Overcoming the false dichotomy between internal R&D and external knowledge acquisition: Absorptive capacity dynamics over time

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Abstract

An important challenge in open innovation is the capability to absorb and exploit external inbound knowledge, and how internal R&D may facilitate or hinder this. Conventionally, internal R&D expenditure is used as a proxy for absorptive capacity, but in the context of open innovation, this can be problematic. Internal R&D may also constrain present and future absorption, and restrict exploitation for a number of reasons, e.g. degree of development, structural, geographical or relevance to existing business units and markets. Conversely, external sources of innovation can be difficult to identify, evaluate and absorb, but may be more codified, as by definition they are available in the market, and more fully-developed to demonstrate commercial potential. Using panel data of 325 firms over five years, we find that contrary to the prescriptions of transaction costs analysis, externally-sourced knowledge takes less time to absorb and exploit than internally-generated knowledge, but that internal knowledge creates higher returns over the longer term. Significantly, the relationship between internal and external knowledge and performance changes over time, whilst the ideal strategic balance needs to consider decisions taken at different times.

Keywords: Technology sourcing; Absorptive Capacity; Knowledge Assets; Listed Companies

1. INTRODUCTION

The open innovation model emphasizes that firms should acquire valuable resources from other organizations and share internal resources for new product/service development, but the question of in what circumstances and how a firm sources external knowledge, shares internal knowledge, and – above all – combines these activities with strategic planning in the medium-long run is less clear.

We argue that two key issues may have undermined research and practice. Firstly, in open innovation research and practice, much of the focus has been on how organizations search for potential inbound innovation (Schweitzer *et al*, 2011; Henttonen and Ritala, 2013; Wang *et* *al.*, 2015), and the extent to which inbound innovation complements or substitutes for internal R&D (Lazzarotti and Manzini, 2009; Denicolai *et al*, 2014). However, although internal R&D and technology sourcing may show some complementarities, they remain two inherently different activities.

In particular, some research suggests internal R&D takes a long time to deliver results, normally years (Kondo, 1999), whilst earnings from open innovation activities are expected to be quicker (Enkel *et al.*, 2009; West *et al.*, 2014). Plans for the future of organizations should take into account such dynamics.

There has therefore been relatively little research on the subsequent challenges of absorbing and exploiting inbound knowledge (Rosell, 2014), and even fewer have studied this process over time (Salge *et al,* 2012), which is the focus of this paper. We therefore contribute to a shift in the debate from potentially misleading general prescriptions, and provide conceptual and empirical insights into the challenges of absorbing and exploiting inbound external sources of innovation.

A second issue concerns what is being measured as the dependent variable. The majority of contributions measure the interaction between R&D and externally acquired knowledge in terms of the impact on firm growth or profitability (e.g. Hung *et al.*, 2013; Tsai *et al.*, 2008). By contrast, we measure the ability of the firm to accumulate knowledge over time as our dependent variable. This is a broader measure of capabilities reflecting the importance of ownership and accumulation of a range of knowledge stocks over time, relevant to a wider range of sectors and types of innovation.

These considerations taken together represent a breakthrough in our understanding of how companies combine 'Internal R&D' and 'Technology sourcing' investments in their strategic planning. Our findings suggest that organizations should pay more attention to finding the right combinations of internal knowledge investment and external sourcing, and less on understanding pros and cons of these two options taken alone.

2. CHALLENGES OF EXPLOITING OPEN INNOVATION

The early conceptual and empirical work on open innovation provided many insights and prescriptions, but these suffered from being universal, and often universally positive. More recently there has been a shift to a more critical approach which attempts to better understand the conditions under which open innovation is most effective (Tidd, 2014). Much of this research has focussed on the strategies for searching and sourcing for external knowledge, but there have been relatively few studies which have examined the subsequent challenges of implementing inbound innovation, and the influences on outcomes and performance over time.

Studies which have examined the implementation of inbound open innovation have focused on the relationships between internal and external knowledge, and whether these are complementary or competing substitutes. Fabrizio (2009) examined the complementary relationships between internal basic research in biotechnology firms and external research from universities. Internal knowledge was critical in identifying problems to solve, but external knowledge was more important to provide knowledge useful in the solution. This resulted in more timely access to relevant knowledge, and faster development.

In contrast, Spithoven et al (2009) examine how firms with low levels of internal R&D, and therefore low absorptive capacity, use alternative mechanisms to identify and internalize inbound knowledge. Wang (2012) offers a framework for exploring R&D investments with external technological complementarity, which leverages on the relationship among integrated technologies, specific technology fields, and patentees. Lazzarotti and Manzini (2009) consider the different phases of the innovation process that a company opens to external contributions, and rather than a simple open or closed dichotomy, find that different degrees and ways of 'openness' can be implemented successfully.

Robertson *et al* (2012) argue that the literatures on open innovation and absorptive capacity have failed to take sufficient account of the challenges in applying external knowledge. They propose three capacities beyond knowledge management: Accessive Capacity, to collect, sort and analyse knowledge from both internal and external sources; Adaptive Capacity, to ensure that new technology is suitable for the organisation's own purposes even though they may have been originally developed for other uses; and Integrative Capacity, to ensure external technology can be applied in existing processes and products with minimum disruption and cost.

