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Profiting from innovation: Evidence from a survey of Queen's Awards winners

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ABSTRACT

Based on a survey of firms that received the Queen's Award for Innovation, we investigate the use and perceived effectiveness of different appropriability strategies in the context of breakthrough innovations. We find that firms consistently combine formal and informal intellectual property to prevent imitation, and that their strategies can vary over time according to the phase of development of the innovation. Our results are consistent also with the growing body of evidence showing that in several economic contexts informal appropriability mechanisms are more effective than patents.

1. Introduction

A fundamental feature of modern industrial capitalism is the continuous introduction of innovations by profit-seeking actors. Once introduced, successful innovations spread throughout the production system thanks to the imitation activities of other profit-seeking actors. This interaction between innovation and diffusion is a powerful engine of economic growth and prompted economic historian David Landes (1969) to invoke the vivid image of the 'Unbound Prometheus' to capture the inbuilt tendency of modern industrial capitalism to foster technological advances and economic change.

In this context, it is interesting to reflect on the intrinsic tension between inventive activities and innovation diffusion. Imitators that adopt the new technologies erode the profits of the innovating firm, reducing the incentive to invest in inventive activities. The rationale and social function of patents is to ensure a temporary monopoly to allow the innovator to appropriate an economic return from its investment in inventive activity. In this perspective, the appropriability strategies of innovators represents a major focus of the economics of innovation literature. Since appropriability strategies can rely on 'formal' mechanisms such as patents and copyrights, and also on less visible means such as secrecy or exploitation of lead times, much of the empirical research in this field adopts a survey methodology. Surveys allow researchers to ask innovating firms about their strategies and behaviors which can provide insights into practices that leave few footprints in economic data and records (Hall et al., 2014).

The present paper adds to this line of research by focusing on innovation rather than the firm as sampling unit. Furthermore, we focus on breakthrough innovations defined as innovations with a sizeable economic impact in the market in which the firm is active.[1] Since such innovations are likely to be the outcomes of substantial investment of resources in search activities, we argue that appropriability concerns are more relevant to these types of inno-

[1] Ahuja and Morris Lampert (2001, p. 523) write that '...Radical or breakthrough inventions can be defined along different dimensions. At a very basic level a distinction can be made between inventions that are radical from a technological perspective vs. inventions that are radical from a user or market perspective...'. In the present paper, we consider innovations as radical based on their commercial impact.

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Table 1
Summary of main survey results.

Firm level survey	Levin et al. (1987)	Arundel et al. (1995), Arundel and Kabla (1998)	Cohen et al. (2000)	Cohen et al. (2002)
Period covered	1981–1983	1990–1992	1994	1994
Country	US	UK, DE, IT, NL, BE, ES, DK, FR	US	US, JP
Coverage	650 R&D publicly traded, mfg companies	414 PACE +190 French large R&D-doing mfg firms	1,165 large R&D-doing mfg firms	593 large R&D-doing mfg firms
Sectors with the highest patent propensity rates	Drugs, Organic chemicals	Pharma, Chemicals	Medical equipment, Pharma	n.a.
% that highly values patents as a form of appropriability	Prod.:4.3*, Proc.:3.5*	Prod.:67%, Proc.:46%	Prod.:35%, Proc.:23%	Prod.:JP 38%; Prod.:US 36%, Proc.:JP 25%, Proc.:US 24%
% that highly values secrecy as a form of appropriability	Prod.:3.6*, Proc.:4.3*	Prod.:54%, Proc.:65%	Prod.:51%, Proc.:51%	Prod.:JP 26%; Prod.:US 51%, Proc.:JP 29%, Proc.:US 53%
% that highly values lead times as a form of appropriabilty	Prod.:5.4*, Proc.:5.1*	Prod.:67%, Proc.:46%	Prod.:53%, Proc.:38%	Prod.:JP 41%; Prod.:US 52%, Proc.:JP 22%, Proc.:US 38%

Notes: DE: Germany, NL: Netherlands, BE: Belgium, DK: Denmark, ES: Spain, IT: Italy, FR: France, JP: Japan; mfg: manufacturing; prod.: product innovation; proc.: process innovation.
*mean scores (range: 1=not at all effective, 7 = very effective). Source: our elaboration based on Hall et al. (2014).

vations compared to innovations emerging from learning by doing or routine, small-scale R&D activities. Finally, another novelty of our sampling approach is that the innovations are not necessarily patented. This allows further insights into alternative appropriability strategies to patents.

This different perspective allows us to capture possible within-firm variations in appropriability strategies rather than supposed "representative" behavior at firm level. Mintzberg et al. (1998) note that, strategy is an inherently elusive notion which includes highly heterogeneous and multi-faceted choices and actions. However, central to most conceptualizations of strategy is that it is a process that unfolds over time (see also Evered, 1983). Building on this idea, we consider an appropriability strategy to comprise a sequence of decisions taken at different points in time, and possibly subject to revision and redefinition. Accordingly, we study the strategic contribution of different appropriability mechanisms at each stage in the innovation development process. Compared to previous research, our investigation of appropriability strategies explicitly considers the timing of the decision, and allows for joint deployment of different appropriability mechanisms in a single innovation.

Our survey is based on a sample of innovations that won the Queen's Award for Innovation during the period 2000–2017. The Queen's Award for Innovation is a high-profile prize which recognizes successful innovations introduced by UK based firms. Our respondents were engineers or managers who had been directly involved in the R&D activities leading to a winning innovation. The rest of the paper is organized as follows. Section 2 provides an overview of the background literature. Section 3 describes the Queen's Award for Innovation competition. Section 4 presents our survey design. Sections 5 and 6 discuss possible selection biases, and set out our findings. Section 7 concludes.

2. Background literature

In a seminal paper, Teece (1986) argued that successful appropriability strategies depend critically on a number of contextual factors which go beyond use of patents and other intellectual property rights (IPR). Building on this work, a substantial empirical literature has developed investigating the different appropriability strategies used by innovators in different contexts. Following Manseld's (1986) and Levin et al.'s (1987) pioneering studies, a number of relatively robust empirical findings have been established.[2]

First, except in the case of the chemical and pharmaceutical industries, patents generally are not regarded as particularly effective appropriability mechanisms. This result is based on the findings from the Yale University survey (Levin et al., 1987) of US manufacturing firms which were confirmed by the follow-up Carnegie Mellon survey (Cohen et al., 2000). Surveys of European firms have provided substantially similar results (Harabi, 1995; Arundel et al., 1995; Arundel and Kabla, 1998; Arundel, 2001).[3] Second, in most contexts, lead times and secrecy are considered the most effective appropriability mechanisms (in addition to the previous studies, see also Hall et al., 2013 for evidence on UK firms). Finally, at the industry level, there are differences related to the protection of product versus process innovations: patents and lead times tend to be favored for product innovations, and secrecy for process innovations. Table 1 summarizes the most important findings in this field.

In all of these studies, the survey sampling unit tends to be the firm. The questionnaires asked respondents to characterize their typical or representative approach to the appropriation of the economic returns from their inventive activities. A parallel stream of work on patenting behavior uses the patented invention as sampling unit, and asked about the motives for patenting and the use of patents. Notable example are the Pat-Val EU survey described by Giuri et al. (2007) which focuses mostly on inventors' background, and the Berkeley Patent Survey on the use of patents (Graham et al., 2009).

The Queen's Award for Innovation prizes allow us to identify a sample of commercially successful breakthroughs which are not necessarily patented. We contribute to the existing literature by providing a detailed assessment of the appropriability strategies adopted by firms to protect specific innovations.[4]

[2] Hall et al. (2014) provide a detailed survey of this literature, focusing on the choice between formal (i.e. relying on formal IPR protection mechanisms) and informal appropriability strategies.

[3] In this respect, Japanese firms which consider patents to be as effective as secrecy and lead time, seem to be an exception (Cohen et al., 2002).

[4] For the purpose of this study, we use data on awards to explore appropriability; a recent survey using this approach is Reichensperger (2018) which focuses on the propensity to patent based on a sample of firms that won the R&D100 competition. Another strand of literature studies the effectiveness of innovation prizes as

3. The Queen's Award for Innovation competition

Originally called 'The Queen's Award to Industry', the scheme was announced in the House of Commons on February 4th, 1965, by Prime Minister Harold Wilson. Over 50 years later, the Queen's Award continues to be the most prestigious prize for innovation activities for individuals and enterprises in the UK (Groom, 2015).

