Measuring Interdisciplinarity

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Introduction

As the other chapters of this book show, bibliometric indicators have been used to measure many aspects of the dynamics of science. Every time a new question has emerged about the changing practices of scientific research, indicators have been designed to try to answer it with empirical data. When the question of the extent of the internationalization of science became a topic of interest to governments and university managers in the 1990s, one could provide an indicator of international collaborations by looking at the presence of different countries in the address field of scientific publications and analyze the evolution of its proportion over time. An even more recent interest on the part of decision- and opinion-makers in higher education and research is the question of the extent of interdisciplinary research and its supposed necessity in a world in which problems are complex and multifaceted. To go beyond buzz words and performative discourses saying interdisciplinarity is inevitable and thus should be generalized (Gibbons *et al*., 1994, Nowotny *et al.,* 2001), bibliometricians have proposed different manners in which it could be operationalized, thus contributing to the recent wave of interest on the nature and growth of interdisciplinary research (Weingart & Stehr, 2000; Frodeman, Thompson Klein, & Mitcham, 2010). For

despite the fact that this idea has been repeated and promoted by many university managers and higher education "gurus", solid data confirming the supposed trend toward increased interdisciplinarity are hard to find. Trying to go beyond vague reference to "inter", "multi" or even "trans" disciplinarity, bibliometric indicators focused on the measure of interactions between disciplines and specialties. A bibliometric approach to the debated question of interdisciplinarity provides a unique possibility to analyze its practice over a long historical period, and to test assertions about its recent increase in different scientific disciplines (Gibbons et al. 1994; Hessels & van Lente, 2008).

The most complete study on the bibliometric measure of interdisciplinarity is that of Porter and Rafols (2009), who analyzed its evolution in six research areas over a 30-year period. Although they found an increase in interdisciplinarity, it was quite small (about 5%). Another recent study by Levitt, Thelwall and Oppenheim (2011) analyzed the evolution of interdisciplinarity in the social sciences using 14 Social Science Citation Index (SSCI) categories for three specific years: 1980, 1990 and 2000. They showed that the median level of interdisciplinarity of these fields had *decreased* between 1980 and 1990, but then climbed back in 2000 to its 1980 level. Van Leeuwen and Tijssen (2000) analyzed changes in specialties' level of interdisciplinarity between 1985 and 1995 and found that very few disciplines displayed significant changes in levels of interdisciplinarity during that time.

Other studies on the evolution of interdisciplinarity either focused on one discipline over a few decades (Tomov & Mutafov, 1996; Rinia, van Leeuwen and van Raan, 2002; Schlummer, 2004; Rafols & Meyer, 2007) or used a few years of data for many disciplines (Adams, Jackson, & Marshall, 2007). Recent work in the visualization of science has provided a global view of the relationships between scientific disciplines (Börner, Chen, & Boyack, 2003; Boyack, Klavans & Börner, 2005). Although they shed some interesting light on the changing relations between disciplines and specialties, none of these studies provides a complete overview of changes over a long historical period. Using macro-level data for the period 1900-2010, this chapter provides the first historical overview of the relationships between all scientific disciplines in the natural and medical sciences as well as in the social sciences and humanities.

After a brief discussion of the necessary distinctions to be made between the discourse *on* and the practice *of* interdisciplinarity, we review the relevant literature on the operationalization of the concept of interdisciplinarity and describe the specific methods used in this chapter. The third section presents the results obtained for each of the disciplines, while the final section discusses the results.

Distinguishing discourses from practices

Before analyzing the *practice* of interdisciplinarity, as defined through bibliometrics, it is worth looking at the evolution of interest in that topic over the course of the 20th century. Abbott (2001) has suggested that interest in interdisciplinarity is in fact almost stable over time. To support this surprising assertion, he calculated the ratio between the number of items from the Social Sciences Citation Index having the word "interdisciplinary" in their title to the number of papers using the word "national" in their title. That ratio being quite stable (around .07 and .08) he concludes that, contrary to what most people think, there is no real upsurge of interest in interdisciplinarity. Given our intuition that discourses on interdisciplinarity were much in vogue in the 1960s and again in the 1990s, there may be reasons to doubt the validity of the rough indicator used by Abbott to support his claim. Indeed, why use a ratio with "national" and not with "race", "sex" or any other term? An increase in interdisciplinarity could be hidden behind a parallel increase of "national" research. It seems obvious that the best way to measure the relative interest in interdisciplinarity is to compare the place of interdisciplinarity in titles across all papers in the SSCI and AHCI (as well as SCI for comparison) – which is a stable base – instead of comparing it with the proportion of papers that use other terms and that are likely to fluctuate from one year to another.

