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Price revisited: on the growth of dissertations in eight research fields

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Abstract This paper studies the production of dissertations in eight research fields in the natural sciences, the social sciences and the humanities. In using doctoral dissertations it builds on De Solla Prices seminal study which used PhD dissertations as one of several indicators of scientific growth (Price, Little science, big science, 1963). Data from the *ProQuest*: *Dissertations and Theses* database covering the years 1950–2007 are used to depict historical trends, and the Gompertz function was used for analysing the data. A decline in the growth of dissertations can be seen in all fields in the mid-eighties and several fields show only a modest growth during the entire period. The growth profiles of specific disciplines could not be explained by traditional dichotomies such as pure/applied or soft/hard, but rather it seems that the age of the discipline appears to be an important factor. Thus, it is obvious that the growth of dissertations must be explained using several factors emerging both inside and outside academia. Consequently, we propose that the output of dissertations can be used as an indicator of growth, especially in fields like the humanities, where journal or article counts are less applicable.

Keywords History of science · Dissertations · Publication analysis · Growth of science

Introduction

Current scientometric research focuses on several aspects of research, science, scholarly communication and innovation, and often applies complex, composite indicators such as

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citation-based journal indicators (e.g. Leydesdorff 2009; Lundberg 2007), h-indices (e.g. Bornmann et al. 2008) or advanced mappings and clusterings (Morris and van Der Veer 2008) to describe various features or attributes of research. One of the historically first units of scientometric research is largely unused today, namely publication counts of dissertations. Derek J. de Solla Price used this unit, alongside other measurements, as an indicator of an addition of a new researcher to a scientific field (Price 1963). Based on the progress of science at the time Price conducted his research, and the natural limitations to exponential growth in a population, he speculated about the growth and saturation of science in the future. Price's research was focused on the sciences, e.g. physics and chemistry, which have a long tradition for publishing short items (e.g. journal articles) in contrast to the humanities which traditionally publish fewer, but larger, items such as monographs. This distinction is also made in most scientometric research today, as there are very clear differences in publishing traditions and scholarly communication in general between natural science, social science and the humanities. This becomes exceedingly apparent when it comes to journal-based indicators. But even within the natural sciences one may observe differences in publishing traditions, where some fields tend to prefer journals and to some degree disregard conference proceedings, while in other fields those proceedings are the primary channel of communication (Larviére et al. 2006).

The purpose of this paper is to discuss the general applicability of dissertations as an indicator of scholarly growth, and to provide a historical view on the growth of research. If dissertations are viable as a growth indicator, it may be a useful metric for comparing growth between particular fields, or possibly even between the humanities and the sciences. This paper thus focuses on research in a broad sense, using the term *research* to frame all those scientific and scholarly fields which may be placed under the labels natural science, health science, social science, engineering and the humanities.

Background

The growth of researchers or manpower can be said to provide a basic indication of scholarly growth in different fields, which could be used to predict future developments (Wood 1988). De Solla Price used 'doctorates in science and engineering' as a measure of the growth of scientific manpower and concluded that the more qualified (e.g. higher degree), the greater the growth rate (Price 1963). We argue that the number of dissertations produced in a specific field can be used as an indicator of growth. This, although we acknowledge differences between fields when it comes to the role of the dissertation, and we also concur with the notion that not every PhD becomes an active researcher in the field of their dissertation work (Bazeley 1999). However, one could also argue that the production of manpower—highly skilled professionals—is an important feature of some research areas, such as engineering or medicine. It can even be argued that this production of 'highly skilled manpower' is as important for society as the production of research articles. Thus, the number of produced dissertations can be seen as an important indicator, alongside other publication types, patents and citations which can be used to measure the output of research.