The accolade was aimed initially at recognizing outstanding export and/or technology performance by business units (Mountbatten-Windsor, 1965). All organizations (large, medium or small) which regularly operate as a 'business unit' in the UK are eligible to apply for the award, and there are no sectoral boundaries or predetermined patterns of regional allocation. Depending on the amount and quality of the applications, a limited number of awards is granted every year. From the outset, the review committees suggested that in each year competition there should not be a predetermined number of awards (McFadzean, 1970). Over the decades, the rules governing the scheme have been revised periodically but the nature of the award has remained largely unchanged. It has never been associated to a tangible reward (such as tax relief) since 'their inclusion would detract from the dignity of the Honour' (McFadzean, 1970). Instead, winners have the right to display the Queen's Award emblem on their letterheads and in their workplaces for five years. The list of winners is announced on April 21st each year, the birthday of Queen Elizabeth II, and published in major British newspapers such as the *Financial Times* and *The Guardian*.

At present, The Queen's Awards for Enterprise recognizes achievements in three fields: innovation, international trade, and sustainability (DTI, 1999). Our survey targets the winners of the Queen's Award for Innovation (hereafter QAI) who can apply to enter the competition based on one of the following criteria:

> Outstanding innovation, resulting in substantial improvement in business performance and commercial success, sustained over not less than two years, to levels which are outstanding for the goods or services concerned and for the size of the applicant's operations, and arising in the fields listed below. Or:
> - Continuous innovation and development, resulting in substantial improvement in business performance and commercial success, sustained over not less than five years, to levels which are outstanding for the goods or services concerned and for the size of the applicant's operations, and arising in the fields listed below.
> Achievements under either criterion may be assessed in any of the following fields: the invention, design, production (in respect of goods), performance (in respect of services, including advice), marketing, distribution, after sale support, of goods or services (BEIS, 2013, p. 6).

As well as providing a detailed description of the innovation, applicants must demonstrate its commercial success by providing data on its market performance in the two to five years before the submission date. For instance, the application must be supported by figures for growth of earnings imputable to the innovation using indicators such as profitability, market share, etc. The first step in the screening process involves a group of technical assessors who select the applications; then the selected applications are judged based on merit by a judging panel chaired by the Permanent Secretary to the Department for Business, Innovation, and Skills (BEIS, 2013). Unsuccessful applicants receive feedback and guidance about how their application might be improved for subsequent submission (Mountbatten-Windsor, 1975).

an incentive for innovation activities (see e.g. Williams, 2012, Moser and Nicholas, 2013).

Between 1966 and 2017, a total of 1,569 innovative products received a QAI, with an average applicant success rate of 10% a year. The winning firms range from large UK firms to UK branches of multinational companies, to small and medium sized enterprises (SMEs). They include among others, British Telecommunications which won six QAI between 1984 and 2014 for innovations such as 'Prestel' (Press Telephone), and the UK Post Office's Viewdata system - the precursor to modern online services. In the late 1980s, British Aerospace together with The Royal Aircraft establishment were awarded the QAI for developing the wings for the Airbus A320 (1988) and in 2001, the Pfizer's UK division won for the development and successful commercialization of the Sildenafil citrate, brand name Viagra. More recently, in 2017 Zettlex UK, a small innovative company, won the award for developing a range of sensors for measuring positions and speeds in extreme environments with a high level of accuracy (Groom, 2017).

The economic and technological significance of the innovations that received the QAI is corroborated by comparison with the well-known SPRU Innovations Database (Pavitt, 1983; Townsend et al., 1981). SPRU's database includes over 4,000 technological breakthroughs introduced in Britain between 1945 and 1983, selected by a team of technical experts. For the period 1966-1983 in which data of the SPRU database overlaps with the QAI competition, the SPRU database includes 2,595 technical achievements, whereas 424 innovations received the QAI. In both cases, we have information on company name and the year of the innovation or of the award, and consider a match as successful if the innovator names coincide and the time difference between inclusion of the innovation in the SPRU database and QAI was at most five years. We identified 144 matching observations, suggesting that 34% of the awards between 1966 and 1983 were for innovations included in the SPRU database. Since the SPRU database contains 'significant technical innovations that had been successfully commercialized', we consider this proportion of matches as supporting not only the economic significance but also the technological relevance/value of the innovations in our sample.

Given the requirement of both innovativeness and commercial success, QAI winners represent an excellent source of data to investigate the structure and effectiveness of appropriability strategies at the innovation level. Also, the absence of restrictions related to sector and firm size allows a representative sample of innovators. Several other works on breakthrough innovations have used QAI winners to study topics such as the relationship in firms between technological and organizational aspects (Langrish et al., 1972), the importance to the innovation process of informal external linkages (Conway, 1995), the role of SMEs in fostering innovative activities in the UK (Tether, 1996; Romijn and Albaladejo, 2002), and the tendency of innovative firms to "co-locate" in metropolitan regions (Simmie, 1998). However, none of these studies focuses specifically on the issue of appropriability.

4. The Queen's Award for Innovation survey

The survey we administered collected information on the innovations that received a QAI between 2000 and 2017, a time span which allowed a sufficiently large number of awarded innovations while limiting the risk of recollection bias. Also, the QAI competition was revised in 1999; for the sake of consistency, we decided to target only innovations awarded after this change.

The target survey respondent was either the inventor or the manager of the firm that produced the winning innovation, who was knowledgeable about the appropriability strategy adopted to exploit it. Given the relatively general and comprehensive nature of the questions, it was not always easy to identify who was the most informed respondent.

After interviewing a few QAI winners, we found that the most effective way to reach the most appropriate person was to email the company, describing the objective of our research, mentioning the QAI, and briefly describing the innovation of interest. At this stage, we asked to be put in contact with the manager or inventor involved in the development or commercialization of the product, who was most able to respond to questions on the innovation. This approach proved effective for three main reasons: (1) we asked the companies to identify the most suitable person, thus benefiting from an insider perspective, (2) we established a first contact with the respondent who was then expecting the survey, (3) a brief personal exchange before sending the questionnaire probably increased the commitment of the survey respondent, thereby increasing our survey response rate. Starting from the 793 winners in our dataset (population), we contacted 269 potential participants who agreed to participate after receiving the email with the survey (sample frame). Most of the remaining 524 failed to reply even after several reminders. In some cases, especially in the case of 'older' QAI winners, the company could not reach the targeted person. In 11 cases, we received negative responses for reasons of confidentiality or lack of interest.

Before sending the full survey, we ran a pilot to check the clarity of the questions and the appropriateness of the targeted respondents. Our main goal was to achieve a one-size-fits-all survey that was appropriate for such a diverse sample of firms. We asked potential participants to complete a preliminary version of the questionnaire and provide immediate feedback on its content, structure, relevance of the questions, and timing of the survey. We managed to repeat this procedure for nine innovations belonging to different technological classes. This exercise yielded some important suggestions which helped us improve the overall design of the survey and increase its face validity. The pilot respondents also responded to the full-scale survey.

The final version of our QAI survey was organized in four main parts. Section A asked about the innovation process, the sources of knowledge and funding, the presence of collaborations, and the market structure. Section B asked respondents to select and rank the different appropriability mechanisms adopted during three stages of the innovation process: proof of concept, testing, and commercialization. The format of the questions allowed us to observe both the use and the relevance of a specific strategy, and allowed for comparability of responses across subjects. Section C asked about the reasons for patenting, use of patents, and their perceived importance. Finally, section D asked for additional information on respondents' background, QAI application and selection process, and incentives and benefits related to winning the prize (we provide the survey questionnaire as online supplementary material). Based on the pilot, we estimated the time required to complete the questionnaire to be about 20 minutes.

In mid-May 2017, we sent a personal email with an individual link to the survey to each of the 269 contacts, setting the deadline for responses three weeks later; we sent weekly reminders. Within a month of full administration of the survey, we had collected 196 full responses; we also received 22 partially completed questionnaires which we discarded because of incomplete responses. We achieved an overall response rate of 25% based on the population but 73% based on the sample frame.[5] As expected, the response rate was higher in relation to more recent awards, and this should ensure a high level of recall accuracy (Coughlin, 1990).

