054)	(0.165)
Process innovator (lag)	0.191***	-0.316	0.193	-0.155	0.261***	0.008	0.203***
	(0.065)	(0.249)	(0.123)	(0.178)	(0.062)	(0.077)	(0.078)
Organisational innovator (lag)	0.418**	0.181*	0.04	0.492***	0.382**	0.044	0.453**
	(0.193)	(0.094)	(0.100)	(0.149)	(0.189)	(0.057)	(0.201)
B. Product/service innovator (-1)							
Design engaged (lag)	0.228***	0.237***	0.315***	0.239***	0.220***	0.261***	0.219***
	(0.054)	(0.061)	(0.110)	(0.067)	(0.079)	(0.071)	(0.069)
Employment (log, lag)	-0.063**	0.026	-0.054**	-0.091***	-0.048	-0.021	-0.069**
	(0.025)	(0.030)	(0.025)	(0.026)	(0.031)	(0.025)	(0.028)
Science Graduates (lag)	0.002	0.002	0.008**	0.003*	0	0.003	0.002
	(0.001)	(0.002)	(0.004)	(0.002)	(0.002)	(0.003)	(0.001)
Other Graduates (lag)	0	0	0	-0.001	0	-0.001	0
	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.001)
Exporting firm (lag)	0.180***	0.213***	0.049	0.126*	0.173***	0.230***	0.166***
	(0.043)	(0.052)	(0.094)	(0.072)	(0.054)	(0.066)	(0.055)
Innovation partners (lag)	0.543***	0.492***	0.515***	0.376***	0.631***	0.481***	0.577***
	(0.042)	(0.043)	(0.068)	(0.057)	(0.054)	(0.055)	(0.052)
Innovation partners squared (lag)	-0.072***	-0.065***	-0.064***	-0.050***	-0.082***	-0.060***	-0.078***
	(0.007)	(0.007)	(0.010)	(0.009)	(0.009)	(0.009)	(0.008)
In-house R&D (lag)	0.517***	0.497***	0.427***	0.543***	0.410***	0.642***	0.462***
	(0.052)	(0.055)	(0.105)	(0.075)	(0.071)	(0.067)	(0.066)
External R&D (lag)	-0.021	-0.057	0.14	0.041	-0.024	-0.017	-0.028
	(0.064)	(0.074)	(0.092)	(0.080)	(0.104)	(0.083)	(0.085)
Training (lag)	0.262***	0.323***	0.097	0.272***	0.249***	0.202***	0.289***
	(0.046)	(0.052)	(0.110)	(0.068)	(0.061)	(0.068)	(0.057)
External knowledge acquisition (lag)	0.120**	0.115*	0.052	0.157*	0.092	0.149*	0.131*
	(0.057)	(0.067)	(0.087)	(0.082)	(0.082)	(0.086)	(0.073)
Market intelligence acquisition (lag)	0.652***	0.657***	0.560***	0.614***	0.635***	0.699***	0.647***
	(0.046)	(0.055)	(0.095)	(0.071)	(0.060)	(0.069)	(0.056)
Machinery acquisition (lag)	0.278***	0.227***	0.368***	0.058	0.347***	0.253***	0.269***
	(0.046)	(0.051)	(0.096)	(0.072)	(0.056)	(0.063)	(0.056)
C. Process innovator (lag)							
Design engaged (lag)	0.097*	0.142**	0.249***	0.068	0.132*	0.095	0.115
	(0.055)	(0.057)	(0.096)	(0.073)	(0.079)	(0.070)	(0.074)
Employment (log, lag)	0.067***	-0.006	-0.037	0.005	0.085***	0.073***	0.057***
	(0.018)	(0.041)	(0.038)	(0.030)	(0.023)	(0.024)	(0.021)
Science Graduates (lag)	0.001	0.001	0	0	0.004*	-0.001	0.002
	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
Other Graduates (lag)	0	0.001	0.001	-0.002	0.001	-0.001	0