As shown in Figure 1, discourse on interdisciplinarity in the SSH emerged after the Second World War but only became fashionable from the mid-1960s to

the end of the 1970s. A second wave of interest began in the 1990s, stabilized at the end of the decade, and then increased again at a very fast pace after 2006. As might be expected there is much less in the natural sciences where titles refer to content and object studied and rarely to methods[1]. Fluctuating interest in the topic of interdisciplinarity underscore the importance of distinguishing between the discourses *on* and rhetoric *of* interdisciplinarity from its actual practice which rarely commands the use of the word itself. The subject is typically addressed in editorials in general interest science periodicals or in papers published in social science journals that consider bringing disciplines together for the purpose of producing new knowledge on a given object of study, be it social or natural. In the latter case, one does not expect to find explicit mention of "interdisciplinarity" a term more suited for use in papers discussing epistemology or methodology. For example, a paper in *Science* in 1944 discussed "General Aspects of Interdisciplinary Research in Experimental Human Biology" (Brozek & Keys, 1944). In 1948, the Harvard economist Wassily Leontief published a paper in the *Journal of Philosophy* entitled "Note on the pluralistic interpretation of history and the problem of interdisciplinary cooperation" (Leontief, 1948). In 1952, the presidential address of Dorothy Swaine Thomas at the annual meeting of the American Sociological Society concerned "experiences in interdisciplinary

[1] A similar trend is obtained using the JSTOR database.

research" (Thomas, 1952). Many others in the 1950s suggested a "framework" or "programs" for interdisciplinary research while some raised "problems", "obstacles" and "challenges" associated with interdisciplinarity in the 2000s. The rhetoric thus seems more recurrent than constant, coming back every 20 to 25 years, but it is not our intention to trace here in detail the historical shifts in the rhetoric of interdisciplinarity. We focus instead on measuring the evolution of interdisciplinarity on the basis of various indicators and see if their results converge to show a tendency toward greater interaction between disciplines as suggested by many, a stable situation or a cyclic pattern typical of fads.

[insert figure 1 here]

Background and methods

From a bibliometric point of view, the concept of interdisciplinarity is generally operationalized on the basis of authors' disciplinary affiliations (departments), using the references papers' contain or the citations they receive (Wagner et al., 2011). Most studies, such as Adams, Jackson and Marshall (2007), Tomov and Mutafov (1996) and Morillo et al. (2001) follow Porter and Chubin (1985) and measure, for a set of papers (or journals), the percentage of citations made by the papers (or the journals) outside their discipline or specialty (which they label as the *Citations Outside Category*). On the other hand, Rinia et al. (2001, 2002) and Rinia, van Leeuwen and van Raan (2002) define interdisciplinarity as the

percentage of papers from a group of researchers published outside their "main" discipline. Others, like Levitt and Thelwall (2008), operationalize the concept using articles published in journals which are classified in more than one field by Thomson Reuters' Web of Science or by Elsevier's Scopus. However simple this approach may sound, it is doubtful that it captures interdisciplinarity since the fact that a journal is attributed to more than one discipline does not necessarily imply that the papers published in this journal are actually "interdisciplinary". Such a journal could, in fact, be publishing papers from different disciplines, with very little interaction between them, as is the case of multidisciplinary journals such as *Science* and *Nature*. Finally, using the researcher as a unit of analysis, Le Pair (1980) constructed a different indicator, based on the migration of scientists from one discipline to another throughout the course of their careers. Though interesting, this indicator is quite difficult to compile because of the lack of systematic data.