Similarly, Enkel and Heil (2014) examine cross-industry innovation, and make the important distinction between ability to identify and value distant knowledge (i.e. recognition), strengthen a firm's knowledge base (i.e. assimilation), and knowledge communication and storage (i.e. maintenance).

More recent research has begun to explore the influences of inbound open innovation on outcomes and performance. Schweitzer *et al* (2011) found that open innovation in general to have a positive influence on performance in dynamic settings, and that customers are central when market dynamics are high, but suppliers are more important in technologically challenging environments. Significantly, inbound knowledge from other industries was found to be effective irrespective of the setting, which is consistent with the notion of complementary assets. Further, Mention and Asikainen (2012) found that co-operation and exploiting external sources of knowledge reduces innovation expenditures, while positively affecting sales of new products.

However, Huang and Rice (2012) found that openness to external information sources may, after a time, lead to decreasing marginal returns, as measured by innovation performance. They found complementarities between internal and external knowledge sources as precursors to the introduction of new products and services, and that investment in absorptive capacity has a declining marginal effect on the innovation performance of new processes, but not on the introduction of new products and services.

This raises an intriguing issue since it suggests that these kinds of complementary assets may interact differently over time. Salge *et al* (2012) develop and test a firm-level contingency model of inbound open innovation to explain the substantial disparities in open innovation payoff that exist between firms. Drawing on longitudinal data from 1,170 firms, econometric analyses reveal that returns from open innovation are greatest when firms maintain their internal research capacity, and advocate strong cross-functional collaboration.

Similarly, based on survey data of 248 high-technology manufacturing firms, Cruz-González *et al* (2014) found that search breadth was positively associated with performance in more mature sectors, but harms performance in technologically dynamic environments. This evidence highlights that interaction between internal and external knowledge is closely associated with the dynamic capabilities of the firm, meaning also with its ability to accumulate and renew knowledge over time (Lichtenthaler *et al.*, 2009; Teece *et al.*, 1997).

We can conclude from this brief review of recent relevant research that the simple dichotomy between open and closed approaches is unhelpful and not realistic. In particular, we need to better understand the interactions between internal and external knowledge, and how these influence performance under different conditions, including the time patterns by which companies engage in internal and/or external R&D strategies. This provides an opportunity to combine contemporary interests in open innovation with the classic notion of absorptive capacity, to investigate how organizations can better manage to absorb and exploit inbound external sources of innovation.

3. ABSORPTION OF INTERNAL AND EXTERNAL KNOWLEDGE

Conventionally internal R&D expenditure is used as a proxy for absorptive capacity. However, in the context of open innovation this is problematic because there is a high degree of uncertainty regarding how the benefits from the acquisition of external knowledge change over time. An important question is the relative ease of absorption and exploitation of internal versus external sources of innovation. The literature from the area organisational capabilities and innovation studies has most commonly framed this through Cohen and Levinthal's (1990) absorptive capacity, which emphasises that successfully recognising the value of external information, assimilating this and applying it for commercial ends requires investment in specific capabilities.

One strand of literature argues that acquisition of external assets can rapidly help establish dynamic capabilities (Teece et al, 1997), and is especially useful in turbulent environments (Escribano et al 2009). Other work cautions that external acquisition is a complex phenomenon and comprehension in some areas can only take place when there is a reduction in the amount of information coming in other areas (Levitt and March 1988). Technological effort – including ex-ante investments – and behavioural variables have been also shown as relevant factors in determining the absorptive capacity of the firm (Srivastava *et al.*, 2015).

In terms of empirical evidence, much of the research on absorptive capacity focuses on whether greater levels of investment in R&D spending facilitates the effective use of external knowledge, for example in terms of alliances (Arora and Gambardella, 1994) or ties with the scientific community (Cockburn and Henderson 1998). Denicolai et al. (2014) showed that organizations with low levels of knowledge intensity benefit most from an 'optimal' investment in externally generated knowledge, whilst knowledge-intensive firms are relatively freer in defining their knowledge sourcing strategy. Similarly, Srivastava et al. (2015) studied the moderating role of absorptive capacity in realizing benefits from external technological resources. They show that as technological capabilities of firms increase, earnings from the alliance network resources come at a lower rate.

However, what is missing from the above studies and the literature more generally is empirical evidence of how R&D expenditure and absorptive capacity impact the effectiveness of external acquisitions over time. We are left to derive this from conceptual studies. Short and long term absorptive capacity is discussed by Zahra and George (2002) who distinguish between a firm's potential and realized capacity and suggest that whilst the latter provides a short term benefit, reflecting exploitation of existing knowledge, potential capacity is associated to a dynamic capability and may therefore be more useful at adapting to the environment. This suggests firms may get a short-term benefit from external acquisition, but need to build longer lasting benefits through a combination of internal and external knowledge.

In a similar vein, in their review of the strategic renewal literature, Ben-Menahem *et al'*s (2013) argue that alignment between internal and external knowledge is critical to achieve a fit with a dynamic environment over time. In one of the few studies that addresses changing absorptive capacity over time, Popaitoon and Siengthai (2014) focus on HRM practices in 198 projects in multinational companies in the Thai automotive industry, and show that the link between realized and potential absorptive capacity depends on HRM practices that facilitate knowledge management from the current project to future projects. This strengthens the relationship between a project team's knowledge and long-term project performance.