	(0.001)	(0.002)	(0.002)	(0.002)	(0.001)	(0.002)	(0.001)
Exporting firm (lag)	0.068	0.095*	-0.255***	-0.018	0.103	0.021	0.102
	(0.049)	(0.056)	(0.087)	(0.077)	(0.064)	(0.066)	(0.066)
Innovation partners (lag)	0.430***	0.364***	0.528***	0.290***	0.542***	0.397***	0.450***
	(0.036)	(0.043)	(0.063)	(0.051)	(0.050)	(0.049)	(0.047)
Innovation partners squared (lag)	-0.050***	-0.042***	-0.064***	-0.026***	-0.069***	-0.041***	-0.054***
	(0.006)	(0.007)	(0.010)	(0.008)	(0.009)	(0.008)	(0.008)
In-house R&D (lag)	0.334***	0.382***	0.306***	0.213**	0.313***	0.231***	0.377***
	(0.052)	(0.056)	(0.099)	(0.084)	(0.071)	(0.072)	(0.069)
External R&D (lag)	-0.02	-0.052	0.071	-0.007	0.009	-0.096	0.024
	(0.065)	(0.067)	(0.094)	(0.076)	(0.107)	(0.080)	(0.089)
Training (lag)	0.285***	0.305***	0.178**	0.318***	0.256***	0.299***	0.283***
	(0.048)	(0.054)	(0.091)	(0.076)	(0.063)	(0.066)	(0.064)
External knowledge acquisition (lag)	0.074	0.104	0.06	0.119	0.033	-0.042	0.131
	(0.062)	(0.069)	(0.100)	(0.079)	(0.089)	(0.082)	(0.083)
Market intelligence acquisition (lag)	0.211***	0.267***	0.167*	0.179**	0.188***	0.150**	0.235***
	(0.047)	(0.061)	(0.096)	(0.074)	(0.062)	(0.070)	(0.062)
Machinery acquisition (lag)	0.643***	0.632***	0.545***	0.623***	0.648***	0.765***	0.602***
	(0.048)	(0.063)	(0.096)	(0.085)	(0.059)	(0.070)	(0.062)
Organisational innovator (lag)							
Design engaged (lag)	0.035	0.022	0.094	0.008	0.102	0.068	0.036
	(0.063)	(0.060)	(0.107)	(0.065)	(0.097)	(0.068)	(0.088)
Employment (log) (lag)	0.157***	0.153***	0.005	0.130***	0.167***	0.083***	0.168***
	(0.034)	(0.025)	(0.027)	(0.026)	(0.040)	(0.023)	(0.035)
Science Graduates (lag)	0.003**	0.002	0.005	0.002	0.002	0	0.003*
	(0.001)	(0.002)	(0.003)	(0.002)	(0.002)	(0.003)	(0.002)
Other Graduates_ (lag)	0.004***	0.004***	0.001	0.003*	0.004***	0.003	0.004***
	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.001)
Exporting firm (lag)	0.026	0.035	0.062	-0.095	0.06	-0.035	0.066
	(0.043)	(0.047)	(0.082)	(0.069)	(0.054)	(0.060)	(0.055)
Innovation partners (lag)	0.235***	0.310***	0.328***	0.261***	0.193***	0.136***	0.279***
	(0.042)	(0.041)	(0.064)	(0.048)	(0.063)	(0.051)	(0.058)
Innovation partners squared (lag)	-0.029***	-0.041***	-0.035***	-0.034***	-0.021*	-0.018**	-0.034***
	(0.007)	(0.007)	(0.010)	(0.008)	(0.011)	(0.009)	(0.010)
In-house R&D (lag)	0.123*	0.232***	0.202**	0.187**	0.05	0.251***	0.061
	(0.071)	(0.054)	(0.094)	(0.073)	(0.118)	(0.064)	(0.099)
External R&D (lag)	0.144**	0.081	0.047	0.166**	0.165	0.163**	0.169*
	(0.067)	(0.075)	(0.105)	(0.072)	(0.113)	(0.079)	(0.094)
Training (lag)	0.278***	0.239***	0.207**	0.153**	0.357***	0.226***	0.299***
	(0.053)	(0.049)	(0.086)	(0.063)	(0.071)	(0.062)	(0.070)
External knowledge acquisition (lag)	0.094	0.136*	-0.055	0.1	0.102	0.092	0.097
	(0.060)	(0.071)	(0.095)	(0.078)	(0.085)	(0.079)	(0.078)
Market intelligence acquisition (lag)	0.667***	0.700***	0.553***	0.550***	0.709***	0.566***	0.708***
	(0.066)	(0.052)	(0.084)	(0.075)	(0.086)	(0.064)	(0.082)
Machinery acquisition (lag)	0.505***	0.455***	0.441***	0.177**	0.616***	0.488***	0.519***
	(0.065)	(0.046)	(0.082)	(0.072)	(0.074)	(0.061)	(0.073)
Number of observations	18735	11300	4178	6110	12620	5284	13450
chi^2	13678.124	16576.919	51405.068	7349.458	11685.31	2.50E+12	1.05E+05
Rho	0	0	0	0	0	0	0
BIC	7.93E+05	6.05E+05	41758.972	2.41E+05	5.42E+05	1.72E+05	6.10E+05