Although Price has inspired a continuous body of work on the growth of science, only few studies have analysed the growth of PhDs. In a recent review of studies following in the footsteps of Price only 2 of 34 used dissertations/number of PhDs as a measurement of scientific growth (Fernández-Cano et al. 2004). Other units used to measure growth were papers, abstracts, journals, funding, patents and citations. Usually these units are used to

Table 1 Selection of research fields

	Fields
Humanities	Literature and history
Social sciences	Sociology, library and information science and history
Life sciences	Medicine
Engineering	Engineering
Natural sciences	Physics and chemistry

determine scientific growth visually using plots on a graph. The different units often converge, and Han et al. (2010) found a correlation between annual numbers of doctorates and worldwide output of scientific articles. However, the growth of article outputs is greater than that of new doctorates, but this is mainly related to emerging countries (e.g. China and India) where article output is increasing rapidly (Han et al. 2010).

A few studies have used dissertations to measure and compare the growth of scholarly fields. Wood (1988) did a comparison between the number of dissertations in the natural sciences, social sciences and the humanities using the *Dissertation Abstracts Database* (e.g. ProQuest) and data from the *National Research Council*. The data showed rapid growth in all fields but also signs of a saturation in the late seventies and the early eighties. The *arts and literature* field showed a sharp rise from the 1950s but also a distinct decline during the seventies while *health sciences* showed a rapid and steady growth from the sixties and onwards. The *hard sciences* also showed a small decline after 1970 and in the *social sciences* stagnation occurred during these years. Han et al. (2010) confirm that the growth of doctoral degrees decline in the 1970s but during the first three quarters of the 20th century the number of PhDs grew by approximately 7% a year. Thus, it seems that with a few exceptions there is a general decline in PhDs during the seventies—a development that is usually explained by economic and political factors (e.g. the Vietnam war, the moon landing, ecological concern and the oil crisis) (Han et al. 2010; Mabe and Amin 2001).

In comparison to earlier research this article uses a fine-grained delineation of research fields—selecting *literature* instead of *humanities* and *physics* instead of *hard science*—which allows for a more in-depth analysis of the results (see Table 1 for complete list[1]). The choice of specific fields is motivated by an effort to compare disciplines that differ in their intellectual organization and which have different characteristics. Using the descriptions used by Becher and Trowler (2001), the chosen disciplines can be described as illustrated in Table 2.[2] The choice of fields that differ from each other both in methods (hard–soft) and in use (pure–applied) makes it possible to discuss how disciplinary difference is related to growth of the field. There are other options for describing and explaining disciplinary differences (e.g. Whitley 1984) but the chosen concepts highlight differences between the disciplines which are important for understanding the growth of scholarly fields.

A problem when measuring a research field is that 'fields' or 'disciplines' are entities that are not always well defined, and a field may grow horizontally (coverage) which may infer on other research fields e.g. gaining ground, or it can grow vertically (amount of research done in a specific field (Becher and Trowler 2001)). This instability and changing

[1] History is often seen as a discipline on the border between the humanities and the social sciences.

[2] In this case, sociology can be seen both as a pure field, sociological theories and models, as well as an applied field focusing on education of professionals and social work.

Table 2 Characteristics of the fields used for analysis

	Hard	Soft
Pure	Physics, chemistry	Literature, history, sociology
Applied	Medicine, engineering	Library and information science, sociology

Table 3 Number of dissertations indexed in ProQuest according to language

Language	Number of dissertations
English	2,487,808
German	115,963
French	60,628
Swedish	3,431
Danish	215

nature of research fields was part of the considerations for the choice of materials and delineations of fields.

Materials and methods

Data on dissertations were gathered using the ProQuest database *Dissertations and Theses*. The ProQuest database has indexed dissertations since 1938 and currently over 2.7 million graduate works from over 700 universities across the world are indexed. The database is the largest dissertation database available and it is said to cover 40% of all dissertations from major universities. However the coverage of different languages differs substantially with a heavy bias towards dissertations written in English (see Table 3), and the dominance of dissertations published in the United States is apparent when looking at country of origin (see Table 4). Thus, this study is limited in its scope as mainly dissertations written in English and at universities in the United States are indexed in the ProQuest database.

