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Document Version
Final published version

Published in:
Research Evaluation

DOI:
[10.1093/reseval/rvv020](https://doi.org/10.1093/reseval/rvv020)

Publication date:
2015

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Citation for published version (APA):
Perkmann, M., Fini, R., Ross, J-M., Salter, A., Silvestri, C., & Tartari, V. (2015). Accounting for Universities' Impact: Using Augmented data to Measure Academic Engagement and Commercialization by Academic Scientists. *Research Evaluation*, 24(4), 380-391. <https://doi.org/10.1093/reseval/rvv020>

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Journal article (Publishers version)

This article was originally published in *Research Evaluation in Finance and Society*,
Volume 24, Issue 4, Pages 380-391.

First published online: 8 September 2015

DOI: 10.1093/reseval/rvv020

Uploaded to Research@CBS: November 2015

Available at:

<http://research.cbs.dk/da/publications/accounting-for-universities-impact%286f638ee3-71fd-4015-81ed-ec86859b7ec7%29.html>

Accounting for universities' impact: using augmented data to measure academic engagement and commercialization by academic scientists

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We present an approach that aims to comprehensively account for scientists' academic engagement and commercialization activities. While previous research has pointed to the economic and social impact of these activities, it has also been hampered by the difficulties of accurately quantifying them. Our approach complements university administrative records with data retrieved from external sources and surveys to quantify academic consulting, patenting, and academic entrepreneurship. This allows us to accurately account for 'independent' activity, i.e., academic engagement and commercialization outside the formal university channels and often not recorded by universities. We illustrate this approach with data for 10,000 scientists at Imperial College London. Results indicate that conventional approaches systematically underestimate the extent of academic scientists' impact-relevant activities by not accounting for independent activities. However, with the exception of consulting, we find no significant differences between individuals involved in supported (university-recorded) and independent activity, respectively. Our study contributes to work concerned with developing appropriate and accurate research metrics for demonstrating the public value of science.

Keywords: academic engagement; commercialization; university-industry relations; academic entrepreneurship.

1. Introduction

The question of 'impact' looms large in the minds of science policymakers, science funders, and university administrators. As stated in a recent Nature special issue, 'every government and organization that funds research wants to support science that makes a difference' (Nature editorial 2013). Among the myriad of measures used for assessing the impact of scientific research is

scientists' direct involvement in activities aimed at exploiting the economic potential of their research. These activities include the commercialization of research via patenting and spin-off companies, and academic engagement, which includes contract research or consulting. Academic scientists have long pursued these activities (Mowery 2009), and most universities and policymakers provide incentives for faculty to do so.

Accounting for involvement in commercialization and engagement strictly speaking does not provide information on actual economic impact, such as the contribution to job growth or the generation of new products. However, it can serve as a useful proxy at least of the potential economic impact to be achieved, particularly as these activities are at least tentatively validated by multiple parties, including technology transfer offices, patent authorities, and industrial collaborators.

Reflecting a broader issue in the evaluation of public value from science, obtaining a full picture of faculty involvement in commercialization and academic engagement is however not a trivial exercise. While using university records represents an obvious starting point, academic scientists often operate alongside or outside their universities (Thursby et al. 2009; Fini et al. 2010), and as a result, their activities may not be fully accounted for in these records. In this article, we propose a solution to this problem. Moreover, we ask to what extent university records underestimate the actual volume of activity, and whether additionally uncovered activity differs in nature from that officially recorded.

We demonstrate an approach to data collection that records a reliable picture of three key activities by academic scientists: consulting, patenting, and entrepreneurship. Using data on 10,000 scientists at Imperial College London, we describe the methods that we deployed to obtain complete information on individuals' activities, present empirical findings, and investigate whether previously 'hidden' activities differ from those commonly reported. We find that in all three categories of impact-relevant activities, university records significantly underestimate the actual extent of activity. Accounting for this 'independent' involvement in consulting, patenting, and entrepreneurship also means that an additional group of scientists can be identified as being involved in these activities. However, with the exception of consulting, we do not find the individuals involved in independent activity to be different from those involved in 'supported' (i.e., official recorded) activity.

2. Background

The concern about the economic and social impact of science occupies the minds of policymakers around the world. Many OECD countries encourage universities to become more active in directly supporting economic development (Florida and Cohen 1999; Mowery and Sampat 2005; Wong et al. 2007). As a result, government support for university research is increasingly conditional on industry collaboration and user engagement in the attempt to amplify the wider social impact of research. For instance, the main public science funding body in the UK (Research Councils UK) requires academic

scientists to specify in advance how their research will generate impact. Simultaneously, the periodic evaluation of universities by the UK government, the Research Excellence Framework, has adopted impact as one of its performance measures. In the USA, the National Institutes of Health's main vision is stated as funding discoveries that improve health and save lives. It explicitly promotes clinical and translational research that transforms discoveries into medical practice.

Policy emphasis has undergone a subtle shift since the Bayh–Dole Act was passed in 1980 in the USA. While in the first phase, policies were mostly focused on supporting technology transfer offices at universities, attention has subsequently moved to a broader notion of knowledge exchange that includes engagement within industry but also the achievement of impact on society, health, and the environment. As result of these policy changes, universities have encouraged their staff and students to become more entrepreneurial, increase their attention to external stakeholders, engage the public, and influence practice.