[5] Appendix table B.1 presents the response rate

5. Possible selection biases among respondents

Before we developed the survey questionnaire, we conducted extensive research to achieve a better understanding of the nature of the prize and the application process for firms. We accessed some specific documents and conducted a range of informal interviews with both members of the Queen's Awards Office and award winners. We included in the survey a series of questions related to the applicants' perceived value of the award and their experience related to the application process. This information proved valuable to shed light on the main selection effects leading to the sample we obtained, namely:

i. selection into applying for a QAI,
ii. selection of a specific innovation to submit for the prize,
iii. selection into winning an award,
iv. selection into the sample of respondents.

5.1. Selection into applying for a QAI

Depending on the availability and accessibility of the information within the candidate firm, it can take up to a week to complete a QAI application form. [6] The survey responses indicated that the decision to apply typically is made by the management a few months prior to submission. In only 20% of cases was this decision made between 12 months and 3 years in advance. Thus, the application procedure seems not to be a major obstacle to participation; in fact, it is not uncommon for applications to be made for the QAI and the Queen's Award for International Trade in the same year (20% of the winners in our sample had applied for both, 35% of them had been awarded both prizes in the same year). Also, at least 25% of respondents had applied previous to their first award; the same share made more applications following a win.

This signals the importance of this award and the significant benefits attached to it. Specifically, Table 2 ranks the average importance of six possible reasons for participating in the QAI competition scored on a 1-5 Likert scale. Regardless of firm size, applications were aimed primarily at boosting the firm's reputation/prestige and advertising its technological strengths. We noted that personal prestige and laboratory reputation were relatively more relevant for micro and small enterprises. Among the effects of winning, we found that increasing brand recognition and boosting employees commitment were the main ones - regardless of firm size (see appendix Table C.1).

5.2. Selection of a specific innovation to submit

The second selection mechanism is the applicants' decision about which innovation to submit for the competition. In this case, we assume that the selection procedure is driven strongly by the conditions laid down by the Queen's Award competition. To be eligible, an innovation should have generated significant sustained profit over a period of two to five years. Novelty and commercial success must be described and documented in detail. Clearly, development and launch of the innovation on the market must be time-related to the QAI application. Finally, although we do not have information on other eligible innovations which the applicants decided not to submit, we believe that the brand recognition and brand equity benefits are sufficient motivation for the firm to select the invention with the highest chance of winning, and

[6] This estimate is based on the information provided during feedback conversations with the pilot study participants.

Table 2
Reasons for submitting the innovation to the QAI, average score on a scale from 1 (Not at all important) to 5 (Extremely important).

Reasons for applying	Company size (headcount)				Sample average
	Micro (<10)	Small (10–50)	Medium (50–250)	Large (>250)	
(1) Improving my own reputation/prestige	2.9	2.1	1.8	1.6	2.1
(2) Improving reputation/ prestige of our laboratory	2.9	2.6	2.4	2.4	2.6
(3) Improving reputation/prestige of our firm	4.6	4.6	4.7	4.6	4.6
(4) Advertise the invention for commercialization	3.5	3.3	3.5	3	3.4
(5) Advertise the invention in order to attract partners	2.1	2.6	2.3	1.8	2.3
(6) Advertise the technological strength of our company	4.3	4.2	4.4	4.4	4.3
(7) Establishing priority and preventing competing firms from entering in this field of research	3.1	2.3	2.3	2	2.4
No. of observations	33	94	43	26	196

Source: The Queen's Award for Innovation survey.

that this is plausibly the most successful innovation in terms of its market impact in the relevant period.

5.3. Selection into winning a QAI

In September 2018, we were able to speak to two contracted technical assessors who provided more detail on the selection process and the criteria related to innovation quality. The applications are allocated to assessors depending on their area of expertise; the number of assessors depends on the number of applications. The assessors are renowned science and technology experts working in different industries; most are doctoral graduates. For example, in year 2018/2019 there were six assessors and one lead assessor who reviewed and evaluated the applications received. At the start of the process, assessors review the applications and produce a shortlist of applicants.

Every application is appraised by two assessors independently, and in the case that they do not agree, their decisions are reviewed by the lead assessor who will ask them to review and discuss the areas of difference, carry out any further research necessary to validate the claims, and try to resolve the differences. If they continue to disagree it is the responsibility of the lead assessor to make the final decision for this stage. This point in the selection process results in a ranking of recommend, reserved or not recommended for each application received.

The assessors evaluate innovativeness based on the current competitors and market. They refer also to the description in the application of the nature of the product, the innovation process, and the difficulties related to developing new solutions. Patents are regarded as supporting evidence rather than a determining signal of novelty since patenting is not a suitable appropriability strategy in every business sector. Financial criteria are considered important: there should be consistency between the numbers applicants claim, their explanation, and the firm's size.

After the first round of assessment, the firms shortlisted for recommendation and reserve are asked to provide certification of an independent audit of the numbers submitted supporting the commercial success of their innovations. At this stage around, 7% of firms are likely to either withdraw from the process or be downgraded to 'not recommended' based on submission of numbers that do not support their case. A few firms, less than 5% per year, might be upgraded from 'reserve'to 'recommended'. During the audit and review process the Queens Awards Office also conducts due diligence on each applicant and at this stage, generally two or three applicants are withdrawn before the applications are submitted to the panel. Thus, in the context of the due diligence checks retention rates for applications initially shortlisted for an award are high.

The third stage of the process involves the applications categorized recommended and reserved being forwarded to a judging panel convened by the Queens Awards Office that includes representation from leading industry, business, and academic people with a track record in successful innovation. The current panel of judges includes eight innovation experts; panelists are appointed after consultations with both government and external stakeholders. The judging panel is reviewed every three years, and membership has no fixed term. The assessors provide the judging panel with the assessments of level of innovation, impact and benefits delivered, wider value to the UK economy and society, and the applicant's description of the firm's corporate social responsibility agenda. The lead assessor attends the judging panel meeting and provides information related to questions they might have about the application and the (expert) grounds for its inclusion for consideration. Following this panel meeting the final agreed shortlist must be approved by a prime ministerial committee prior to a public announcement (personal communication with two contracted technical assessors, 28/09/2018). This rigorous and multi-step procedure ensures high quality of the winners.

Access to the complete list of applicants is restricted; this was a major limitation which prevented our ability to compare the quality of the winning innovations to those submissions that did not receive an award. As a result, our analysis is focused only on successful innovations, and therefore on what we could call effective appropriability strategies. Also, we were unable to test whether there might be systematic bias against certain types of innovations or applicants. However, the high variations among winners in firm size and technical field of the innovations, suggests that the selection criteria and the multiple stage selection process are effective in avoiding these biases. [7]

5.4. Selection into the sample of respondents

All the responses obtained were from private companies which represent the largest share of the targeted entities.[8] Table 3 presents the innovations by technology field and company size. Among our respondents, we observe a prevalence of SMEs while the size distribution of those firms that provided incomplete responses

[7] We asked the Queen's Awards Office for access to these data but were told by email that the Queen's Awards Office was unable to share any details on unsuccessful applicants for data protection reasons. To our knowledge, to date, no researcher working on the Queen's Awards has had access to this type of information. A study based partially on the Queen's Award winning innovations in 1996 conducted by Bruce Tether was subject to the same limitation. Because of the restricted access to the selection process details, his paper relies on the working assumption that the quality of the winning innovations is constant over time (Tether, 1996).

[8] The only exception was the responses from a charity organization.

Table 3
Innovations classified by technology field and company size.

Respondents	Company size (headcount)					
Technology field	Micro (<10)	Small (10–50)	Medium (50–250)	Large (>250)	Total	% Technology field
Chemistry	4	17	5	3	29	14.80%
Instruments	5	15	14	10	44	22.45%
Electrical engineering	15	39	11	4	69	35.20%
Mechanical engineering	4	11	7	5	27	14.29%
Other fields	3	11	4	2	20	9.69%
Service	2	1	2	2	7	3.57%
Total	33	94	43	26	196	100.00%
% Company size	16.84%	47.96%	21.94%	13.27%	100.00%	
Non-respondents						
Total	15	18	21	19	73	
% Company size	20.55%	24.66%	28.77%	26.03%	100.00%	

Notes: the technology field classification is based on Schmoch (2008). Source: The Queen's Award for Innovation survey.

is rather uniform.[9] Interestingly, among non-respondents, we observe a relatively higher share of large companies. Large firms are likely to have stricter confidentiality policies which might have prevented them from answering the survey questions, and also it might be more difficult for large firms to retrieve the information on a specific innovation.

