Examining Biases in Measures of Firm Innovation*

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Abstract

A challenge for applied studies of innovation is to find quality-adjusted and unbiased measures for the extent and type of innovative activity in firms. This paper considers, in the light of the uses for these measures, how well we expect these common indicators quantify innovative services and how well they actually correlate using data from a sample of 641 companies. The results suggest that while the correlations between indicators are positive, they are quite small. In addition, our findings show that compared with survey measures, the accounting and administrative measures have different biases with respect to firm size, industry sector and innovation type. This should be born in mind when using these measures to depict trends in innovative activity and reveal relationships between firm activities.

Introduction

For some decades now, economic analysis of the causes and distribution of economic prosperity has been shifting from examining static allocation or point-in-time production processes to the study of the nature, causes and effects of the *changes* in these processes over time. Innovation, creation and imitation are the sole sources of endogenous change to these processes, and as such, must figure in any dynamic analysis of the economy[1]. Applied studies of this dynamic process are immediately confronted with the problem of how to measure innovative effort. Typically, economists have used proxies for innovation services such as R&D expenditure or counts of intellectual property (IP) rights that are 'known' to favour one type of activity over another. This paper reviews the conceptual issues confronted when seeking to measure innovative activity at the firm level and assesses the biases of the available innovation measures.

Accurate measurement of innovation matters for at least two reasons. First, to know *how much* innovation is being conducted within a jurisdiction. This is an accounting function which is of direct interest to firm managers, investors and politicians who want to track changes in a firm's or economy's innovative efforts over time and to judge this against comparable entities. Secondly, to understand *how* innovation affects economic and social well-being since it enables us to answer questions such as: Are innovative companies more profitable? Do they achieve faster productivity growth than their less innovative counterparts? And, are current social rates of return to innovation above their private rates?

Two recent papers have presented some of the problems with commonly-used indicators of innovation and considered the use of multiple indicators of innovation in order to address the measurement problem (see Hagedoorn and Cloodt 2003, Kleinknecht *et al.* 2002). While these studies provide discussions on the correlations between different measures of innovation at both the firm and national level, the relevance of their results is

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[1] Exogenous sources of change can arise from the social and political system (i.e. changes to government policies) and the physical world (i.e. natural events).

limited, either because price changes over time are not accounted for, or because the scope of the analysis is limited to high-tech industries, or because the variation in quality of innovative effort is overlooked.

The remaining parts of this paper are structured as follows. First, innovation is defined. Secondly, some conceptual issues associated with measurement of innovation are presented. Thirdly, a critique of commonly-used firm-level measures of innovation such as R&D expenditure and patent counts is undertaken. Finally, existing measures of innovation are empirically evaluated by examining the correlation between them and an independent measure of innovation developed from the Melbourne Institute Business Surveys. The latter is assumed to be the least biased measure currently available. The results show that the correlation between the various innovation measures is low and supports some, but not all, our prior views regarding the biases in the various measures.

Defining innovation

One of the enduring features of capitalist societies is the incessant search for new and improved goods and services that will find a niche in the market. Economists often argue that this search – which in very broad terms is referred to as "innovation" – is one of the primary drivers of economic development in capitalist nations. In principle, such statements are very hard to refute because of the loose way in which innovation is defined. Does the definition of innovation include only goods and services or are improvements in production processes also important? Should changes in work culture or management practice be included in the definition? For the purpose of this paper, it is worth reflecting on issues relating to the definition of innovation.

The classic economic schematic representation of innovation is found in the work of Schumpeter (1934), who articulated five aspects of innovation, which we condense to four: product innovation, process innovation, organisational innovation and market innovation. Although these components of innovation are not mutually exclusive, using this rubric enables us to get a clearer picture of what we are referring to when we talk of "innovation". Product innovation refers to the creation of new (or improved) goods or services that are launched on to the market. Whilst both goods and services are included in this aspect of innovation, much of the literature on is dominated by innovations in physical goods[2]. Process innovations, on the other hand, refer to changes in the way in which goods and services are produced. Such process innovations include new technology that improves the productivity of a production line or softer technological improvements such as the development of a new work culture or improvements in the flow of information between management and workers.

Organisational innovation refers to changes in the architecture of production and accounts for innovations in management structure, corporate governance, financial systems or changes in the way workers are paid. For instance, changing from a flat per-hour rate of pay to a piece-rate scheme where workers are paid for each unit of output produced is an organisational innovation. A final type of innovation is market innovation, which refers to improved ways of sourcing supplies of raw inputs or intermediate goods and services as well as opening up new market opportunities (which could relate to either creating new domestic or export markets). The current convention however, is to focus only on product and process innovative services and unless otherwise specified, the remaining discussion is limited to these two types.

Whilst this framework provides a means of categorising the different kinds of innovation, it also implicitly outlines another important dimension of innovation: whether it constitutes something that is new to the world or whether it is simply something that is new to the firm. The former is a narrow definition of innovation that only includes inventions, while the latter is a much broader definition that includes imitation and adaptation of existing products as well as invention. The extent of novelty included in the definition of innovation is a critical factor in understanding the effects of innovation since the risks and returns of the two definitions are fundamentally different[3]. In this paper, we try to limit ourselves to the narrow definition of the concept.

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[2] Although recent work by Drejer (2004) highlights recent attempts to redress this imbalance.

[3] Innovation that is new to the world is a much riskier prospect than innovation that is new to the firm and therefore involves higher expected returns since a risk-averse inventor will charge a premium for bearing risk.

Conceptual issues in measuring innovation

A common way to measure the level of innovative activity, or flows of innovative services (in either a firm or a nation), is to examine the number of new products and processes introduced over any given period of time. However, measurement is not simply adding up objects that can be counted. The act of measuring is concerned with quantifying homogeneous, standardized or commensurate elements of an activity. The only reason we can add up hours of labour services is by assuming that the effort involved in each hour is constant, give or take a tolerable variance. However, simply summing patent counts may be like adding together ants and elephants in terms of the effort that went into creating each patent or the economic value associated with each patent.

Measurement problems are endemic in economic analysis. One reason for this is that we must rely on static indicators to measure inherently dynamic processes. When trying to measure productivity of a car manufacturer, for example, one must try and measure both inputs (capital, labour) and outputs (number of cars) of the production process. Ideally, we would like a simple measure of productivity that says 1 car is made every 10,000 labour-hours which could then be compared to previous performance or other firm’s performance. But how do we account for the fact that neither all cars nor all man-hours have the same value? The fundamental problem here is how to combine disparate activities into a meaningful aggregate – a problem that is especially acute in the innovation production process, where difference is the essential ingredient.

We have identified four specific dimensions to the innovation measurement problem. First, the innovation process follows a pathway that may take many years from start to finish: it is not a point in time. In order to measure innovative activity, therefore, some decisions must be made about what stage of the innovation pathway our indicators should come from. Secondly, if we use the narrow definition, innovation involves novelty which makes it virtually impossible to compare, and then quantify, all new products and processes in any meaningful way since each innovation is unique. As a consequence of this, both inputs and outputs of the innovation production process are highly heterogeneous which makes quality-adjustment difficult and inter-temporal and cross-sectional comparisons of performance (either firm or national) problematic. Thirdly, time is an important component of the innovation production process. As a result, innovation measurement must have some way to adjust for changes in price (of inputs and outputs) over time. Fourthly, regardless of whether the narrow or broad definition of innovation is adopted, much of the activity that is categorised as innovation is largely unobservable because it occurs within organisations and is not reported in any conventional statistics. In this section, we consider these four conceptual issues in more detail.

