Service Lives of R&D Assets: Comparing Survey and Patent-based Approaches

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Abstract

Research and Development (R&D) is recognised as an asset in the System of National Accounts (SNA) 2008 (United Nations, 2009) and European System of Accounts (ESA) 2010 (European Union, 2013). This creates not only a need to accurately estimate R&D investment but also a need for representative estimates of the period over which R&D assets remain in the capital stock – the service lives of R&D assets.

After a brief background on R&D asset lives, this paper builds upon previous ONS research (Ker, 2013) using further service life data collected via the 2012 Business Enterprise R&D (BERD) survey alongside the data from 2011. These results are compared to estimates derived from Patent administration data. The strengths and limitations of these different sources, and the methods that may be applied to them, are also discussed.

1. Introduction

The 2008 revision of the System of National Accounts (United Nations, 2009) requires R&D expenditures to be treated as investment in knowledge assets. This reflects the on-going contribution of knowledge produced through R&D to production and output over multiple years. This new accounting will provide insight into the role of knowledge in the economy, the allocation of resources to R&D, and will improve understanding of the relationship between knowledge and productivity. Capitalisation also recognises R&D assets in the National Balance Sheet and therefore affects the measurement of National Wealth.

The change poses a variety of challenges for National Accountants; much effort has been invested in developing methods to measure investment in R&D assets in particular. But establishing the appropriate valuation for R&D assets is only part of the task, it is then necessary to establish which sectors have economic ownership of these assets (see Steer & Ker (2013)) and how long they are useful for.

This paper provides an overview and update of ONS research into the useful lives of R&D assets.

2. Service Lives

The service life of an asset is *'the total period during which it remains in use, or ready to be used, in a productive process'* (OECD, 2001, p. 95). During its service life an asset may have more than one owner.

> *'Asset life is understood here as an economic notion, and not as a physical or engineering notion of capital goods. This is important because it implies that assets can change over time simply due to economic considerations even if the asset remains physically unchanged'* (OECD, 2009, p. 106).

The end of an asset's useful life may commonly result from obsolescence, wear and tear, or loss through accidental damage. For R&D, the majority of these concepts have no meaning due to its intangible nature. Knowledge does not suffer from 'wear and tear', nor can it be 'accidentally damaged' or subsequently 'repaired'; it has a theoretically infinite lifespan. However, economists are concerned with the length of time over which knowledge directly contributes to economic output and to companies' profits. This productively useful 'economic service life' will be finite.

The finite nature of R&D service lives can be explained by 'creative destruction' through which knowledge can be rendered obsolete and displaced by new discoveries (Bitzer & Stephan, 2007). Peleg (2008) found evidence that use of knowledge may be gradually scaled back over time suggesting a gradual superseding of the R&D or a process of gradual spill-over whereby, over time, the knowledge becomes available more widely until it is common knowledge and of no remaining specific value to its owner. R&D 'depreciates' therefore because it makes a decreasing contribution to owners' profits and to economic output over time.

2.1 Why Service Lives Matter

Aside from the volume of R&D investment, service lives of R&D assets are the main determinant of the R&D stock used in analyses of productivity and National Wealth. In the Perpetual Inventory Method (PIM) used to compile asset stocks, service lives are key parameters to survival functions which adjust for obsolescence; age-price (depreciation) functions which estimate the decline in assets' values as they age; and age-efficiency functions which estimate the age-related decline in efficiency. As a result:

> *'the accuracy of capital stock estimates derived from a PIM is* ***crucially dependent*** *on service lives - i.e. on the length of time that assets are retained in the capital stock, whether in the stock of the original purchaser or in the stocks of producers who purchase them as second hand assets'* (OECD, 2009, p. 106).

Shorter service lives give greater weight to more recent innovations in capital stock estimates (Australian Bureau of Statistics, 2009, p. 48), as (OECD, 2010, p. 33) clarifies;

> *'Specifying a service life of 10 years rather than 5 years would make a huge difference to estimates of capital measures. Net capital stock would be approximately double, and with a typical scenario of strong growth, consumption of fixed capital would be appreciably* smaller.'

The importance of reliable service lives for R&D assets is heightened by the use of sum-of-costs valuation for R&D (where the value of R&D produced is set equal to the total costs incurred in its production). In a fully integrated system, the contribution of existing R&D capital to the production of further R&D would be included amongst the costs summed; the effect of this on output and hence Gross Domestic Product is partially determined by the service life adopted for R&D assets.

2.2 European Task-Force Recommendation

Relatively few countries have produced R&D life estimates of any sort. The Second European Task-Force on R&D Capitalisation therefore offered the pragmatic alternative of *ten years* as a default in the absence of empirical information:

> *Service Life estimates used in the calculations of R&D should be based on dedicated surveys or other relevant research information, including information of other countries with comparable market/industry characteristics. In cases, where such information is not available, a single average Service Life of 10 years should be retained.*
>
> *It is also recommended that the above mentioned Service Life estimates should be investigated regularly, e.g. every 10 years.* (Eurostat, 2012)

However, there is no reason to assume that R&D service lives are equal between sectors in the same economy and much less between different countries with varied industrial mixes. Nor is it likely that the 'European average service life of R&D' happens to be 10 years – the minimum of the 10-20 year range suggested by the OECD (2010, p. 62). Furthermore, standardising the service life across countries removes one of the key determinants of the knowledge capital stock leaving the volume of R&D investment as the sole explanatory variable for countries' differing economic performance. It is therefore desirable for country-specific R&D asset lives to be estimated.

3. Estimating R&D Service Lives

Each individual asset will have a unique service life - two identical machines will not usually last the same amount of time before wearing out. In the case of R&D, no two knowledge assets are the same (by definition) and thus will have different useful lives. However, it is not viable to collect data at the asset level and instead information on the typical lives of different types of assets (such as buildings, machines, vehicles, and R&D) is used.

Though average lives receive the most attention, in general three descriptive statistics are needed to estimate the various functions used in the PIM:

> *'The average or mean service life has to be distinguished from the maximum service life of a cohort of assets because the service lives of the same assets within a cohort are normally described by a retirement or mortality function which defines the distribution of asset retirements around the mean and between the minimum and maximum service lives'* (OECD, 2009, p. 106).

