United Nations ECE/CES/GE.20/2014/17

Economic and Social Council

Distr.: General
4 April 2014

English only

Economic Commission for Europe

Conference of European Statisticians

Group of Experts on National Accounts

Thirteenth session
Geneva, 6-9 May 2014
Agenda item 5
Expanded accounts for the Household sector including non-profit institutions, serving households (NPISH)

Service Lives of Research and Development Assets: comparing survey and patent based approaches

Prepared by the United Kingdom Office for National Statistics

Summary

This paper draws together Office for National Statistics research into the service lives of Research and Development assets which will be capitalised in the National Accounts from 2014. The characteristics of service lives are considered and results from two sources are presented; a new question on service lives implemented on the United Kingdom's Research and Development surveys, and estimates derived from Patent administration data. These are compared and theoretical underpinnings, strengths, and limitations discussed.

I. Introduction

1. The 2008 revision of the System of National Accounts (SNA) (United Nations, 2009) requires Research and Development (R&D) expenditures to be treated as investment in knowledge assets. This reflects the contribution of the knowledge produced through R&D to production and output over multiple years. This new information 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.

2. The change poses a variety of challenges for National Accountants. In particular, much effort has been invested in developing methods for measuring the knowledge assets produced (also referred to as 'R&D assets'). Having established an appropriate valuation for R&D assets, it is then necessary to establish which sectors have economic ownership of them (see Steer & Ker (2013)) and to establish how long they are useful for.

3. This paper provides an overview of Office for National Statistics (ONS) research into the useful lives of R&D assets.

II. Service Lives

4. 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'* (Organisation for Economic Co-operation and Development (OECD), 2001, p. 95). Put simply, the service life of an asset is the number of years for which it is useful to its owner(s) in generating returns. 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).

5. Typically, the end of an asset's useful life may result from economic 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.

6. However, the length of time over which knowledge directly contributes to economic output and to companies' profits is different and is thought of as the 'economic service life', which will usually be finite. The finite nature of the economic service lives of R&D can be explained by 'creative destruction' where knowledge can be rendered obsolete and displaced by new discoveries (Bitzer & Stephan, 2007). Peleg (2008) found evidence that the 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.

A. Why Service Lives Matter

7. Aside from the volume of R&D investment itself, service lives of R&D assets are the main determinant of the R&D stock used in analyses of productivity and National Wealth. Service lives are key inputs to the Perpetual Inventory Method (PIM) used to compile asset stocks (see ONS, 2008); they are 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).

8. 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."*

9. 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.

B. European Task-Force Recommendation

10. Relatively few countries have produced R&D life estimates of any sort and the recommendation of the Second European Task-Force on R&D Capitalisation 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)

11. 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 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.

III. Estimating R&D Service Lives

12. 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 typical lives for different types of assets (such as buildings, machines, vehicles, R&D) is used.

13. Though average lives receive the most attention, in general three descriptive statistics are needed for the estimation of 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).*

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

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

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

IV. Sources of Information

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

17. This research compares and contrasts two approaches for estimating service lives of United Kingdom's (UK) R&D assets: Survey of business R&D service lives and the method based on the information on the payment of annual patent renewal fees.

A. Survey of business R&D service lives

18. The UK has conducted one of the largest surveys of business R&D service lives to date with 650 responses to a new question introduced to the UK Business Enterprise R&D Survey (BERD) from 2011 onwards. The wording was developed from a question used in the earlier 'Investment in Intangible Assets' survey and was improved through two rounds of pilot testing. It asked: "How long does the business expect to benefit from a typical investment in 'Basic Research', 'Applied Research', and/or 'Experimental Development'?"

19. These different ‘types’ of R&D are defined in the OECD Frascati Manual (OECD, 2002), which provides the internationally accepted framework for measuring R&D. They are also used in other questions on UK the R&D surveys. They are differentiated in their degree of focus on specific applications or products.

20. The question was included on the BERD ‘long form’ which is sent to the businesses which spend the most on R&D (covering around 80 percent of all business R&D expenditure). Responses were received from 86 per cent of these firms. The question was also included on all forms in Northern Ireland which adds some coverage of firms which spend less on R&D, though the response rate was much lower. In total, the results directly represent over 66 per cent of UK business R&D (based on their 2011 current expenditure).