These demands on academics are not new. Indeed, academics have traditionally had high levels of engagement with non-academics and are often keen to explore opportunities to ensure their research has impact on the wider world. They often see connections with non-academics as a way of improving their own research efforts by securing greater resources, generating more take and spread of their research, identifying interesting research problems, and finding employment for their students (Salter et al. 2010; D'Este and Perkmann 2011; Hughes and Kitson 2012; Perkmann et al. 2013).

Amongst the activities that may lead to direct impact, one can broadly distinguish between academic engagement and commercialization. Academic engagement can be defined as knowledge-related collaboration by academic researchers with non-academic organizations (Perkmann et al. 2013), comprising activities such as collaborative research, contract research, and consulting, but also extending to informal activities such as ad-hoc advice and networking with practitioners (Bonaccorsi and Piccaluga 1994; Meyer-Krahmer and Schmoch 1998; D'Este and Patel 2007; Link et al. 2007; Abreu et al. 2009; Perkmann and Walsh 2009). Commercialization, by contrast, refers to academics' activities aimed at generating intellectual property (invention disclosures and patenting) as well as commercial exploitation via the creation of spin-out companies or the licensing of inventions (Shane 2004; Agrawal 2006; Rothaermel et al. 2007; Bercovitz and Feldman 2008; Bolzani et al. 2014).

Extant research extensively explores both academic engagement and commercialization. Academic engagement is often highly complementary with academics' research. On the one hand, contract research, sponsored research, and to a lesser extent consulting, provide additional funds for

research, partly by helping academics obtain public grants (Ambos et al. 2008). On the other, these activities also provide sources for new project ideas, and may enable access to resources such as data, materials, or equipment (Mansfield 1991; Cohen et al. 2002; D'Este and Perkmann 2011). Studies across a variety of national contexts indicate that a considerable share of academics, particularly in disciplines emphasizing science, technology, engineering, and mathematics, engage with industry and other external organizations via contract research, sponsored research, and consulting. For instance, around 47% of UK engineering faculty engaged in contract research and 38% in consulting over a 2-year period (D'Este and Perkmann 2011). In the USA, 17% of academics employed at research-intensive universities worked on a project funded by industry over a 12-month period, and 18% provided consulting to a firm (Bozeman and Gaughan 2007). Similarly, 20% of German university scientists published jointly with industrial partners, and 17% engaged in consulting over a 12-month period (Grimpe and Fier 2010).

Compared to academic engagement, fewer scientists practice commercialization. In Europe, approximately 4–5% of all academics are patent inventors (Lissoni et al. 2008), while the equivalent figure for the USA is 5% (Bozeman and Gaughan 2007). The proportion of individuals engaged in academic entrepreneurship ranges between 3 and 10% in the USA (Bozeman and Gaughan 2007; Fini et al. 2010) and in Europe (Gulbrandsen and Smeby 2005; D'Este and Perkmann 2011; Haeussler and Colyvas 2011), but large differences exist between different fields and national contexts (Kenney and Goe 2004).

All of the above types of academic engagement and commercialization are indicative of direct impact generated by an academic. For instance, the provision of consulting services suggests that a client puts a certain economic value on the expertise of an academic and is prepared to financially remunerate the service. The monetary value of a consulting contract can therefore be read as providing an economic value added that should at least equal the amount paid to the university. In the same way, the acquisition of licenses on university-generated intellectual property is indicative of economic impact. The formation of companies also implies the generation of value that can be measured, for instance, by considering the amount of funding provided by external parties such as venture capitalists or business angels.

On a second level, all types of activities can also be seen as proxies for achieving wider impact. For instance, the purchase of consulting services or the licensing of university patents may help a firm to develop new products or improve processes, as well as allowing academic spin-out companies to generate new jobs. While it remains notoriously difficult to directly evaluate and measure this second-order impact of university activities, the volume of the latter can provide approximate measures that are easier to obtain.

To this end, it is important that the extent of these activities is reliably measured and recorded. In this respect, however, extant research has been hampered by several challenges. The measurement of academic engagement is deterred by the absence of publicly available records, notably in contrast to patents. Hence, some researchers have used co-authorship between university researchers and industry scientists (Liebeskind et al. 1996; Murray and Stern 2007; Tijssen 2012; Wong and Singh 2013) as proxies for academic engagement. However, this procedure will under-represent more applied collaboration, such as consulting, that does not tend to result in publications.

Many extant studies have measured engagement by requesting information from academics via surveys (for a review, see Perkmann et al. 2013). Questionnaire-based studies obviously come with their own challenges, including response and recall bias. Moreover, survey-based studies rarely result in longitudinal data sets due to the cost of administering them and the difficulty of obtaining repeat information from individuals. Comparability across studies is also stymied by the use of different construct definitions and ways of operationalization. These challenges can be addressed by directly accessing university-held archival records on academic engagement (Banal-Estanol et al. 2012). However, a difficulty with consulting is that a significant share of consulting activities is not disclosed to the university administration but is conducted through personal contract with firms and academic scientists (Perkmann and Walsh 2008). This means that university records on consulting tend to underestimate the amount of consulting by an unknown amount.