The average, minimum, and maximum lives are likely to vary across:

- asset types – the average service live for R&D assets is likely to be less than for buildings for example; similarly 'Basic Research' might generally have a useful life different to 'Applied Research'
- industries and products – aeronautical research may generally be useful for longer than knowledge in software for example
- Institutional sectors - government-produced R&D might be useful for longer on average than businesses' R&D for example
- Time periods – the pace o
- f technological change is likely to vary over time

A practical, affordable, and robust source is needed to provide sufficient detail to capture the essential variation in R&D lives over these characteristics.

4. Sources of Information

As R&D is not usually treated as capital investment in financial reporting standards, the tax lives and information from company accounts commonly used for other assets are often unavailable for R&D. Expert opinions have provided useful information for some types of assets, but survey questions and analyses of data from patent administration systems are generally the most favoured sources of R&D service life estimates.

This research compares and contrasts two approaches for estimating service lives of R&D assets:

1. The UK has conducted one of the largest surveys of business R&D service lives to date with 882 businesses providing responses to questions on R&D asset lives added to the 2011 and 2012 BERD surveys. This was developed from a question used in the 2009 'Investment in Intangible Assets' survey and was improved through two rounds of pilot testing. It asked:

   For how long does the business expect to benefit from a typical investment in:
   - *i. 'Basic Research'*
   - *ii. 'Applied Research'*
   - *iii. 'Experimental Development'?*

   These different 'types' of R&D are defined in the Frascati Manual (OECD, 2002) and are also used in other R&D survey questions. They are differentiated by the degree of focus on specific applications or products. Answers for each were recorded in years.

   The question was included on the BERD 'long form' which is sent to around 400 businesses which spend the most on R&D. Over 87% of these firms provided one or more R&D service lives in 2012 (a rate similar to 2011). The question was also included on all forms in Northern Ireland which adds some coverage of firms which spend less on R&D (around 2.5% of business R&D expenditure takes place in Northern Ireland), though the response rate for these firms was much lower. In total, the responses directly represent over 68% of UK business R&D (based on their 2012 current expenditure).

   The paper Service Lives of R&D Assets: Questionnaire Approach (Ker, 2013b) provides further detail on the development of this question, the data collected, and results from the 2011 data.

   In the latest survey (2012) 743 businesses responded to the service lives questions, 14% more than in 2011. There were 1,358 service lives relating to each firm's basic research/applied research/experimental development individually. This compares to 1,167 individual lives in 2011 and the increase was driven by firms that responded in 2011 providing estimates for more types of R&D as well as the overall increase in respondents.

   As the question used is general rather than relating specifically to R&D performed in the survey reference year, the responses were pooled to give 1,665 lives representing 882 R&D performing businesses. 342 of these related to basic research, 669 to applied research, and 654 to experimental development.

   Where a firm provided different responses in each of the two years the average was taken. These cases are discussed further in **section 5.2**.

2. The second source is administrative information on the payment of annual patent renewal fees. This can be used to make inferences about the useful lives of R&D protected by patents. ONS used information extracted from the UK Intellectual Property Office (IPO) and European

Patent Office (EPO) patent administration systems, covering patents filed and/or approved between 1986 and 2010.

Each patent's 'life' can be taken as the number of years (from application) over which the patent is renewed through the payment of the relevant fees. In the UK fees vary between £75 (US$130) in the first year up to £600 (US$1,000) for the 20th renewal. Every year, each patent's owners choose whether or not to renew; it can be asserted that if the patent is renewed, its value must at least be equal to the cost of renewal and therefore the knowledge asset still exists.

The patent lives estimated can be used to draw conclusions about the service lives of R&D assets by assuming that patents represent R&D.

'Fuzzy matching' was used to identify businesses owning the patents based upon details such as the name and address of the owner. This was challenging both because fuzzy matching is not precise or quick (requiring considerable manual intervention to achieve an acceptable degree of matching), and because many patents are registered to individuals rather than businesses. Nevertheless, for the 35% of patents (>70,000) successfully matched to businesses this provides further information on the characteristics of the owner (notably their Standard Industrial Classification).

The paper Service Lives of R&D Assets: Patent Approach (Ker, 2013c) provides greater detail on the patent data used and the methods applied.

This paper compares the survey and patent-based methods both theoretically and in the context of results for the UK, and considers the implications of choosing one over the other.

5. Strengths and Limitations of these Sources

5.1 Link to R&D

The questionnaire approach benefits from specifically targeting the benefits expected from R&D the respondent undertakes. In contrast, using patent lives as an indicator of R&D lives requires the fundamental assumptions that all patents embody R&D (as opposed to resulting from other processes) and that the lives of all R&D assets can be represented by patent lives.

However, only some R&D will be patented. The degree of patenting varies considerably between industries with some choosing to use alternatives such as commercial secrecy to protect their intellectual property (Department for Business, Innovation, and Skills, 2012), this suggests that patent estiates will only be appropriate for some industries.

5.2 Reliability of estimates

Such general and abstract survey questions may be challenging for respondents to answer; they require sufficient information and expertise in order to provide an estimate that is representative of the R&D they undertake. Although the question distinguishes three different types of R&D, estimation may require averaging across a number of varied R&D projects. Some respondents may implicitly or explicitly give greater weight to the most expensive or most 'important' R&D and there is no way of knowing precisely what factors any respondent considered when providing their answer.

However, similar survey questions have been used in various studies and pilot testing of the ONS question showed that most respondents understood the principle and could answer. By contrast, the

US Bureau of Economic Analysis found that respondents could not answer such general questions and instead had success when asking about benefits from a specific product embodying R&D (Li, 2012).

As the ONS has collected these questions in 2 consecutive years it is possible to investigate the consistency of responses over time. 510 businesses responded in both years and of these 118 provided a different response for 1 or more types of R&D in the second year compared to the first.

Investigating these, the majority are located in Northern Ireland. As ONS does not conduct the BERD in Northern Ireland it was not possible to investigate these cases in detail. Of the forms completed by firms located elsewhere in the UK, 17 were completed by the same people (i.e. employees of the R&D performer) in both periods, while 16 were completed by different people.

