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Incidence and extent of co-authorship in environmental and resource economics: evidence from the *Journal of Environmental Economics and Management*

Michael Schymura · Andreas Löschel

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Abstract We examine the incidence and extent of co-authorship in environmental and resource economics by investigating the leading journal of environmental and resource economics: the *Journal of Environmental Economics and Management*. Previous studies of general economic journals have offered empirical evidence for the fact that intellectual collaboration is most prevalent in the field of environmental and resource economics. However, no previous study has examined this finding more carefully. This is a gap in the literature we hope to fill. Accordingly, we investigate all 1,436 papers published in *JEEM* from 1974 until 2010 with respect to potential drivers of co-authorship. We start with a descriptive analysis in order to depict the most important trends in the past 36 years. We then employ empirical methods to test several hypotheses that are commonly used to analyze the structure of co-authorship. However, we do not stick to hypotheses but investigate also other potentially relevant drivers of co-authorship as e.g. external funding. We find empirical support for a relation between the number of authors and key characteristics of an article like the number of equations, tables or the presence of external funding. Research in environmental and resource economics is demanding in terms of both disciplinary and interdisciplinary skills, so the likelihood of collaboration and jointly written publications is present and significant.

Keywords Environmental and resource economics · Co-authorship · Production of knowledge

JEL Classification Q0 · Q50

M. Schymura (✉) · A. Löschel
Centre for European Economic Research (ZEW), Mannheim, L7,1, 68161 Mannheim, Germany
e-mail: schymura@zew.de

A. Löschel
e-mail: loeschel@zew.de

A. Löschel
University of Heidelberg, Heidelberg, Germany

Introduction

Since the first decades of the 20th century scholarly activity in economics has expanded rapidly.[1] A century ago, co-authored scientific articles in general and economic papers in particular were, in stark contrast to today, more the exception than the rule. A representative example of this, as we will show in this paper, is the development of publication trends in the *Journal of Environmental Economics and Management*, which is the leading journal in the field of environmental and resource economics.[2] In this paper, we empirically investigate the first 36 years of the *Journal of Environmental Economics and Management* by analyzing all articles published in the journal up to 2010. We focus especially on the development of structural patterns of co-authorship, the increasing complexity of the discussed subject matter, publications by female economists in *JEEM*, and the incremental growth in international collaboration.

Analyses of the structure of co-authorship are commonly based on various hypotheses: First, the *division of labor hypothesis*, which states that specialization occurs in line with the growth of a market, an argument dating back to Adam Smith. The second hypothesis is the *opportunity cost of time hypothesis*, which posits that there are increasing pressures to publish in the field of economics. The third hypothesis is the the *quality hypothesis*, which is a synthesis of the first and second hypotheses. This hypothesis states that due to increasing complexity and specialization, researchers are pushed to collaborate in order to maximize the quality of an article. However, we do not stick to the commonly used hypotheses but that we investigate also other potentially relevant drivers of co-authorship. We use the three hypotheses as a starting ground for further analysis. Previous studies have focused in particular on either a relatively rough measure of the quantitative content of each article (McDowell and Melvin 1983; Barnett et al. 1988) or have examined a very short timeframe [1984–1986 in Piette and Ross (1992)]. We investigate every article in *JEEM* from Volume 1 in 1974 to Volume 60 in 2010 in terms of their quantitative content (equations, figures, tables, appendix), acknowledgment of individuals and financial support, the gender structure of the authors, and the geographical distribution of co-authors if the article was written by more than one person.

This paper is organized as follows: Part one charts notable developments in the publication of articles in *JEEM* in a descriptive fashion. Our disaggregated data set describes a variety of article characteristics. We show that the incident and extent of co-authorship have increased significantly, that empirical research has gained more attention over time, that the number of acknowledged persons has increased and that the fraction of articles in which a

[1] Lovell (1973) notes that the cumulative stock of journal articles in economics doubles every 14 years.

[2] According to the ISI Web of Knowledge, *JEEM* was ranked number 17 of all economic journals and number one among environmental economics journals with an impact factor of 2.989 in 2010. Rousseau et al. (2009) offer evidence that *JEEM* "is the leading publication in the field" (Rousseau et al. 2009, p. 283). Auffhammer (2009) states that "*JEEM* is the most highly ranked journal in the environmental and resource economics field" (Auffhammer 2009, p. 254). Moreover, the journal was the sole official journal of the Association of Environmental and Resource Economists (AERE) and has a long publication history which makes it the ideal journal for our purpose. We have analyzed three other leading publications in the field, *Ecological Economics, Environmental and Resource Economics and Energy Economics*. Energy Economics started publishing in 1981, Ecological Economics in 1993 and Environmental and Resource Economics in 1995. We have compared the figures for number of authors and single-authored publications in *JEEM* and the other three journals from 1981 onwards. The pattern is similar for number of authors. In 1981, the number of authors was 1.52 in *JEEM* and 1.5 in *Energy Economics*. This number increased until 2009 to 2.49 in *JEEM* and 2.51 in the other three journals. Additionally, the first issue of *JEEM* was published in 1974 and our sample allows us therefore to determine important trends in environmental and resource economics over a longer timespan.