Difficulties also arise in the attempt to reliably account for intellectual property production by academic scientists. University records usually contain only patents that originate from inventions disclosed to them, and are forthwith assigned to the university. However, this measure omits any patents that are invented by university researchers yet assigned to third parties including firms or the researchers' own start-ups. Studies both in Europe and in the USA show that perhaps a third of all academic patents are not assigned to universities (Lissoni et al. 2008; Thursby et al. 2009), and are unaccounted for in university records or patent searches which only identify university-assigned patents as university-generated.

Equally, the measurement of academic entrepreneurship often relies on information recorded by universities, which is limited to companies that universities are aware of, or that are supported through their technology transfer offices and commercialization arms. However, this method of accounting for academic entrepreneurship risks omitting companies that are created independently by academics and not supported by universities (Fini et al. 2010).

The above challenges can be addressed by ensuring complete data coverage when accounting for both academic engagement and commercialization. In the remainder of this article, we report on a study that we conducted at Imperial College London. We retrieved longitudinal data from internal and external sources on the population of academics employed at Imperial between 2001 and 2013. We first detail the methodological approaches that we took to achieve complete data coverage, before presenting our findings to illustrate the extent of 'hidden' activities omitted by conventional data collection techniques. We subsequently explore whether the characteristics of scientists engaging in the previously unaccounted for activities differ from those in activities with more readily available records.

3. Data and methods

3.1 Study context

Imperial College London is a large research university emphasizing natural sciences, engineering, medicine, and business. In 2013/14, it enrolled approximately 14,000 students and employed 1,200 faculty and 2,200 research staff. It received £351 m in research grants and contracts of which £108 m were UK research council (government) grants. Imperial was founded in 1907 by bringing together a number of colleges, including the Royal School of Mines and the Royal College of Science. Its founding charter stipulates that it shall provide the 'most advanced instruction (...), training and research in various branches of science, especially in its application to industry'.¹ These objectives are both reiterated in the College's mission today and echoed in its track record in generating impact for its research via spin-offs, licenses, and industry-funded research centers and contracts.

Using Imperial as our setting, this study aims to paint a comprehensive picture of the whole range of activities that potentially lead to impact. Our approach is built on the assumption that science is conducted by individuals, and that the scientific, economic, and societal impact of research is the outcome of individuals' skilful efforts within team contexts. Therefore, we sought to collect data points on the full range of activities and outputs by Imperial academic staff. We proceeded in three stages to build a comprehensive data resource called the 'TRansfer of knowledge at Imperial College' (TRIC) database. First, we pooled existing College records on the patenting of inventions, creation of spin-off businesses, collaboration with industrial partners, and consulting activities, to generate a detailed picture of the determinants and consequences of industry engagement. Second, we linked these records with external data sources. Third, we carried out a survey of the College's academic staff in September 2013, to collect information that was not contained within the archival records. The three phases are detailed in Section 3.2.

3.2 Data

The TRIC database was created with the support of the College's Management Board and the Information and Communication Technologies (ICT) department, part of the College's Support Services function, which was central in building the technical infrastructure for the database and populating it with data from across the College. A series of measures was taken to ensure data confidentiality and safety. The ICT department acted as data owner and ensured the anonymization of the data set. As the numerous data tables were imported from the systems owned by various administrative departments, individuals' direct identifiers (names, email addresses, college identification numbers (CIDs)) were replaced with an anonymous unique identifier ('encrypted CID') for each person. Simultaneously, the ICT department retained the ability to convert the encrypted CIDs back to individuals' real CIDs by using a key. This was important when additional data, such as survey results, were added to the database. The key for this procedure was kept by the ICT department, and not disclosed to the research team or other parties.

The TRIC database captures individual-level information on the full population of approximately 10,000 academics, including postdoctoral researchers, employed by Imperial College London during the period 2001–13. It includes information on all grant applications and awards for all individuals acting as investigators as well as the postdoctoral researchers associated with them. The recorded awards include grants and donations, given by various types of research funders both in the UK and abroad. They also include information on all research contracts acquired by academics, stemming from collaboration with business, public sector, and not-for-profit organizations. Furthermore, the records contain individuals' publication records, invention disclosures, patents, courses taught, and the supervision of PhD students. Each record also includes demographic and human resource-related information. To retrieve additional data on entrepreneurial and patenting activities, we linked the TRIC records with the FAME and AMADEUS databases—containing information on UK and European public and private companies—as well as with the European Patent Office (EPO) database. Additionally, we conducted a survey of all Imperial staff in October 2013 to capture data not available from records for those academics affiliated with the College at that date. Table 1 provides an overview on the information contained in the TRIC database.