The last column in Table 3 shows that the fields of electrical engineering (including digital communications, telecommunications, audio-visual technology, computer technology, management information technology, etc.) and instruments (measurement, control, optics, medical technology, biological materials analysis) prevail; the former predominates for micro and small firms, and the latter for medium and large enterprises.[10] Given the time interval covered by the QAI survey (around 70% of the respondent had received the award after 2010), this might represent the emergence and consolidation of information and communications technology (ICT) as a new techno-economic paradigm (Freeman and Louçã, 2001). In a study based on R&D100 competition data, Fontana et al. (2012) found a similar skew towards 'high-tech' sectors such as instruments and ICT. These findings suggest also that these types of innovation competitions are likely to attract 'high tech' firms that want to showcase and benefit from technological expertise. Finally, the sectoral distribution is consistent with the results of the UK Innovation Survey 2015 (UKIS), which is the UK contribution to the 9th Europe-wide Community Innovation Survey (CIS). The main report shows that 'Manufacture of Electrical and Optical Equipment' was the most innovative class over the most recent two survey waves (2010-2012, 2012-2014) with 71% and 62% of the businesses operating in this field being innovative (BEIS, 2016).

6. Appropriability strategies employed by Queen's Award for Innovation winners

To our knowledge, this study is the first analysis of appropriability strategies to include a time dimension. We are interested, in particular, in the possible combination of formal (patents, trademarks, publications) and informal (secrecy, lead times, complementary assets) appropriability mechanisms related to a single product. We asked respondents to rank these separately from 1 (most important) to n (total number of mechanisms in place, ranging from 1 to 7) the mechanisms they used to protect their innovations during three product development phases: (1) proof of concept, (2) testing and (3) commercialization. We distinguish between 'real-time' appropriability strategies and 'grand' appropriability strategies. The former refers to the set of separate mechanisms applied in each development phase; the latter refers to the (coordinated) set of real-time strategies employed along the whole innovation development process.

6.1. Appropriability and the phases of product development

In the case of real-time appropriability strategies, respondents could select three per innovation. Table 4 presents the number of real-time strategies where a single mechanism was used and ranked as most important (see supplementary material, survey section B).[11] We present this frequency also as a percentage of the total number of real-time strategies deploying that same mechanism within a specific phase.

At proof of concept stage, secrecy was ranked as the most important mechanism for 45 innovations, corresponding to 53% of the times that secrecy was adopted in this phase. Not surprisingly, both the use and relative effectiveness of secrecy tend to decrease as the innovation approaches commercialization. However, in the case of patents, there is no clear pattern along the product development process. Overall, they were ranked as the most relevant appropriability mechanism in 37% of the real-time strategies that use patenting. Similarly, lead time is ranked high and its frequency is stable across development phases. Lead time was included 51% of the time within a real-time appropriability strategy whereas complementary assets and complexity were considered to be the most important mechanisms in respectively 31% and 23% of all the real-time strategies that deploy them.[12] For trademarks and publications across the three development phases the figures drop to 11%. Laursen and Salter (2005) considered legal and first mover mechanisms separately and found that firms favor the latter; the aim is to be 'silent, complex and quick'. Overall, our results support this finding.

6.2. Appropriability across sectors and firm sizes

We compared the average ranking of appropriability mechanisms and their frequency of adoption. In particular, we provide a comprehensive picture of appropriability strategies, by considering the appropriability mechanisms listed in the different phases. We consider a mechanism as 'used' if it is mentioned in relation to at least one phase of product development. Tables 5 and 6 report

[9] Respondents were asked to indicate the size of the winning firm at the time of the award. Since we do not have this information for the winning firms that did not respond to our survey, Table 3 reports current size for non-respondents.

[10] The technology field classification is similar to Schmoch's (2008) patent classes. We included an additional category to account for service innovations.

[11] Note that the number of possible real-time appropriability strategies is 196 innovations times 3 phases i.e. 588. However, we obtained only 568 strategies. Missing values occur whenever the number of development phases is less than 3.

[12] Complementary assets comprise complementary technologies, sales and services capabilities, and manufacturing capabilities.

Table 4
Number of real-time strategies in which a single mechanism has been ranked as the most important (rank = 1).

Appropriability mechanisms	Proof of concept		Testing		Commercialization		Total	
	No.	% of total	No.	% of total	No.	% of total	No.	% of total
Secrecy	45	53%	32	46%	18	33%	95	45%
Patents	26	36%	20	37%	26	38%	72	37%
Trademarks	2	8%	3	13%	6	12%	11	11%
Publications	1	7%	0	0%	6	19%	7	11%
Complementary asset	43	21%	49	25%	46	19%	138	31%
Lead time	57	50%	52	50%	69	54%	178	51%
Complexity	18	17%	30	30%	19	22%	67	23%
No. of observations	192		186		190		568	

Notes: '% of total' presents the number of real-time strategies in which a mechanism was ranked most important as a share of the total number of real-time strategies mentioning the same mechanism (i.e. not just most important) for that product development phase. Source: The Queen's Award for Innovation survey.

Table 5
Frequency of adoption and perceived importance of different appropriability mechanisms per technology field, no. of observations: 196.

Technology fields	No.	Secrecy		Patents		Trademarks		Publications		Complementary assets		Lead time		Complexity	
		Use	Rank	Use	Rank	Use	Rank	Use	Rank	Use	Rank	Use	Rank	Use	Rank
Chemistry	29	69%	2.0	55%	1.5	34%	2.5	14%	2.9	97%	2.7	93%	2.0	38%	2.4
Electrical engineering	69	38%	2.4	35%	2.8	29%	3.5	16%	3.7	90%	2.7	81%	1.6	80%	2.4
Instruments	44	64%	2.4	68%	2.7	34%	4.5	32%	4.7	93%	2.8	80%	1.7	64%	2.9
Mechanical engineering	28	54%	1.5	86%	1.8	32%	3.4	14%	6.8	89%	2.9	82%	2.4	57%	3.1
Other fields	19	37%	1.5	58%	2.1	26%	3.9	21%	2.7	100%	2.5	89%	1.7	63%	2.5
Services	7	0%	NA	0%	NA	0%	NA	0%	NA	86%	1.8	71%	1.7	43%	2.2
Full sample	196	49%	2.1	54%	2.2	30%	3.6	19%	4.2	92%	2.7	83%	1.8	64%	2.6

Notes: 'Use' reports the share of innovations in which a mechanism is listed in at least one real-time strategy. 'Rank' reports the average rank position that a mechanism received when it was deployed. Rank=1 is the highest value, thus, the lower the number, the more a mechanism is perceived as important. Source: The Queen's Award for Innovation survey.

Table 6
Frequency of adoption and perceived importance of different appropriability mechanisms per company size, no. of observations: 196.

Company size	No.	Secrecy		Patents		Trademarks		Publications		Complementary assets		Lead time		Complexity	
		Use	Rank	Use	Rank	Use	Rank	Use	Rank	Use	Rank	Use	Rank	Use	Rank
Micro (<10)	33	39%	2.3	52%	2.6	36%	3.3	18%	4.9	97%	2.7	82%	1.8	70%	2.5
Small (10–50)	94	53%	2.1	50%	2.2	29%	3.6	18%	3.8	88%	2.8	84%	1.9	70%	2.5
Medium (50–250)	43	51%	2.1	58%	1.9	26%	3.1	19%	4.0	98%	2.4	84%	1.7	60%	2.8
Large (>250)	26	42%	2.1	62%	2.3	35%	4.2	23%	4.8	92%	2.6	81%	1.8	42%	2.8
Full sample	196	49%	2.1	54%	2.2	30%	3.6	19%	4.2	92%	2.7	83%	1.8	64%	2.6

Notes: 'Use' reports the share of innovations in which a mechanism is listed in at least one real-time strategy. 'Rank' reports the average rank position that a mechanism received when it was deployed. Rank=1 is the highest value, thus, the lower the number, the more a mechanism is perceived as important. Source: The Queen's Award for Innovation survey.

the share of innovations protected by a given mechanism (use) and its average ranking. To investigate possible patterns in use and effectiveness, we disaggregated the results by technology field and company size [13]

The disaggregation highlights some interesting patterns. First, our overview confirms that lead time is one of the most important and frequent mechanisms across all technology fields and regardless of company size, with an overall adoption rate of 83% and an average ranking of 1.8. Secrecy and patents are used to protect around 50% of the innovations and exhibit comparable patterns. Secrecy is preferred in chemistry (69%) but consistent with the literature, patents are considered more effective on average, with a ranking of 1.5 (e.g. Levin et al., 1987, Arora, 1997). The reverse applies to mechanical engineering innovations. Patents showed the lowest levels of adoption and perceived effectiveness for electrical engineering which covers 50% of the supposedly non-patentable innovations in the dataset.[14] We found that focusing on development of complementary assets is a key determinant of success across technology fields. Complexity is mentioned frequently in electrical engineering but does not emerge as important (average rank=2.4). Trademarks and publications are characterized by their low adoption and perceived effectiveness; however, their low ranking suggests they are used only when there are other mechanisms in place.