The innovation pathway

Innovation is a dynamic process which has no beginning and no end: it is a continual process in which products and processes are in a constant state of flux. The innovation process follows a complex pathway which involves feedback loops generated by on-the-job learning, trial-and-error and other discontinuities in production. Capturing the complexity of this process with a simple, static indicator is difficult. In attempting to make innovation measurement tractable, some assumptions about the beginning and end of the innovation pathway have to be made (either implicitly or explicitly). The standard convention is that innovation pathways for economic entities ‘begin’ with their own formal and informal R&D[4]. Following this, some outputs may become encoded into registered IP, integrated into business secrets or embodied in tacit organisational knowledge. With good management and fortune, this may evolve into new products or production technologies. At the end the innovation pathway, the introduction of new products and processes may give rise to a change in the distribution of firm profits and/or a transformation in industrial organisation through exit or entry into new markets. However, this may take a considerable period of time. Figures 1 and 2 present a stylised illustration of the life cycle of product and process innovations.

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[4] However, innovation does not truly begin with R&D. Similar to all knowledge-based phenomena, the true genesis of contemporary innovation extends back into the realm of pre-history since all inventions build upon the foundations laid by others. As Newton humbly pointed out: “If I have seen further than (you and Descartes) it is by standing on the shoulders of Giants”.

Figure 1: Life cycle of a product innovation and associated signposts

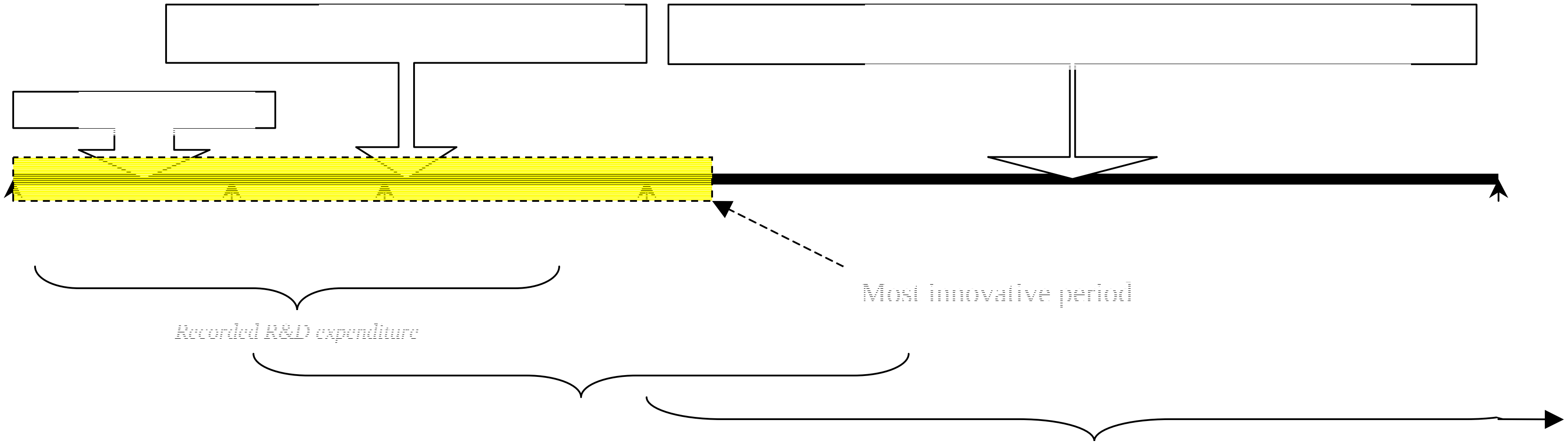
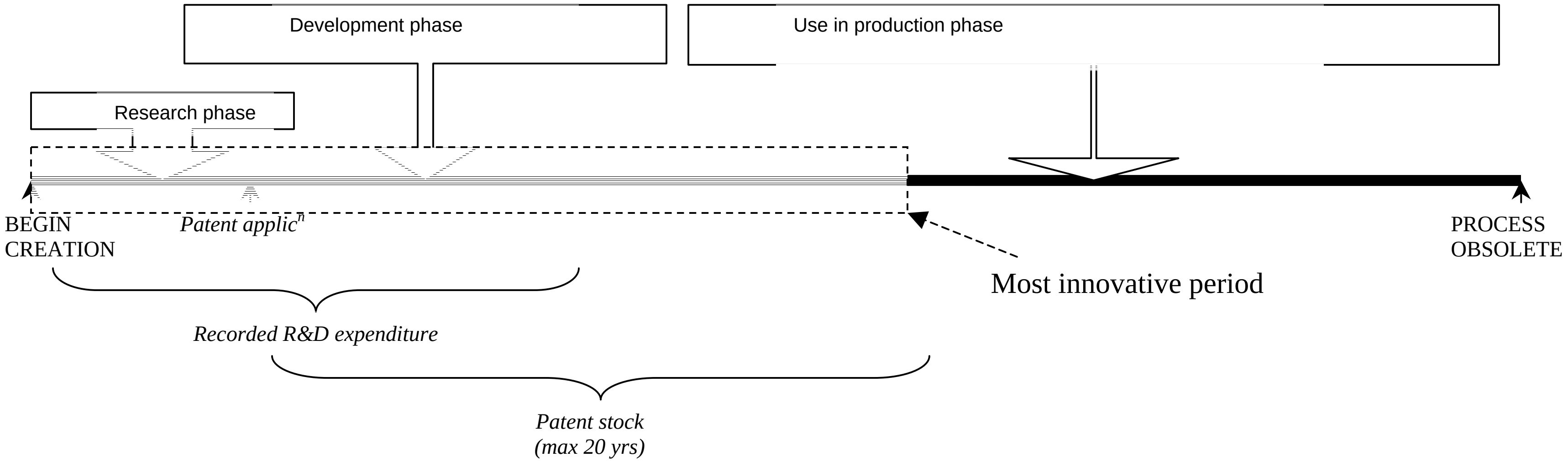


Figure 2: Life cycle of a process innovation and associated signposts



This illustration of the innovation pathway highlights some of the problems with using static measures of output at a given stage of the process as a proxy for innovation. One of the main problems is that the further we progress down the innovation pathway, the more we are defining the outcomes of a given innovation rather than the activity itself. Thus, we are implicitly using a measure of ‘successful’ innovation rather than innovation *per se*. Thus, using an indicator of innovation such as the number of trade marks can bias our understanding of innovation.

Accounting for heterogeneity and uniqueness

Assuming that some accepted convention is used to identify different stages of the innovation pathway, an economist wanting to measure innovation must then deal with two further issues: the fact that both inputs and outputs to the innovation process are heterogeneous and that all inventions should be unique to the world. This causes a problem because as mentioned above, measuring an activity is much more involved that simply adding up numbers: it requires ensuring that the units of analysis are standardised. The need to isolate and quantify the commensurate elements of an activity strikes a discord with measuring innovation, which is, by its very definition, always something unique. While this problem is present in other economic processes, it is a lesser concern when there is some continuity in the content of the activity over time.