3.3 Accounting for engagement and commercialization

We now detail how we accounted for three specific activities that form an essential part of academics'

Table 1. Data overview

Data	Source	Observation period		Records
		Start	End	
Demographics and employment	Imperial Human Resource Department	01/01/2001	10/10/2013	10,899 individuals
Publications	Imperial Symplectic	01/01/1949	18/09/2013	214,000
Grant applications	Imperial InfoEd (Research Office)	01/01/2001	18/09/2013	33,000
Grants and contracts	Imperial Grant Management System (Research Office)	01/01/2001	18/03/2014	10,000 grants, 3,600 contracts, 200 donations
Teaching	Imperial teaching records	01/01/2007	01/01/2012	83,000 courses
Consulting	Imperial Consultants	01/01/2004	01/12/2011	2,700 contracts
Intellectual property	Wellspring (Research Office)	01/01/2001	22/11/2013	4,100 disclosures, 1,200 patents (of which 368 EPO)
Independent patents	European Patent Office	31/03/1983	10/10/2008	145 EPO patents
Engagement, work-life balance, academic practice	Survey of all Imperial academics, Sep 2013	10/10/2013	20/11/2013	3,148 responses (1,909 from employed academic staff)
Entrepreneurship	Bureau Van Dijk: FAME and AMADEUS (data from Companies House)	08/10/1988	01/01/2012	507 spin-out firms
Research project outcomes	UK Medical Research Council: Research-Fish	01/01/2001	01/01/2012	255 projects

impact-relevant activities: consulting, patenting, and entrepreneurship.

First, we accessed information on all *consulting contracts* by Imperial academics. Consulting is an important channel for academics to engage external actors, but its actual extent is notoriously difficult to capture (Perkmann and Walsh 2008; Thursby et al. 2009). We use information from College records between 2004 and 2011 in combination with survey responses to describe the extent of consulting within the College. In the survey, we asked respondents to provide an estimate of the total days that they had dedicated to consulting in 2012. The College encourages but does not require staff to route their consulting activities via its consulting arm, Imperial Consultants, a fully owned subsidiary that returns all profits to the College. Imperial Consultants acts as an intermediary between academics acting as consultants and the external parties contracting the consulting service. It deals with all legal, administrative, and financial aspects, and, in return, takes a proportion of the consulting fee. However, academics are free to pursue consulting on a personal basis, or via their own firms, as long as no College facilities are used.

The College only has information on activities routed through its Consultants unit but not on the ones conducted personally by academics. For this reason, the volume of activity recorded by the College may underestimate the actual volume of consulting. Our data provide a rare opportunity to shed light on the ratio between consulting carried out via the university and consulting pursued on a personal basis.

Second, we sought to obtain a full picture of individuals' *patenting activities*. As at many other universities, all

intellectual property generated by Imperial employees in the course of their normal duties belong to the College. Imperial scientists are therefore obliged to disclose any potentially valuable discoveries or designs to the technology transfer staff, and any arising patents will be assigned to the College or its commercialization company. The College records information on all these patents which we call 'supported patents'. However, this list of patents does not include patents that feature an Imperial scientist as inventor but are assigned to a third entity. We retrieved information on these 'independent patents' (patents invented by Imperial researchers yet not assigned to Imperial) by using EPO data. Independent patents may stem from activities by College employees that do not result from their regular employment duties; for instance, they may originate from employees' work with their spin-out companies. Alternatively, independent patents may be created in the context of contracts with industrial collaborators that stipulate intellectual property ownership to accrue to the latter.

To identify the independent patents, we implemented the following four-step procedure. We started by using information on Imperial academic publications provided via the College's publication management system. We compiled a list of authors with an Imperial affiliation between 2001 and 2013, identifying their first name, surname, and middle name. We then used the APE-INV database, which stores name-disambiguated information for all EPO-patent holders up to 2008, to compile a list of EPO inventors with a UK address (Lissoni 2013). Subsequently, we created a filtered list of UK-based EPO inventors with names (first name, middle name, and surname) identical

with Imperial authors. In order to remove false positives (i.e., non-Imperial-employed inventors who may share their name with Imperial academics), we verified whether any keyword in the titles of individuals' journal publications, grants, or supported patents matched a keyword in an EPO patent title. In parallel, we also compared the academic's research area with the patent's research domain. If both comparisons resulted in a positive match, we counted the EPO patent as an independent Imperial patent, i.e., a patent invented by an Imperial academic yet not assigned to Imperial, and linked the patent to the individual's record. As a final step, we retained only those patents that were filed when the inventor was employed at Imperial. The list obtained via the above procedure represents a relatively accurate picture of independent patenting at Imperial, with the limitation that we capture only EPO patents.

Finally, we collected information on academics' *entrepreneurial* activities. An academic entrepreneur we define as an individual who sits on a UK or Irish company board in the first year of its existence, and is simultaneously employed by Imperial as an academic. We refer to the respective firms as spin-out firms. Imperial encourages its academics to found firms as long as this does not encroach on their regular job duties. Some of the spin-outs are based on Imperial-owned intellectual property and are usually operated with involvement of Imperial Innovations, the technology commercialization company affiliated with Imperial. We refer to these firms as 'supported spin-outs'. Many other firms are however not based on Imperial intellectual property, including typically consulting firms or medical practices, and are as a result, established without involvement by Imperial Innovations. We call these firms 'independent spin-outs'.