The database consists of two individual databases; *Dissertations and Theses*: *The Humanities and Social Sciences Collection* covering more than one million dissertations and *Dissertations and Theses*: *The Sciences and Engineering* covering more than 1.5 million dissertations and theses.

Table 4 Number of dissertations indexed in ProQuest according to country of origin

Country	Number of dissertations
United States of America	1,935,361
Germany	99,639
United Kingdom	77,231
France	47,991
Sweden	23,841
Denmark	802

Table 5 Search queries used

Field	Query
Literature	African literature OR American literature OR Asian literature OR Australian literature OR Canadian literature OR Comparative literature OR English literature OR French Canadian literature OR German literature OR Icelandic and Scandinavian literature OR Latin American literature OR Literature OR Literature of Oceania OR Medieval literature OR Middle Eastern literature OR Modern literature OR New Zealand literature OR Romance literature
History	African history OR American history OR Black history OR Canadian history OR History, History of Oceania OR Latin American history OR Military history OR Modern history OR Science history OR World history
Sociology	Social research OR Social work OR Sociology
LIS	Library and information science
Physics	Nuclear physics OR Physics OR Quantum physics
Chemistry	Chemistry OR Physical chemistry OR Polymer chemistry
Engineering	Aerospace engineering OR Agricultural engineering OR Automotive engineering OR Biomedical engineering OR Chemical engineering OR Computer engineering OR Electrical engineering OR Environmental engineering OR Engineering OR Industrial engineering OR Nuclear engineering
Medicine	Biomedicine OR Medicine

Table 6 Coverage in the fields of study

Field	Number of dissertations
Literature	113,362
History	107,171
Sociology	74,406
Library and information science	5,542
Physics	53,877
Chemistry	147,045
Engineering	233,797
Medicine	34,233

In order to retrieve dissertation numbers for specific fields, subject names were used to define the fields and query the database (Table 5). These subject names were selected from ProQuests controlled vocabulary, so they would cover the entirety of the chosen fields. The numbers of dissertations indexed in the database differs substantially between the studied fields (Table 6). The largest number of dissertations is found in engineering and this can be related to the broad definition of this field, as used in this study.

The definition and delineation of fields is as always important for the results gained. In general we aimed at aggregating research fields into larger units in order to retrieve a larger dataset. In some sense this can result in loss of precision, however, data accuracy was perceived as the key issue. Longer queries, as e.g. for literature or engineering, can also to some degree be a way of avoiding the problem of further specialisation within research; as the further delineation into smaller fields could distort the results if only more general field definitions as 'Literature', 'Physics' or 'Chemistry' were used. This, as the specialisation and changes within research fields, must be a factor to take into consideration when studying the output of dissertations. An example is the field of literature where the emergence of cultural studies may have affected the number of dissertations as 'cultural studies' to some extent incorporates and challenges to the 'old' discipline of literature.

Assessment

Price suggested that science would grow in a manner resembling the growth of any other population, a growth type referred to as the logistic growth function. This function has been used much in ecological research, and has been developed to not only cover the standard logistic growth function (1), resembling the logistic function, but also variations thereof (cf. Tsoularis and Wallace 2002).

$$C(t) = \frac{K}{1 + \frac{K}{C(0)-1} e^{-at}} \tag{1}$$

Price himself suggested that the growth of science would follow one of four types of logistic growth; (a) the standard logistic growth (S-shape), (b) escalation, where renewed growth is initiated after maturity has been reached (stacked S-shapes), (c) logistic growth followed by oscillation (divergent or convergent). While the predictions of Price appear reasonable, progress at the time did not allow further testing of these assumptions (Scientific fields had not yet reached anything near saturation). Other types of growth of literature have been discussed and tested by Egghe and Rao (1992), namely the Gompertz function (2), Ware's model (3) and the power model of growth (4).