Why do we need commensurability when measuring an economic activity? One of the reasons why relates to the uses of such data: prediction of future activity levels through the use of econometric modelling. Almost all econometric models seek to explain the effects of one activity on another and to predict what might happen in the future if the level of one activity changes. A typical study of innovation, for example, might attempt to discover whether there is a significant relationship between the number of patents and firm profits. Upon finding a positive and significant relationship between the two, the researcher is tempted to conclude that each additional patent will have a similarly positive effect on future financial performance[5]. Such a conclusion may encourage businesses to spend money on new ways to come up with patentable inventions.

Given that some patents are worth a lot while the vast majority are worth nothing[6], it is questionable whether there is any merit in such a conclusion unless something has been done to account for the fact that one patent isn't equivalent to another. But this raises the problem of how the respective patents should be quality-adjusted or weighted. Other heterogenous products, such as educational and health care services, can be treated with techniques such as hedonic indexes since there is always enough of the old in each successive activity to splice on the new. However, there are not established ways of treating and adding together activities or products that in addition to heterogeneity may have no overlap with last period's activities or products.

Similar problems arise when talking about the relationship between R&D and profitability. How should we interpret results that show that an expansion of innovative activity increases profitability? Does this mean employ more scientists and engineers, and to do what? What effort should we put into product versus process innovations and what type should we pursue? Unlike the application of skilled labour services to a production line, which yields a predictable level of output, R&D workers are heterogeneous and can have a highly variable effect on the output of valuable ideas. How clearly then do we have to define a concept to make it generic enough so that it can be reproduced? In theory, and sometimes in practice, we can disaggregate innovative measures according to their observable characteristics, such as whether it represents a product or process innovation, the type of technology or quality of scientists employed. However, it does not follow that classifying innovative activities in this way reduces the variation in the quality of innovative effort. If most of the source of this variation comes from unobservable attributes of effort, then disaggregating by observable characteristics will add little explanatory power.

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[5] Of course, such a conclusion could only be drawn if there is some theoretical reason for assuming that R&D affects profits (i.e. that the causality is not the other way around) and that the model controls for events that are external to the firm or are the consequence of other decisions taken within the firm.

[6] Recent evidence from the United States and Europe suggests that only a small proportion of patents have any economic value (Harhoff *et al.* 1999, Allison, Lemley, Moore & Trunkey 2003).

Unfortunately, there are no clear and uncontroversial solutions to these problems. There is no accepted rule for judging the level of acceptable variation in the characteristics of an item below which a simple count can provide analytical meaning. We expect, however, that simple counts of innovative services and their intermediate products, such as R&D expenditures, patents and so on, will produce highly variable effects and these will be revealed in large standard errors in statistical estimation.

Adjusting for price changes over time

Measures of innovation must also have some way of dealing with changes in prices over time. As already mentioned, it may take a long period of time from start to finish of the innovation process which means that the value of R&D spent will diminish because of the effects of inflation. Thus, any comparisons of inputs such as R&D expenditure which are based on dollar values must be price-adjusted. This typically involves deflating expenditure using the consumer price index (CPI) or the GDP deflator. However, analysis of the measurement of the CPI suggests that the indexing method used to calculate changes in the price of goods over time overestimates the CPI figure by 1-2 percentage points – that is, it underestimates the increase in quality of new products (see Boskin *et al.* 1997). The size of the underestimate in the change in quality of new products will be even greater for individual firms if we are applying an economy-wide average deflator to a firm with many new products since the firm will appear to be producing lower output than it really is[7].

Part of the source of this bias arises because the construction of price deflators relies on fixed-weight indexes. A standard price index measures the change in price over a period of time for a specific bundle of goods using a base year to compare with the current price. The choice of the base year for construction of an index plays an important role here since choosing a base year for the index that is from many years prior will tend to place too high a weight on the good in question and therefore overstate the aggregate measure

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[7] The ramifications of this statistical bias are profound since it implies that important economic indicators of innovation (as well as productivity, national debt, government expenditure and other economic factors) may also be biased. It has also been argued that the productivity paradox – the notion that investment in information technology has not resulted in a comparable improvement in total factor productivity – may also be partly attributable to measurement biases in the CPI (see Sharpe 1997 for a discussion).

of growth. This well-known property of index numbers varies across products and industries but it is particularly acute for high-tech goods such as computers where output has grown rapidly while price has fallen. Fixed-weight indexes are also problematic when applied to products whose characteristics change rapidly or whose life-cycle is short – computers, mobile phones, and the like.

Unobservability of innovative activities

Many of the activities that are included in the definition of innovation are difficult for an external analyst to observe. For instance, many process and organisation innovations do not result in end-products that are sold in the market. Unlike product innovations which may end up as patents or trade marks, process and organisation innovations occur within the firm and are either kept as trade secrets or simply not signalled to the world. Market innovations, as key planks in the firm's competitive advantage, are not generally publicised. Activities involved in changing the work culture for example, which may be new to the world, can have a demonstrable effect on productivity within the firm, but it is almost impossible for the economist to detect it since it leaves no trail of administrative data. Furthermore, there may be no itemised record of expenditure on this innovation, such that even if it were detected it would be difficult to measure.

In the next section, these general conceptual issues are used to critique the use of common indicators of innovation based on expenditure data (such as R&D expenditure and employment), count-based data (such as patent counts and new product announcements) and qualitative innovation assessments (such as surveys).

Biases in commonly-used measures of innovation

The data traditionally used to measure innovation come from a number of sources: census data (R&D employment – Scherer 1965, 1980), accounting (R&D expenditures – i.e. Grabowski and Mueller 1978, Ben-Zion 1984, Griliches 1986, Chauvin and Hirschey 1993, Cohen *et al.* 1987, Bosworth and Rogers 2001), and administrative data - i.e. (Griliches 1981, Griliches *et al.* 1991, Geroski *et al.* 2002, Bosworth and Rogers 2001, Greenhalgh and Longland 2001). Less common, and more difficult to collect, are the emerging softer measures of informal R&D and the accumulation of innovative non-IP intangible assets (Kleinknecht 1996, Hinloopen 2003). In addition, some studies use the numbers of commercialised inventions identified either by experts in each field, such as those collected by the Science Policy Research Unit in the UK (i.e. Blundell *et al.* 1999) or industry journals (i.e. Acs and Audretsch 1993).

Aside from the conceptual measurement issues raised in the preceding section, each of the abovementioned measures embody a range of *a priori* biases with respect to the nature of the innovation (e.g. whether it is a product or process innovation) and the stage of the innovation pathway that the measure is calculated. Recalling the innovation life cycles presented in Figure 1 and Figure 2, note that while both product and process innovations start with R&D expenditure, there is a difference between the two with regard to registered IP rights: product innovations result in patents, trade marks and/or designs while process innovations are typically only patentable (and only a few are ever patented because process innovations are often kept as trade secrets). This indicates that using IP rights as a measure of innovation may be biased towards product innovations. In the next section of the paper, these biases, as they affect to different measurement proxies are discussed in more detail.