We first gathered firm-level information on the 102 spin-outs listed by Imperial Innovations. We then complemented this information by collecting data on directorship positions held by Imperial academics, looking up each individual on the Bureau Van Dijk's FAME database by using their name and date of birth. FAME stores longitudinal, multilevel information on 3 million public and private UK and Irish companies. The data provided include time-variant information on shareholders and directors since incorporation.

4. Findings

When reporting our findings, we use the labels 'supported' to refer to activities that are conducted via the university and 'independent' to refer to those conducted outside the university channels. Supported activities include consulting routed via Imperial's consultancy arm, patents assigned to Imperial (supported patents), and involvement in an Imperial-supported spin-out firm. Conversely, independent activities include personal consulting not routed

through Imperial, patents not assigned to Imperial (independent patents), and the founding of spin-out firms not supported by Imperial Innovations.

Of the population considered in this study, 72% of individuals are junior researchers ('postdocs'), 14% are junior faculty (lecturers/senior lecturers/assistant professors), 11% are senior faculty (readers/associate professors and full professors), and 3% are senior researchers.

4.1 Consulting

Imperial categorizes projects into different types that include consulting in a strict sense, as well as activities as diverse as expert witness services, testing, and research for the European Commission. We first report the volume of all of these activities taken together, which we refer to as 'advisory services' (see Table 2, column 1). With £5,800 per person per year, staff in the Engineering faculty have the highest annual income from advisory services, followed by the Business School with an average of £4,000, Medicine with £1,700, and Natural Sciences with £1,300. If one considers only consulting activities in a narrow sense—we refer to this as 'consulting'—the values obtained are around half of those for advisory services (see Table 2, column 2).

Via the survey, we also obtained an estimate of the number of days of consulting carried out by Imperial academic staff in 2012, and we are able to compare those figures with the ones on consulting activities routed via Imperial.² By assuming an average of £1,200 as a daily rate for consulting (including overheads), we estimated the volume of funds raised (Table 2, column 4). Comparing these latter figures with the volume of consulting routed via Imperial (column 2), we can calculate the difference between the two, estimating the percentage of consulting that is routed via Imperial (see Table 2 column 5). This figure ranges between 28 and 54%. More specifically, the engineers conduct the highest proportion (54%) of consulting via the College, while the amount of consulting routed through Imperial Consultants by medical, natural sciences, and business academics ranges from 28 to 40% of their survey-reported consulting volume.

Overall, assuming that survey responses provide an accurate approximation of the total consulting conducted by faculty, our results suggest that this figure is on average about 3 days per person per year. Putting a monetary value on this figure suggests that just over a half of the consulting efforts are routed through Imperial Consultants.

The distribution of consulting activity is highly skewed. The total volume of consulting services conducted via the College, for instance, is shared among 10% of individuals. The concentration of activity is lower if one considers the self-reported number of consulting days from the survey; here, the top 10% of individuals account for 76% of activity. It follows that academics route larger consulting

Table 2. Comparison of consulting routes

Faculty	Annual income per person from consulting activities and annual estimated income				
	(1) Advisory services (broad) £	(2) Consulting (narrow) £	(3) Consulting days (survey)	(4) Consulting days, estimated £	(5) % routed via Imperial (2)/(4)
Engineering	5,800	3,000	4.66	5,592	54%
Natural Sciences	1,300	890	2.44	2,928	30%
Medicine	1,700	530	1.59	1,908	28%
Business School	4,000	2,600	5.43	6,516	40%

The table compares the annual amount of 'supported' advisory services and consulting (routed through Imperial, columns 1 and 2), the number of annual consulting days as self-reported by individuals via the survey (3), and the estimated income from the latter by applying a daily rate of £1,200 (4). Column 5 indicates the estimated share of supported consulting (percentage of (2) of (4)). Data from the university records (columns 1 and 2) refer to the period 2004–11, whereas survey data refer to year 2012. The entire population, including junior researchers, is considered.

projects via the College, whereas smaller projects are carried out on a personal basis.

Overall, our results suggest that consulting is an important element in the portfolio of activities associated with industry engagement. Accounting for only the consulting activities routed via Imperial Consultants fails to capture the real scale of consulting performed by academics, with our results suggesting that this level could be more than twice as large as that reported in official statistics, such as the Higher Education Business and Community Interaction (HEBCI) survey.³

4.2 Patenting

The College's patent applications feed from a pool of disclosures made by Imperial academics, whereby they notify the College of a potentially valuable discovery. From the pool of 2,189 disclosures filed in the period 2001–11, the College filed 710 patents invented by 558 staff members.⁴ This corresponds to an annual patenting rate of approximately 2 patents per 100 Imperial academics.⁵

The above figures, drawn from university records, only contain patents that are assigned to Imperial College London (i.e., supported patents). In order to conduct our analysis of independent patents, and hence obtain a full picture of inventive activity at Imperial, we focused on the subset of patents granted to Imperial inventors by the EPO, between 2001 and 2008 that are assigned to entities other than Imperial. The limitation to EPO patents is justifiable on the grounds that patents of any value will usually be filed with EPO, along with other important patent offices.