$$C(t) = D \cdot A^{B^t} \tag{2}$$

$$C(t) = \delta(1 - \varphi^t) \tag{3}$$

$$C(t) = \alpha + \beta \cdot t^{\gamma} \tag{4}$$

Egghe and Rao (1992) find the Gompertz function to fit S-shaped better than the logistic function, and the power model to fit other informetric growth types, e.g. exponential-like growth, better. Gupta and Karisiddappa (2000) used the approach and also found the power model to fit their data best, however, their data resembled exponential growth, which agrees with Egghe and Rao's findings (1992). While this is the case for certain literature types and in certain fields, we expect dissertation data to be explained by S-shaped growth rather than exponential, and therefore attempt to fit growth through the Gompertz function. The power model may be used to explain certain other growth types, such as exponential-like growth.

Results

A complete annual count of all dissertations in the ProQuest database was performed (see Fig. 1a) for the period 1950–2007. Data from more recent years showed a very sudden decline, indicating that indexing may not be complete as of yet. The growth at the early end of the figure (1950–1970) is not unlike a standard S-shaped distribution, while the further growth shows signs of escalation. In order to validate the use of *ProQuest Dissertations and Theses* database we used data from the *National Science Foundation* (NSF) for the

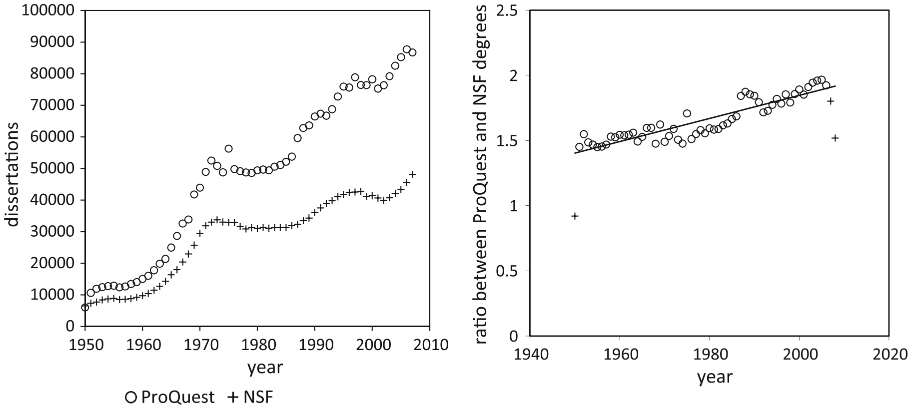

Fig. 1 **a** All dissertations in all fields registered in the *ProQuest Dissertations and Theses* database with NSF data as comparison, 1950–2007. **b** Ratio between dissertations from ProQuest and NSF awarded degrees. Data points marked with + are regarded as outliers and not included in the fitted line

years 1950–2007 for comparison[3] (Fig. 1a). The numbers for the databases correspond very well (Fig. 1b), and this is not surprising as a majority of the indexed dissertations in *ProQuest* are from the United States (see Table 4). The coverage of *ProQuest* outside the US has increased from the mid seventies and that explains the increasing gap in the number of registered dissertations for the two sources. Thus, in depicting the general growth of dissertations the two data sources shows a similar trend throughout the time period. Drawing on this similarity and previous findings on the growth of dissertations (Thurgood et al. 2006) we conclude that the *Pro Quest Dissertation and Theses* database is a valid and reliable source for studying the growth of doctorates.

The analysis of dissertations in all fields shows a pattern which is similar to other studies (Han et al. 2010) analysing the growth of dissertations: standard S-shaped growth during the sixties and the early seventies, followed by stagnation during the late seventies and early eighties. Several reasons have been proposed for this decline; a saturated academic labour market, less spending on research due to the Vietnam war and the oil crisis and the economic recession that followed (Thurgood et al. 2006).