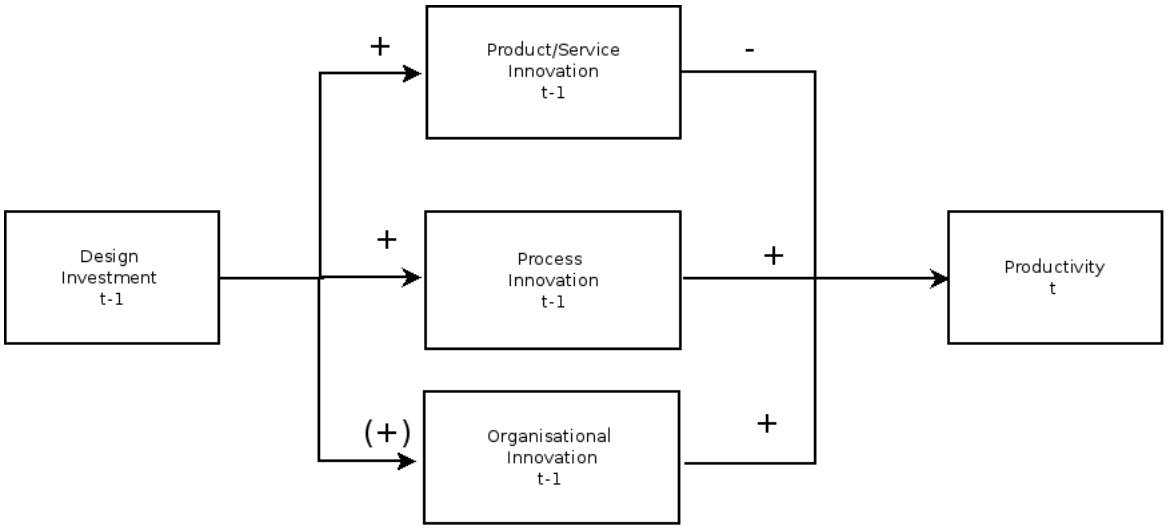
Notes: Estimated coefficients are reported. Data from waves 4-9 of the UK Innovation Survey, pooled CMP estimation. All models include wave dummies and 2-digit sectoral dummies. Observations are weighted to give representative results.

In the productivity model (Table 4, Part A), process and organisational innovation have positive and significant effects on productivity. Indeed, organisational innovation has a positive and significant effect for all firms, SMEs, R&D performers and non-performers and non-manufacturing firms. Similarly, process innovation has a positive effect for all

firm, non-R&D performers and non-manufacturing firms. Product/service innovation has a consistently negative effect where it is significant, perhaps suggesting a disruption effect when new innovative products are first introduced. The potential for such short-term disruption effects has been noted in other analyses of both product and organisational change[3].

Reflecting the earlier findings, design engagement has significant positive effects on both process innovation and product/service innovation (Table 4, Parts B and C) but no significant effect on organisational innovation (Table 4, Part D). The implication is that design engagement – at least in the short term – may have an ambiguous aggregate effect on productivity. On the positive side, design engagement will increase the probability of process innovation which in turn contributes positively to productivity. Offsetting this positive effect, however, is the positive effect of design on product/service innovation and its *negative* effect on productivity in the short-term. Figure 2 illustrates the key results by assigning a sign to each of the links in our conceptual model where they are statistically significant.