As our analysis suggests, a unique focus on university-assigned patents (supported patents) underestimates the production of intellectual property at universities considerably. In fact, out of 298 EPO patents invented by Imperial academics between 2001 and 2008, 207 (69%) are supported patents and 91 (31%) are independent patents. This means the number of supported

patents—commonly used as a measure of academic patenting—has to be increased by approximately 45% to reflect the actual nature of inventive activity by academics at Imperial.

Adding the inventors of independent EPO patents to the inventors of supported patents raises the share of inventors in the overall Imperial population of academics from 2.8 to 3.2%. As for the distribution of inventive activity across Imperial's faculties, the Engineering Faculty exhibits the highest patenting activity with approximately 1.6 patents per 100 individuals per year, arising from a pool of approximately seven invention disclosures per 100 individuals. This means about a fifth of disclosures are converted into an EPO patent; this is a conservative estimate as some disclosures are likely to have been converted into patents in other jurisdictions. Conversion rates as well as the ratio between supported and independent patents are similar across faculties (except Business School). Overall, senior researchers hold a higher number of independent patents than supported patents; 41% of their patents are independent compared to an average value for all faculty of 31%.

In terms of technological content, the ratio of independent patents versus supported patents is high (97%) in chemicals and materials (Class 3), and is higher than average in electrical engineering and electronics (Class 1), and pharmaceuticals and biotechnology (Class 4).

Finally, one may presume that many of the patents invented by Imperial academics but not assigned to Imperial may instead be assigned to Imperial's numerous spin-out companies. In fact, we find that approximately 63% of independent patents are owned by an Imperial spin-out. Two thirds of these patents are assigned to a 'supported spin-out', that is a company classed by Imperial Innovations as a spin-out. The remaining third of these patents are assigned to companies founded by Imperial academics but not otherwise supported by the College ('independent spin-out'). A further 24% of independent patents belong to firms unrelated to Imperial, with

the balance being assigned to firms that funded the inventor's research via contract research or a consulting contract (7%) or another university or public research institution (5%).

4.3 Entrepreneurship

Consistent with our definition of entrepreneurship, we used the FAME database to identify 325 individuals who founded at least one firm in the years 2001–11. These 325 individuals established 360 spin-out companies. Of these firms, 29 are classified by Imperial Innovations as spin-out companies. These firms are supported spin-outs as they can be assumed to receive a measure of support from the university's commercialization company. The remaining 331 firms are by implication independent spin-outs.

The above suggests that augmenting university records with data on company directorships means we obtain a number of spin-out companies approximately 10 times the original figure. Simultaneously, our methodology fails to identify approximately two thirds of companies classed by the College as spin-outs. The reason for this discrepancy is that in some cases, professors become directors of a company only in the second or a subsequent year of its existence, or the company is based on an Imperial-licensed technology and does not include an academic in the board of directors.

The proportion of supported versus independent entrepreneurial efforts varies by faculty. The percentage of supported entrepreneurial activity ranges between 5% for Medicine and 14% for Engineering (see Table 3). In terms of sectoral distribution (two-digit SIC codes), the highest number of firms belongs to 'professional, scientific, and technical activities' (30%), followed by companies associated with 'information and communication' (15%), and 'human health and social work activities' (14%). Within the most frequent sectors, professional, scientific, and technical activities account for the highest proportion of supported firms, whereas firms in the areas of human health and social work activities, and information and communication have the highest proportion of independent spin-outs.

5. Differences between supported and independent activity

Our findings suggest not only that by using augmented data additional segments of activity can be uncovered but also that there are differences between the attributes of internally recorded activities and newly uncovered activities.

For consulting, independent activity consists primarily of smaller projects that are considerably more widely distributed across faculty. In intellectual property, the incidence of independent patents is particularly pronounced

Table 3. Comparison of entrepreneurship routes

Faculty	Supported firms per 100 individuals	Independent firms per 100 individuals	Proportion supported
Engineering	0.1	0.9	14%
Natural Sciences	0.1	0.7	13%
Medicine	0.1	1.3	5%
Business School	0.3	1.8	11%

Selected sectors (SIC)	Supported firms	Independent firms	Proportion supported
Administrative and support service activities	1	19	5%
Human health and social work activities	2	50	4%
Information and communication	3	51	6%
Professional, scientific, and technical activities	20	87	23%

Figures for 2001–11. Firms may be established by individuals belonging to different faculties.

in specific technology areas including chemicals and materials, electrical and electronics, and pharmaceuticals and biotechnology. In entrepreneurship, sectors such as health and information and communication specifically feature a high proportion of independent spin-outs.

We now consider the distribution of supported and independent activities across individuals and ask to what extent the characteristics of the scientists who engage in supported and independent activity, respectively, differ. Answering these questions is important because the characteristics of the individuals who engage in independent activities may be unknown to university administrators and policymakers, particularly if they systematically differ from those who engage in supported mode.

Regarding the distribution across individuals, we find that a considerable proportion of individuals engage exclusively in independent activity, particularly in consulting and entrepreneurship. As a consequence, looking exclusively at supported consulting, fails to capture the 41% of consultants who only pursue personal consulting. Similarly, only focusing on supported entrepreneurship omits 88% of individuals involved in founding companies. By contrast, only 12% of individuals engage only in independent patenting. Overall, across all three types of activity, by focusing only on supported individuals, one fails to account for 44% who only engage independently. The incidence of not accounting for independently active individuals is exacerbated by the fact that they more rarely engage in multiple activities (fewer than 5%), than those who engage in supported mode. The broader the portfolio of an academic's activities, the higher the likelihood that they will engage in supported mode.