This finding underlines the need for internal investment – in people and firm practices – in order to self-renew and sustain the firm's dynamic fit over time. Absorptive capacity is commonly taken as a kind of 'passive' outcome of R&D investments, whilst organizational characteristics – such as slack resources or external openness - are key antecedents for knowledge absorption and accumulation processes, as they both prevent inertia and enable future opportunities (Burcharth *et al.*, 2015).

Yet, it is still the case that with a few exceptions, the absence of empirical evidence in measuring absorptive capacity (AC) over time remains an important omission (e.g. Kostopoulos et al., 2011; Schildt et al., 2012; Srivastava et al., 2015). Among these few contributions, Kostopoulos et al. (2011) shows external knowledge inflows are directly related to absorptive capacity and indirectly related to innovation, but in different time spans. Schildt et al. (2012) support that that the initial ability to learn from technology sourcing and partnership is constrained by the capacity to absorb knowledge, while later-stage learning processes are constrained by exploitation capacity.

This research gap is particularly problematic given emerging evidence from disparate sources suggesting that the widespread use of information technology tools such as *TRIZ* (Horn et al 2007), greater modularisation and prototyping techniques (Schmickl and Kieser 2008) and the use of common accounting systems Grant (1996) may be allowing firms to leverage external knowledge more effectively and reducing the costs of coordination between firms. Savary (1999) and Hansen et al (1999) moreover suggest that firm strategies on use of external knowledge in knowledge management vary, with some firms going for rapid adjustments through external acquisition, whereas others rely on more careful combinations of investment in internal and external knowledge. The above discussion has emphasized that internal R&D may be difficult to absorb and exploit for a number of reasons, e.g. degree of development, structural, geographical or relevance to existing business units and markets (Graves *et al.*, 1996; Nieto, 2003).

A conventional transaction cost perspective suggests that organizations choose an optimal internal or external governance form and minimize the costs of every single transaction, including those related to technology acquisition and licensing (Kogut, Zander, 1996; Fosfuri, 2006; Presutti et al., 2011). In particular, external technology sourcing implies a number of transaction costs, for example external sources of innovation can be difficult to identify, evaluate and contract. (Aulakh et al., 2010).

In contrast, within an open innovation approach, in which the innovation process is largely embedded in a complex eco-system of inbound and outbound knowledge flows and relationships, this dichotomy between 'make' or 'buy' R&D may no longer sufficient to capture the nature and dynamics of absorptive capacity (Bianchi et al., 2014). Conversely, external sources of innovation can be difficult to identify, evaluate and contract. However, external sources may be more codified, as by definition they are available in the market, and be more fully-developed to demonstrate commercial potential.

Therefore in contrast to the traditional predictions of transaction costs analysis and absorptive capacity, internally-generated innovation may be more difficult to absorb and exploit than externally-sourced, at least in the short-term. However, over time, as internally generated R&D is consolidated within the firm, and the ability to combine internal and external knowledge improves, so we might expect a more positive effect of internal R&D on performance.

We therefore develop and test the following related hypotheses:

H1. Expenditure on internal R&D promotes the accumulation of knowledge over time, but in the short-term the impact on performance is negative.

H2. Expenditure on external knowledge has a more immediate effect on performance, but is less efficient in the longer-term.

H3. Over time, excessive reliance on external knowledge may have a negative effect on performance, if not supported by prior investment in internal R&D.

4. SAMPLE AND METHODOLOGY

The empirical analysis relies on a panel regression analysis. The data gathering consisted of two main steps and is developed through a rigorous protocol and leverages on accounting values. First, a preliminary analysis was conducted on all companies listed on stock market exchanges (Frankfurt, Paris, London, Milan, and Madrid) of the five largest European countries. All these countries have adopted IFRS (International Financial Reporting Standards) provisions, hence the data could be assumed to be comparable.

After the exclusion of companies in some idiosyncratic industries (i.e. banks, retail, equity investment, financial services, insurance, real estate, tobacco), we selected only those companies which satisfied the following three conditions. First, unambiguous details about the content of 'intangible assets' must be provided in the annual reports. We included only those firms where the annual reports allowed us to identify the values of the following knowledge assets: patents, copyrights, design models, licenses, capitalized development costs, and self-generated software. Thus we capture data on codified technological knowledge only, not intangibles as a whole, such as trademarks or goodwill.

Second, only reports showing a clear-cut distinction between 'internally-generated intangible assets' and 'externally-generated intangible assets' were accepted. Finally, the company headquarters must be in the same country as the stock exchange. Similar metrics have been already accepted in literature (Denicolai et al, 2014; Filatotchev *et al.*, 2009; Villalonga, 2004).

This procedure left a database consisting of 325 European listed companies over a period of five years (2008-2012), meaning 1625 observations in totals. Table 1 shows the distribution of the sample in terms of industries – ICB classification – and countries. At this stage, we analyzed five consecutive annual reports (2008-2012) for each of these companies.