Overall, secrecy and patenting seem to be the most sector specific with other mechanisms used more homogeneously and considered more effective across technology fields. The observed discrepancy between the comparatively high ranking and low frequency of these mechanisms, might be indicative of this specificity and imply that secrecy and patents are effective only in contexts where certain market conditions/product features are in place (e.g. Arundel, 2001).

[13] The ranking ranges from 1 (most important) to 7 least important when all the mechanisms are used. The average ranking of a mechanism is computed first as the average rank among the real-time strategies for a single innovation. The values reported in Tables 5 and 6 are the means of the innovation level averages in each sector and each firm-size category.

[14] This was the direct assessment of survey respondents. Out of 40 innovations deemed non-patentable, 20 were electrical engineering related, and 11 were described as Software.

Table 7
Co-occurrence matrix of different appropriability mechanisms at the innovation level, no. of observations: 196.

Appropriability mechanism	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Secrecy	96						
(2) Patents	58	105					
(3) Trademark	34	42	59				
(4) Publications	24	20	19	37			
(5) Complementary assets	87	89	55	36	181		
(6) Lead time	81	84	51	29	154	163	
(7) Complexity	61	52	36	28	120	102	125

Source: The Queen's Award for Innovation survey.

Table 6 shows that use of patenting increases slightly with company size, highlighting the patent enforcement burden for small and micro companies (Cohen et al., 2000; Lanjouw and Schankerman, 2001; Leiponen and Byma, 2009). Conversely, product complexity is more frequent among smaller firms.

If we move from rankings for single mechanisms to occurrence of combinations of mechanisms, we observe high levels of complementarity. In the case of grand appropriability strategies, Table 7 shows that the development of complementary assets, lead time, and complexity are widely used in combination with secrecy and patents. We observed also that 58/196 innovations are protected by both patents and secrecy (30%). This extends the findings in Arora (1997) which apply only to the chemical sector. It is consistent also with the findings in Hall et al. (2013) for UK firms, showing that firms use different appropriability mechanisms simultaneously, possibly using patenting and other formal IPR means with informal measures.

6.3. The choice to patent

Based on the survey results, 80% of the innovations in our sample were deemed patentable, and 67% of those were patented (54% of the 196 responses). As a next step, we investigate the motivations for applying for patent protection, Tables 8 and 9 show the average importance of five common reasons to patent, by company size and technology field. To prevent imitation and to block competitors are the most important, followed by signaling. Licensing and cross-licensing are less relevant: only 26% of patents have been exploited commercially, and only 17% have been licensed. Overall, there seems to be a combination of 'orthodox' and 'heterodox' use of patents: on the one hand, protecting innovations was the main reason cited; on the other hand, the signaling effect of patents appears relevant for micro and small firms. Similarly, we observe a higher share of small and micro firms seeking external finance compared to larger companies (19% vs. 7%). This gap increases in the case of patented innovations (26% vs. 8%).

In line with the existing literature, our study reveals that the decision to patent is affected by strategic motives which go beyond protection of the innovation from imitation (e.g. Blind et al., 2006, Hall and Ziedonis, 2001). We left space for respondents to add other relevant reasons not included in our list; 12 respondents used this opportunity. Eight gave more refined explanations related to the reasons listed in the questionnaire. Four cases referred to the possibility to get patent box tax relief to benefit from 'a lower corporate tax for associated profits from the product'.

We also included the counterfactual question of whether the innovation would have been developed had patent protection been unavailable. This question was originally proposed by Mansfield (1986). Remarkably, 91% of the QAI respondents who chose to patent, confirmed that the relevant innovation would still have been developed even in absence of patent protection.[15] On the one hand, this result is consistent with the increasing tendency towards strategic use of patenting, on the other hand, it supports the effectiveness of informal appropriability mechanisms for profiting from innovations. In a broader framework, this finding would seem to question policy perspectives characterized by 'patent fundamentalism', and positing a critical role for strong patent systems for providing a fundamental incentive for R&D activities.[16]

Among the reasons not to patent, we found that 40/196 innovations in our dataset were considered non-patentable (20%). Our specific question, allowed respondents to select more than one options (see Table 10): 'Believe the innovation was not patentable' was the only motive in 25 cases. Tables 10 and 11 present five possible reasons not to patent disaggregated by company size and technology field. Some options such as cost related issues are perceived differently by different sized firms; others are more sector specific. We observe that the costs of applying for and enforcing a patent are particularly relevant for micro and small enterprises while information disclosure is a relatively bigger concern for large companies. In some cases, trade secret is considered an adequate appropriability mechanism by both small and large firms. Consistent with the findings presented in Table 4, in chemistry, trade secret tends to be preferred over patents to avoid information disclosure.

6.4. Empirical characterization of appropriability strategies

In this section, we provide an empirical characterization of grand appropriability strategies, i.e. sequences of decisions about appropriability mechanisms made by the companies at different points in time. The aim is to identify possible sectoral patterns in appropriability strategies. Traditionally, the sectoral dimension was considered an important determinant of differences in firms' innovative behavior (e.g. Pavitt, 1984, Malerba and Orsenigo, 1996). However, more recent studies show that sectoral specificities account for only a small part of these differences and most is explained by firm-level heterogeneity (Srholec and Verspagen, 2012).

Following the procedure in Srholec and Verspagen (2012), we designed a two-stage factor analysis to provide an empirical characterization of the temporal profile of the grand appropriability strategies identified in our survey. In the first stage, we capture the interplay among different appropriability mechanisms in each phase of the innovation development process i.e. the real-time strategy level. In the second stage, we aggregate phase-specific behavior to distinguish the grand strategy which emerges as a latent factor spanning the three phases of innovation development (appendix D provides a description of the process).

We identify three grand strategies. The first we call 'Formal protection and secrecy' which is characterized by use of patents, complemented by trademarks, publications, and secrecy. The second grand strategy, 'Complexity and complementary assets', is characterized by complexity as the main protection mechanism across the development phases. The third grand strategy we call 'Exploitation of lead times and complementary assets'; this strategy relies heavily on lead time combined in the early development stages with use of complementary assets. It should be noted that

[15] Mansfield (1986) found that patents were not considered essential for 35%-70% of the inventions developed in pharmaceutical and chemicals, 82%-88% in petroleum, machinery and fabricated metal products, and more than 90% in another 7 industries. The average share of inventions that would have been developed even without patents across the 12 industries Mansfield considered was 86%.

[16] For more elaborated discussions see Dosi et al. (2006) and Boldrin and Levine (2008).

Table 8
Importance of 5 reasons to patent per company size, average score on a scale from 1 (Not at all important) to 5 (Extremely important).

	Company size (headcount)				
Reasons for patenting	Micro (<10)	Small (10–50)	Medium (50–250)	Large (>250)	Sample average
Licensing	2.2	2.2	2.2	1.4	2.1
Cross-licensing	1.4	1.5	1.6	1.3	1.5
Prevent imitation	4.5	4.4	4.7	4.8	4.6
Blocking	4.1	3.8	4.4	4.2	4.1
Signaling	2.8	2.8	2.4	1.6	2.5
No. of observations	17	47	25	16	105
Patented innovations as % of total	52%	50%	58%	62%	54%

Notes: The question in the survey was as follows: ‘how important were the following reasons for patenting the awarded product?’ Source: The Queen’s Award for Innovation survey.

Table 9
Importance of 5 reasons for patenting per technology field, average score on a scale from 1 (Not at all important) to 5 (Extremely important).

	Technology fields						
Reasons for patenting	Chemistry	Electrical engineering	Instruments	Mechanical engineering	Other fields	Services	Sample average
Licensing	2.1	2.4	1.8	2.4	1.4	NA	2.1
Cross-licensing	1.5	1.8	1.2	1.5	1.1	NA	1.5
Prevent imitation	4.3	4.4	4.6	4.6	5	NA	4.6
Blocking	3.5	4.2	4.1	4	5	NA	4.1
Signaling	2.1	2.4	2.7	2.5	2.9	NA	2.5
No. of observations	16	24	30	24	11	0	105
Patented innovations as % of total	55%	35%	68%	86%	58%	0%	54%

Notes: The question in the survey was as follows: ‘how important were the following reasons for patenting the awarded product?’ Source: The Queen’s Award for Innovation survey.