The analysis presented here uses the references contained in papers as a basis to construct indicators of interdisciplinarity and interspecialty (within a given discipline). It is based on Thomson Scientific's databases which are the only ones covering over a century of both papers and references. For the 1900-1944 period, data are drawn from the Century of Science, which indexes 266 distinct journal titles covering most natural sciences and medical fields. For the social sciences, data between 1900 and 1956 come from the Century of Social

Science Index, which indexes 308 journals from these disciplines. From 1945 to 2010, data are from the Web of Science (WoS), which includes the Science Citations Index Expanded, the Social Sciences Citation Index, and the Arts and Humanities Citation Index. The disciplinary classification of journals used in this paper is that of the U.S. National Science Foundation (NSF). This classification categorizes each journal into one discipline and one specialty. For the social sciences and humanities, the NSF categorization was completed with our own classification. The classification defines 14 disciplines divided into 143 specialties. For the sake of graphical representation, these 14 disciplines have been regrouped into 4 larger domains: medical fields (MED), natural sciences and engineering (NSE), social sciences (SS) and arts and humanities (A&H).

For each document indexed in Thomson's databases (source items), a list of references is included. Following Porter and Chubin (1985), we measure the degree of interdisciplinarity of a given paper using the relationship between the discipline of that paper and those of its cited documents. Two dimensions of interdisciplinarity were measured: the interdisciplinarity of references made and the interdisciplinarity of citations received. However, given that the tendencies observed were almost identical for the two measures at this level of aggregation—they are the two sides of the same coin—interdisciplinarity measures presented here are only those based on the interdisciplinarity of references made.

Following Rinia's (2007) typology, we calculated two types of interdisciplinarity: 1) references made to journals classified in a discipline different form that of the paper, and 2) references made to journals classified in the same discipline but in a specialty different from that of the paper. We call the first measure "interdisciplinarity" since it measures the link with other disciplines (e.g., links between biology and physics) and the second "interspecialty" since it measures the relationships between different specialties within a given discipline (e.g., links between optics and nuclear physics). More specifically, the measure of interdisciplinarity presented in the Figures is the percentage of references made to papers published in journals categorized into a specialty of another discipline and the measure of interspecialty is the percent of references made to another specialty of the same discipline. The other measure presented is the percentage of references made to journals of the same specialty. For example, an article published in a particle physics journal that includes 12 references to papers published in journals from the same specialty, 8 to journals in other specialties (optics, nuclear physics, etc.) of the same discipline (physics) and 10 to journals of specialties of other disciplines—for a total of 30 references—will obtain an interdisciplinarity score of 33.3% (10/30), an interspecialty index of 26.7 % (8/30) and a same specialty index of 40.0% (12/30).

Our method of measuring interdisciplinarity has its limitations. First, despite important changes in the structure of scientific disciplines during the last

century, our list of disciplines remains the same throughout the period studied. However, given that very few fields have ceased to exist and that many new fields have emerged, using today's disciplinary and specialty categories should not cause important anachronisms. For example, the *American Journal of Surgery* is categorized in the specialty of surgery throughout the period, and has indeed always published papers related to surgery. On the other hand, there are no papers in the field of cancer or computer science before, respectively, the 1940s and the 1950s. As a consequence, the references they cited during the first couple of years of their existence can only come from outside their specialty. Similarly, journals that change scope generally change name and, hence, are reclassified accordingly.

Another limitation is that we have discipline and specialty information only for references made to articles published in journals that are also indexed in the Web of Science (source items). Hence, a more or less significant percentage—depending on the discipline and the publication year—of the cited literature is excluded from the analysis and this proportion changes over time. In all disciplines combined (Figure 2.C), we see that, in 2010, about 70% of the references are made to source items These results are similar to those obtained by Larivière et al. (2006), which showed that serials' share of cited literature globally increased steadily since the early eighties. However, at the beginning of the period, a lower share of the references is made to WoS-covered material. This is normal, given the fact that older papers cite a larger proportion of pre-1900 papers

that are not indexed in the WoS. Also, the fact that the WoS indexes a smaller number of journals and papers over the period 1900-1945 lessens the chance that references made by articles indexed are indeed made to other source items. One might argue that these references to non-source items would reveal a different trend than the one observed here. However, we also analyzed the trends using citations received, which by definition has 100% coverage, and the overall trends are almost identical, a finding which supports our argument that the results obtained for the references made to source items are a representative sample of the whole population of references. The different panels of Figure 2 also show that the number of papers (A) and number of cited references (B) have been increasing steadily in all domains except in Arts and Humanities (A&H). Using the CD-ROM version of SCI, Larivière, Archambault and Gingras (2008) argued that the rate of exponential growth of publications declined in the seventies; Figure 2.A shows that this trend is also valid for the expanded version of the SCI, which confirms that these global trends do not heavily depend on the sample used. The results presented here are based on 768 million references made by about 35 million papers. Out of these 768 million references, about 470 million were made to these 35 million source items, meaning that the 61% of referenced were covered.