Table 1. Sample distribution in terms of industries and countries: number of companies, and percentage among brackets

	Industrial goods and services	**Technology**	**Health care**	**Media**	**Telecom**	**Auto-mobiles & parts**	**Other**	***Total***
UK	65 (20%)	51 (15.7%)	15 (4.6%)	8 (2.5%)	4 (1.2%)	2 (0.6%)	8 (2.5%)	*153 (47.1%)*
Germany	21 (6.5%)	29 (8.9%)	6 (1.8%)	1 (0.3%)	10 (3.1%)	6 (1.8%)	6 (1.8%)	*79 (24.3%)*
France	16 (4.9%)	10 (3.1%)	9 (2.8%)	6 (1.8%)	1 (0.3%)	3 (0.9%)	6 (1.8%)	*51 (15.7%)*
Italy	9 (2.8%)	3 (0.9%)	2 (0.6%)	3 (0.9%)	1 (0.3%)	2 (0.6%)	2 (0.6%)	*22 (6.8%)*
Spain	3 (0.9%)	1 (0.3%)	6 (1.8%)	3 (0.9%)	1 (0.3%)	1 (0.3%)	5 (1.5%)	*20 (6.2%)*
Total	**114 (35.1%)**	**94 (28.9%)**	**38 (11.7%)**	**21 (6.5%)**	**17 (5.2%)**	**14 (4.3%)**	**27 (8.3%)**	***325 (100%)***

4.1. Dependent Variable: Knowledge Growth

A major obstacle in understanding these dynamics of knowledge and innovation is that it may take a long time and many steps along the value chain to convert knowledge development investments into economic performance (Cefis *et al*., 2001; Tushman *et al*., 1996; Wang *et al*., 2012). Therefore we argue that more investigations are necessary on smaller portions of this long chain to disentangle the 'knowledge-innovation-growth' relationship. Our study contributes to this by examining the upstream of the innovation process and focusing on the association between R&D investments – internal R&D vs technology sourcing – and knowledge accumulation over time.

In this study we consider the ability of the firm to accumulate knowledge over time as a measure of performance. A number of motives suggest this choice. First of all, our focus on temporal patterns of interaction among knowledge development strategies supports a longitudinal view, so that 'firm growth' would appear as a compelling fit. But, growth in terms of what? A frequent choice in the field is 'sales growth'(e.g. He *et al.*, 2004; Lee *et al.*, 2001). Nevertheless, despite much research, the relationships between knowledge, innovation and (sales or employment) growth remain ambiguous, with a large body of empirical work which fails in establishing a strong link between innovativeness and sales growth (Coad *et al.*, 2008). Therefore our chosen dependent variable is the 'firm growth' in terms of knowledge, rather than sales.

In particular, we consider the growth of *internal* knowledge only, instead of the growth of total knowledge assets. Though the investigation of the effect of R&D expenditure is significant in both cases, the positive influence of external knowledge assets on the accumulation of total assets is tautological, since the total knowledge assets comprise – by definition – the externally generated knowledge assets.

Hence, we measure the Internal Knowledge Growth (IKG) as the difference of the logarithms of internal knowledge assets stock in two consecutive years. These intangible assets provide a compelling proxy for the amount of technological knowledge possessed by the firm. This evidence has been already recognized in literature (Wyatt, 2005) and has become more robust after the crisis in 2008, which imposed new controls on listed companies (as those in our sample). For instance, IFRS and IAS standards have fixed rules to mitigate the risk for manipulation of intangible assets. The 'Impairment Tests' – performed annually – reinforce the consistency of these values.

4.2. Explanatory Variables

The regression study relies on two key factors: expenditure in Internal R&D (IRD), and expenditure in externally generated knowledge assets (EXT). These are absolute values, not ratios: the goal is to reveal to what extent these two kinds of investments contribute to the accumulation of knowledge over time, and thus their relative weights along this process (degrees of absorption).

On the other hand, the balance between internal and external development of knowledge – here as a ratio – is taken into account as third explanatory variable (EXTratio). The time lag of these dynamics is a key consideration to this study. In particular, we explore a time span of three years by which internal R&D and external knowledge may influence the growth of firm's knowledge stock. Since data spans five years, we could have extended the analysis to time lag of four years. Nevertheless each additional year of delay reduces the number of observations, so we decided to set a maximum of 3 years as lag time in order to preserve an acceptable amount of data.

The findings (see below) suggest we measure the balance between internal and external knowledge also through a second method: the company's efforts in different times. In other words, we relate the investments in external knowledge at time 't' with the investment in internal R&D in the previous year (t-1), instead of calculating the ratio by comparing data of the same period. Further details and motives for this choice are shown below.

Finally, we included control variables, namely firm size in terms of turnover (SIZE) and industry dummies for industrial goods and services (IND), technology (TECH), health care (HC), telecommunications (TELCO), media (MEDIA) and automotive (AUTO). We use country dummies for UK (UK), French (FR), German (GE) companies, which taken together represent 87.1% of the whole sample.

Table 2 defines all the variables of the research model.

Table2. Research model: definitions of dependent and explanatory variables

	VARIABLE	DESCRIPTION	TYPE	OPERATIONALIZATION
Control variables	Country	Location of the Headquarter	Dummies	UK = United Kingdom
				GE = Germany
				FR = France
	Sector	Main sector of activity	Dummies	IND = Industrial goods and services
				TECH = Technology
				HC = Health Care
				TELCOM = Telecommunication
				MEDIA = Media
				AUTO = Automotive and parts
	SIZE	Size of the firm in terms of turnover	Continuous	Log ($Turnover_t$)
Independent variables	$IRD_{[t]}$	Investment in Internal R&D	Continuous	Log (Total Expenditure in Internal R&D $_{[t]}$)
	$EXT_{[t]}$	Investment in External Knowledge	Continuous	Log (Value of Acquired Knowledge Assets from outside $_{[t]}$)
	EXTratio	External Ratio (balance between investments in external and internal knowledge)		$EXT_{[t]} / (EXT_{[t]} + IRD_{[t]})$
	ALEXTratio	'Asymmetric' Lagged External Ratio		$EXT_{[t]} / (EXT_{[t]} + IRD_{[t-1]})$
Dependent variable	IRG	Firm performance in terms of knowledge assets stock growth	Continuous	Log (Knowledge $Assets_{[t+1]}$) - Log (Knowledge $Assets_{[t]}$)

5. RESULTS

Table 3 provides the range, mean and standard deviation for the continuous variables, as well as the Pearson correlation coefficients. The correlations between the key explanatory variables are small, thus reducing the likelihood of multi-collinearity problems in the regression analysis.