When comparing the annual number of doctorates in the eight selected fields we observe certain resemblances and differences (see Fig. 2). Physics stands out the most, with a type of distribution resembling neither the expected S-shape, exponential, logarithmic nor other well-known growth types. The variance of data in the library and information science (LIS)-field is too great to provide sensible analysis of the data. While it would be possible to fit a curve to the data, the explanatory power of this curve would be very small, given the huge differences from year to year. This is likely due to the relatively small size of the field, and thus relatively large impact just a few additional dissertations have. The fields of LIS and physics are therefore omitted from the further analysis. Chemistry, engineering, history, literature, sociology and to some extent medicine apparently follow some type of S-shaped distribution in two parts. The first part seems to mature in the early 1980s, with renewed growth around 1985. Literature appears to be better described by a single S-shape,

[3] The data was gathered from two reports: *Number of U.S. doctorates awarded rise for sixth year, but growth slower was used for the latest years and US doctorates in the twentieth century. Special report* for the years 1950–2000.

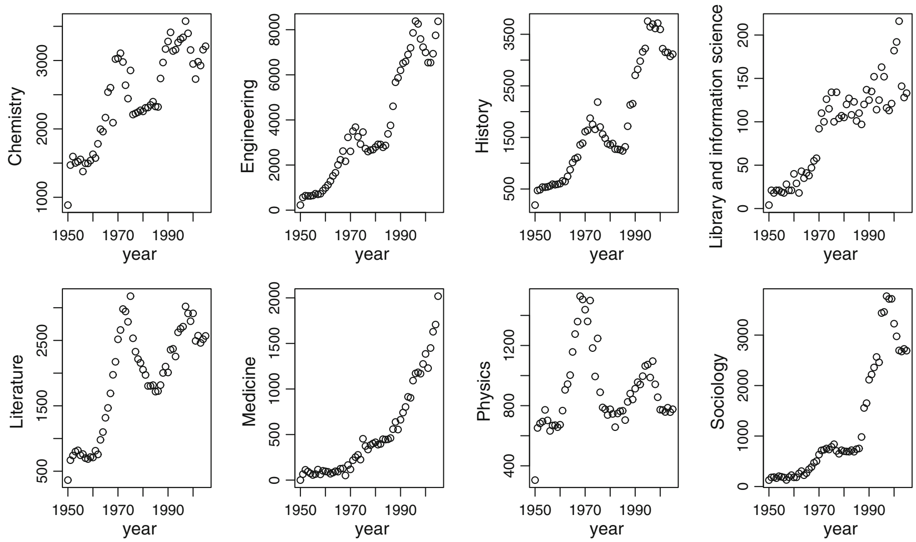

Fig. 2 Dissertation counts in selected fields

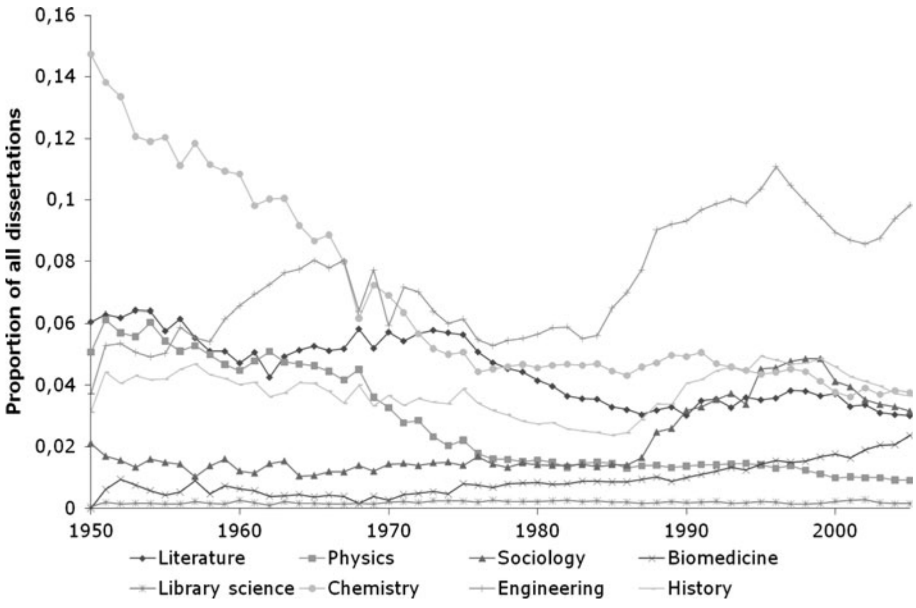

Fig. 3 Relative size of fields compared to total dissertations

followed by strong oscillations. Medicine may be explained both as a power model and a two part S-shape.