The average (absolute) difference of the responses provided in each period is much greater when the person filling in the form was different (7.2 years difference on average, compared to only 3.9 years average difference when the person completing the form was the same in both periods). However this is considerably affected by one firm where the life given in 2012 was over multiple times greater than the life given in 2011. Comments from the respondent stated that the company had been restructured and the survey was being completed in a new area. Excluding this case reduces the average difference when the respondent changes to 4.5 years but it illustrates how variable responses can be between periods.

Given the general nature of the question, the size of the differences observed (over 10 years in a number of cases), and the fact that only one year had elapsed between responses, it seems unlikely that these differences are driven by real-world changes in the useful life of R&D. Although this data is not sufficient to draw firm conclusions it does appear to indicate three things:

1. Firms responses may be inconsistent, even over short periods of time
2. This may be caused by a change in the person tasked with responding to the survey, if this is the case differences are likely to be greater
3. Even when the respondent is the same they may give different estimates but the scale of the differences appears to be smaller on average (than when 2 is the case)

By contrast, patent-based lives are derived from administrative records of the periods in which each patent has been renewed. Patent sources provide a large number of direct observations on the lives of patents rather than relying on respondents to provide a robust estimate.

However, it may not always be the case that patent holders only renew when the patent continues to be of use; some companies, especially those holding large numbers of patents, may renew by default as the cost of annually reassessing each patent may outweigh the relatively low renewal fees. Furthermore, with patent litigation continuing to increase amid growing awareness of the value of patents (PwC, 2012) patent holders may also choose to renew as a precautionary measure or speculatively because developments *might* give the patent value in future.

The patent dataset contained records for a large number of patents but many of these were still be being renewed. In these cases the service life is unknown as the patent is still ‘alive’. Of over 200,000 patents in the ONS dataset only 56,000 have been observed through to the cessation of renewal payments. As explained in **section 6.4**, data of this type requires the use of specialised analytical tools in order to achieve robust estimates.

5.3 Generalisation

Using patent lives as a proxy assumes they represent the lives of R&D more generally. However, it is likely that the lives of patented R&D are systematically different from non-patented R&D because patent renewals are only permitted for a set number of years (20 renewals in the UK). Once the patent is discontinued anybody can make use of the ideas it had protected. If an R&D performer believes they can benefit for a longer period they may choose other methods of protection. This reduces the ability to use patent lives as an indicator of R&D asset lives.

Patent analysis is also inherently backward-looking as it requires observation of the 'death' of a sufficient number of patents to draw conclusions. By contrast, survey estimates may be more forward-looking and responsive to changes in the pace of obsolescence provided they are benchmarked sufficiently frequently (e.g. every 5 years).

5.4 Practicalities

The patent approach may be attractive as it can produce estimates without the expense, time, and respondent burden involved with surveys.

5.5 Strengths and limitations of the sources - conclusions

Neither approach is perfect. Survey estimates might credibly claim to be representative of R&D (as defined in the SNA) and more up-to-date, but they can be costly to collect and the estimates will be inherently less precise than those based on large numbers of patent renewal records.

By contrast, patent data can provide cost effective, quick, and accurate estimates of lives but it is questionable how well these will represent the true lives of R&D assets. Furthermore, the benefit of having such detailed data can be reduced if the most appropriate analytical methods are not used (see section 6.4).

6. Comparison of Methods

There is a wide range of analytical methods which might reasonably be applied to these sources in order to derive average service lives. These are discussed in the following sections.

6.1 Mean and Median Average Lives

The analysis showed that both the questionnaire and patent data were positively skewed. In the questionnaire data this is because very long periods of benefit (e.g. above 30 years) do occur but are relatively uncommon. The data from both sources remained skewed even after the optimal Box-Cox transformation (Box & Cox, 1964) (Osborne, 2010) had been applied. Kurtosis was also common in the questionnaire data due to 'clustering' of responses at 'round numbers' such as 5, 10, 15, 20, 25, and 30 years.

As explained by Kitchen (2009); with the presence of only one arbitrarily large outlier the mean becomes arbitrarily large, by contrast, the median will not break down as long as only a minority of observations are corrupted. As such, in the presence of skewed data the median is likely to provide a better estimate of central location.

Some analyses (such as Australian Bureau of Statistics, 2009) have tended to take mean rather than median lives. For the purposes of this research, both were calculated so that the differences between them may be observed.

6.2 Weighted and un-weighted averages

There are also options to calculating simple average lives or to apply weights with the aim of deriving estimates that are more representative.

Survey responses were weighted by the firms' shares in total (current) expenditure on R&D so that service life estimates provided by firms that spend more on R&D were given more weight.

Researchers at Statistics Netherlands (Tanriseven, van Rooijen-Horsten, & de Haan, 2010) proposed to weight the distribution of patent lives based upon information from the 'PatVal' study (Gambardella, Giuri, & Mariani, 2005). This study surveyed the inventors of over 9,000 patents accross 5 EU countries (France, Germany, Italy, The Netherlands, Spain, UK) and used a hypothetical question to elicit a respondent estimate of the financial worth of the patent on the day it was approved. This is used to weight the observed patent lives by assuming a perfect correlation between patents' longevity and their value - i.e. the longest-lived patents are assumed to be more valuable and these are given more weight as the lives of the most valuable patents are of most interest.

Such value-weighted patent lives are also calculated for the UK for the purposes of comparison. However, the PatVal survey's emphasis on the patents which are likely to be most valuable (those which have been cited or contested), plus the strong assumption required about the correlation between patent longevity and value suggest that this approach should be used with care. Furthermore, for most countries this option will not be available (as they were not covered by PatVal) and thus the use of this method in only a few countries may reduce international comparability.

6.3 Missing survey data

For each firm the average current expenditure on basic research, applied research, and experimental development over the decade from 2003-2012 is used to weight the individual responses together to derive a representative composite life for the R&D of each firm. This data is also used for weighting each firm's lives to give more emphasis to the firms which spend the most on R&D. The weights exclude capital expenditures both because this is desirable due to capex volatility and because only current expenditures are classified by R&D type in the survey results.

This can lead to 2 issues:

1. In some cases firms have provided lives for a type of R&D which they have not spent money on over the last 10 years. Such responses receive a zero weight and are effectively ignored in weighted estimates.

2. More frequently, the respondent has not provided a life for a type of R&D which they have spent money on over the last 10 years. This affects the ability to calculate meaningful composite R&D lives for each firm.