Table 4 shows the correlations among expenditure in IRD and EXT in different periods spanning three years. These findings suggest that internal R&D tends to remain relatively stable over time (high correlations among IRDs in different periods). This evidence is also reported in case of EXT, though the correlations are slightly lower, thus suggesting a relatively higher volatility of investment in external knowledge (and of related strategies).

Correlations among IRD and EXT are fairly small and non significant: apparently, the decision to invest in R&D is not associated with the effort in technology sourcing campaigns. This assures that the sample is balanced under this view, and comprises the following groups: companies that focus on internal R&D (IRD=high; EXT=low), companies that focus on open innovation (IRD=low; EXT=high), companies which significantly invest on both (IRD=high; EXT=high), companies where knowledge development is not a key priority (IRD=low; EXT=low).

Table3. Descriptive Statistics and Correlations

Variable	Obs	Mean	St. Dev.	Min	Max	IKG	SIZE	IRD	EXT	EXTratio
IKG	1120	0.1296	1.7822	-7.2301	7.6487	1				
SIZE	1199	18.5829	2.3524	0.0000	23.2662	0.0040	1			
IRD	1204	12.0621	6.4127	0.0000	20.7778	-0.0849	0.0160	1		
EXT	1204	8.1082	6.9514	0.0000	20.7206	0.0670	0.3532	0.0431	1	
EXTratio	1109	0.3727	0.3300	0.0000	1.0000	0.1114	0.2834	-0.6687	0.8341	1

Table 4. Knowledge investments in different years: Correlation matrix

	$IRD_{(t)}$	$IRD_{(t-1)}$	$IRD_{(t-2)}$	EXT	$EXT_{(t-1)}$	$EXT_{(t-2)}$
$IRD_{(t)}$	1					
$IRD_{(t-1)}$	0.8053	1				
$IRD_{(t-2)}$	0.7782	0.8317	1			
$EXT_{(t)}$	0.0431	0.0244	0.0305	1		
$EXT_{(t-1)}$	0.0581	0.0573	0.0523	0.7814	1	
$EXT_{(t-2)}$	0.0821	0.0525	0.0688	0.6948	0.7788	1

Table 5 presents the outcome of the first regression study. It shows the impact of investment in IRD and EXT on the accumulation of knowledge over time (IKG). We report the results using both fixed (models 1,2 and 3) and random effects (model 4,5 and 6). The Hausman test suggests that the random effects models outline strongest models. However, the fixed effects models are also reliable, we therefore consider both methods as a check of robustness.

Models 1 and 4 study the impact of IRD on the dependent variable IKG, in three different periods (t ; t-1 ; t-2). Findings shows that both terms of IRD at time 't' and 't-1' are significant (p-value respectively at <0.05 and <0.01). However, the former coefficient (t) is negative (M1: -0.0855; M4: -0.0656), whilst the latter (t-1) is positive (M1: 0.1620; M4: 0.0565).

This evidence is stable across fixed and random effects models and mitigates possible issues caused by omitted variables. The only significant difference among the two methods regards a positive impact of IDR also at 't-2' in the Fixed Effect Model, though less significant than the one at 't-1'. It supports the finding that internal R&D promotes the accumulation of knowledge in the medium to long run, though the exact time-lag may be subject to time-invariant factors (e.g. industry or country landscape). Hence, H1 is strongly supported: expenditure in R&D fosters the accumulation of knowledge over time, but it takes time. Companies have to be aware that in the short run the impact of R&D may be negative.

Models 2 and 5 investigate to what extent EXT helps accumulate the stock of internal knowledge assets. Once again, three time lags are considered: t, t-1 and t-2. We report a significant (p-value<0.1) and positive effect (M2: 0.0748; M5: 0.0401) at time 't', whilst the other two terms (t-1 ; t-2) are non-significant. This evidence supports H2: investments in external knowledge have a more immediate effect in positively supporting the development of internal knowledge assets, likely shortening the time needed to get returns from R&D expenditure (complementary assets).

On the other hand, the coefficient of EXT(t) is lower than IRD(t-1) suggesting that R&D takes time and perseverance, but is relatively more efficient. By contrast, EXT has a quick effect, but companies must spend a higher amount of money to have comparable results. Significant coefficients are the same in both fixed- and random-effects regressions, thus supporting the reliability of findings and that endogeneity issues are a minor concern in this study.

Model 3 and 6 analyses simultaneously the effect of IRD and EXT: the coefficients remain stable thus further confirming the above mentioned findings and reinforcing their consistency. Table 6 investigates the pattern of interaction between IRD and EXT. First, we study the balance between internal and external knowledge. It reveals the investment strategy of the firm in terms of knowledge development, once given a budget for such an objective.