Expenditure based measures

R&D data – expenditure and employment

Company R&D expenditure data are generally collected through either company annual reports or official government surveys. Companies may formally record their R&D expenditure for two reasons. In the first place, they may be permitted through national accounting standards to capitalise some parts of these expenses. Usually this requires the firms to argue, with some level of persuasion, that benefits are expected to accrue beyond the current year. Depending on how the firm wants to temporally distribute their earnings and profits (for tax benefits and to inform the stock market), they may or may not avail themselves of the opportunity to capitalise rather than expense R&D. In addition, not all firms that collect R&D data will formally report it in their annual reports even though this is required by many national accounting standards[8]. Secondly, from time to time national governments operate R&D incentive programs which require formal documentation of R&D activities. Often the R&D that is required to be recorded is a subset of the accounting definition; in some countries, such as Australia, the current tax rebate program is skewed towards R rather than D.

Aside from the issue of whether companies choose to report R&D or not, it has not been documented, to our knowledge, which definition of R&D expenditure companies report in surveys and annual reports. We should expect that whether or not R&D expenditure is reported, and what is reported, varies according to the firm's motives with respect to the reasons given above. Accordingly, it is never clear whether the high incidence of missing data in most accounting based firm data sets are excluded for strategic reasons, are positive values below a certain threshold or are true zeros. Other than the familiar view that SMEs under-report R&D, it is not clear what the systematic biases in reported R&D are, although we expect that due to the greater public scrutiny, public companies will be more likely to report R&D and report it appropriately[9].

HYPOTHESIS 1. The use of R&D data as a true measure of innovative services is biased towards large firms.

HYPOTHESIS 2. The use of R&D data as a true measure of innovative services is biased towards public companies.

The analysis of innovative behaviour requires the R&D variable to be included on a dataset which includes, *inter alia,* economic variables such as profits, employment, sales, technology area and industry sector. Many official R&D surveys do not provide depth among the co-variables and thus cannot be used for firm level analysis by non-government researchers. The issue of commercial confidentiality may also be an issue for micro data analysis, however, increasingly government statistical bureaus are permitting remote access statistical interrogation of their micro data which, although expensive, does

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[8] For example, Australia and the UK.

[9] Kleinknecht *et al.* (2002) report that the number of firms receiving R&D subsidies in the Netherlands is close in number to the numbers reported on the CIS innovation surveys, but exceeds the official R&D survey by orders of magnitude.

expand the scope of data considerably. To the extent though that government datasets have limited co-variables and that entities are not linked over time, economists are forced to rely upon commercially provided annual report based datasets. Official datasets are nonetheless valuable sources of information on the level of R&D activity within and between economies.

A further difficulty with using data on nominal R&D expenditure is that it fails to account for differences in price and quality of each R&D dollar spent over time. Inflationary effects are typically accounted for using price indexes, but as noted above, these imperfectly solve the problem. As already discussed, one way of dealing with the heterogeneity in the value of R&D expenditure is to consider differences in the education levels and skill sets of employees involved in R&D. Such data is collected by organisations such as the OECD (see OECD 2004 for details), but the data is typically drawn from household surveys and can only be used on an industry or country level – it is not possible to match this data through to individual companies and it therefore has little value when trying to measure the impact of R&D employment on firm-level innovation.

Count based measures

Registered IP

IP applications – patents, designs and trade marks – are popular measures of innovation but it is widely accepted that '…patents appear to be a good indicator for …inventive activity…[only] at a very aggregated level.' (Griliches 1995, p54). Nonetheless, using administrative data on IP provides certain benefits for the researcher since long time-series datasets exist and simple counts of applications for registration of IP provide information on inventions that are both new to the firm and the world. Measures of innovation based on registered IP are sometimes criticised on the basis that they are inputs or outputs of innovation rather than the activity itself. However this is a misconception. All static measures of innovation are snapshots at different stages of the process of creating change: the art of economic modelling is to try and adjust for this.

As a measure of the number of potentially significant inventions, however, registered IP data can have considerable biases. For instance, only firms who believe that the legal protection offered by registered IP is more valuable than it costs will attempt to apply for it. Accordingly, innovations in areas not well covered by patent laws, (eg services), inventions that can be protected by other methods (eg secrecy, unregistered copyright or keeping-ahead), inventions that are otherwise hard to imitate – usually because they are embedded in complex production systems – and firms which do not have the resources to support litigation and enforcement (such as SMEs) are expected, *a priori*, to have a lower correlation between IP rights and innovation (see Griliches 1990).

HYPOTHESIS 3. Using patent applications as a true measure of innovative services is biased towards large firms.

HYPOTHESIS 4. Using patent applications as a true measure of innovative services is biased against service sector firms.

The extent of industry sector and firm size 'distortions' in patent data are not expected to translate directly to trade marks since there is provision under the law for service marks and the costs of registering a trade mark are considerably lower than for patents. Use of trade mark applications and stocks as an indicator of innovative activity is clouded because firms trademark for non-innovation reasons, leading to larger than expected standard errors in estimation procedures. Nonetheless, we expect that trade mark applications will be a better measure of innovative service for service and smaller firms than the converse, *ceteris paribus*.

HYPOTHESIS 5. Using trade mark applications and stocks data as a true measure of innovative services is less biased towards large firms than for SMEs.

HYPOTHESIS 6. Using trade mark applications and stocks data as a true measure of innovative services is less biased towards service sector firms than for manufacturing firms.

Beyond this, each type of IP right differs in what it purports to measure. Patents and design applications are only made for inventions or designs the inventor believes are new to the world. Trade marks, on the other hand, can be used to herald the formal launch of a product, which is only new to the firm, or to the local market. While designs and trade marks are most clearly applied to product innovations only, there is also some evidence that the use of patents for process innovations is low (see Levin *et al.* 1985, Cohen *et al.* 2000).

HYPOTHESIS 7. Using trade mark and design applications as a true measure of innovative services is biased towards firms which invent new products rather than new processes.

HYPOTHESIS 8. Using patent applications and stocks as a true measure of innovative services is biased towards firms which invent new products rather than new processes, but this bias is less than for trade marks and designs.

While patents are intended to be used to encourage firm innovation, the strategic use of patents to block innovation by rivals through the creation of patent thickets is being increasingly reported in the US (see Shapiro 2001, Beard and Kaserman 2002). Rubinfeld and Maness (2004) also report that patent portfolios can be used strategically to raise rivals' costs. One such strategy is "patent flooding", where a firm files a multitude of patent applications claiming minute variations on a competitor's key technology, thereby increasing the credibility of any threat to litigate against infringement. A firm's ability to use patents for such strategic reasons depends on the ease with which patent are granted, which may vary across countries and over time. While it is not clear how prevalent these practices are, especially outside the US, they suggest that using patent counts as a measure of innovative activity could be (increasingly) flawed since such strategic use of patents has little to do with innovation *per se*. This suggests that, in some instances, patents may be a poor proxy for innovation but a good predictor of profitability.

HYPOTHESIS 9. Using patent applications as a proxy for innovation is biased towards firms that are more profitable than others.