The second issue can be addressed in several ways. The most basic is to exclude all firms for which there is any expenditure with no accompanying life from the calculation of composite lives. However, this reduces the sample size and ignores the other responses that firm has provided.

The alternative is to impute the missing estimates. To that end, a structural equation model was constructed in SPSS Statistics AMOS (IBM, 2013) with the composite single representative R&D life for each firm as the dependant variable and the following explanatory variables:

- the shares of basic research, applied research, and experimental development in the firm's total R&D expenditure – these are always present though they may be zero in some cases (i.e. where the firm just doesn't perform certain types of R&D)

- the firm's relative share of total R&D expenditure (indicating how much they spend on R&D relative to other firms) – present for all respondents

- industry group – present for all respondents

- the live(s) which the firm has provided for basic research/applied research/experimental development – in some cases 1 or 2 of these will be missing, this is why it is necessary to impute the composite R&D life for those cases.

All variables were transformed by the natural logarithm to make them approximately normal for use in estimation while maintaining the relationships between them.

In 507 cases all expenditures were matched by lives the business had reported so those units already had composite R&D lives. The missing values for the other 375 firms were then estimated by Maximum Likelihood, providing 20 iterated datasets with missing values filled in. Results are found by pooling medians and means from these imputed datasets according to Rubin's rules (Rubin, 1987). The results are included in **Section 7** for comparison. Unfortunately it was not possible to produce weighted estimates using the imputed data for inclusion in this report; this is an area for future development.

6.4 'Censoring' in Patent Data

The patent data are extracts from live administrative systems which are updated as patents are filed, approved or denied, renewed, etc. They cover patents filed and/or approved in the 24 years between 1986 and 2010. Importantly, this is only slightly longer than the maximum patent life of 21 years and only the relatively few patents filed before 1989 would have had the opportunity to achieve this longevity. The data observe not only patents which have ceased being renewed ('died') but also many more patents which have been filed and approved but were still being renewed in 2010 (the latest period in the dataset). These cases are described as 'right censored'.

While the information about these patents is incomplete (because they will die in periods after 2010), this partial information can be valuable. For example, if patent was filed in 1995 and is still being renewed in 2010, it can be seen that it will have survived *at least* 15 years. Focussing only on patents which have reached death disregards such useful information and, due to the narrow band of years covered (i.e. only 24 years), has a considerable downward bias on the results.

Kaplan-Meier Survival analysis techniques make use of all the information available – both on patents which died during the period and on those which existed but did not die before the end of the period covered by the data. This reduces the downward bias present in other methods.

6.5 Summary of Methods

Annex 1 provides a table summarising the key features, assumptions, benefits, and limitations of estimates derived from survey and patent sources.

7. Results

7.1 Median Lives

Table 1 presents median service lives derived using the different sources and approaches outlined. It is immediately apparent that the questionnaire data only sustain disaggregation to a number of key R&D performing industries. By contrast, the larger patent data samples facilitate a more detailed breakdown; though sample sizes are very small for 'Public administration and defence' and 'Activities of households as employers' and so these estimates should be treated with caution. The Kaplan-Meier survival method benefits from larger samples as it makes use of the information on all patents including those observed to exist but which had not died before 2010.

Weighting questionnaire responses by firms' average shares in total business expenditure on each R&D type tends to make the median life longer. This is especially the case in industry M- R&D where weighting increases the life from 10 to 14 years. However, weighting causes the median life to fall slightly in the software and 'all other industries' groups.

Table 1: Comparison of median lives from questionnaire and patent sources

	Questionnaire			Patent			
	Median	Median with imputation of missing data	Expenditure weighted median	Median	Value weighted median	Average of medians	Kaplan-Meier survival median
Total	**6**	**6**	**7**	**8**	**20**	**14**	**20**
A - Agriculture, forestry, and fishing				8	20	14	12
B - Mining and quarrying				8	20	14	*
C - Manufacturing	7	7	7	9	20	15	19
D - Electricity, gas, steam, etc.				7	13	10	11
E - Water supply, sewerage, etc.				7	13	10	12
F - Construction				7	20	14	14
G - Wholesale and retail trade, etc.				8	20	14	17
H - Transportation and storage				9	20	15	15
I - Accommodation and food service				8	20	14	16
J - Information and comms (ex. software)	5	5	6	8	19	14	19
J - Software	5	5	4	6	12	9	*
K - Financial and insurance activities				8	20	14	20
L - Real estate activities				8	20	14	15
M - Professional, scientific and tech (ex. R&D)	5	5	5	7	20	14	19
M - Research & Development	10	9	14	9	20	15	20
N - Administrative and support activities				8	20	14	20
O - Public administration and defence, etc.				8	8	8	10
P - Education				8	20	14	*
Q - Human health and social work activities				9	20	15	16
R - Arts, entertainment, and recreation				7	20	14	12
S - Other service activities				8	20	14	20
T - Activities of households as employers				7	12	10	12
U - Activities of extraterritorial organisations	-	-	-	-	-	-	-
All other industries**	6	6	5	*8*	*20*	*14*	*20*

Source: ONS BERD 2011, 2012 and IPO patent data
- not published: low sample size
* median undefined (survival probability has not declined below 50%)
** for patent estimates this category is an aggregation of individual indistrial sections provided for comparison purposes

The imputation of missing survey data outlined in section 6.3 has little effect on the medians observed, the only difference occurs in the M-R&D industry where the median falls slightly from 10 to 9 years -

indicating that most of the imputed values were in the lower half of the distribution (which should be expected given the positive skew of the service life distribution being analysed).

Comparing the different sources, the unweighted patent estimates are typically 2 years more than the various survey-based medians. This may be because patents tend to be used to protect longer-lived R&D. Although these differences are not ignorable it does suggest that unweighted patent estimates may provide *roughly* similar results to survey questions. A notable exception is the expenditure-weighted median in industry M-R&D; at 14 years this is 5 years longer than the unweighted patent life for that industry.

Value-weighted patent estimates are considerably higher as they place greater weight on longer-lasting patents. This may lead to upward bias of estimates, although selecting the median (rather than the mean) will mitigate this effect somewhat. Even so, it seems preferable to also take the 'average of averages' (the mean of the weighted and unweighted median estimates) to moderate the bias introduced through weighting - as proposed by Tanriseven, van Rooijen-Horsten, & de Haan (2010).