[insert figure 2 here]

Rinia et al. (2001) showed that there is a delay in interdisciplinary knowledge exchange such that one has to wait a couple of years for interdisciplinary citations to accumulate. That result is interesting as it suggests that it takes more time for discoveries to permeate disciplinary boundaries and be cited in other disciplines and specialties than is the case for knowledge circulating within the discipline or specialty. The data presented in Figure 3 show that the same phenomenon occurs in all domains, albeit at a lower level in MED—which could be expected given the shorter half-life of papers in these disciplines (Larivière, Archambault, & Gingras, 2008)—and that the percentage of references made to papers published in journals outside the discipline or specialty of the citing document rises steadily as one increases the citation window to include older documents. On the other hand, references to younger material are more often being made to papers published in the same specialty. On the whole, this figure shows that, in order to have a good measure of interdisciplinarity, one cannot limit the analysis to references made to papers published during the two previous years. For that reason, our measures of interdisciplinarity use citing years for which there is at least five years of reference data. In other words, given that cited papers published before 1900 are not source items and, therefore, do not have a field associated to them and that we used a 5-year citation window, data for MED, NSE and SS start in 1905, and data for A&H start in 1980.

[insert figure 3 here]

Varying relations between disciplines and specialties

Figure 4 presents, for each of the four broad fields of science, three measures of the relations between disciplines and specialties, defined at the level of the citing paper:

1) the percentage of references made to papers outside the discipline of the citing paper, which provides an indicator of interdisciplinarity;
2) the percentage of references made to papers from other specialties than of the citing paper but in the same discipline, which provides a measure of the relations between specialties within a given discipline (interspecialty);
3) the percentage of references made to papers from the same specialties than that of the citing paper, which measures the internal focus of the specialty.

For NSE and MED, three broad periods can be distinguished: 1) 1900-1945, where the degree of specialization diminishes along with a rise in interdisciplinarity for the NSE and an increase of interspecialty for MED; 2) 1945-1980, a period during which we observe in MED a decline in interdisciplinarity and a growing emphasis on specialties, which tend to refer more to themselves, while the interactions between specialties are stable; In NSE, the same period also sees a decline in interdisciplinarity accompanied by a rise in references to other specialties of the discipline between 1945 and 1965, followed

by a period of stability up to the mid-1980s; and 3) mid-1980 to 2010, where the relationships between disciplines increase again at the expense of the internal focus of the specialties, while the proportion of references made to other specialties of the same remains stable.

As could be expected, the social sciences and the humanities follow a quite different pattern. In the social sciences, the level of specialization, measured by the proportion of intra-specialty references, remains stable between 1935 and 1965 (discounting the strong fluctuations in the data before the 1930s) and then increase until the mid-1990s to about 50%, to drop again just below 40% in face of growing interdisciplinarity. By 2010, about 50% of the references were to disciplines others than that of the paper, while interspecialty was at its lowest point (35%). This means that after the mid-1990s, a paper in a given specialty is more open to other disciplines than to other specialties of its own discipline. Though not shown, the evolution of the interdisciplinarity of *citations received* follows the same pattern.

The trends in the humanities are much simpler: we observe a surge in interdisciplinary references around 2000, at the expense of intra-specialty references. Before that period, there is a quite stable practice and about 60% of the references are to papers from the same specialty, with a slow but continuous decline of references to other specialties in the same discipline. It is worth mentioning that, although SSH researchers discuss the notion of interdisciplinarity

five times more often than their NSE colleagues (Figure 1), both disciplines have similar levels of interdisciplinarity (around 25-30% before the mid-1990s) when measured in terms of their referencing practices.

[insert figure 4 here]

Discussion and conclusion

Over the course of a century, we observe that for the NSE as well as for the MED disciplines, the percentage of references made to the literature published in journals categorized in the same specialty has been decreasing, from 70% to 40% in NSE and from 50% to about 35% in MED. This decline in the internal focus of specialties has taken two roads: in the NSE it first corresponded to a rise in interdisciplinarity until 1945, while for the same period the MED disciplines saw a rise in interspecialty relations. This latter trend makes sense as an effect of the creation of the various medical specialties. In the 30-years period following the end of the Second World War, we observe a decline in interdisciplinarity in NSE accompanied by a greater focus on the specialties of the discipline, which again is consistent with the multiplication of specialties in most disciplines during that period. In MED, we also observe a slight decline in interdisciplinarity until the 1980s and a small rise in interspecialty concentration. From about the mid-1980s, both NSE and MED raised their level of interdisciplinarity at the expense of a focus on specialties.