Some economists have argued that firm level IP data should be adjusted for economic value because only a very small proportion of patents had significant value (see Harhoff *et al.* 1999). As a result, there have been several moves to systematically value-adjust patent applications by weighting applications counts according to whether they have been granted (sealed), how often they had been renewed (Lanjouw *et al.* 1998) or how often they have been cited by subsequent patents (Jaffe *et al.* 1998). In addition, stocks of IP rights rather than the flow of applications, weighted by time since lodgement, have been used in firm performance equations (Griffiths and Webster 2004).

In practice, weighting individual firm patents by forward-citations or renewal rates is not without difficulties because citation rates for recent patents may be unreliable (see Narin 1999) and renewals can take several years to occur. Accordingly, applications may need to be over a decade old before the renewal data adds information about quality. The study by Harhoff *et al.* (1999) also revealed that while patents paid until full-term were more valuable than those which expired prematurely, there still remained considerable variation in the value of patents of the fully paid group. A further major disadvantage of these methods of adjusting for quality is that they do not allow us to identify *ex ante* the determinants of patent value.

Counts of innovations in trade journals

The oldest example of journal-based innovation counts is the US Small Business Administration's Innovation Data Base compiled in 1982 by the Futures Group, and used by Acs and Audretsch (1993). The method has subsequently been employed in the Netherlands, Ireland, UK and Austria [see the collection of papers in Kleinknecht and Bain (1993) and see Brouwer and Kleinknecht (1996)]. The advantages of this measure are that it does not require firm compliance (which introduces considerable selection bias), it is relatively cheap to collect and that a time series can be collated *ex post* since historic records are usually available. Furthermore, journal based counts are not subject to the same technical and economic biases that shape the patenting decision. The cost of being reported in a journal is negligible and articles are not limited to patentable innovations.

Nonetheless, this measure has also several shortcomings. It is unlikely that these measures can distinguish between true inventions and imitated products and thus market leaders. In addition, while journal counts can be reasonable records of product innovation, they are considered to provide relatively poor sources of information about process innovations. Firms have clear incentives to publicise product innovations but also to conceal new processes. Given this, Kleinknecht (1993) suggests that these data should be primarily regarded as sources of product innovations and that attention should be paid to possible biases across industry or market areas and over time arising from varying journal coverage rates. This type of measure typically does not adjust for quality and generally represents the end stage of the innovation pathway.

Qualitative assessments

Qualitative estimates have been introduced as a way to record the scope of innovative activities and the quality of effort expended. There are two main forms that are considered here: expert assessments drawn from outside the firm and surveys of firm managers.

Expert assessments

Expert assessments constitute a round table discussion of firms' innovative activities. New products and processes are judged by people who have deep technical or market knowledge. As a measure of the number of launches of new products to market, expert innovation counts have an intrinsic subjective human element, especially the rating of its significance. An early (international) example of this data was collected by the Gellman Research Associates in the early 1970s (Acs and Audretsch 1993) and subsequent ventures include the innovation database at the Science Policy Research Unit at the University of Sussex (UK) (Robson *et al.* 1988). A major advantage of this type of measure is that it includes product and process innovations and can potentially adjust for heterogeneity and novelty factors.

While these data sources are very valuable, they also have several shortcomings. Only inventions that are known outside the firm are counted and there is likely to be as many different outcomes as there are potential experts. According to Griliches (1995), these measures suffer from an undisclosed degree of selectivity and incompleteness in coverage and are accordingly not bias free. Furthermore, if experts' ratings of innovations are influenced by the firm’s subsequent success, then innovation counts are not truly exogenous in equations to explain market value or profits. Another disadvantage is that they are very expensive to collect and this may lead researchers to use other data sources Kleinknecht (1996).

Surveys of managers

Since the 1980s, a number of survey based innovation measures have been developed. Work in this area by the OECD and EU has been published as the ‘Oslo Manual’ and culminated in the Community Innovation Surveys (CIS) (see Kleinknecht 1993, Baldwin *et al.* 2002, Kleinknecht *et al.* 2002). These surveys require managers to quantify or rate the firm’s innovative activities during a defined time-period, such as the number of new products, the extent of introduction of new processes and technologies, the type of R&D activity, the level of advertising expenditure etc. A major advantage of this type of measure is its comparability across firms operating in different markets and technology areas and its sensitivity to the more informal forms of innovation. As such, it is less biased towards manufacturing firms or firms with large R&D infrastructure than other innovation proxies. A further strength of this type of measure is that it can potentially account for heterogeneity and uniqueness factors through appropriate survey design.

As with all survey techniques, however, biases arise because of the large number of different individuals involved in the assessments and the difficulty of inter-personal comparisons. This can be an issue when a study models relationships drawn from variables described by the same survey respondent. These measures are survey based, usually through a postal survey, and can be expensive to collect and usually have low response rates. The study by Levin *et al.* (1985) is among one of the most cited early uses of this type of measure and there has been considerable research undertaken on the (CIS) (see Kleinknecht *et al.* 2002, Kleinknecht and Bain 1993, Kleinknecht 1996).

Table 1 presents key characteristics of the commonly-used innovation indicators and a summary of the inherent biases. Because of the flexibility of survey questions, we argue that it is a less biased measure on innovation with respect to the main observable characteristics of innovation and the firm. Accordingly, we will use this measure as the benchmark against which other measures should be compared.

Table 1: Summary of the main characteristics of selected innovation measures

Less biased indicator of….	*R&D data*	*Patent applications*	*Trade mark applications*	*Design applications*	*Expert assessments*	*Journal counts*	*Survey of managers*
Type of innovation							
Product	X	X	X	X	X	X	X
Process	X				X		X
Organisation							X
Market			X				X
New to firm			X				X
New to world	X	X		X	X	X	X
tage of pathway							
Early	X				X		
Middle		X		X	X		X
Late			X		X	X	X
irm characteristic							
Large firms	X	X					X
Manufacturing firms	X	X		X			X
Service firms			X				X
Successful firms					X		X
Public companies	X						X
ther features							
mall sample problems							X
Cheap to collect	X	X	X	X		X	
Adjust for quality					X		X

Correlations between innovation measures

The remaining sections of this paper compare, on a firm basis, our survey based measure of innovation against other innovation measures based on R&D expenditure and registered IP rights. Ideally, we would have included other innovation proxies such as trade journal counts and expert assessments in our analysis. However, Australian data on these measures is not available. The survey measure of innovation used here comes from the Melbourne Institute Business Surveys, R&D data was taken from the IBISWorld data base and the firm-level IP data was obtained by matching IP Australia data with listed or parent companies from IBISWorld. All in all, we have 641 firm level observations for comparison. The construction of the independent measure of innovation is discussed in the following section and then the correlations with other innovation measures are analysed.