The Kaplan-Meier survival estimates vary in their proximity to the other various patent estimates; in some cases they fall towards the lower end of the range between the unweighted median patent life and in other cases fall in line with the value-weighted estimates. This may result from some industrial sections generally holding the long-lived patents which are given more weight.

There is considerable variation across industry sections, suggesting that this dimension is important. Pairwise Kruskal-Wallis tests found highly significant differences between the all the industry groups in the questionnaire data (p<000). The various approaches generally agree that service lives are shorter in software and longer in the R&D sector, which consists of both specialist research firms and the research branches of larger firms (where they have been separately identified and classified to this sector). As a result, the R&D performed by units in this sector is likely to be highly heterogeneous.

Comparing the results to those based on 2011 only (as presented in Service Lives of R&D Assets: Questionnaire Approach, Ker, 2013b), there is little change to the unweighted medians with only a slight increase to the life for 'all other industries' from 7 years to 8. There are greater changes to the weighted estimates; most notably the median life for manufacturing decreased from 8 to 7 years, M-R&D increased from 12 to 14 years, and 'all other industries' decreased from 7 to 5 years. Due to the increased responses from firms in the 'manufacturing' and 'all other industries' groups, and their relative importance in terms of R&D spending, the downward effect dominated and the overall expenditure-weighted median life for R&D fell from 10 years to 7.

This indicates that questionnaire estimates of service lives can be sensitive to missing responses, particularly when these relate to firms which perform large volumes of R&D.

7.2 Mean Lives

Although, as explained in section 6.1, mean lives are more susceptible to bias when the data to be averaged are skewed, they are commonly presented in analyses of service lives. **Table 2** compares mean lives estimated using the different sources and approaches.

As expected, the mean lives are generally longer than the median lives due to the positive skew of the data; though this is not the case for the value-weighted and Kaplan-Meier patent totals which are shorter than the medians. Considerable variation across industries remains.

The mean lives have also been affected by the new data. Again, the unweighted mean lives have changed relatively little compared to the previous estimates based on 2011 data only with the estimates for manufacturing, J – Information and comms, and M-R&D each having fallen by 1 year. The weighted means are also affected less, with the estimates for both 'M' industries having reduced by 1 year, as has the overall expenditure weighted mean life which fell from 11 to 10 with the addition of this new data.

Table 2: Comparison of mean lives from questionnaire and patent sources

	Questionnaire			Patent			
	Mean	Median with imputation of missing data	Expenditure weighted mean	Mean	Value weighted mean	Average of means	Kaplan-Meier survival mean
Total	**8**	**8**	**10**	**10**	**19**	**14**	**17**
A - Agriculture, forestry, and fishing				9	19	14	14
B - Mining and quarrying				9	17	13	20
C - Manufacturing	8	8	10	10	19	14	17
D - Electricity, gas, steam, etc.				8	11	9	14
E - Water supply, sewerage, etc.				8	13	11	14
F - Construction				8	19	14	15
G - Wholesale and retail trade, etc.				10	19	14	16
H - Transportation and storage				10	19	14	16
I - Accommodation and food service				10	19	14	16
J - Information and comms (ex. software)	7	7	8	10	18	14	18
J - Software	5	5	4	7	11	9	19
K - Financial and insurance activities				10	20	15	17
L - Real estate activities				9	19	14	15
M - Professional, scientific and tech (ex. R&D)	7	7	6	8	19	14	16
M - Research & Development	10	10	13	10	19	14	18
N - Administrative and support activities				9	19	14	18
O - Public administration and defence, etc.				7	8	8	12
P - Education				9	17	13	19
Q - Human health and social work activities				10	19	14	17
R - Arts, entertainment, and recreation				8	18	13	13
S - Other service activities				9	19	14	17
T - Activities of households as employers				8	11	9	12
U - Activities of extraterritorial organisations	-	-	-	-	-	-	-
All other industries**	8	7	9	*9*	*19*	*14*	*17*

Source: ONS BERD 2011, 2012 and IPO patent data
- not published: low sample size
* median undefined (survival probability has not declined below 50%)
** for patent estimates this category is an aggregation of individual indistrial sections provided for comparison purposes

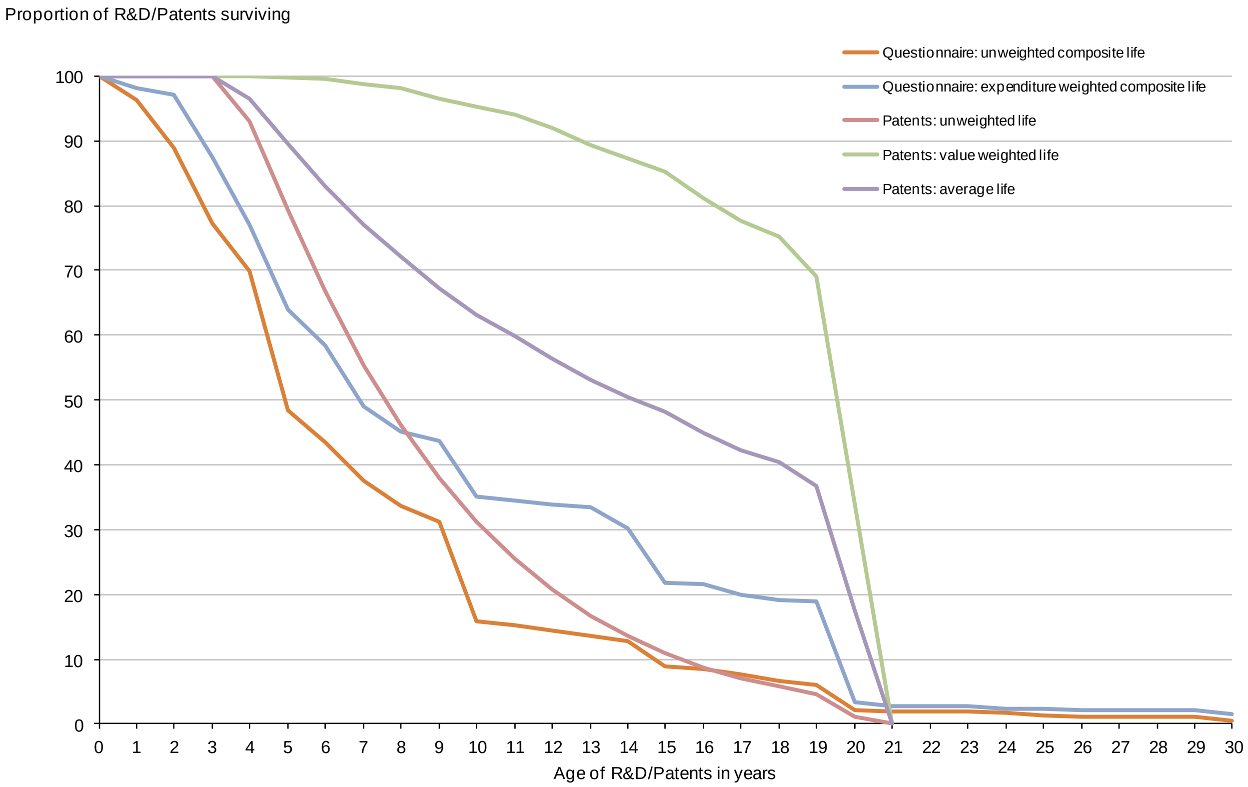
Annex 2 presents bootstrap standard errors and 95% confidence intervals for the median and mean service lives presented.