Taken globally, these results suggest that, while specialties within disciplines multiplied during the first two-thirds of the century and then maintained a certain level of stability, exchanges between different disciplines started to increase again thereafter, particularly after the mid-1980s. By the end of the century the referencing practices in MED disciplines are roughly equally distributed among the specialty of the paper, other specialties of the same discipline and other disciplines with, in general, and for most of the century, intraspecialty references tending to dominate. As Figure 4 shows, the social sciences as well as the arts and humanities are most open to other disciplines, while the MED disciplines tend to stay within themselves while being receptive to other specialties of the same discipline. For their part, NSE papers are mostly focused on their own specialty, something that can be related to the use of highly specialized instrumentation in very narrow specialties.

It is to be noted that, though interdisciplinarity has risen significantly since the mid-1980s, the level attained by the end of the century is not much higher than what it was in the 1930s and never declined below 20% even in SNE and MED. Though a more detailed historical analysis would be needed to confirm our hypothesis, everything suggests that the growth in the availability of research money during the “golden” years from 1945 to 1975, brought a stop to interdisciplinarity and a turn toward the growth of disciplines through the multiplication of specialties. Additionally, the new wave of interdisciplinarity

visible in the data from the mid-1980s could be the effect of specific government programs and discourses promoting interdisciplinarity as a good thing in itself and urging scientists to collaborate with colleagues from different disciplines and be attentive to the kind of knowledge created outside their own specialty in order to solve "complex" problems. This new influx of money, with *interdisciplinary* and other collaborative strings attached, also seems to be instrumental in making researchers more open to neighboring disciplines.

The changing relations between disciplines and specialties are obviously complex and can be affected as much by the internal development of new concepts or instruments as by monetary pressures. Whereas specialties tend to emerge from the internal dynamics of disciplines (Mullins, 1972), the recent drive toward greater integration through interdisciplinarity seems to depend more on discourse and policies than on internal forces. Whatever the case, and even taking into account the inherent limitation of bibliometric indicators, our analysis shows that the process of disciplinarization and specialization is a complex one and that interdisciplinarity is itself an artifact of the complex dynamics of knowledge growth.

As discussed by Bornmann et al. and Gingras in this book, there is a need for standard bibliometric indicators in research evaluation, and our analysis of interdisciplinarity sheds lights on another technical aspect of their use in such context. The observed reconfiguration of the relationships between disciplines and

specialties has methodological consequences for the measurement of the scientific impact of papers. As papers increasingly refer to different specialties having different citation practices and are cited by papers also coming from different disciplines, the usual normalization of citations, based only on the discipline of the journal in which the paper appears, is increasingly biased and should be replaced by new kinds of normalizations that take into account the mix of disciplines and specialties present in the references as well as in the citations (Zitt & Small, 2008; Moed, 2010; Zitt, 2010).

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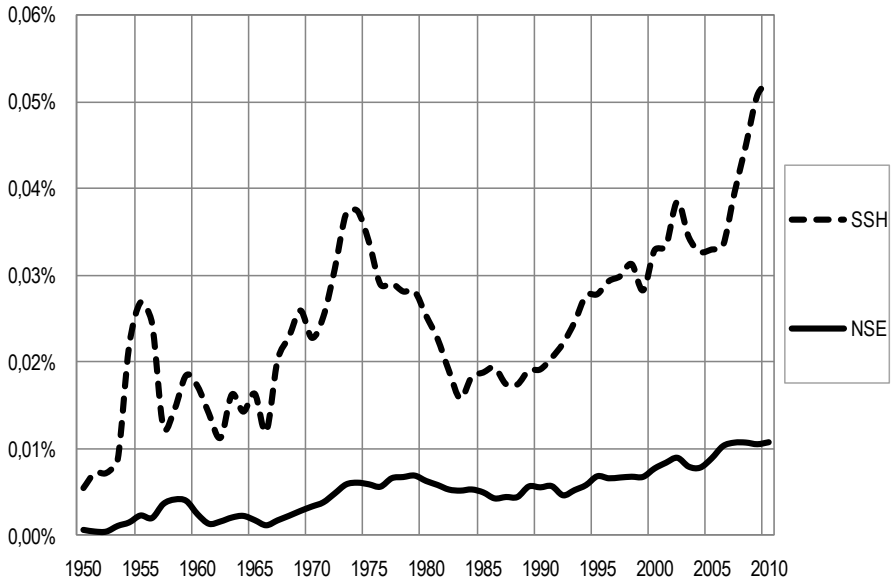