Table5. Regression analysis 'A': Absorption of Internal R&D(IRD) and External knowledge (EXT) over time

	Fixed Effects			**Random Effects**		
DV=IKG	**(1) Fe1**	**(2) Fe2**	**(3) Fe3**	**(4) Re1**	**(5) Re2**	**(6) Re3**
UK				-0.0154	0.1650	0.2307
				(0.353)	(0.366)	(0.366)
GE				-0.1446	-0.0222	0.0247
				(0.364)	(0.371)	(0.368)
FR				0.1859	0.1859	0.2522
				(0.405)	(0.407)	(0.404)
AUTO				-0.0874	-0.1852	-0.0716
				(0.614)	(0.610)	(0.611)
HC				-0.2649	-0.3522	-0.3233
				(0.389)	(0.390)	(0.389)
IND				-0.0881	-0.0919	-0.0967
				(0.339)	(0.340)	(0.339)
MEDIA				-0.2319	-0.1251	-0.3898
				(0.462)	(0.452)	(0.467)
TECH				-0.2454	-0.3424	-0.3005
				(0.346)	(0.347)	(0.345)
TELCO				-0.1984	-0.1494	-0.3046
				(0.480)	(0.478)	(0.482)
SIZE	0.1619	0.2047	0.1970	0.0366	0.0017	0.0024
	(0.279)	(0.283)	(0.279)	(0.042)	(0.044)	(0.044)
IRD (t)	-0.0855*		-0.0809*	-0.0656***		-0.0689***
	(0.047)		(0.048)	(0.025)		(0.025)
IRD (t-1)	0.1615**		0.1722**	0.0565**		0.0575**
	(0.075)		(0.075)	(0.028)		(0.028)
IRD (t-2)	0.1220*		0.1245*	-0.0162		-0.0183
	(0.070)		(0.070)	(0.026)		(0.026)
EXT (t)		0.0748*	0.0799*		0.0401*	0.0397*
		(0.043)	(0.043)		(0.021)	(0.020)
EXT (t-1)		0.0522	0.0428		-0.0114	-0.0097
		(0.052)	(0.051)		(0.023)	(0.023)
EXT (t-2)		0.0155	0.0104		0.0022	0.0072
		(0.040)	(0.040)		(0.019)	(0.019)
Constant	-5.2323	-4.8069	-7.1712	-0.0044	-0.0134	0.2461
	(5.428)	(5.405)	(5.547)	(0.921)	(0.926)	(0.923)
Observations	513	513	513	513	513	513
R-squared	0.044	0.016	0.060			
Number of ID	290	290	290	290	290	290

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Models 1 and 5 posit a linear effect, whilst Models 2 and 6 consider a curvilinear relationship. Outcomes support a positive linear function (M1: 1.889 , $p\text{-value}<0.01$; M5: 0.855, $p\text{-value}<0.01$): the higher the portion of EXT in the budget for knowledge development, the stronger the growth of internal knowledge stock. This finding is also strongly consistent over time: EXTratio considers diversified (IRD & EXT) but simultaneous investments, made in the same year. So, the quick impact of EXT on the knowledge stock of the subsequent year prevails over the slow ripening of the internal R&D.

This finding suggests that practitioners should plan their knowledge development strategies considering at least two years and – most important – considering the interactions among investments made in different years. Second, the synergy between internal and external knowledge over years should be considered.

Hence we introduce a new metric regarding the knowledge balance, that we call 'Asymmetric' Lagged External Ratio (ALEXTratio), defined as $EXT_{[t]}$ divided by $(EXT_{[t]}+IRD_{[t-1]})$. It allows a ratio to be created that relates EXT and IRD in different years and allows optimal combinations of EXT(t) and IRD(t-1) to be found. In doing so, a curvilinear and significant function emerges (Model 3), where the best balance consists of 34% of EXT at time 't' combined with 66% of IRD at time 't-1'. This configuration further reinforces the above mentioned conclusion: IRD is slow but efficient, EXT is quick but costly (the yield of IRD is about twice than EXT). The findings also show that a very high leverage on external knowledge (more than 67%; see Figure 1) may even have a negative effect, if not supported by R&D investment *already done* in the previous years. This is the case with 13.2% of companies in our sample.

These findings are supported by fixed effects regression only. It suggests that some relevant omitted variables may exist, but the latter largely rely on time-invariant factors. Since our goal is to capture how absorption of internal and external knowledge evolves over time within the organization, the above mentioned findings are pertinent, however, further analysis is needed to understand how these dynamics change across different environmental contexts (since the magnitude of this variance could be relevant). To this end, we introduce three variables which study the role of IRD – considering three time lags – as a moderator for the effect of EXT at time 't':

- $EXTratio\_IRD_{(t)} = EXTratio_{(t)} * IRD_{(t)}$
- $EXTratio\_IRD_{(t-1)} = EXTratio_{(t)} * IRD_{(t-1)}$
- $EXTratio\_IRD_{(t-2)} = EXTratio_{(t)} * IRD_{(t-2)}$