7.2 'Survival' profiles

Comparing the survival profiles of R&D/patent lives from each source shows that profiles based on questionnaire data are quite similar to the profile of unweighted patent estimates. Using the unweighted patent estimates would reduce the estimated obsolescence a little in the first 8 years, before it falls roughly into line with the questionnaire based profiles. The average patent profile moderates the upward bias in the weighted profile but still shows a very different shape from the other lines.

The figure also illustrates the impact of using patent data, which is effectively capped at a maximum life of 21 years. Around 35% of patents are renewed for the maximum number of years, causing the large falls seen between 20 and 21 years. The survey responses suggest that around four percent of R&D survives beyond 21 year. Though this proportion is small, the number of years' further life is considerable at up to 50 years (though the figure presented is cut at 30 years). This is relevant because maximum life estimates are also used in some implementations of the PIM.

Figure 1: Comparison of R&D Survival Profiles



Source: ONS BERD 2011, 2012 and IPO patent data

8. Comparison to Other Studies

Peleg (2008) reviewed the depreciation rates and service lives from ten different service studies covering differing countries and time periods. The works used various econometric models including approaches based on patent renewals. Findings showed (or implied through depreciation rates) average service lives ranging between 3.8 years and 18.2 years. Results varied considerably between industries and by R&D field (eg. 'Chemicals', 'Electrical Equipment', etc.), emphasising the need to consider these differences when measuring service lives.

All UK estimates lie within this range or slightly above it, though this is partially a product of the range being so wide. The results also further confirm the presence of considerable variation in lives between industries.

The average lives of R&D estimated from UK questionnaires are all greater than that found by the United States National Science Foundation (NSF), Bureau of Economic Analysis (BEA), and Census

Bureau, which together conducted a large-scale survey (covering almost 40,000 firms) in 2010. Their question asked about the life of specific products embodying R&D (that is, over how many years the business sold a product which made use of R&D). Although many firms did not provide responses, the survey gained almost 1,000 answers - making it the largest survey of R&D lives to date. The result was an overall average life of 5.46 years, with variation between the 25 industries covered (Li, 2012). By comparison the UK results are an unweighted median life of 6 years and an unweighted mean service life of 8 years.

The unweighted mean patent life is 9.5 years in the UK, a little lower than the 11 years found by the Australian Bureau of Statistics (2009). Meanwhile, the unweighted median patent life of eight years is greater than the seven years found in The Netherlands by Tanriseven, van Rooijen-Horsten, & de Haan, (2010). The value-weighted median patent life was longer in the UK than The Netherlands at 20 years compared to 18 years in The Netherlands; influenced by comparatively higher values of UK patents. As a result, the UK 'average of averages' was also longer at 14 years compared to 12.5 years.

Comparing the UK unweighted survival profile to the Australian Bureau of Statistics and that implied by the survival probabilities provided by Tanriseven, van Rooijen-Horsten, & de Haan; all share a very similar smooth declining pattern with little attrition over the first four years and an acceleration between 19 and 21 years.

Looking at the top level results in the context of the EU default of 10 years and the 10-20 year range suggested by the OECD (2010, p. 62) in **Table 3** it is clear that while a number of the estimates lie between 10 and 20 years, in no case is the life estimated equal to the suggested default of 10 years. That said, the weighted survey mean is very close (10.1 years), as is the unweighted patent mean of 9.5 years. However, median lives are more statistically robust for skewed data such as this.

This proximity of the expenditure weighted mean to 10 years could be driven by 'clustering' of businesses' responses at focal numbers (e.g. 5, 10, 15, 20, etc), with 10 years being the most significant cluster point.

Table 3: Comparison of results by source

		Questionnaire: composite lives		Patent lives			
Estimate		Unweighted	Expenditure weighted	Unweighted	Value Weighted	Average of averages	Survival estimate
Median		**6**	**7**	**8.0**	**20.0**	**14.0**	**20.0**
Equals 10 year EU default?		✗	✗	✗	✗	✗	✗
In 10 - 20 year range?		✗	✗	✗	✓	✓	✓
95% CI	Lower	5.0	7.0	8.0	20.0	14.0	19.8
	Upper	6.4	7.0	8.0	20.0	14.0	20.2
	spans 10 year EU default?	✗	✗	✗	✗	✗	✗
Mean		**7.9**	**10.1**	**9.5**	**18.8**	**14.1**	**16.9**
Equals 10 year EU default?		✗	✗	✗	✗	✗	✗
In 10 - 20 year range?		✗	✓	✗	✓	✓	✓
95% CI	Lower	7.6	10.1	9.4	18.7	14.0	16.8
	Upper	8.3	10.1	9.5	18.9	14.2	16.9
	spans 10 year EU default?	✗	✗	✗	✗	✗	✗

Source: ONS BERD 2011, 2012 and IPO patent data

9. Impact of Alternative Estimates

Aside from the volume of investment in R&D itself, the choice of average service life is a key determinant of the size of the R&D stock, which has implications for analysis of productivity and National Wealth.