21. The paper “*Service Lives of R&D Assets: Questionnaire Approach”* (Ker, 2013a) provides further detail on the development of this question and analyses conducted to derive these results.

B. Information on the payment of annual patent renewal fees

22. Information on the payment of annual patent renewal fees can also be used to make inferences about the 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, and covers patents filed and/or approved between 1986 and 2010.

23. 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 in the first year of payment up to £600 in the 21st year after application. 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.

24. 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.

25. ONS used ‘fuzzy matching’ to match the patents to businesses based upon details such as the name and address of the owner. Where this was successful it provides further information on the characteristics of the owner (notably their industry).

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

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

V. Strengths and Limitations of these Sources

28. The questionnaire approach specifically targets the benefits which accrue from R&D the respondent has undertaken. In contrast, only some R&D will be patented, and also some patents may relate to knowledge or ideas produced through channels other R&D (i.e. the coverage of patents may be broader than the definition of R&D defined in the Frascati Manual).

29. However, there are several difficulties in using a survey question approach. The questions used are often of a general nature; this is the case in the UK where R&D is only split into ‘basic research’, ‘applied research’, and ‘experimental development’. Providing a single figure estimate of the period over which benefits will accrue (i.e. an estimate of the

average for R&D projects undertaken by the responding business) can require the respondent to attempt to aggregate over a large number of different R&D projects. They also may or may not factor in R&D which is deemed unsuccessful (i.e. providing no benefit). The approach relies upon respondents' ability to meaningfully average across their R&D projects and programmes and the sample design will affect how well results can be generalised to R&D more widely

30. Despite this, pilot testing of the ONS question showed that respondents understood the principle and could provide an answer. By contrast, the US Bureau of Economic Analysis (Li, 2012) found that respondents could not answer such general questions and instead had success when asking about benefits delivered by a specific product embodying R&D.

31. Patent sources benefit from providing direct observations of life lengths, rather than relying on respondents providing a robust estimate. However, patent analysis requires that the whole life of the patent has been observed, this can be up to 21 years and so the analysis will be less up-to date than survey estimates which can provide insight into changes in the rate of technological advance when conducted at regular interval (e.g. every 5-10 years).

32. The patent approach offers the possibility of producing estimates without expense and time required to collect data through a survey. Such sources provide a large number of direct observations on the lives of patents. 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 (PricewaterhouseCoopers (PwC), 2012) patent holders may also choose to renew as a precautionary measure or because the actions of other businesses *might* give the patent value in future.

33. More fundamentally, using patent lives as an indicator of R&D lives requires the assumptions that all patents embody R&D (as opposed to resulting from other processes). There is a logical relationship between R&D and the production of patents. However, the evidence suggests that in practice this link is not firm and will vary between industries. Furthermore, generalisation effectively requires the assumption that all R&D is patented (so that patent lives are assumed to be representative of all R&D). Meanwhile as the analysis is 'backwards looking' it requires that the patent lives derived for the period 1986 – 2010 can be applied to other periods, foregoing the possibility that lives may be altered by changes in the pace of technological advance.

VI. Comparison of Methods

A. Mean and Median Average Lives

34. The analysis showed that both the questionnaire and patent data were highly positively skewed because longer lives (i.e. periods over which benefits from the R&D accrue) of 25 years or more are much less common than shorter lives. This means that there is a large peak in the frequency distributions between 5 and 15 years and a long right hand tail (illustrated in Ker 2013a, Ker 2013b). The data remained skewed even after the optimal Box-Cox transformation (Box & Cox, 1964) (Osborne, 2010) had been applied.

35. This has implications for the descriptive statistics (and tests of statistical significance) used. As explained in Kitchen (2009), the presence of only one arbitrarily large outlier the mean becomes arbitrarily large; by contrast, the median will not

breakdown as long as only a minority of observations are corrupted. As such, in the presence of skewed data such as this, the median is likely to provide a better estimate of central location.