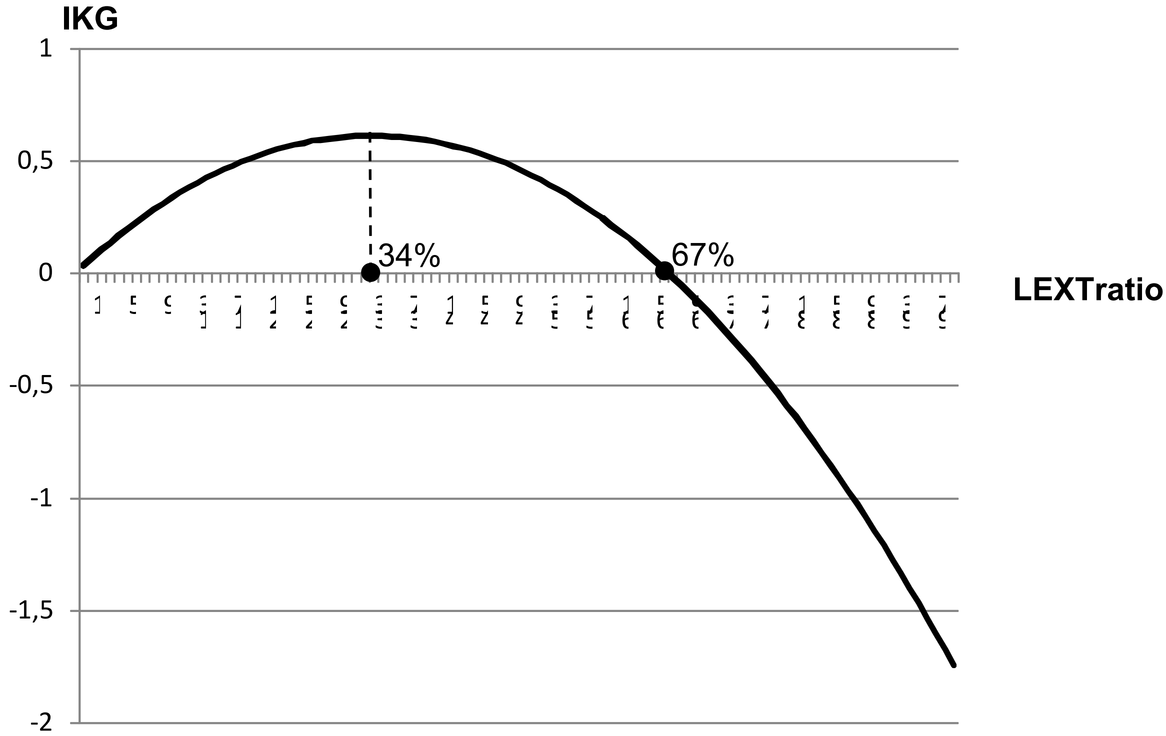
The result in models 4 and 8 show a significant and positive interaction between the variable EXT at time ‘t’ and variable IRD at time ‘t-1’. This test provides support for our finding regarding the relationship between EXT and IRD.

Table 6. Regression analysis ‘B’: Interactions between InternalR&D (IRD) and External knowledge (EXT) over time

	Fixed Effects				**Random Effects**			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
VARIABLES	**Fe1**	**Fe2**	**Fe3**	**Fe4**	**Re1**	**Re2**	**Re3**	**Re4**
UK					0.3137	0.3072	0.2884	0.2000
					(0.236)	(0.236)	(0.279)	(0.363)
GE					0.1253	0.1206	0.1914	-0.0657
					(0.238)	(0.239)	(0.282)	(0.368)
FR					0.0939	0.0970	0.1328	0.2272
					(0.258)	(0.258)	(0.306)	(0.406)
AUTO					0.2343	0.2470	0.2099	-0.0300
					(0.383)	(0.384)	(0.461)	(0.612)
HC					-0.0541	-0.0329	-0.0835	-0.2799
					(0.258)	(0.258)	(0.304)	(0.398)
IND					-0.2072	-0.2097	0.0044	-0.0472
					(0.225)	(0.225)	(0.266)	(0.349)
MEDIA					-0.4697	-0.5279*	-0.1508	-0.5410
					(0.312)	(0.317)	(0.370)	(0.493)
TECH					-0.2619	-0.2572	-0.1086	-0.2597
					(0.228)	(0.228)	(0.269)	(0.354)
TELCO					-0.4803	-0.5078	-0.1632	-0.2537
					(0.336)	(0.337)	(0.398)	(0.516)
SIZE	0.0155	0.0115	0.1396	0.1998	-0.0116	-0.0082	-0.0038	0.0229
	(0.108)	(0.108)	(0.199)	(0.278)	(0.026)	(0.026)	(0.032)	(0.044)
EXTratio	1.8887***	0.4262		-1.0534	0.8552***	0.4043		0.9902***
	(0.441)	(0.934)		(2.416)	(0.198)	(0.474)		(0.346)
EXTratio2		1.8446*				0.5147		
		(1.039)				(0.491)		
ALEXTratio			3.6432***				0.9051	
			(1.375)				(0.560)	
ALEXTratio2			-5.3892***				-0.4219	
			(1.577)				(0.583)	
EXTratio * $IRD_{(t)}$				-0.0967				-0.0520
				(0.085)				(0.043)
EXTratio * $IRD_{(t-1)}$				0.2590**				0.1637***
				(0.112)				(0.058)
EXTratio * $IRD_{(t-2)}$				-0.0058				-0.1260**
				(0.125)				(0.062)
Constant	-0.8788	-0.7138	-2.4622	-3.7797	0.0094	-0.0078	-0.1673	-0.5111
	(2.019)	(2.018)	(3.724)	(5.256)	(0.574)	(0.574)	(0.694)	(0.934)
Observations	1,029	1,029	751	475	1,029	1,029	751	475
R-squared	0.024	0.029	0.027	0.056				
Number of ID	295	295	290	275	295	295	290	275

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Figure 1 The inversed U-shaped relationship between LEXTratio and IKG



6. DISCUSSION

This study has important implications for the understanding of absorptive capacity and indeed open innovation. On the one hand it reinforces prior research that expenditure in R&D is one source of absorptive capacity that promotes the accumulation of knowledge (Burcharth *et al.*, 2015; Gebauer *et al.*, 2012). On the other hand, our results also suggest that in the shorter term, up to two years, the impact of R&D may be negative (HP1).