Table 4. Comparison of individuals engaging in supported and independent activity

Variable	(1) Mean Supported consulting N = 158	(2) Mean Independent consulting only N = 295	(3) <i>t</i>	(4) Mean Supported patenting N = 220	(5) Mean Independent patenting only N = 30	(6) <i>t</i>	(7) Mean Supported entrepreneurship N = 38	(8) Mean Independent entrepreneurship only N = 287	(9) <i>t</i>
Male	0.81	0.80	-0.26	0.86	0.86	0.02	0.89	0.84	-0.87
Age	48.45	44.20	-4.11***	41.34	41.4	0.03	45.00	42.67	-1.26
Industry contracts £	54,393	19,991	-3.95***	29,177	28,414	-0.04	30,464	36,515	0.16
Publications impact factor	83.54	103.87	1.23	84.28	73.23	-0.39	88.79	85.27	-0.11
Salary band £	74.43	66.71	-2.22*	50.82	50.00	-0.19	55.52	56.97	0.26

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$. Figures for supported consulting are for 2010 and for independent consulting are for 2012. Figures for patenting and entrepreneurship are for 2001–11, with the figures indicating annual averages. The 'publications impact factor' indicates, for each academic, the sum of the impact factors of the journals for each of the articles published by the academic. The salary band indicates the approximate salary of each academic (in 1,000 British Pound). British Pound Sterling.

We are also able to explore whether individuals who engage independently differ from those who engage in supported mode. To this purpose, we carried out a series of *t*-tests (Table 4), the results of which suggest that individuals engaging in supported or independent consulting respectively differ significantly, while the same is not true for patenting and entrepreneurship. In this analysis, we classified individuals who engage in both supported and independent activities as belonging to the supported category. Those engaging in independent consulting exclusively are more likely to be younger, in receipt of fewer industry contracts and in a lower salary band than those who engage in supported mode. The more junior members of the university choose to conduct consulting independently. By contrast, no significant differences exist between supported and independent activities with respect to patenting or entrepreneurship. A chi-square test suggests that there are statistically significant differences with respect to supported and independent engagement across faculties; on the whole, independent engagement is more likely in the social sciences (Business School) than other faculties.

Overall, our findings indicate that differences among individuals engaging in supported versus independent activities exist only with respect to consulting where more junior and hence less organizationally established members are more likely to choose exclusively the independent channel for working with external parties. In other words, considering only those individuals captured by university records (via supported consulting) leads to an overestimation of their seniority and track record, and an overestimation of the concentration of consulting activities amongst university faculty. By contrast, neglecting individuals engaging in independent commercialization merely leads to an underestimation of the overall volume of activity but does not lead to an incorrect characterization of their personal attributes.

6. Conclusions

In this article, we presented evidence from archival and survey data on a range of impact-relevant activities by academics at Imperial College London, including consulting, patenting, and academic entrepreneurship. We illustrated how an augmented data approach helps to more accurately quantify the extent of academic engagement and commercialization. Our data approach consists of pooling university-held archival records with data from non-university databases and survey data. This allowed us to collect a larger number of data points for each scientist compared to existing studies, enabling us to uncover a greater extent of impact-relevant activities that have hitherto remained hidden. Overall, we demonstrated that the volume of impact-relevant activities by academics is considerably higher if one connects university records with external data and conducts a complementary survey, rather than relying on university-held records only.

We specify three types of activities likely to be frequently under-reported. First, by comparing survey and archival data, we provide an estimate of the volume of independent consulting activities that academics conduct—almost three times the amount of supported consulting which is routed via the university's consulting company. If one assumes that universities at least in the UK operate in a similar manner to Imperial, one may extrapolate that a considerable share of consulting by UK academics may go unreported. Second, we found that the number of patents invented by Imperial academics increases by 45% if one considers patents which are not assigned to Imperial but list an Imperial academic as inventor. This figure is consistent with evidence presented by recent US-focused studies (Thursby et al. 2009). Third, we explored academics' involvement in founding firms by taking account of all firms, rather than merely those facilitated by the university's technology transfer office and built on

Table 5. Comparison of university-held records with augmented data

Activity	Supported activity only (university records)		All activity (including independent)	
	Average all staff	% of staff involved ^a	Average all staff	% of staff involved ^a
Consulting (narrow definition)	£1,330	5%	£3,615 ^b	26%
Patenting (EPO patents per 100 individuals)	2.7	2.8%	3.9	3.2%
Entrepreneurship (founding directorships per 100 individuals) ^c	0.3	0.4%	3.6	3.3%

Time period considered 2001–11, average annual values.

^aThe participation rate (% of staff involved) indicates whether an individual has participated at least once in a multiyear period.

^bThe augmented figures for consulting stem from survey data and apply to 2012 only.