The proportion of the selected fields is diminishing in comparison to the total number of indexed dissertations (Fig. 3). This could be the result of changing policies regarding the indexing and coverage of the field in the database, but it could also be a result of a dispersion and dissemination of research into more specialised fields. Most apparent is the development within the field of chemistry which in 1950 contributed almost 15% of the indexed dissertation, diminishing to 5% in 2008.

Assessment

In Fig. 2 we observed S-shaped growth for chemistry, engineering, literature, sociology, history and medicine. We attempted to fit the Gompertz function to data from these fields (see Fig. 4 for fitted curves). In the case of escalation, we fitted different parameters to sequences of data. The goodness of each fit is reported in Table 7, with R^2 values indicating the proportion of total variation explained by the fitted curve. For escalating curves, the goodness of each fit is reported, with $seq_1(x_1, y_1)\ldots seq_n(x_n, y_n)$ labelling the chronologically consecutive sequences from year x_i to y_i. We used the R statistical software (R Development Core Team 2010) for fitting, using the Gompert growth function, variation 2,

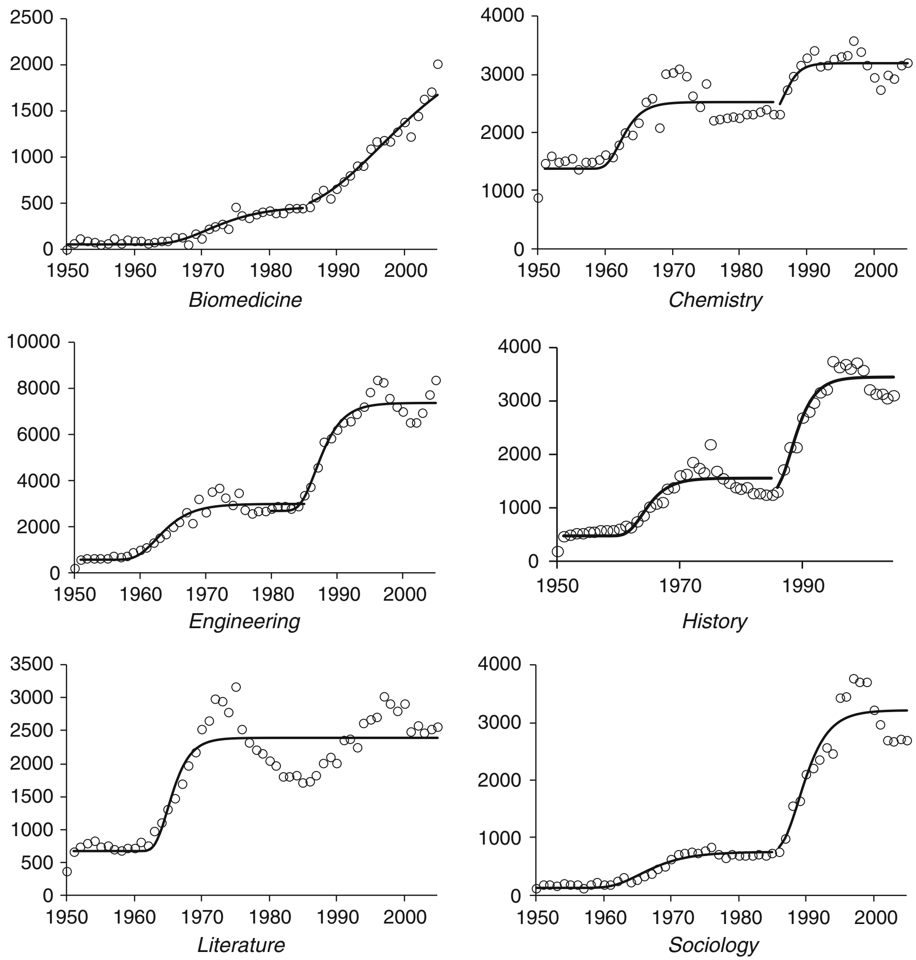

Fig. 4 Fitted Gompertz functions for chemistry, engineering, history, literature, medicine and sociology

Table 7 Fitted values and R^2 error for the Gompertz function for six of the included research fields

Field	Seq	Gompertz parameters				R^2
		A	B	C	D	
Chemistry	1	0.5246	1962.1	1145.4	1378	0.8742
	2	0.7640	1986.7	870.2	2322	0.7227
Engineering	1	0.3373	1962.5	2424.1	564	0.9628
	2	0.4331	1986.7	4690.8	2684	0.9696
History	1	0.4152	1963.9	1083.8	472	0.9215
	2	0.4606	1988.2	2214.4	1240	0.9412
Literature	1	0.5417	1964.9	1721.4	670	0.8994
Medicine	1	0.2019	1970.7	417.46	52	0.9679
	2	0.0996	1996.5	1974.2	390	0.9725
Sociology	1	0.2524	1965.3	626.4	128	0.9739
	2	0.4109	1988.9	2473.4	741	0.8961

from the drc package (Ritz and Streibig 2005). The definition of this variation of the Gompertz function is given in (5), with A, B and C as parameters.

$$f(t) = C \cdot \exp(-\exp(A(B - t))) \tag{5}$$

As our data did not start at the birth of these research fields, it was necessary to add a parameter, D, for adjusting the Gompertz function to the starting point of each sequence (6). In each sequence D was set to min $(seq_i) + 1$.

$$f(t) = C \cdot \exp(\exp(A(B - t))) + D \tag{6}$$