Figure 2: From design investment to productivity: evidencing the links



[3] Bourke, J., & Roper, S. (2017). Innovation, quality management and learning: Short-term and longer-term effects. *Research Policy, 46*(8), 1505-1518. doi:10.1016/j.respol.2017.07.005

5. DISCUSSION

Design engagement increases the probability that firms will undertake both product/service and process innovation. This effect is consistent across most groups of firms but is slightly larger in manufacturing firms and where firms are undertaking in-house R&D. As process innovation is positively related to subsequent productivity, the effect of design engagement on process change leads to productivity increases. The design effect through product/service innovation is offsetting as product/service innovation is linked negatively to productivity, at least in the short-term.

ANNEX 1: ESTIMATION APPROACH

Our estimation approach comprises two elements. First, we use a series of simple probit models to model the impact of design engagement on the probability of innovation. Models are based on pooled data from waves 4-9 of the UK innovation survey and use all available observations. All models include wave and sectoral dummy variables.

The second stage of our estimation approach links the innovation probit models with a simple productivity equation. Innovation variables (and the determinants) are lagged to reflect the time taken for innovation to influence productivity. This model is estimated using the CMP procedure in Stata 14 which allows us to instrument binary right hand side variables such as the innovation indicators. The inclusion of the lagged productivity measure and the lagged innovation and design measures significantly reduces the number of observations available.

ANNEX 2: DETAILED ESTIMATION RESULTS

Table A2.1: Modelling the effects of design engagement on the probability of innovation: SMEs

	Product/service innovator	Process innovator	Organisational innovator
	b/se	b/se	b/se
Design engaged	0.081***	0.034***	0.011
	(0.011)	(0.006)	(0.013)
Employment (log)	0	0.005***	0.047***
	(0.003)	(0.002)	(0.004)
Science Graduates	0.001**	0	0.001***
	(0.000)	(0.000)	(0.000)
Other Graduates	0.000**	0	0.002***
	(0.000)	(0.000)	(0.000)
Exporting firm	0.057***	0.006	0.009
	(0.008)	(0.005)	(0.010)
Innovation partners	0.145***	0.071***	0.123***
	(0.007)	(0.004)	(0.009)
Innovation partners - squared	-0.017***	-0.008***	-0.013***
	(0.001)	(0.001)	(0.001)
In-house R&D	0.170***	0.061***	0.080***
	(0.010)	(0.007)	(0.012)
External R&D	-0.001	-0.007	0.011
	(0.012)	(0.006)	(0.016)
Training	0.066***	0.056***	0.095***
	(0.009)	(0.006)	(0.010)
External knowledge acquisition	0.024**	0.014**	0.035**
	(0.011)	(0.007)	(0.015)
Market intelligence acquisition	0.198***	0.039***	0.278***
	(0.009)	(0.006)	(0.010)
Machinery acquisition	0.069***	0.088***	0.190***
	(0.008)	(0.005)	(0.009)
Number of observations	36215	36215	36215
chi^2	6264.6	4465.231	5692.134
Rho	0	0	0
Pseudo R^2	0.332	0.27	0.277
BIC	28923.844	23172.155	35616.118

Notes: Marginal effects are reported. Data from waves 4-9 of the UK Innovation Survey, pooled probit estimation. All models include wave dummies and 2-digit sectoral dummies. Observations are weighted to give representative results.

Table A2.2: Modelling the effects of design engagement on the probability of innovation: Large firms

	Product/service innovator	Process innovator	Organisational innovator
	b/se	b/se	b/se
Design engaged	0.041	0.079***	0.023
	(0.027)	(0.017)	(0.023)
Employment (log)	-0.007	0.009	0.008
	(0.009)	(0.007)	(0.008)
Science Graduates	0.001	0	0.001**
	(0.001)	(0.000)	(0.001)
Other Graduates	0.001	0	0
	(0.000)	(0.000)	(0.000)
Exporting firm	0.012	0.005	0.021
	(0.019)	(0.016)	(0.021)
Innovation partners	0.161***	0.118***	0.122***
	(0.016)	(0.010)	(0.014)
Innovation partners - squared	-0.018***	-0.014***	-0.011***
	(0.003)	(0.002)	(0.002)
In-house R&D	0.178***	0.092***	0.037*
	(0.024)	(0.019)	(0.021)
External R&D	0.007	-0.006	-0.01
	(0.022)	(0.015)	(0.024)
Training	0.064**	0.102***	0.050**
	(0.025)	(0.017)	(0.021)
External knowledge acquisition	0.047*	0.018	-0.016
	(0.027)	(0.018)	(0.025)
Market intelligence acquisition	0.268***	0.019	0.219***
	(0.022)	(0.016)	(0.020)
Machinery acquisition	0.042*	0.098***	0.158***
	(0.023)	(0.016)	(0.019)
Number of observations	8246	8251	8251
chi^2	1957.354	.	1106.329
Rho	0	.	0
Pseudo R^2	0.325	0.253	0.184
BIC	7928.13	7613.139	9756.981