Figure 1. Percentage of Web of Science papers with 'Interdisciplinar*' in their titles, by domain, 1950-2010. Three-year moving averages.

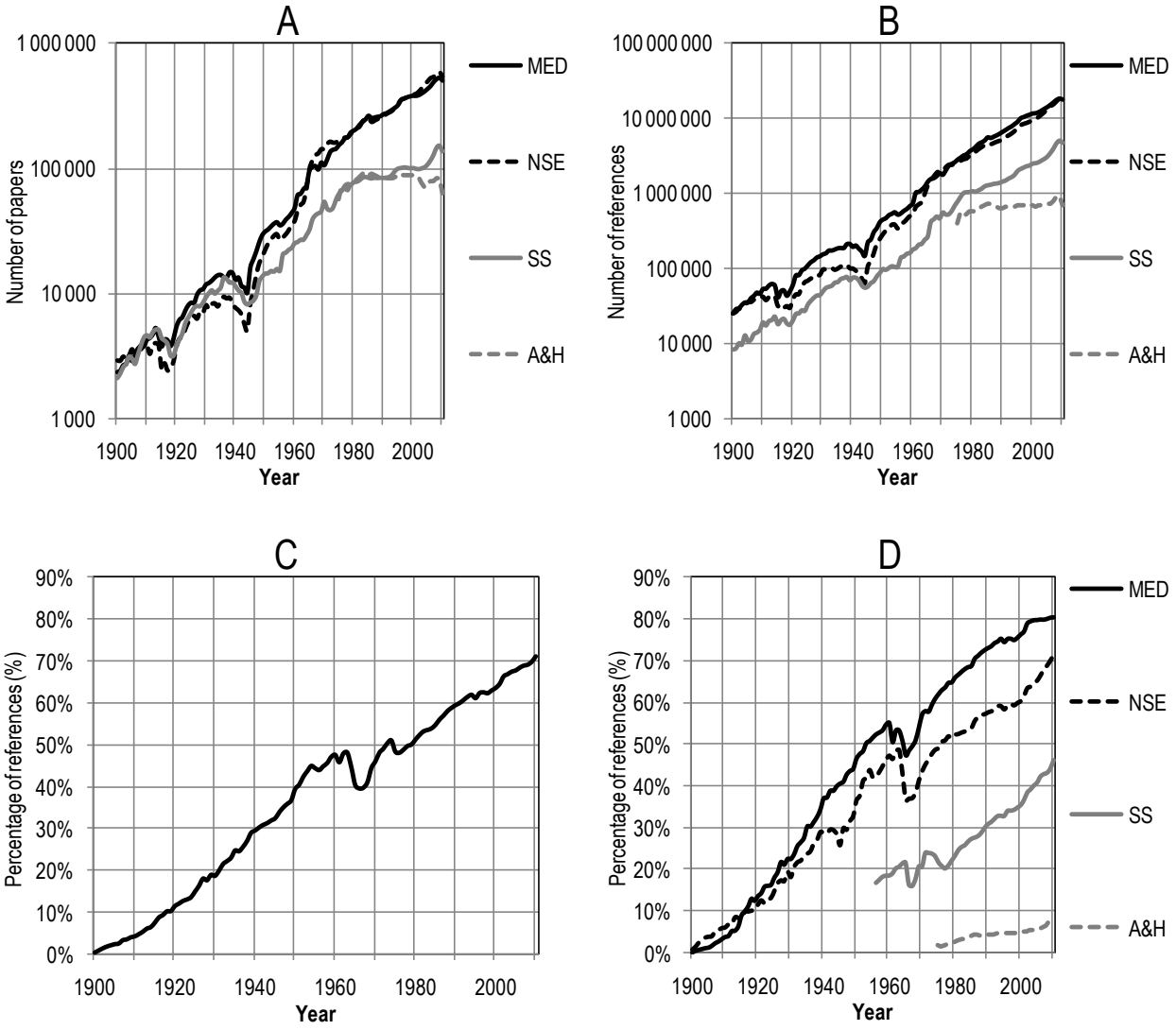

Figure 2. Yearly number of papers (A), references (B) and percentage of references made to source items, all domains combined (C) and by domain (D), 1900-2010.