The dissertation data from physics did not fit into either the power model or the Gompertz function. While it is possible to produce e.g. polynomial fits that somewhat resemble the distribution of the data, we do not believe this to be theoretically based, and therefore omit such attempts. Based on previous findings (Price 1963), we believe it is more likely that the behaviour is some type of oscillation, or possibly an unidentified error source.

Overall, the R^2 values correspond well with the patterns illustrated in Fig. 4. Chemistry and literature have a fairly high error rate which can be explained by the large oscillations. Despite the high error rate, the fitted function does describe a general pattern of these fields. The same patterns can be seen in other fields, although the errors are somewhat lower in most cases. Biomedical data was fitted well by the Gompertz function, and as this is also the tendency for other fields, we believe this to be a good fit, rather than attempting to fit the power model to these data.

Discussion

The results show significant differences in the growth profiles of the analyzed research fields, however no general explanation could be found that explains these differences. The studied fields were selected in order to compare the growth between fields in the humanities, the social science and the natural sciences. We also selected fields that had different methods (hard/soft) and different outcomes (pure/applied); however, these dichotomies which often are used to characterize research fields could not explain the different growth profiles. An example of this is history (pure/soft) and engineering (applied/hard) which have similar growth profiles (Fig. 2). Rather no single factor could be found that explains the different growth types but it seems that the growth of fields is strongly related to the age of the field, and it would appear that societal circumstances also play an important role.

Whichever circumstances influence the growth of dissertations, it would appear to affect all the included fields at roughly the same time, indicating that all research fields are affected by the same, or simultaneous, events. A general decline in the growth of dissertations is observed in the seventies—this is also confirmed by previous studies—and the explanation for this cannot be found in the individual fields. Instead more wide-ranging reasons must be identified, and while it is not our goal to find these explanations, as it would be pure speculation, we propose a few potential factors, which likely have some effect or other.