Table 2: Characteristics of organisations in the innovation survey, Australia 2001-2003

	Respondent (%)	Top 1000 (%)
Major industry group		
Agriculture, Forestry & Fishing	1.0	0.7
Mining	3.1	2.8
Manufacturing	26.2	24.1
Electricity, Gas & Water Supply	4.5	6.8
Construction	3.2	4.5
Wholesale Trade	11.7	11.3
Retail Trade	5.0	5.9
Accommodation, Cafes & Restaurants	0.5	0.5
Transport & Storage	3.9	3.8
Communication Services	0.3	0.2
Finance & Insurance	12.0	14.2
Property & Business Services	7.2	10.6
Government Administration & Defence	0.9	1.2
Education	4.4	3.8
Health & Community Services	3.8	4.5
Cultural & Recreational Services	2.3	3.3
Personal & Other Services	1.7	1.9
Missing	8.2	
Total	*100.0*	*100.0*
Employment size		
Under 200	11.2	12.2
200 to under 500	17.7	20.4
500 to under 1000	19.8	19.8
1000 to under 5000	39.0	38.6
Over 5000	12.3	9.0
Total	*100.0*	*100.0*

Source: Melbourne Institute Business Survey 2001, 2002 and 2003

The survey measure of innovation

The independent survey measure of innovation used in this paper was constructed using the Melbourne Institute Business Surveys 2001-2003. In this survey, the top 1000 firms (as measured by total revenue) from the IBISWorld firm database in each of the years 2001, 2002 and 2003 were sent out a survey covering a wide range of issues from innovation to workplace relations. Approximately 3000 surveys were mailed out in total with 641 useable surveys returned, representing a response rate of 21 per cent, which is consistent with other surveys of this type (see for example, Huselid 1995, Covin *et al.* 2001)[10].

Descriptive statistics presented in Table 2 provide information on the major industry categories and employment size for the organisations in our sample. More than a quarter of organisations were located in manufacturing, with the next highest proportion represented by finance and insurance, property and business services and wholesale and retail trade. Importantly however, the distribution of responses across characteristics does not differ markedly from the initial selected population, implying that the responses should are not biased towards a particular industry. The main exceptions are a slight over-representation of manufacturing and middle range sized companies.

The survey was addressed to senior managers with responsibility for innovation policies, and as such, responses regarding the innovation may be biased toward the perspective of this single manager. The innovation questions used a seven-point Likert scale with the anchors 1=strongly disagree and 7=strongly agree. Perceptual measures permit comparisons across very different organisations and industries and are easy to collect because they place fewer burdens on respondents than administrative or factual entries. However, they contain a subjective element and thus an undefined error and some caution must be used when analysing the results.

The survey asked a range of questions relating to the firm’s emphasis on R&D, technological leadership, whether they are often the first organisation to introduce new

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[10] Of these, 266 are repeated firms (the same firm in the sample in successive years).

products or operating technologies, how often they develop new process innovations that reduce costs, and whether they develop products which are considered the best in the industry. As such, the survey measure of innovation constructed here is biased towards product and process innovations that are new to the world. Other types of innovations – such as organisation, input and market innovations – are not included in the survey measure.

Similar to other studies of this type (see for example Arvanitis 2002, Hollenstein 2002), the innovation variable used in this paper has been constructed using a data reduction method and does not rely upon a single variable. The use of a single variable is unlikely to adequately measure the underlying latent construct of interest, such as the level of innovation within the firm, or the management style adopted. However, we do not want to use a data reduction method that will exclude cases if there is a missing response. Accordingly, the measures of innovation are means of the non-missing innovation questions.[11]. Because the variables are averages of up to 16 items, they are like continuous variables bounded between 1 and 7. Table 3 which presents the mean values for each of our innovation measures, that while the average level of innovativeness from the survey measure was equivalent on average across the major characteristics of size, sector, type and success dimension, this was not true for the other measures. In particular, there were clear differences in the rate of R&D, IP stocks and patent stocks.

Analysis of the correlations between the survey measure and other innovation proxies

To test for the relationship between the survey measure of innovation and other measures, a series of pair-wise correlations were calculated and are shown in Table 4. The first correlate presented in Table 4 is R&D expenditure divided by tangible assets, while the second of the correlates is “All IP stocks” divided by tangible assets, which is a variable

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[11] Where appropriate, the 1 to 7 scales were reversed to order items in a consistent direction. All *a priori* innovation items were included in its summated scale. Using means implies that these scales should be treated as cardinal, so that the distance of the extremes from the score of 4 is given equal weight. This implies that the results of the analysis are invariant with respect to monotonic transformations of the scale, such as giving a different number to each category.

Table 3: Descriptive statistics of the survey measure of innovation and alternative measures of innovation

Measures of innovation	***All firms***	***Firm size***		***Sector***		***Firm type***		***Success dimension***	
		SME	*Large*	*Manufacturing*	*Services*	*Public*	*Private*	*Positive profits*	*Negative profits*
Survey measure (a)– mean	4.538	4.542	4.519	4.711	4.494	4.590	4.686	4.558	4.474
standard deviation	1.003	1.136	0.971	0.947	1.018	0.953	1.040	0.984	1.059
R&D expenditure(b) / tangible assets - mean	6.882	11.693	6.505	11.110	5.947	5.991	10.215	7.438	5.590
standard deviation	190.715	383.801	31.011	35.882	222.670	29.270	322.401	218.202	32.929
All IP stocks / tangible assets (factor)	956.9	163.9	1873.8	1950.9	784.1	1513.2	354.8	1394.8	1344.8
standard deviation	10119.3	1422.1	14908.7	10441.4	11215.6	9252.7	2204.2	11875.1	14942.3
Patent stocks / tangible assets	0.021	0.030	0.018	0.026	0.020	0.021	0.026	0.021	0.021
standard deviation	0.159	0.292	0.090	0.092	0.182	0.104	0.117	0.169	0.122
Trade mark applications / tangible assets	0.001	0.001	0.001	0.003	0.001	0.002	0.001	0.001	0.001
standard deviation	0.013	0.015	0.012	0.021	0.010	0.015	0.015	0.015	0.009
Design applications / tangible assets	4.538	4.542	4.519	4.711	4.494	4.590	4.686	4.558	4.474
standard deviation	1.003	1.136	0.971	0.947	1.018	0.953	1.040	0.984	1.059

Notes: (a) Composite of the following questions: In general the managers in my organisation favour a strong emphasis on the marketing of tried and true products and services; In dealing with its competitors, my organisation is very seldom the first organisation to introduce new products/services, operating technologies; Description of your organisation's competitive strategy (i) develops new process innovations that reduce costs (ii) produces a continuous stream of state-of-the-art products/services (iii) is "first to marker with new products/services (iv) develops products/services which are considered the best in the industry.

(b) Assumes that firms which do not report R&D, and have never reported R&D over the whole data period and have never applied for a patent over the whole data period, have zero R&D expenditure.

**, *, † significant at the 1, 5 and 10 per cent levels respectively.

Table 4: Correlations between the survey measure of innovation[a] and alternative measures of innovation

Alternative measures of innovation	***All firms***	***Firm size***		***Sector***		***Firm type***		***Success dimension***	
		SME	*Large*	*Manufacturing*	*Services*	*Public*	*Private*	*Positive profits*	*Negative profits*
R&D expenditure[b] / tangible assets	0.0555	0.3032	0.0219	0.2713**	-0.0173	0.1185†	0.1781†	0.0147	0.3252**
n	375	38	309	85	274	165	113	298	69
All IP stocks / tangible assets (factor)	0.1681**	0.3573*	0.1340*	0.2579**	0.1227*	0.2249**	0.1704*	0.1317**	0.3327**
n	524	46	442	119	383	223	136	419	96
Patent stocks / tangible assets	0.0789*	0.2968*	0.0625	0.1877*	0.0373	0.1243†	0.1736*	0.0457	0.1993*
n	639	65	499	138	470	245	189	432	103
Trade mark applications / tangible assets	0.1420**	0.141	0.1504**	0.1611†	0.1320**	0.1100	0.1705*	0.1527**	0.1037
n	524	46	442	119	383	223	136	419	96
Design applications / tangible assets	0.1158**	0.2765	0.0966*	0.2194*	0.0261	0.1664*	0.0611	0.1055*	0.2114*
n	524	46	442	119	383	223	136	419	96

Notes: (a) Composite of the following questions: In general the managers in my organisation favour a strong emphasis on the marketing of tried and true products and services; In dealing with its competitors, my organisation is very seldom the first organisation to introduce new products/services, operating technologies; Description of your organisation's competitive strategy (i) develops new process innovations that reduce costs (ii) produces a continuous stream of state-of-the-art products/services (iii) is "first to marker with new products/services (iv) develops products/services which are considered the best in the industry.