In other words, the inherent immaturity and uncertainty of R&D limit the speed of development and exploitation. Organizational factors, such as structural functional barriers may further slow the identification and implementation of internal innovation . Conversely, investments in external knowledge have a more immediate effect in positively supporting the development of total knowledge assets, and creating higher returns in the shorter term (HP2). This is partly due to the higher maturity and codification of knowledge available in the market, especially through patents or licenses (Hakanson, 2007; Kostoff *et al.*, 2004).

Our findings also suggest that knowledge acquired externally is more expensive and less efficient than internally-generated R&D. Therefore, although internal R&D takes time and perseverance, in the longer term it is relatively more efficient than acquiring knowledge from external sources. This evidence supports the synergic effect of complementary assets according to the dynamic capability view, as opposed to the motivation-reducing effects advanced by transaction cost-based analyses (Yasuda, 2015; Bianchi et al. 2014). Indeed, companies which seek to exploit the markets for technology - e.g. through acquisition or licensing of inbound open innovation - need to recognize that a lack of absorptive capacity may in the longer-term significantly reduce their performance, more than the shorter-term costs and risks of internal technology development. In such a context, decisions about R&D activity and technology sources can be understood only as a strategic sequence of interdependent steps over time.

These findings also contribute to an ongoing debate regarding the ability of firms to leverage not only internal knowledge but also external knowledge, and the complex relationship that exists between open innovation and absorptive capacity. As Chesbrough and Crowther (2006) suggest, many firms undertake what they call "inbound open innovation" that does not rely exclusively on in-house R&D through sophisticated search techniques. Spithoven et al (2011) showed that firms can do this by teaming up with client firms that perform activities that include gate keeping, technology watch, road mapping and knowledge repository activities (technical libraries, study days, etc.).

However, our empirical analysis also reveals the limitations of this strategy and that past a certain point, the opportunity cost of assimilating external knowledge becomes high and can out-weigh the short-term benefits. Hence, the benefits of greater codification and streamlining of external knowledge, that some have argued reduce costs of knowledge transfer, should not be exaggerated. Our arguments indeed suggest knowledge is not a commodity and as Arrow (1974) suggested some time ago, requires considerable investment.

Hence, our third hypothesis regarding the relationship between internal and external knowledge requires some adaptation. We find not a linear but a more complex curvilinear relationship between internal and external knowledge which suggests that it is less a question of "substitute or complement", and more the appropriate balance between the two, and – even more intriguing – the sequence by which the company invests in such strategies matters.

These findings also have important implications for practitioners and strategic planning, especially in assessing directions of future internal/external R&D activities. They suggest that firms investing in knowledge development strategies should not necessarily expect short-term returns to R&D and instead consider at least a 2 year time-frame. At the same time, the positive returns to acquisition of external knowledge in the short–term are unlikely to last as competitors can also purchase the same technology. By contrast, what appears to pay off is understanding the interactions between different types of investment made over time, which is consistent with an options approach (Kogut, 2008; McGrath and Nerkar, 2004; Ernst *et al.*, 2010).

Further, the focus on 'knowledge growth' as the dependent variable should pave the way for a better measurement of the interaction between the relative value and returns to internal R&D expenditures and external acquisition of knowledge assets.

7. CONCLUSIONS

A key issue in open innovation discourse regards how internal R&D may facilitate or hinder the ability of the firm to absorb knowledge from outside (e.g. Arranz *et al.*, 2006; Tsai *et al.*, 2009). Our study argues that we need a much better understanding about the temporal patterns by which internal R&D and technology sourcing interact with each other and that this is fundamental to make a step forward in the field. To this purpose, both dependent and independent variables have to be reconsidered, as well as new metrics are needed.

Our results offer both theoretical and empirical arguments suggesting that the simplistic debate about ‘Internal R&D’ vs ‘technology sourcing’ should be replaced by one that asks questions about the appropriate balance for each firm taking into consideration managerial choices at different times.

Hence, internal R&D is not simply a proxy for absorptive capacity, but rather a basis to create complementary assets and capabilities, which enable opportunities for *future* technology acquisitions and combinations. By examining the interactions between internal R&D and acquisition of external knowledge over time, and the influence on performance, we contribute to the “substitute or complement” debate about the influence of external knowledge on internal R&D. The time dimension and dynamics help to overcome this simple dichotomy.

Finally, we suggests that future research needs to capture the synergy between internal and external knowledge and incorporate a broader range of knowledge types over time, in particular broader measures of knowledge, e.g. codified knowledge beyond internal R&D expenditure or patents, which are more relevant to a wider range of sectors.

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