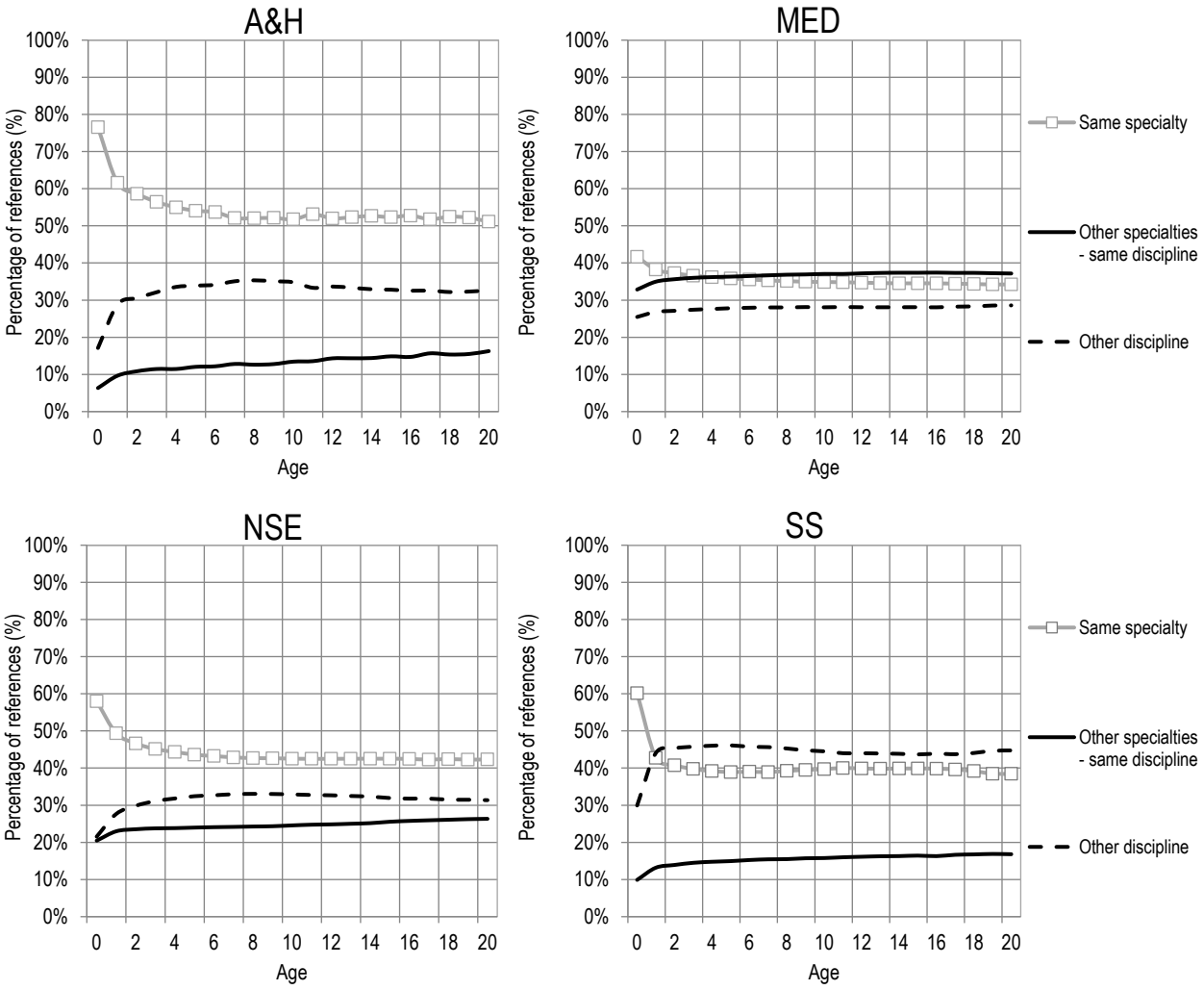

Figure 3. Percentage of references to a different discipline, to the same specialty and to other specialties of the same discipline, by age of cited paper and domain, 1998-2007.