Table 10
Reasons not to patent by company size, no. of observations: 91.

	Company size (headcount)							
Reasons not to patent	Micro (<10)	%	Small (10–50)	%	Medium (50–250)	%	Large (>250)	%
(1) Did not want to disclose information	2	13%	9	19%	3	17%	4	40%
(2) Cost of getting a patent	3	19%	13	28%	2	11%	0	0%
(3) Believed secrecy was adequate	4	25%	10	21%		22%	1	10%
(4) Cost of enforcing patents	6	38%	13	28%	3	17%	2	20%
(5) Believed technology was not patentable	8	50%	20	43%	10	56%	2	20%

Notes: the question in the survey was as follows: ‘If the awarded product is not patented, which of the following influenced your company’s decision not to patent?’. The Table reports the frequency of innovations identifying a specific reason as relevant. The percentage shares are the share of innovations mentioning the answer on the total innovations made by that company size category. Source: The Queen’s Award for Innovation survey.

Table 11
Reasons not to patent by technology field, no. of observations: 91.

	Technology field											
Reasons not to patent	Chemistry	%	Electrical engineering	%	Instruments	%	Mechanical engineering	%l	Other fields	%	Services	%
(1) Did not want to disclose information	7	54%	6	13%	3	21%	0	0%	0	0%	2	29%
(2) Cost of getting a patent	2	15%	9	20%	4	29%	1	25%	1	13%	1	14%
(3) Believed trade secret was adequate protection	6	46%	8	18%	3	21%	0	0%	1	13%	1	14%
(4) Cost of enforcing a patent	2	15%	10	22%	4	29%	3	75%	4	50%	1	14%
(5) Believed technology was not patentable	4	31%	20	44%	5	36%	1	25%	6	75%	4	57%

Notes: the question in the survey was as follows: ‘If the awarded product is not patented, which of the following influenced your company’s decision not to patent?’. The Table reports the frequency of innovations identifying a specific reason as relevant. The percentage share are the share of innovations mentioning the answer on the total innovations in that sector. Source: The Queen’s Award for Innovation survey.

secrecy is the only informal mechanism positively correlated to use of formal IPR alternatives, despite the long-standing perception that it is a substitute for patents (Hall et al., 2014). Depending on the factor scores, we relate each innovation in our dataset to one specific grand appropriability strategy. Fig. 1 depicts the relative frequency of the strategies per sector.

This graphical presentation does not reveal relevant differences across sectors apart from services where as expected, the strategy ‘Formal protection and secrecy’ is not used. In line with the literature, we find that strategies based on informal mechanisms prevail without exception. ‘Formal protection and secrecy’ is particularly important in chemistry and mechanical engineering, ‘Complexity and complementary assets’ is relevant in electrical engineering while a grand strategy based on lead time shows a relatively high share in civil engineering innovations (other fields). Nevertheless, the variance captured by sectoral differences is small.[17]

[17] The role of sectors for explaining differences in appropriability strategies can be assessed using a multilevel mixed-effects linear regression. The model shows that

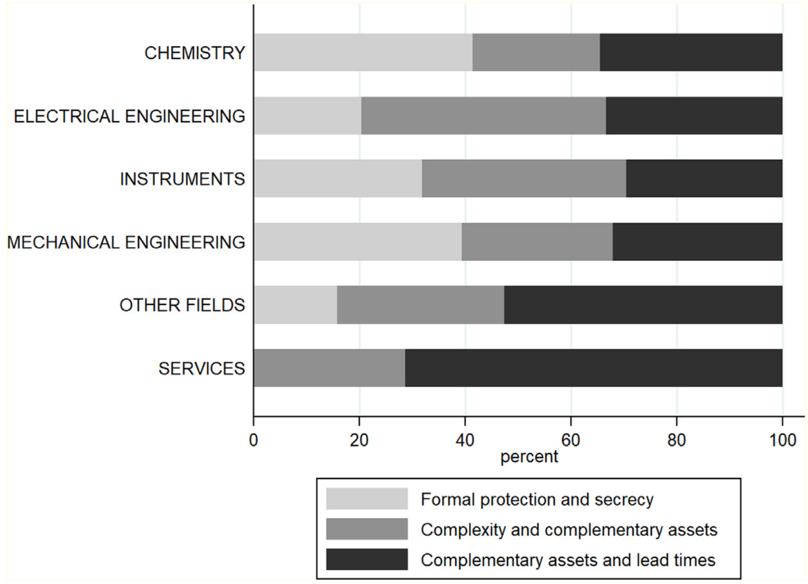

Fig. 1. Sectoral patterns in appropriability strategies.

7. Conclusion

This paper investigated appropriability strategies used for successful breakthrough innovations. Our study contributes to the literature by adopting an innovation-level rather than a firm perspective. Our survey collected detailed information on the development and commercialization of Queen's Award-winning innovations and how firm protect them from imitators. This level of analysis allowed us to capture the firm's decisions related to protecting important innovations during their development. The responses to the survey provided information which does not typically emerge neither from traditional firm level surveys nor from patent-based studies.

We found evidence that appropriability strategies designed to protect successful innovations include combinations of different appropriability mechanisms. A firm's initial grand strategy can change depending on the innovation development phase, and can include different protection mechanisms which may be more or less effective at each point in time. Trade secret is considered to be more effective in the early development phases while lead time is particularly relevant during product commercialization. Other mechanisms seem not to be exclusive to specific phases. However, it is interesting that even when adopted in combination with other mechanisms, patents are perceived as less effective than informal alternatives. More specifically, we observed a contrasting outcome in line with the 'patent paradox' (Hall and Ziedonis, 2001): on the one hand, 54% of the innovations in our sample had at least one of their features patented, and in general, non-patentability was cited as the main reason for not resorting to formal IPR protection. On the other hand, we found that only 9% of the cases considered patents to be crucial for the development of the innovation. Over the full sample, strategic motivations for patenting such as blocking competitors and signaling were seen as more important than licensing and cross-licensing.

An empirical characterization based on exploratory factor analysis showed that firms opt for specific combinations of appropriability mechanisms. Consistent with the existing literature, we found that the most common strategies are based on informal mechanisms, while secrecy tends to be associated more to formal than informal mechanisms. We did not identify any well-defined sectoral patterns in the use of particular strategies. This might suggest that, beyond sectoral specificities and size constraints, individual firms tend to have a preference for a specific strategy.

The survey responses would seem to confirm this notion. Based on the six respondent companies that had won a QAI twice between 2000 and 2017, and completed a survey questionnaire for each winning product, when we compare the appropriability mechanisms employed in these six pairs of innovations, we observe that the firms deployed the same strategy in each case (i.e. employing or not a specific mechanism for both products) for an average of 5.2/7 mechanisms.[18]

These findings support the notion of relative stability in the general appropriability strategies adopted by a firm. Therefore, sectoral conditions are not the only determinant of the firm's appropriability behavior. It seems that the firms' idiosyncratic characteristics are also important. From an evolutionary perspective, each sector can be seen as a complex ecosystem in which firms with different appropriability strategies can co-exist successfully.[19] In line with Srholec and Verspagen (2012) who highlight a remarkable degree of heterogeneity in firms' innovative behaviors within sectors, we found evidence of heterogeneity also at the level of appropriability strategies. A detailed account of the sources of this firm heterogeneity is beyond the scope of this paper; however, using an evolutionary lens, the natural candidates would include routines which tend to exemplify firms' responses and behaviors.

This study has some limitations. First, the empirical analysis includes only successful innovations and the impossibility of constructing counterfactual cases (i.e. lack of information on the appropriability strategies employed to protect innovations that did not receive a QAI) does not allow empirical assessment of the effect

sectors explain a small but significant proportion of the individual variance (around 4%). This result is in line with the findings in Srholec and Verspagen (2012) who argue that despite the significant contribution of firm level variance, accounting for sectoral differences leaves 95% of it unexplained. Detailed results are available upon request.

[18] We refer to the 7 main mechanisms considered in this paper: trade secret, patents, trademarks, publications, complementary assets, lead time and complexity.

[19] For a historical case study of the co-existence of different appropriability strategies at sectoral level see Nuvolari and Sumner (2013).