36. 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.

B. Weighted and un-weighted averages

37. Another choice is the use of simple average lives or applying weights with the aim of deriving estimates that are more representative.

38. 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.

39. 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 European Union (EU) countries (France, Germany, Italy, The Netherlands, Spain, UK) and used a hypothetical question to elicit an 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.

40. Such value-weighted patent lives are also calculated for the UK for the purposes of comparison. However, the emphasis of the PatVal survey 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 mean that this approach should be used with care. Furthermore, for most countries not covered by PatVal, this option will not be available and thus its adoption in only a few countries may reduce international comparability.

C. 'Censoring' in Patent Data

41. 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 renewal period of 21 years and only those patents filed before 1989 would have had the opportunity to reach the full 21 years. As a result these extracts cover not only patents which have ceased being renewed ('died') but also provides many more observations of patents which have been filed and approved but were still being renewed in 2010. These cases are described as 'right censored'.

42. 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 we observe that a patent was filed in 1995 and is still being renewed in 2010, we can see that, when it does stop being renewed, it will have survived *at least* 15 years. Focussing only on patents for which death was observed 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.

43. 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.

D. Summary of Methods

44. Table 1 summarises the key features, assumptions, benefits, and limitations of estimates derived from survey and patent sources.

Table 1

Comparison of methods for estimating R&D service lives

	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 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.)	Patents assumed to represent R&D. Strong assumption of perfect correlation between patent age and value.	Patents assumed to represent R&D.
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).	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.

VII. Results

45. Table 2 presents median service lives derived using the different approaches. It is immediately apparent that the questionnaire data was only sufficient to sustain disaggregation to a number of key R&D performing industries including manufacturing. By contrast, the patent data facilitates the a more complete 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 patents observed to exist but which did not die before the end of the observation period in 2010.

46. Weighting questionnaire responses by firms' average shares in total business expenditure on each R&D type makes the overall median life longer. The effect is similar at the industrial section level, although the median life actually falls from five to four years in software. Confidence intervals are presented in Ker 2013a, Ker 2013b.

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

	Questionnaire		Patent			
	Median	Expenditure weighted median	Median	Value weighted median	Average of medians	Kaplan-Meier survival median
Total	**6.0**	**10.0**	**8.0**	**20.0**	**14.0**	**20.0**
A - Agriculture, forestry, and fishing			8.0	20.0	14.0	12.0
B - Mining and quarrying			8.0	20.0	14.0	*
C - Manufacturing	7.0	8.0	9.0	20.0	14.5	19.0
D - Electricity, gas, steam, etc.			7.0	13.0	10.0	11.0
E - Water supply, sewerage, etc.			7.0	13.0	10.0	12.0
F - Construction			7.0	20.0	13.5	14.0
G - Wholesale and retail trade, etc.			8.0	20.0	14.0	17.0
H - Transportation and storage			9.0	20.0	14.5	15.0
I - Accommodation and food service			8.0	20.0	14.0	16.0
J - Information and comms (ex. software)	5.0	5.0	8.0	19.0	13.5	19.0
J - Software	5.0	4.0	6.0	12.0	9.0	*
K - Financial and insurance activities			8.0	20.0	14.0	20.0
L - Real estate activities			8.0	20.0	14.0	15.0
M - Professional, scientific and tech (ex. R&D)	5.0	5.0	7.0	20.0	13.5	19.0
M - Research & Development	10.0	12.0	9.0	20.0	14.5	20.0
N - Administrative and support activities			8.0	20.0	14.0	20.0
O - Public administration and defence, etc.			8.0	8.0	8.0	10.0
P - Education			8.0	20.0	14.0	*
Q - Human health and social work activities			9.0	20.0	14.5	16.0
R - Arts, entertainment, and recreation			7.0	20.0	13.5	12.0
S - Other service activities			8.0	20.0	14.0	20.0
T - Activities of households as employers			7.0	12.0	9.5	12.0
U - Activities of extraterritorial organisations	-	-	-	-	-	-
All other industries**	7.0	7.0	*8.0*	*20.0*	*14.0*	*20.0*

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 industrial sections provided for comparison purposes

47. Comparing the different sources, the questionnaire estimates are in the same approximate "ball-park" as the unweighted patent medians. This suggests that unweighted patent estimates may provide similar results to questionnaires. This holds at the aggregate

level but in some industries the spread between patent and questionnaire estimates is considerable (eg. three years in ‘Information and communications excluding software). This might be because only longer-lived R&D is patented in this industry and so the survey results better reflect the average life of all R&D.