Notes: Marginal effects are reported. Data from waves 4-9 of the UK Innovation Survey, pooled probit estimation. All models include wave dummies and 2-digit sectoral dummies. Observations are weighted to give representative results.

Table A2.3: Modelling the effects of design engagement on the probability of innovation: firms with in-house R&D capabilities

	Product/service innovator	Process innovator	Organisational innovator
	b/se	b/se	b/se
Design engaged	0.099***	0.079***	0.018
	(0.015)	(0.014)	(0.013)
Employment (log)	-0.011**	0.009**	0.015***
	(0.005)	(0.004)	(0.004)
Science Graduates	0.001**	0	0
	(0.000)	(0.000)	(0.000)
Other Graduates	0	0	0.001***
	(0.000)	(0.000)	(0.000)
Exporting firm	0.065***	-0.003	-0.043***
	(0.014)	(0.015)	(0.014)
Innovation partners	0.128***	0.128***	0.067***
	(0.013)	(0.010)	(0.010)
Innovation partners - squared	-0.014***	-0.014***	-0.006***
	(0.002)	(0.002)	(0.002)
External R&D	0.013	-0.013	0.024*
	(0.015)	(0.014)	(0.014)
Training	0.080***	0.106***	0.083***
	(0.023)	(0.014)	(0.015)
External knowledge acquisition	0.018	0.013	0.023
	(0.016)	(0.016)	(0.015)
Market intelligence acquisition	0.205***	0.070***	0.188***
	(0.020)	(0.015)	(0.015)
Machinery acquisition	0.004	0.145***	0.070***
	(0.024)	(0.015)	(0.017)
Number of observations	16816	14609	16816
chi^2	1193.98	916.522	1332.904
Rho	0	0	0
Pseudo R^2	0.156	0.117	0.148
BIC	19472.124	17417.727	18653.505

Notes: Marginal effects are reported. Data from waves 4-9 of the UK Innovation Survey, pooled probit estimation. All models include wave dummies and 2-digit sectoral dummies. Observations are weighted to give representative results.

Table A2.4: Modelling the effects of design engagement on the probability of innovation: firms with no in-house R&D capabilities

	Product/service innovator	Process innovator	Organisational innovator
	b/se	b/se	b/se
Design engaged	0.066***	0.021***	0.025
	(0.013)	(0.007)	(0.019)
Employment (log)	0.002	0.004***	0.044***
	(0.002)	(0.001)	(0.003)
Science Graduates	0.001***	0	0.001***
	(0.000)	(0.000)	(0.000)
Other Graduates	0	0	0.001***
	(0.000)	(0.000)	(0.000)
Exporting firm	0.031***	0.009**	0.027**
	(0.007)	(0.004)	(0.011)
Innovation partners	0.097***	0.051***	0.136***
	(0.006)	(0.003)	(0.012)
Innovation partners - squared	-0.011***	-0.006***	-0.015***
	(0.001)	(0.001)	(0.002)
External R&D	0.012	0.01	-0.007
	(0.015)	(0.009)	(0.028)
Training	0.047***	0.033***	0.080***
	(0.008)	(0.006)	(0.013)
External knowledge acquisition	0.036***	0.020***	0.053***
	(0.012)	(0.007)	(0.020)
Market intelligence acquisition	0.145***	0.022***	0.305***
	(0.010)	(0.005)	(0.013)
Machinery acquisition	0.055***	0.058***	0.264***
	(0.006)	(0.004)	(0.010)
Number of observations	34770	29761	34770
chi^2	2487.722	1944.65	3841.593
Rho	0	0	0
Pseudo R^2	0.209	0.226	0.273
BIC	22948.312	13211.327	32355.013

Notes: Marginal effects are reported. Data from waves 4-9 of the UK Innovation Survey, pooled probit estimation. All models include wave dummies and 2-digit sectoral dummies. Observations are weighted to give representative results.