Table B.1
Queen's Award for Innovation survey response rate

Population		Sample frame		Full-responses		
Year	Population	No.	% Population	No.	% Population	% Sample frame
2000	32	8	25%	4	13%	50%
2001	42	4	10%	3	7%	75%
2002	37	7	19%	2	5%	29%
2003	51	13	25%	10	20%	77%
2004	39	9	23%	3	8%	33%
2005	41	8	20%	5	12%	63%
2006	48	12	25%	7	15%	58%
2007	40	9	23%	4	10%	44%
2008	42	15	36%	11	26%	73%
2009	49	25	51%	12	24%	48%
2010	38	17	45%	13	34%	76%
2011	44	14	32%	14	32%	100%
2012	50	17	34%	13	26%	76%
2013	27	7	26%	6	22%	86%
2014	39	19	49%	15	38%	79%
2015	25	16	64%	11	44%	69%
2016	92	52	57%	47	51%	90%
2017	57	17	30%	16	28%	94%
Total	**793**	**269**	**34%**	**196**	**25%**	**73%**

of different strategies on innovation success. However, given the descriptive nature of the paper, we consider this constraint to have limited impact. Second, we examined all possible sources of bias in our data. While we believe that our results are not undermined by bias, we hope that our study will spark further data-driven research on breakthrough innovations.

Acknowledgements

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Appendix A. Preliminary data steps

This investigation started from the short descriptions of QAI winners reported every year in *The Gazette*, the UK official public record. Each entry includes the name of the company, the location at the time of the award and a brief description of the winning innovation; an example from 2008:

4fx Healthcare Ltd
Mansfield, Nottinghamshire
Baby nose-clear infant nasal aspirator

Since 2009, the Queen's Award Office has provided more detailed explanations that include the number of employees in the winning company or branch, and a reference contact for press inquiries. An example of the most recent descriptions is:

Forge Europa Limited
The Old Railway, Princes Street, ULVERSTON, Cumbria LA12 7NQ
Website: www.forge-europa.co.uk
Employees:
Managing Director: Mr R P J Barton23
Ultimate Parent: N/A
Contact for press enquiries: Julie Barton,
Tel: 01229580000
E-mail: Julie@forge-europa.co.uk
An Innovation Award is made to Forge Europa Limited for the design and manufacture of LED displays, assemblies and lighting solutions. Having identified the emerging market for solid state lighting products, in 2004 the company invested in capability, including technical staff and laboratories, to supply customised LED lighting. This has inherent benefits of low energy consumption, long life, compactness and high controllability. Thermal management techniques were developed to optimise light output efficiency and colour consistency and intensity. Successful developments include traffic signals, passenger information displays, street lighting, marine lighting, portable floodlighting and vehicle lighting. Since the investment the company has enjoyed increasing commercial success.

In a related study, we performed patent matching on the innovations awarded from 1976 to 2015 and found that 32% were patented.[20] This finding was the conceptual basis for the survey investigation, and provided an initial pool of inventor names. This listing was helpful for understanding how to reach the target respondents.

Appendix B. Tabulation of the response rate

[20] The different patent propensity rate is due to both content-related and methodological issues. First, 32% of the survey responses are from years 2016 and 2017 which were not considered in the previous investigation. Second, when performing the patent matching, we searched within a specific time lag preceding the award. On the one hand, we assumed a patent to be effective only if the company filed it before commercializing the innovation, thus we disregarded the two years before the award. On the other hand, we searched as far back as 10 years before winning on the assumption that a patent filed more than 10 years earlier would refer to a previous version of the innovation. Given these restrictions, we correctly classified 72% of the product innovations covered by both the survey and the matching procedure.

Table C.1
Main consequences of winning a QAI, average score on a scale from 1 (Not at all important) to 5 (Extremely important).

Consequences of winning	Company size (headcount) Micro (<10)	Small (10–50)	Medium (50–250)	Large (>250)	Sample average
(1) Facilitating entry in new markets	3.6	3.6	3.6	3.5	3.6
(2) Increase brand equity	4.3	4.4	4.3	4.3	4.3
(3) Increase sales of the awarded product	4	4	4.1	3.9	4
(4) Boost employees commitment and motivation	4.2	4.3	4.4	4.2	4.3
(5) Foster marketing effort at firm level	3.9	3.9	4	4.1	3.9
No. of observations	33	94	43	26	196

Source: The Queen's Award for Innovation survey.

Table C.2
Importance of 10 sources of knowledge per innovations' technology field, average score on a scale from 1 (Not at all important) to 5 (Extremely important).

External sources of knowledge	Technology fields Chemistry	Electrical engineering	Instruments	Mechanical engineering	Other fields	Services	Sample average
University laboratories and faculty	2.1	1.4	1.6	2.3	1.5	1.2	1.7
Non university public laboratories	1.9	1.2	1.7	2.4	1.6	1.3	1.6
Technical conferences and workshops	2	2.2	2	2.2	1.8	1.2	2.1
Scientific literature	2.6	2.1	2.7	2.2	2.4	1.2	2.3
Patent literature	2.7	1.7	2.5	2.7	2.3	1.5	2.2
Customers or product users	3.8	4.4	4.4	4	3.9	4.5	4.2
Suppliers	2.6	2.6	3	3	3.3	2.2	2.8
Competitors	2.1	2.8	2.5	2.5	2.2	2.2	2.5
Market data	2.8	3.4	3.3	3.2	3.1	3	3.2
Open source software	1.3	2	1.6	1.6	1.1	2.2	1.7
No. of observations	29	69	44	28	19	7	196

Source: The Queen's Award for Innovation survey.

Appendix C

C.1 Consequences of winning a QAI

Table C.1

C.2 Characteristics of the innovations

Throughout the survey, we asked respondents to answer the questions bearing in mind the specific case of the QAI winning 'product'. Based on the perceived importance of external sources of knowledge, we find that customers/product users are by far the most relevant source which is largely consistent with the literature (Freeman and Soete, 1997; Tether, 2002; Laursen and Salter, 2004; Von Hippel, 2005; Giuri et al., 2007). Market data and suppliers also scored high across sectors.[21] According to the UKIS, the ranking of external sources of knowledge has been stable through the years, and market sources are consistently ranked as the most important. In contrast, institutional sources such as universities and public research institutes were the least frequent (BEIS, 2016). We find that university and non-university laboratories received a relatively higher score for innovations in the fields of chemistry and mechanical engineering but on average, are the least relevant sources of external knowledge. This outcome reflects the award's parameters which stress the successful commercialization of the innovations: the closer a product is to the market, the less relevant is basic research.

Table C.2

There are some interesting differences between our results and the outcome of the PatVal- EU survey (Giuri et al., 2007). While customers and product users stand out as the most important source of external knowledge in both surveys, PatVal inventors also ranked patent literature and scientific literature as valuable inputs. In the QAI survey, we observe a significantly higher score for these categories when considering only patented innovations. This result implies a bias emerging from limiting the focus to patented inventions.

The role of other firms tends to be regulated by contractual agreements: 30% of the innovations in our sample were the result of a formal collaboration, with the top three collaborators being suppliers, customers and product users, and other firms. In a very few cases (8% of collaborators), the development of an innovation involved formal cooperation with a university: 54% of innovations in the field of mechanical engineering were based on a formal collaboration, and 12% in electrical engineering. The share for chemistry and instruments is 30%. As expected, the presence of a formal collaboration does not hinder use of other external sources of knowledge. Instead, collaborating firms are more likely to value external sources of knowledge in general (Cassiman and Veugelers, 2002). Table C.3 shows that the influence of universities, public laboratories and patent literature (inter alia) is significantly more important for innovations backed by a formal collaboration.

We find that the majority of the innovations developed within a formal collaboration are patented (62%) which is in line with the so-called 'open innovation paradox' (Bogers, 2011). This share is particularly high for the fields of instruments and mechanical engineering, 77% and 80% respectively.

Finally, Table C.4 shows that reliance on external sources of knowledge depends on the firm's familiarity with the characteristics of the novel product. If the award-winning innovation builds on a product developed by the same company, reliance on external sources of knowledge/partners/finance decreases.

To understand the monetary value and the effort involved in the development of the QAI winning innovations, we included a question originally formulated by Giuri et al. (2007) as part of the PatVal-EU Survey.[22] Fig. C.1plots the joint frequency of the esti-

[21] 'Market data' was an option suggested by two respondents during the pilot phase, it covers intelligence data on market trends and dynamics.