48. The 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 as proposed by Tanriseven, van Rooijen-Horsten, & de Haan (2010).

49. 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 falling 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 by taking values into account.

50. There is considerable variation across industry sections, suggesting that this dimension is important. 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 these businesses is likely to be highly heterogeneous.

51. Table 3 compares mean lives estimated from the different sources and approaches. As expected, the mean lives are generally considerably longer than the median lives (due to the bias discussed earlier) - though this is not the case for the value-weighted and Kaplan-Meier patent totals which are shorter than the medians. The variation here is generally similar to that of the medians in Table 2, although the questionnaire means and the unweighted patent mean life are even closer, lying within 1.3 years of each other. There is still considerable variation across industries.

Table 3: Comparison of mean lives from questionnaire and patent sources

	Questionnaire		Patent			
	Mean	Expenditure weighted mean	Mean	Value weighted mean	Average of means	Kaplan-Meier survival mean
Total	**8.2**	**10.5**	**9.5**	**18.8**	**14.1**	**16.9**
A - Agriculture, forestry, and fishing			8.7	18.6	13.6	13.5
B - Mining and quarrying			8.6	17.1	12.9	20.3
C - Manufacturing	8.6	10.0	9.5	18.7	14.1	16.7
D - Electricity, gas, steam, etc.			7.6	11.2	9.4	14.2
E - Water supply, sewerage, etc.			8.3	13.4	10.8	13.6
F - Construction			8.4	19.0	13.7	15.1
G - Wholesale and retail trade, etc.			9.5	18.6	14.0	16.1
H - Transportation and storage			10.0	18.8	14.4	15.7
I - Accommodation and food service			9.5	18.6	14.0	16.4
J - Information and comms (ex. software)	6.3	8.4	9.6	17.9	13.8	17.5
J - Software	5.1	4.1	7.1	10.8	8.9	19.3
K - Financial and insurance activities			9.7	19.5	14.6	16.7
L - Real estate activities			9.0	18.6	13.8	15.2
M - Professional, scientific and tech (ex. R&D)	7.4	7.4	8.4	18.5	13.5	16.4
M - Research & Development	10.9	13.8	9.7	18.6	14.2	17.9
N - Administrative and support activities			9.4	18.9	14.2	17.5
O - Public administration and defence, etc.			7.2	8.1	7.7	11.8
P - Education			9.2	17.3	13.3	18.5
Q - Human health and social work activities			9.9	18.8	14.3	16.7
R - Arts, entertainment, and recreation			7.9	18.1	13.0	12.8
S - Other service activities			9.1	19.0	14.1	16.9
T - Activities of households as employers			7.7	11.0	9.3	11.6
U - Activities of extraterritorial organisations	-	-	-	-	-	-
All other industries**	8.0	9.5	*9.4*	*19.0*	*14.2*	*16.7*