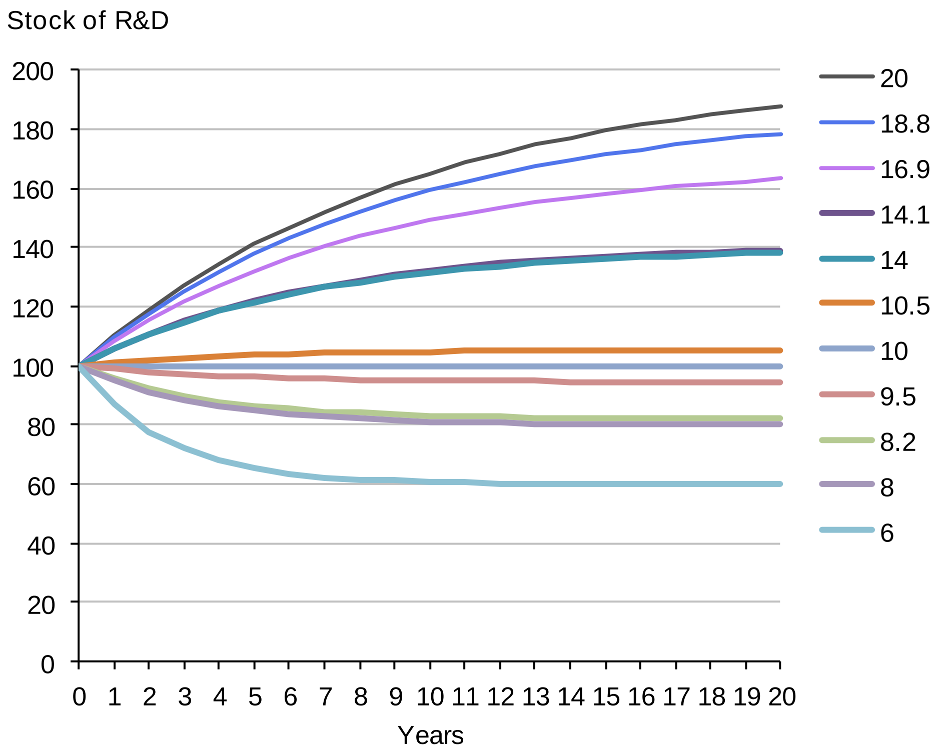
Table 3 illustrates the breadth of estimates of the 'overall average life of R&D assets' that can be found by using different estimation methods with just two data sources; the lives found range from 6 to 20 years.

Beyond this 'artificial' variation caused by statistical methods, service lives also vary by industry and overall representative lives will therefore vary between countries according to their different industrial structures. The 10-20 year range offered by the OECD is a useful guide but less significance should be attached to being within or outside this range than to the robustness of the methods chosen.

Figure 2 presents a stylised illustration of the impact of applying these different service life estimates in the PIM used to compile capital stocks in the National Accounts. The 'double-declining' geometric rate used here offers a convenient approximation of the integrated survival/age-price/age-efficiency profile (OECD, 2009, p. 97) accounting for the retirement of assets from productive use and for falling values (depreciation) and efficiency.

By construction, annual R&D investment is set at £20 to exactly offset this adjustment when the life is 10 years so that the R&D stock remains constant over time. With the initial stock set at £100, the vertical axis can therefore be interpreted as an index and shows that shorter lives then imply a shrinking R&D stock, while the longer lives imply different degrees of R&D stock growth.

Figure 2: Illustrative Impact of Different Service Lives on R&D Stocks



Source: ONS BERD 2011, 2012 and IPO patent data

In this example, a service life of 6 years is consistent with a 40% decline in the stock of R&D over 20 years and therefore a move away from knowledge driven growth (assuming the productivity of knowledge has not changed). By contrast, an R&D service life of 20 years would give a rapidly expanding national stock of knowledge, with the stock continuing to grow beyond 20 years and doubling in 40 years. This is an extremely stylised example but it serves to demonstrate that in the real world the stock of R&D capital depends upon both the volume of investment in R&D and the period over which the resulting knowledge is useful.

Differentials in service lives will therefore also be a key determinant of international variation in R&D stocks and so of the effect that R&D has in different economies. As such, the choice of service life is non-neutral and it is desirable to investigate the specific service lives of individual countries.

10. Evaluation and Conclusions

This research has outlined two different sources for estimating R&D service lives:

- survey questions gather expected or 'typical' service lives based on the premise that respondents can correctly interpret the question and can provide consistent and meaningful answers
- patents administration data provide observations on renewals based on the assumption that agents will only renew as long as the benefits outweigh the costs

Each offers different benefits and limitations; for example survey questions require money and time for design and implementation, and also add to respondent burden. If patent data are available it may be possible to obtain an estimate at relatively low cost. Patent data may also offer a large amount of observations for analysis. Industry analysis is also possible, though patents may first need to be matched to business information; this can be challenging.

Both approaches require assumptions about the ability to generalise results to other R&D. However, while results from the BERD can claim to directly represent at least 68% of UK business R&D, the strength of the link between R&D and patents is unclear; there are various reasons why business (and other types of organisation) may choose not to patent R&D including the costs involved, lags between application and approval, and the renewal limit. Additionally, low renewal fees and precautionary motives may lead firms to renew by default rather than only when there is clear value to the patent, a fundamental assumption of the approach.

Generalisation over time is also necessary, and while survey questions might easily be re-run every five or ten years to collect benchmarks, patent data are backwards looking and most analytical methods require waiting to observe death. Kaplan-Meier survival analysis techniques can be used to address this second problem.

Both methodologies can be used to identify the industry producing the R&D (or patent), but the R&D may be sold or otherwise transferred across industries. The general nature of the question posed should mean that survey results are fairly representative of R&D invested in and used by the different industries (whether it has been created on own account or bought in). The more specific nature of patent analysis, coupled with the potential for bias in the 'fuzzy matching' of patents to businesses does not afford that approach the same level of resilience.

There are 3 key points which should be drawn from this analysis:

- Service lives vary between industries; therefore national average lives will vary based on countries' differing industrial structures. It is therefore theoretically undesirable to standardise the service life across countries as this neutralises one of the two key determinants of the R&D stocks.