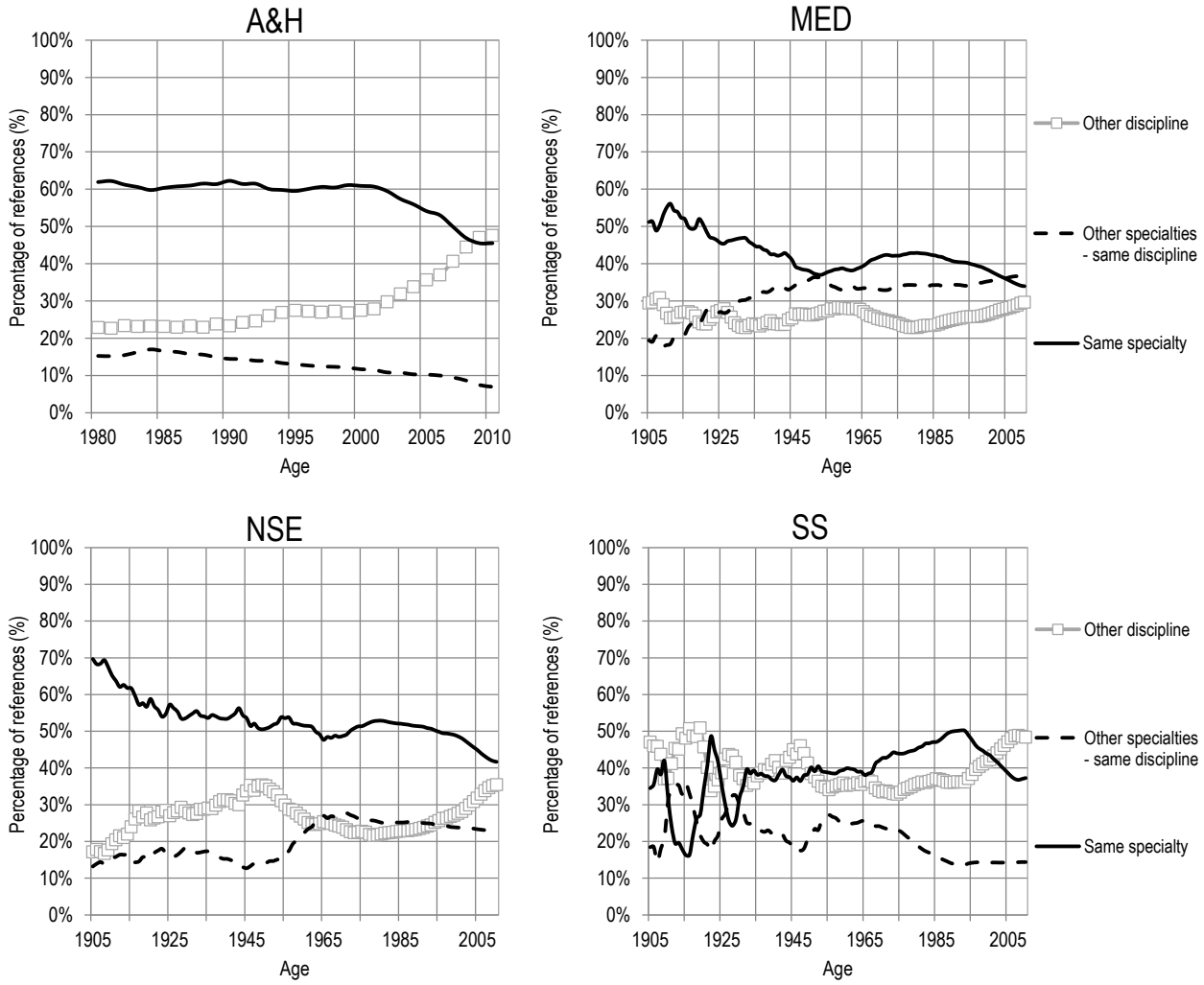

Figure 4. Percentage of references made to papers from other disciplines, other specialties of the same discipline and to the same specialty, by domains, 1900-2010. (Three-year moving average)