Source: ONS BERD 2011 (2012) and IPO patent data

- not published: low sample size

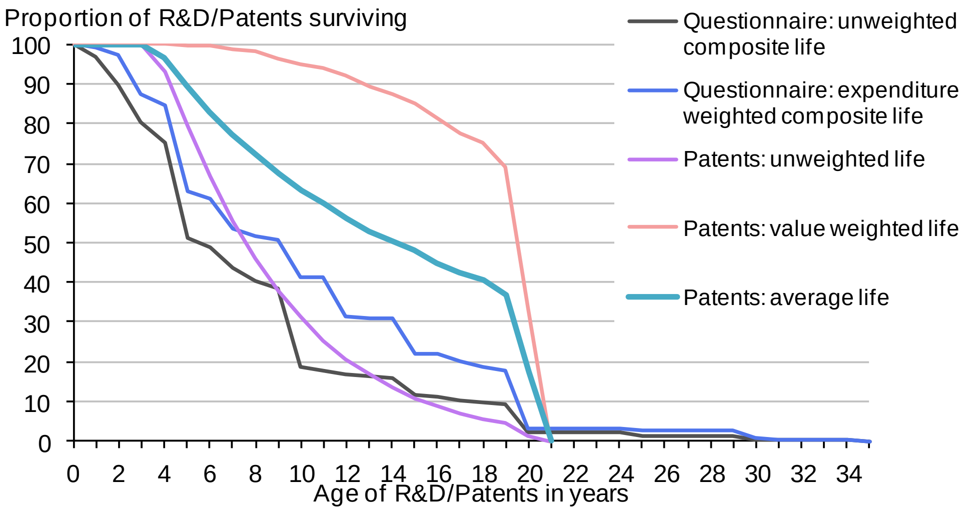
* median undefined (survival probability has not declined below 50%)

** for patent estimates this category is an aggregation of individual indistrial sections provided for comparison purposes

52. Comparing the survival profiles of R&D/patent lives from each source shows that survival from the questionnaire is quite similar to the profile given by unweighted patent estimates. By comparison, using the unweighted patent estimates would under estimate obsolescence in the first 7 years before falling approximately into line with the questionnaire based profiles. The average patent profile moderates the upward bias in the weighted profile and lies in the middle.

53. The figure also illustrates the impact of using patent data, which is (effectively) capped at a maximum life of 21 years. The survey responses suggest that around four per cent of R&D survives beyond 21 years but, though this proportion is small, the number of years further life is considerable at up to 35 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

VIII. Comparison to Other Studies

54. Peleg (2008) reviewed depreciation rates and service lives from ten different studies covering differing geographical areas and time periods. They 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.

55. The majority of estimates lie within this range or slightly above it, although this is as much a product of the broad width of this range in the first place. These results also re-confirm the presence of considerable variation between industrial sections.

56. The average lives of R&D from UK questionnaires are all greater than that found by the United States National Science Foundation (NSF) which also conducted a large-scale survey (covering over 6,000 firms) in 2012. The question used asked about the life of 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 to date. The results gave an average of 5.46 years and showed variation between the 25 industries covered (Li, 2012). The most comparable estimate from the UK survey, the unweighted mean service life, is 8.2 years.

57. 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 (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.

58. Comparing the 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.

59. 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 4 it is clear that while many of the estimates lie between 10 and 20 years, only in one case is the life estimated equal to the suggested default of 10 years. The median, weighted to reflect the relative shares of different respondents in total R&D output is also the most appealing questionnaire-based estimate. However, this could be driven by 'clustering' at focal numbers (e.g. 5, 10, 15, 20, etc) which can be observed in businesses' responses.

60. Furthermore, the breadth of alternative estimates available (the confidence intervals of which show that they are significantly different from 10) suggests that this is somewhat of a coincidence in the case of the UK. Estimates vary by industry and will overall average lives will therefore vary across countries with different industrial structures. The 10-20 year range is a useful guide but researchers should attach less significance to being within or outside this range than to the robustness of the methods chosen.

Table 4: Comparison of results by source

		Questionnaire: composite lives		Patent lives			
Estimate		Unweighted	Expenditure weighted	Unweighted	Value Weighted	Average of averages	Survival estimate
Median		**6.0**	**10.0**	**8.0**	**20.0**	**14.0**	**20.0**
Equals 10 year EU default?		✗	✓	✗	✗	✗	✗
In 10 - 20 year range?		✗	✓	✗	✓	✓	✓
95% CI	Lower	5.0	5.0	8.0	20.0	14.0	19.8
	Upper	7.0	12.0	8.0	20.0	14.0	20.2
	Includes 10 year EU default?	✗	✓	✗	✗	✗	✗
Mean		**8.2**	**10.5**	**9.5**	**18.8**	**14.1**	**16.9**
Equals 10 year EU default?		✗	✗	✗	✗	✗	✗
In 10 - 20 year range?		✗	✓	✗	✓	✓	✓
95% CI	Lower	7.8	8.4	9.4	18.7	14.0	16.8
	Upper	8.7	12.7	9.5	18.9	14.2	16.9
	Includes 10 year EU default?	✗	✓	✗	✗	✗	✗