As the growth of scientific manpower is dependent on the population from which the manpower is drawn, a natural limitation to growth is that of the general population, or perhaps more specifically the part of the population holding university degrees. We conducted a brief comparison of these two parameters (general population of the USA and the number of US inhabitants holding a bachelors degree or higher, according to the US National Census) and the growth of dissertations (data not shown). Results indicated a connection between dissertations and other degrees, showing a clearer stagnation in the oldest fields. However, the number of inhabitants holding university degrees is also dependant on other factors and as such is not a singular explanation.

Also the dissemination and diffusion of research fields is likely to play an important role in the explanation of growth. If one compares the combined growth of the selected fields to the total growth, a steady decline from 40 to 20% occurs from 1950 to 1985, followed by growth (peaking at 31% in 1996) and renewed declination (26% in 2006). Thus, it is obvious that other fields, not included in this study, must experience opposite relative growth. This could for example be due to the formation of subfields not included in our definitions, or new emerging interdisciplinary research areas such as ‘cultural studies’ or ‘gender studies’, in the case of literature studies, which are not covered by older disciplinary definitions. Thus, the disciplinary landscape has changed substantially—both in the natural sciences, the social sciences and the humanities—and this obviously affects the results of a study grasping over a long period of time.

We do believe that longitudinal studies of research production are important in order to understand historical and contemporary developments in research, but a more complete and detailed dataset would be needed to study the growth of smaller, more specified research fields. In regards to this it would also be interesting to track the careers of researchers—whether they continue in the field of their PhD, or move towards other disciplines or more interdisciplinary settings, or if they leave academia for other organizations or companies. In this respect there are major differences between research fields and disciplines, especially between the applied and pure sciences.

The database used for this study is predominantly indexing dissertations produced in America, and as the growth of research is clearly affected by the economic and political context, it would not be surprising if the growth in other countries or regions show other patterns. Furthermore, it could be of interest to compare the production of PhDs between countries or regions, and such studies could complement similar comparisons regarding the production of journal papers. Thus, the study of dissertations as a measurement is, although Price used it already in the early sixties, still an underdeveloped area of bibliometric research which has the potential to further our understanding of growth and development of research.

We identified S-shaped growth in most of the included research fields, and found the Gompertz function to fit the growth well in four of our studied fields (medicine, sociology, history and engineering) and reasonable well in two other (literature and chemistry), while physics and LIS could not be analyzed due to age of the field and the size of the field. The goodness of the Gompertz function fit agrees with Egghe and Raos (1992) findings, although the actual growth curves disagrees somewhat with their findings as well as those of Gupta and Karisiddappa (2000), who found the power model to better describe the growth of scientific literature. However, the object of our study, dissertations, is very different from their objects, articles, and the disagreement is not consequential.

The largest source for error in the Gompertz function fits are the oscillations occurring in the maturity-periods between the S-shaped growth periods. Some particular logistic functions enable the description of oscillation (cf. Hartwich and Fick 1993), but we were unable to fit these functions to our data. Further research into this may be potentially useful for more exact, mathematical descriptions of these distributions.

Using dissertation counts it was possible to document different growth profiles for different research fields, and we argue that dissertation counts are an important unit of analysis when discussing the growth of research. Using dissertations has several advantages over other, common units. First and foremost, the unit can be utilised across fields as it is applicable in the humanities, social sciences, natural sciences, engineering and life sciences. Secondly, dissertations are an output or research activity that can complement other publication-based measures. Third, the production of PhDs is not only a measure of research output, but it is also a measure of the production of qualified manpower; a resource that is essential for contemporary knowledge societies. Fourth, databases like *Pro Quest*: *Dissertations and abstracts* provide an extensive and largely unexplored source of data.

Dissertations are an underdeveloped unit of analysis in contemporary bibliometric research; a unit which could be used for comparison over time, between research areas and as a comparison between countries and regions. In conclusion, it is our firm belief that the analysis of dissertations can provide valuable insights into the growth and structure of scientific fields and disciplines.

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