Table A2.5: Modelling the effects of design engagement on the probability of innovation: manufacturing firms

	Product/service innovator	Process innovator	Organisational innovator
	b/se	b/se	b/se
Design engaged	0.117***	0.034***	-0.003
	(0.017)	(0.012)	(0.016)
Employment (log)	-0.007	0.012***	0.037***
	(0.005)	(0.004)	(0.005)
Science Graduates	0.001	-0.001**	0
	(0.001)	(0.000)	(0.001)
Other Graduates	0	0	0.001***
	(0.001)	(0.000)	(0.000)
Exporting firm	0.068***	0.002	-0.018
	(0.014)	(0.011)	(0.014)
Innovation partners	0.187***	0.114***	0.103***
	(0.012)	(0.008)	(0.012)
Innovation partners - squared	-0.022***	-0.013***	-0.012***
	(0.002)	(0.001)	(0.002)
In-house R&D	0.222***	0.079***	0.076***
	(0.015)	(0.012)	(0.016)
External R&D	0.019	-0.024*	0.015
	(0.020)	(0.012)	(0.019)
Training	0.035**	0.096***	0.085***
	(0.015)	(0.012)	(0.015)
External knowledge acquisition	0.022	0.017	0.061***
	(0.021)	(0.014)	(0.019)
Market intelligence acquisition	0.258***	0.042***	0.233***
	(0.015)	(0.012)	(0.015)
Machinery acquisition	0.095***	0.166***	0.185***
	(0.014)	(0.010)	(0.013)
Number of observations	13503	12228	13503
chi^2	.	.	.
Rho	.	.	.
Pseudo R^2	0.338	0.215	0.21
BIC	12413.645	10964.453	15129.572

Notes: Marginal effects are reported. Data from waves 4-9 of the UK Innovation Survey, pooled probit estimation. All models include wave dummies and 2-digit sectoral dummies. Observations are weighted to give representative results.

Table A2.6: Modelling the effects of design engagement on the probability of innovation: Non-manufacturing firms

	Product/service innovator	Process innovator	Organisational innovator
	b/se	b/se	b/se
Design engaged	0.070***	0.036***	0.006
	(0.013)	(0.007)	(0.016)
Employment (log)	0.002	0.005***	0.043***
	(0.003)	(0.002)	(0.004)
Science Graduates	0.001***	0	0.001**
	(0.000)	(0.000)	(0.000)
Other Graduates	0.000*	0	0.002***
	(0.000)	(0.000)	(0.000)
Exporting firm	0.046***	0.006	0.011
	(0.009)	(0.005)	(0.012)
Innovation partners	0.119***	0.064***	0.122***
	(0.008)	(0.004)	(0.011)
Innovation partners - squared	-0.013***	-0.007***	-0.012***
	(0.001)	(0.001)	(0.002)
In-house R&D	0.170***	0.058***	0.084***
	(0.019)	(0.007)	(0.018)
External R&D	-0.013	-0.003	-0.005
	(0.012)	(0.007)	(0.020)
Training	0.081***	0.049***	0.102***
	(0.015)	(0.006)	(0.015)
External knowledge acquisition	0.024*	0.014*	0.023
	(0.012)	(0.007)	(0.018)
Market intelligence acquisition	0.172***	0.039***	0.295***
	(0.012)	(0.006)	(0.012)
Machinery acquisition	0.058***	0.069***	0.261***
	(0.010)	(0.005)	(0.011)
Number of observations	38070	32205	38067
chi^2	4593.592	3250.507	4510.769
Rho	0	0	0
Pseudo R^2	0.318	0.278	0.304
BIC	29222.347	18812.84	36391.748

Notes: Marginal effects are reported. Data from waves 4-9 of the UK Innovation Survey, pooled probit estimation. All models include wave dummies and 2-digit sectoral dummies. Observations are weighted to give representative results

ERC
Enterprise Research Centre

Centre Manager
Enterprise Research Centre
Warwick Business School
Coventry, CV4 7AL
CentreManager@enterpriseresearch.ac.uk

Centre Manager
Enterprise Research Centre
Aston Business School
Birmingham B4 7ET
CentreManager@enterpriseresearch.ac.uk

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL
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