(b) Assumes that firms which do not report R&D, and have never reported R&D over the whole data period and have never applied for a patent over the whole data period, have zero R&D expenditure.

**, *, † significant at the 1, 5 and 10 per cent levels respectively.

that has been constructed by combining patent, trade mark and design stocks (per firm tangible assets) into a common factor.[12] The correlation between the survey measure of innovation and the stocks of patents and flows of trade marks and designs is also presented[13].

The first column in Table 4 presents the correlations between the various innovation measures for all of the firms in the sample. Of the 375 individual firms for which we had data on both R&D expenditure and the innovation survey, the correlation between the two is 0.0555 which is quite low and somewhat surprising given that typical studies of innovation normally posit that there is a strong (positive) relationship between the two. Although the correlation is statistically insignificant, this result tends to suggest that those firms that are reporting that they are highly innovative in the survey are not necessarily those that are investing in R&D. Of the relationship between innovation and registered IP, the relationship is much stronger: for example, the correlation between all IP stocks and the survey innovation measure is 0.1681 and is significant at the 1 per cent level. Looking at the correlations for individual IP rights, it appears that the strongest effect is between the survey innovation measure and trade mark applications, which is positive (0.1420) and significant. Patent stocks, on the other hand, only have a correlation of 0.0789 with the survey innovation measure.

These low level correlations are not dissimilar to those found by Acs and Audretsch (1993) on the US Small Business innovation data base 1982. Similar to our survey, they found no precise correlation at the firm level between their survey measure of innovation and R&D expenditure as a proportion of sales. However, when they grouped his cross-sectional data by (20 manufacturing) industries, the correlations were considerably higher. The correlation between R&D spending & journal counts was 0.746, for patents & journal counts, 0.467, R&D spending & patents, 0.327[14]. Kleinknecht *et al.* (1993) has

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[12] Only design applications were used as design stock data is not yet available.

[13] Note that when analysing the impact of individual IP rights, we have used applications (i.e. flows) of trade marks and designs but for patents we have used stocks rather than flows. The life of a patent is more parallel to the innovation period (boxed in Figures 1 and 2) while the life of the (perpetual) trade mark extends well into the established part of the product life. Trade mark applications (flows) on the other hand, correlate with the latter part of the innovative period.

[14] R&D data from 1977 and patent data in 1976-77.

also assessed the relationship between different innovation measures. Using firm data grouped by 34 manufacturing sectors, he found the correlation between R&D expenditure and journal innovation counts to be 0.64. The correlation between patent applications and these innovation counts was 0.53[15].

We estimate also pair-wise correlations between our measures, disaggregated by firm size, industry sector, corporate structure and profitability. These correlations do not control for secondary variables, so that, for example, the correlations on corporate structure do not account for firm size. The next two columns in Table 4 present these correlations[16]. The distribution between large and SME firms in the sample is skewed towards large firms – there are roughly 8 times as many large firms as there are SMEs. The results on the correlations between self-reported innovation and measure of firm size are surprising given our *a priori* hypotheses. Looking at R&D, we expected that this may be biased towards large firms on the basis that large firms are more likely to be actively involved in R&D (and that they are often more likely to report R&D expenditure) than SMEs. However, the results suggest that this bias doesn't exist: the correlation between SMEs reported innovation and R&D expenditure is 0.3032, while for large firms it is 0.0219. Although neither correlation is statistically significant, this result provides no support for Hypothesis 1. Similar counter-intuitive results are found with regard to the relationship between the survey innovation measure and IP rights: we expected patent stocks to be stronger for large firms (Hypothesis 3) and trade mark applications to be biased towards SMEs (Hypothesis 5). However, neither bias is borne out in the data: patents stocks are more strongly correlated with SMEs (0.2968) than large firms (0.0625) and trade marks are more strongly correlated with large firms (0.1504) than SMEs (0.141).

Table 4 also includes correlations between the survey measure of innovation and administrative data for manufacturing and service firms. The separation of the two industry categories was made using data from IBISWorld. Manufacturing is a stand-alone industry category, while the service industry was defined as including all other industry

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[15] Data were for 1988 – 89.

[16] In order to differentiate between large and SME firms, we have used the ABS definition of SMEs – firms that have less than 200 employees.

groups except for primary industries such as agriculture, fisheries, and mining. The results are broadly consistent with our hypotheses. The first interesting observation that can be made from the results is that the relationship between R&D expenditure and the survey measure of innovation is highly biased towards manufacturing firms. In fact, for service firms, the relationship is negative (-0.0173), although it is not statistically significant. Furthermore, the relationship between the survey innovation measure and patent stocks is biased towards manufacturing industries (which has a correlation of 0.1877) (hypothesis 4). However, there does not appear to be any bias with regard to trade mark applications (hypothesis 6). The correlations are almost the same for manufacturing and service firms.

Using the IBISWorld data, we also separated the innovation surveys into public/private firms and according to whether they earn positive or negative profits. The results of the correlation with alternative innovation proxies based on administrative data are presented in the last four columns of Table 4. While the relationship between all IP stocks and public firms is strong and positive, the relationship between patent stocks and public firms is much weaker and not biased towards public firms (the correlation for public firms is 0.1243 while for private firms it is 0.1736). With regard to R&D data, the results suggest that the correlation is higher for private firms (0.1781) than for public firms (0.1185). Thus, there is no evidence supporting Hypothesis 2 that public companies report R&D more systematically. Similarly, there is little evidence to support our contention in Hypothesis 9 that the relationship between innovation and patent stocks would be stronger for firms with positive firms than for firms with negative profits.

Another interesting feature of the literature on innovation is that there is tendency to focus on product rather than process innovations (which is reflected in Hypotheses 7 and 8). This may be partly caused by the fact that product innovations are easier to observe. In order to examine whether this has any substance in fact, we have split the data from the innovation survey measure into questions that related solely to product innovations and those that related solely to process innovations. These two data sets have then been correlated with R&D expenditure and IP rights in the same way as before. The results, which are presented in Table 5 strongly support hypotheses 7 and 8. Apart from R&D

expenditure, the results for all other innovation proxies are highly skewed towards product innovations. For example, the correlation between product innovations reported in the survey and patent stocks is 0.1034 (and statistically significant at the 1 per cent level), whereas for process innovations the figure is much lower at 0.0149 and is insignificant.[17] Similarly, trade marks and design applications are skewed towards product innovations.