[22] The question was: 'This is a hypothetical question: 'Suppose that on the day in which the patent on this product was granted, the applicant had all the information

Table C.3
Average importance of 10 sources of knowledge per innovations' collaboration status, average score on a scale from 1 (Not at all important) to 5 (Extremely important).

Sources of knowledge	No formal collaborations	Yes formal collaborations	P-value on H_0 = equality of means
University laboratories and faculty	1.5	2.08	0.026
Non university public laboratories	1.45	2.2	0.053
Technical conferences and workshops	2.01	2.12	0.630
Scientific literature	2.25	2.59	0.152
Patent literature	2.06	2.66	0.025
Customers or product users	4.23	4.13	0.394
Suppliers	2.61	3.37	0.000
Competitors	2.61	2.24	0.087
Market data	3.2	3.23	0.897
Open source software	1.69	1.63	0.993
No. of observations	137	55	–

Notes: p-value results from the two-Sample Fligner-Policello robust rank order test. Source: The Queen's Award for Innovation survey.

Table C.4
Types of innovation and use of external sources of knowledge, number of observations: 196.

Follow-up innovation	No.	Formal collaboration Yes	External knowledge Extremely important	External finance Yes
Yes	78	26%	53%	37%
No	118	30%	64%	63%

Notes: An innovation is classified as a follow-up if 'Yes' was the answer to both questions: (a) 'Did the awarded product build in a substantial way on other products you were aware of?' (Yes, No, Do not know), (b) 'Was this previous product developed by the award winning organization?' (Yes, No, Do not know). External knowledge is considered important if there is at least one item with score=5 (Extremely important). The question on external finance was as follows: 'Did your firm apply for external funding to partially finance the research leading to the awarded product?' (Yes, No). Source: The Queen's Award for Innovation survey.

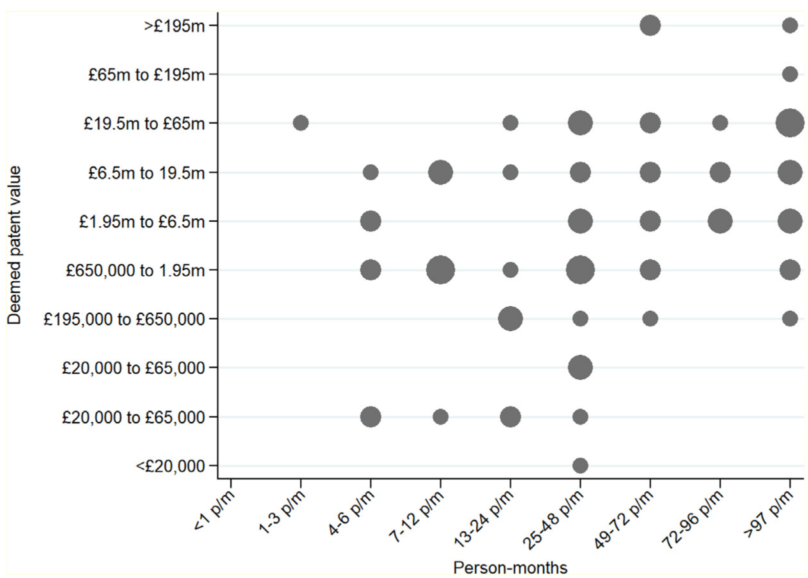

Fig. C.1. Joint frequency distribution of deemed patent value and person/month working on the innovations, based on 74 innovations (70% of the patented innovations, the remaining 30% answered 'Do not know' about the patent monetary value). The marker size indicates a number of innovations that ranges from 1 (small circles) to 4 (large circles). Source: The Queen's Award for Innovation survey.

mated patent value and the person/months spent working on the QAI product. It confirms that our sample is characterized by a relatively large share of high-value and high-commitment innovations. This provides further support for the 'breakthrough' nature of the innovations we consider and the relevance of our findings for firms' appropriability strategies.

about the value of the patent that is available today. If a potential competitor of the applicant was interested in buying the patent at that time, what would be the minimum price the applicant would demand?'

Appendix D. Appropriability strategies factor analysis

We perform a two-stage factor analysis to identify the prevailing appropriability strategies in the dataset. In a preliminary step, we codify the use of the seven appropriability mechanisms considered in our study. To capture the variability in the real-time strategies, we create seven dummy variables for each development phase (21 variables in total) that take the value 1 if a particular mechanism was adopted in a specific phase, and 0 otherwise. In the first-stage factor analysis, we extract factors separately for each development stage to see how different mechanisms are combined at one moment in time. Then, we run factor analysis on the factor scores obtained from the first-stage. The second-stage factors then

Table D.1
First-stage factor loadings, number of observations: 192.

Appropriability mechanisms	Formal protection	Rely on complexity	Complementary assets and lead times
Secrecy	0.2762	−0.0193	−0.8533
Publishing	0.6731	0.5837	−0.1315
Patent	0.6367	−0.5983	−0.0107
Trademark	0.8938	0.0240	−0.0709
Complementary assets	0.1715	0.1062	0.6636
Lead times	0.3740	0.0224	0.5015
Complexity	0.0508	0.9194	0.0899

(a) Stage 1: proof of concept

Appropriability mechanisms	Formal protection and secrecy	Rely on complexity	Complementary assets and lead times
Secrecy	0.4460	−0.1103	−0.5065
Publishing	0.7738	0.4904	−0.0595
Patent	0.7523	−0.4191	−0.0045
Trademark	0.8498	−0.0144	−0.0234
Complementary assets	−0.0157	0.3064	0.7222
Lead times	0.0642	−0.5488	0.5692
Complexity	0.0114	0.8779	0.1751

(b) Stage 2: testing

Appropriability mechanisms	Formal protection and secrecy	Complexity and complementary assets	Lead times and patents
Secrecy	0.5868	0.2131	0.1344
Publishing	0.4899	0.5710	−0.5183
Patent	0.6523	−0.1752	0.3794
Trademark	0.8619	−0.0876	0.0002
Complementary assets	−0.0834	0.7802	−0.0596
Lead times	0.3740	0.0224	0.5015
Complexity	0.0508	0.9194	0.0899

(c) Stage 3: commercialization

Source: The Queen's Award for Innovation survey.

Table D.2
Second-stage factor loadings, number of observations: 196.

Stage one factors	Formal protection and secrecy	Complexity and complementary assets	Complementary assets and lead times
(1.1) Formal protection	0.7700	−0.1159	0.1976
(1.2) Rely on complexity	−0.2770	0.8428	0.0003
(1.3) Complementary assets and lead times	−0.2041	−0.0517	0.8622
(2.1) Formal protection and secrecy	0.8797	0.0288	−0.0837
(2.2) Rely on complexity	−0.2082	0.7496	−0.1074
(2.3) Complementary assets and lead times	0.0982	0.1246	0.8901
(3.1) Formal protection and secrecy	0.7141	−0.2566	−0.2933
(3.2) Complexity and complementary assets	0.2445	0.8276	0.2034
(3.3) Lead times and patent	0.3458	0.1298	0.3108

Source: The Queen's Award for Innovation survey.

represent the grand appropriability strategies protecting the QAI winning products.

D.1 First-stage

Table D.1 reports the factor loadings of the seven mechanisms in different phases. Since we have binary variables, we use polychoric correlation in the factor procedure (Kolenikov and Ángeles, 2004). Factors are extracted following the principal component method and rotated with a standard varimax normalized rotation. We kept only factors with eigenvalues greater than 1. Based on the loadings in this first stage, we define the factors as reported in Table D.1.

In general, the appropriability strategies appear to be consistent over time. It is interesting that the positive correlation between secrecy and formal protection tends to increase as the product approaches the commercialization stage. Also, the factor analysis shows a strong negative correlation between complexity and patents, especially in the early development phases.

D.2 Second-stage

We next derive the grand appropriability strategies using factor analysis of the variables described in Table D.1. In this second-stage, we extract three factors which define a strategy along both a longitudinal and a cross-sectional dimension. Table D.2 shows the factor loadings.

Looking at the scores, we interpret the first strategy as a combination of formal protection and secrecy. The second strategy captures a strong reliance on complexity which is enhanced by the development of complementary assets in the commercialization phase. The third strategy is based on the exploitation of lead time, combined with complementary assets in the phases of proof of concept and testing.

Appendix E. Supplementary Data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.strueco.2019.02.002.

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