Source: ONS BERD 2011 (2012) and IPO patent data

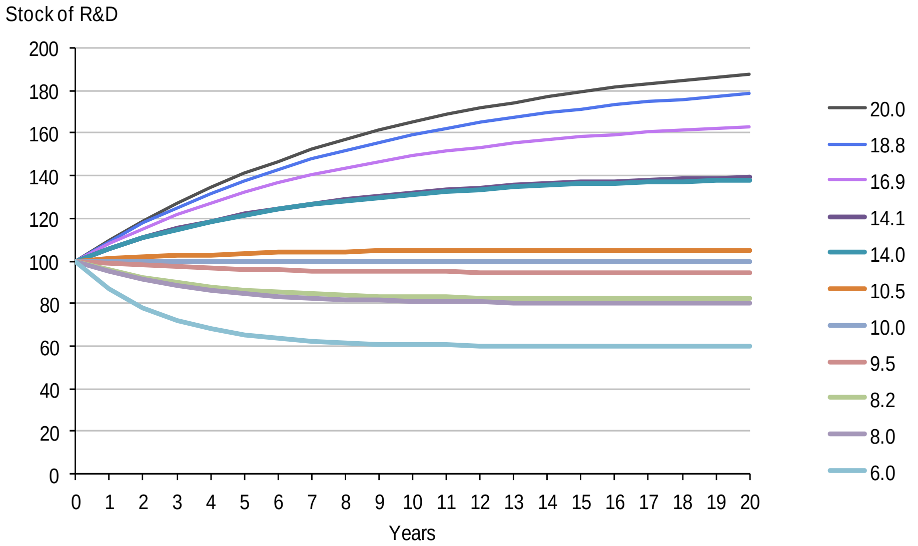
IX. Impact of Alternative Estimates

61. This research has provided considerable number of different estimates of R&D service life for the UK which range from 6 to 20 years. 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.

62. Figure 2 presents a stylised illustration of the impact of using these different service life estimates in the Perpetual Inventory Method 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.

63. In this example, 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

64. In this example, over 20 years, a service life of 6 years (rather than 10) is consistent with a 40 per cent decline in the stock of R&D and therefore a move away from knowledge driven growth. By contrast, an R&D service life of 20 years would contribute to 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.

65. 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 details in different countries.

X. Evaluation

66. This research has outlined two different approaches to estimating R&D service lives:

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

67. Each offers different benefits and limitations; for example survey questions require money and time for design and implementation, and also add to respondent. Patent research may benefit from lower cost and time requirements, and offers a large amount of observed information. Industry analysis is also possible, though patents may first need to be matched to business information.

68. Both approaches require assumptions about generalisation of results to other R&D. However, while results from the BERD can claim to be representative of 80 per cent 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.

69. Generalisation over time is also an issue, and while survey questions might easily be re-run every five or ten years to collect benchmarks, patent data is backwards looking and most analytical methods require waiting to observe death. The Kaplan-Meier survival analysis techniques demonstrated address this to some extent.

70. Both methodologies classify based on the industry producing the R&D (or patent) but R&D may be sold or otherwise transferred across industries. However, 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 industrial groupings (whether it is 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 this approach the same level of resilience.

XI. Conclusions

71. There are three 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 country as this neutralises one of the two key determinants of the R&D stock.
- Countries making different choices between these data sources, and between different analytical methods to apply to that data introduces artificial variation between countries. This will reduce our ability to compare 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)

72. On the basis of this full and thorough analysis of Business R&D service lives results, the ONS proposes to adopt weighted median service lives estimated from the survey data. While the level of industry disaggregation is less satisfactory, this approach offers the advantage of being clearly linked to R&D.

73. Correct understanding of the impact of R&D on the economy and on productivity 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 adopted. Estimating R&D service lives is challenging, but this research provides a detailed comparison of two popular methods.

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