- Where countries make different choices between the various data sources and analytical methods available this will introduce artificial variation between countries' R&D stocks and reduce the ability to compare R&D statistics meaningfully across countries.

- The service life of 10 years offered as a 'pragmatic' option by the European Task Force on R&D Capitalisation does appear to be the most appropriate focal number (i.e. 10 is better than 5, 15, or 20) based on UK survey results. However, this does not provide theoretical justification for adopting 10 years as a standard and even with the strong clustering seen in the UK survey responses the majority of service lives differ from 10 years (both at the total and industry levels).

Correct understanding of the impact of R&D on the economy can only be gained by using data and methods that produce results of sufficient detail and accuracy. One key parameter determining the size of the R&D stock and thus the economic impact of R&D capitalisation is the service life of R&D assets. Estimating R&D service lives is challenging, but this research provides a detailed comparison of two popular methods. It is hoped that this, and the work of others highlighted, will provide a useful foundation for colleagues internationally.

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Annex 1: Comparison of methods for estimating R&D service lives, by source

	Questionnaire	Patent Lives	Patent Lives w/ value weighting	Patent survival analysis
Method	Survey question asking about '*expected benefit from a typical investment in R&D'*	Use data on patent renewals from patent administration systems to estimate number of years after patent application when patent 'death' (expiry/lapse) occurs	Patent analysis supplemented with patent value weights estimated from PatVal report (Gambardella, Giuri, & Mariani, 2005). Average of weighted and unweighted estimates taken	Kaplan-Meier survival method examines *all patents'* probability of survival to successive ages
Coverage	Target population is all R&D performers. Results represent around 66% of 2011 UK business R&D	All patents filed and/or approved in a given period (1986-2010 in this analysis) which also died in this period	All patents filed and/or approved in a given period (1986-2010 in this analysis) which also died in this period	Dead patents *and* patents which did not die in observation period
Advantages	Answers relate to R&D specifically. More forward looking (so more responsive to changing pace of technological change) than patent data	Potentially less costly and less time to implement than survey. Observed data from administrative source rather than expectations.	Giving greater weight to more valuable patents is theoretically desirable	Uses all information available; patents which died and those that outlived the observation period). Method built into statistical software (eg SPSS, STATA). Reduced downward bias compared to analysis of dead patents only
Disadvantages	Expectations rather than observations Incurs survey costs for design, testing, implementation, processing Takes time to achieve results Adds to respondent burden	Requires access to patent data. Backward looking – likely to be less responsive to changes in pace of technological change.	Requires access to patent data. Backward looking. Patent value information only available for a minority of EU countries.	Requires access to patent data. Backward looking. Reliability known to reduce as censoring increases. Median cannot be calculated if the survival probability function has not reached >50%
Key assumptions required	Respondents can average over their multiple R&D projects to provide meaningful answers. Responses can be generalised over all R&D.	Patents assumed to represent R&D. However, some businesses may choose alternatives e.g. industrial secrecy; - lags in granting disincentivise	Patents assumed to represent R&D. Strong assumption of perfect correlation between patent age and value.	Patents assumed to represent R&D.

		- patenting knowledge with short expected benefit - 21 year maximum disincentivises patenting knowledge with long expected benefit Patents renewal implies remaining value; but holders may renew by default (especially those holding many patents) as renewal fees are relatively low (£600 max.)		
Potential sources of bias	Sample focussed on businesses which spend the most on R&D. These firms also more likely to respond. Therefore results may be less representative of other firms' R&D. Responses gather at 'focal numbers' (eg 5, 10, 15 years etc). Missing data treatment can also affect results obtained (e.g. pairwise exclusion vs imputation)	Examining only patents which died during the observation period will cause downward bias; data spans only 24 years, only patents filed before 1990 can reach maximum age (21) in this time. This issue is reduced with data covering longer periods.	Assumption of perfect correlation between patent age and value simply gives more weight to longer-lasting patents. This is likely to over-estimate the average service life.	Censoring increases downward bias. Maximum life of 21 years imposed by patent rules will reduce this effect. Still less bias than analysis of dead patents alone.

Annex 2: Bootstrap Standard Errors and 95% Confidence Intervals

Survey Estimates

	Median	Bootstrap Standard Error	Bootstrap 95% C.I. Lower	Bootstrap 95% C.I. Upper	Mean	Bootstrap Standard Error	Bootstrap 95% C.I. Lower	Bootstrap 95% C.I. Upper	Min	Max
Unweighted										
Total	6	0.4	5.0	6.4	7.9	0.2	7.6	8.3	1	50
C - Manufacturing	7	0.5	5.5	7.5	8.5	0.3	7.9	9.1	1	50
J - Information and comms (ex. software)	5	0.2	4.6	5.5	6.6	0.8	5.3	8.4	1	50
J - Software	5	0.2	4.0	5.0	5.3	0.3	4.7	6.0	1	20
M - Professional, scientific and tech (ex. R&D)	5	0.4	4.9	6.5	7.1	0.6	6.0	8.2	1	20
M - Research & Development	10	0.8	7.1	10.0	10.4	0.6	9.2	11.6	1	30
All other industries**	6	0.9	5.0	7.5	7.6	0.5	6.7	8.5	1	30
Expenditure Weighted										
Total	7	0.0	7.0	7.0	10.1	0.0	10.1	10.1		
C - Manufacturing	7	0.0	7.0	7.0	10.1	0.0	10.0	10.1		
J - Information and comms (ex. software)	6	0.0	6.3	6.3	7.9	0.0	7.9	7.9		
J - Software	4	0.0	4.0	4.0	4.2	0.0	4.2	4.2		
M - Professional, scientific and tech (ex. R&D)	5	0.0	5.0	5.0	6.1	0.0	6.1	6.1		
M - Research & Development	14	0.0	13.7	13.7	13.1	0.0	13.1	13.1		
All other industries	5	0.0	5.0	5.0	8.9	0.0	8.8	8.9		

Bootstraps with 10000 resamples.

Standard errors and confidence intervals for the patent-based estimates are presented in Service Lives of R&D Assets: Patent Approach (Ker, 2013c), along with statistical tests of differences between the industries and types of R&D.