^cEntrepreneurship is calculated using the number of spin-out companies founded by Imperial academics 2001–11.

university-owned intellectual property. In this way, we established that the number of companies where an Imperial academic is a founding director supersedes the number of companies classed as supported spin-outs by a factor of 10. This also corroborates findings from a US-focused study by Fini et al. (2010).

This result, however, needs to be interpreted with caution. In fact, it is more than likely that firms with the highest impact on economic value generation and job creation will be supported spin-outs. By contrast, many independent spin-outs will be small, low-growth firms such as consultancy firms or medical practices that have little in common with those in biotechnology or information technology that are underpinned by university inventions and funded by venture capital. Nevertheless, it appears appropriate to consider the whole span of entrepreneurial activity by academics at least as a starting point for an analytical exercise. In Table 5, we summarize our findings by outlining the differences between evidence obtained from university records, and those augmented with additional data.

Our analysis also allowed us to probe whether there are differences between the profiles of the scientists engaging in supported and independent activity, respectively. The evidence shows that individuals engaged in independent consulting tend to be younger and more junior, and their contracts tend to be smaller compared to the supported consulting route, suggesting that independent activity may act as an entry point for higher volume work carried out via the existing university channels. By contrast, for patenting and entrepreneurship, no significant differences exist between individuals engaging in supported and independent activity if one takes into account individuals' basic demographic or performance-related characteristics. Future research is required to explore under what circumstances individuals choose one route over another when commercializing.

Our article demonstrates the value of pooling information from various sets of archival records as well as surveys. For instance, by combining information on academics' resource acquisition (e.g., consulting) with records on publications and commercialization outcomes (e.g., patents, firms), it is possible to relate inputs to outputs over time without having to rely exclusively on individuals' self-reported information, as is the case with survey-based systems. Surveys have been used successfully to capture academics values and attitudes, but they are less suitable for providing information on past activities, due to recall bias and the more limited information density of surveys (Perkmann et al. 2013). They also commonly do not allow for comprehensively and accurately collecting information that identifies specific patents or firms. However, where it is known that archival records are incomplete, as we demonstrated with the case of academic consulting, surveys are a crucial 'second-best' solution for capturing information.

Importantly, by linking university records with external databases on firms and patents, we demonstrated that impact-relevant activity at universities may be significantly higher than commonly reported by universities themselves. By implication, this means that the figures reported officially—e.g., in the UK via the HEBCI survey—are likely to underestimate the extent of activities being pursued at universities as these figures are based on universities' own records.

Overall, our work contributes to on-going efforts to develop new, better metrics for assessing the social value of public science (Marburger 2005; Lane et al. 2015). The approach that we propose is admittedly more resource intensive to implement than exclusive reliance on university-held archival records or surveys administered to university scientists, respectively. This is exacerbated by the fact that for each type of activity, a separate external data source needs to be accessed. With respect to resource need, the

identification of patents filed by academic scientists independent of their institutions represents the most costly exercise, followed by data collection on independent consulting via surveys, and data collection on entrepreneurial activity via public registers of companies. In the interest of cost reduction, one may conduct these exercises for a randomly sampled part of the whole population of scientists of a university, or a nation. While not providing full information, such an approach would still enable research evaluators to estimate the relative proportion of supported and independent activity for the entire population. Policymakers need accurate estimates of the frequency of engagement as well as information on who engages and why. In this respect, the methodology that we applied in this study can inform a larger-scale implementation of a system for measuring engagement and commercialization.

Acknowledgements

We thank the editors and two anonymous reviewers for their thoughtful comments. We are grateful to G Anand Anandalingam, Laura Bailey, David Begg, Adam Bury, Matthew Cain, Bruno Cotta, Margaret Dallman, Audrey Fraser, David Gann, Dorothy Griffiths, Sandra Griffiths, Laura Guida, Tony Hickson, Dermot Kelleher, Peter Knight, Josie Lewis-Gibbs, Jeff Magee, Andrew Mclean, Polly Meudell, Eoin Murphy, Tatiana Schofield, and Emma Toumi for their support. Special thanks are due to Okan Kibaroglu. We appreciated the research assistance of Maria Vittoria Amaduzzi, Antonella Bedini, Caterina Bissoni, Adele Gori, and Andrea Maisto. We are also grateful to Francesco Lissoni for granting us access to the APE-INV database. The raw data used in this work cannot be shared because it may allow the identification of specific individuals, contravening the Ethics Committee approval for this project. Funding was provided by the Engineering and Physical Sciences Research Council (EP/F036930/1), the Economic and Social Research Council (RES-331-27-0063), the UK Innovation Research Centre (RES-598-28-0001), the European Commission (FP7-PEOPLE-2009-IEF-252018), and the Imperial Natural Environment Research Council impact acceleration account.

Notes

1. Imperial College London (2007): Charter and Statutes.
2. Our figures on IC consulting relate to 2004–11, while the survey relates to 2012. Our analysis suggests that consulting activities have remained largely stable across different years.
3. <http://www.hefce.ac.uk/whatwedo/kes/measureke/hebci>
4. The figures refer to 'patent families', i.e., a set of patents with the same content filed in different jurisdictions. This means that, even if there are several

patents in a patent family, this only counts as one patent.

5. For the population without junior researchers, the annual patenting rate is 4.5 patents per 100 academics.

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