Table 5: Correlations between disaggregated survey measures of innovation and expenditure and alternative measures of innovation

	All firms		
Innovation proxies	***Product and process innovations***[(a)]	***Product innovations***[(b)]	***Process innovations***[(c)]
R&D expenditure[(d)] / tangible assets	0.0555	0.0744	0.0031
n	375	374	375
All IP stocks / tangible assets (factor)	0.1681**	0.2012**	0.0259
n	524	523	524
Patent stocks / tangible assets	0.0789*	0.1034**	0.0149
n	639	638	639
Trade mark applications / tangible assets	0.1420**	0.1482**	0.0192
n	524	523	524
Design applications / tangible assets	0.1158**	0.1436**	0.0115
n	524	523	524

Notes: (a) Composite of the following questions: In general the managers in my organisation favour a strong emphasis on the marketing of tried and true products and services; In dealing with its competitors, my organisation is very seldom the first organisation to introduce new products/services, operating technologies; Description of your organisation's competitive strategy (i) develops new process innovations that reduce costs (ii) produces a continuous stream of state-of-the-art products/services (iii) is "first to marker with new products/services (iv) develops products/services which are considered the best in the industry.
(b) Composite of the following questions: In general the managers in my organisation favour a strong emphasis on the marketing of tried and true products and services; In dealing with its competitors, my organisation is very seldom the first organisation to introduce new products/services, operating technologies; Description of your organisation's competitive strategy (i) produces a continuous stream of state-of-the-art products/services (ii) is "first to marker with new products/services (iii) develops products/services which are considered the best in the industry.
(c) Composite of the following questions: In general the managers in my organisation favour a strong emphasis on the marketing of tried and true products and services; Description of your organisation's competitive strategy (i) a strong emphasis on the marketing of tried and true products and services (ii) develops new process innovations that reduce costs (iii) focuses on increasing productivity (iv) increases operating efficiencies.
(d) Assumes that firms which do not report R&D, and have never reported R&D over the whole data period and have never applied for a patent over the whole data period, have zero R&D expenditure.
**, *, † significant at the 1, 5 and 10 per cent levels respectively.

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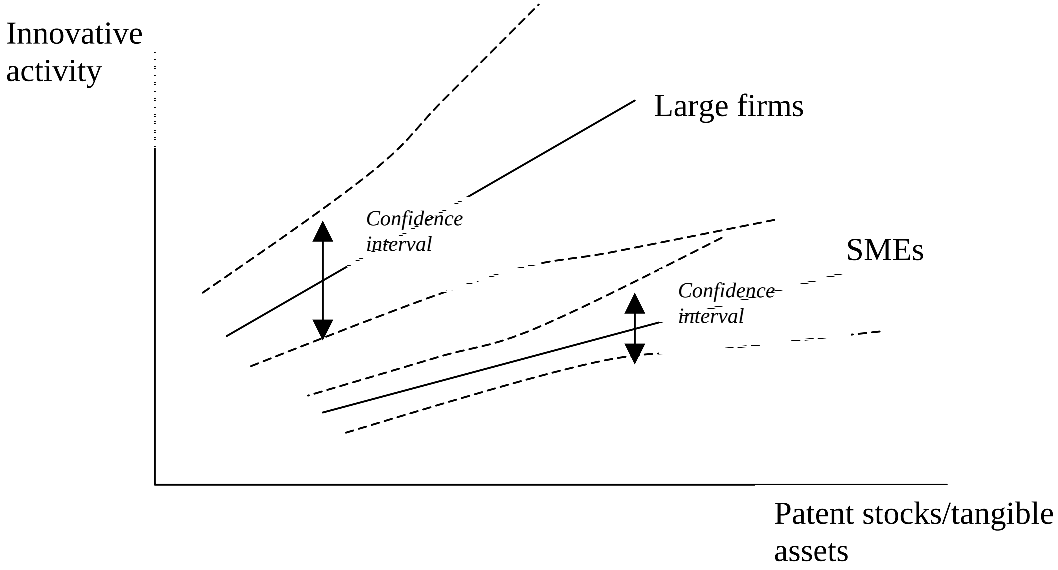
[17] This is consistent with the survey work of Levin *et al.* 1987, p830) who found that most firms regarded patents as of limited use for protection process innovations.

Figure 3 provides a representation of the relationship between innovative activity and the patent stock measure implied from our results. Not only is the average level of patent stocks per tangible asset is lower for large firms than for SMEs for a given level of innovativeness (see the comparative means in the appendix), but the confidence interval around the estimated line is considerably greater for large companies than for SMEs.

Figure 3: Representation of the relationship between patent stocks and innovative activity by firm size.



Conclusion

Measuring the level of innovation in firms or economies is antecedent to most applied economic analyses of productivity and firm performance. It is also difficult to do well given the ephemeral nature of innovation. In this paper, we have highlighted the main conceptual difficulties associated with defining and measuring innovation and empirically examined some of the potential biases associated with commonly-used ways to measure innovation at the firm level. One of the overall conclusions from this analysis is that firm level correlations between self-reported measures of innovation such as the survey and the accounting and administrative measures, are much lower than expected *a priori*.

Much of the literature on innovation doesn’t question the use of patents (weighted by citations) or R&D expenditure as a proxy for innovation. However, the results presented here suggest that at an aggregate level such an assumption is questionable since the correlation between patents (and in fact all IP rights) is less than 20 per cent. In other words, there is only a weak relationship between those firms that report that they are innovative and those that take out IP rights. A similar conclusion can be drawn with regards to R&D expenditure. This implies that these accounting and administrative measures do not make good measures for a company by company analysis. However, this does not mean they have no information content. Carefully interpreted they can provide both descriptive and analytical content.

They can be used to estimate trends in innovative activity provided adjustment is made for differences, between jurisdictions or over time, in the distribution of firms by size and industry sector. Furthermore, they should primarily be used to depict product rather than process innovations. There is less need to adjust the data for difference in company structure as its effect on the relationship between the survey measure and the other measures is less obvious.

The accounting and administrative measures can also supplement econometric modelling, but we expect large standard errors on the estimates. Some adjustment should also be made for firm size and industry sector. The example of large firms and SMEs given in Figure 3 illustrates that both adjustments to the estimated position of the ‘true’ function and the confidence interval surrounding the estimate should be considered.

Finally, some consideration should be given to the conceptual conundrums posed in the earlier part of the paper. One of the major difficulties we discussed was how to adjust for the difference in quality of simple expenditure and item counts. One option for adding interpretive meaning to these counts is to include, for both accounting and modelling exercises, more than one measure of innovative services. A second way is to include supplementary information on the characteristics of the measures. The latter may include the skills of the innovation workers, the number of applications for any patent, the class of the trade mark and etcetera. This method however, will only work for observable and recorded characteristics and to account, in a crude way, for the unobservable aspects of innovation services a fixed and random effects estimation is required.

We also discussed the problem of adjusting for inflation when characteristics of the innovative services are changing rapidly. The use of hedonic price indexes – which attempt to explain changes in prices by consideration of changes in quality characteristics – provide one way of remedying this problem (see Landefeld and Grimm 2000). However, hedonic indexes are only a partial solution since there is no way to control for quality of a product such as the DVD that did not exist 5 years ago.

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