woman has participated has risen from just over 0 % to more than 30 %. Furthermore, we show that only 16 % of co-authored articles in 1975 were written by authors in different geographical locations, while this number increased to more than 75 % in 2010. In the second part of the paper we investigate empirically how these characteristics affect the status of co-authorship. We find empirical support for a relation between the number of authors and key characteristics of an article like the number of equations, tables or the presence of external funding. Beside the three main hypotheses, we test an additional fourth hypothesis: the *competition for external funding hypothesis*. Research in environmental and resource economics is demanding in terms of both disciplinary and interdisciplinary skills, so a critical mass of expertise and reputation is now necessary in order to obtain external funding. Furthermore, "it is also conceivable that the possible tendency of some grant-giving agencies to favor collaborative research may also have been a significant factor in explaining the growth of multi-authored papers" (Hudson 1996, p. 157). Environmental and resource economics is characterized by a high degree of interdisciplinarity (see e.g. Bjurström and Polk 2011). As a consequence, there is an increased likelihood of collaborative research and jointly written publications. Our empirical model finds strong support for this external funding hypothesis; the presence of external funding thus seems to be an important driver of intellectual collaboration in environmental and resource economics.

Following this introduction, we briefly summarize the relevant literature in section "Relevant literature". We then start our analysis by describing our data and variables in section "Data and descriptive statistics". Next, we present a descriptive analysis. Our empirical models are subsequently introduced in section "Searching for empirical evidence". Lastly, we draw some tentative conclusions.

Relevant literature

In 1991 Shogren and Durden conducted a review of the first 15 years of the *Journal of Environmental Economics and Management* (*JEEM*). They identified the 25 institutions that had contributed most to the research output of *JEEM*, investigated which countries alongside the United States had contributed the most, examined how articles from *JEEM* had been recognized by other economic journals, and determined which ten articles were the most cited.[3] In 2000 the *Journal of Environmental Economics and Management* celebrated its 25th birthday. Fisher and Ward (2000) and Smith (2000) investigated these 25 years empirically. Fisher and Ward (2000) focused their analysis on natural resource economics and research trends in this subfield. They found that about half of the articles published in the first 35 volumes dealt with natural resources. Smith (2000) investigated the development of non-market valuation in the first 25 years of *JEEM*. However, none of these articles has focused on intellectual collaboration and co-authorship in *JEEM*. This is an noticeable gap in the literature that we seek to address. An example of a theoretical treatment of co-authorship issues can be found in Engers et al. (1999). The authors derive the result that "an alphabetical name ordering will exist as a norm in a noncooperative game with self-interested agents" (Engers et al. 1999, p. 881). Past empirical studies have examined the production of scientific knowledge in economics (Lovell, 1973), patterns of co-authorship for individual economists (McDowell and Melvin 1983; Hollis 2001, Hilmer

[3] Resources for the Future, the University of British Columbia, the University of Maryland, the University of California, Berkeley, and the University of Wyoming all had more than 10 papers published in *JEEM*. Canada, the United Kingdom, Israel, Norway, and Australia were the top foreign contributing countries.

and Hilmer 2005), the development of co-authorship in certain economic subfields,[4] or, like most of the studies, the focus was set on the major economic journals (McDowell and Melvin 1983; Barnett et al. 1988; Piette and Ross 1992; Hudson 1996; Medoff 2007). McDowell and Melvin (1983) develop a utility-based microeconomic model for an individual researcher and tested various hypotheses regarding the co-authorship of articles. Barnett et al. (1988) extend this framework and explore the incidence of co-authorship for *The American Economic Review* between 1960 and 1985. Piette and Ross (1992) show that the frequency of co-authorship differs for different economic specialties. Hudson (1996) identifies potential reasons for co-authorship and compares eight leading journals and Medoff (2007) employs a production function approach to show that co-authors in economics are equivalent substitutes in production. All of these studies find a rising incidence and extent of co-authorship in economic publications, the reasons for which are explored below. Notably, Laband and Tollison (2000) compare the social science of economics with the natural science of biology, concluding that the "social sciences may indeed be more 'social' than the natural sciences" (Laband and Tollison 2000, p. 661) in terms of the frequency of co-authorship. Nevertheless, surprisingly few articles deal with environmental and resource economics, a subfield which has become more and more important in the economics profession. Costanza et al. (2004) investigate the subtopic of ecological economics and which ecological economics publications have had the biggest impact. Ma and Stern (2006) focus particularly on the two leading field journals (*JEEM* and *Ecological Economics*). Auffhammer (2009) broadens the scope of the analysis but he focuses on *Google Scholar* as a source of information on citations and article impact. As Auffhammer (2009) pessimistically notes in his first sentence, one could "conclude that nothing published in environmental and resource economics has mattered to the general economics profession" (Auffhammer 2009, p. 251). This is a somewhat glaring gap in the literature, for Piette and Ross (1992) and Laband and Tollison (2000) have both offered empirical evidence for the fact that intellectual collaboration is most important in the field of the environmental and resource economics.[5] In this study, we build on the work of McDowell and Melvin (1983), Barnett et al. (1988), Piette and Ross (1992), and especially Laband and Tollison (2000) to assess empirically the structural pattern of co-authorship and its impact on the relevance of an article published in *JEEM*.

Data and descriptive statistics

Before turning to the empirical analysis, we first describe the data used and how we have constructed the variables we control for. Subsequently we present some interesting descriptive facts about how *JEEM* has evolved over the past 36 years. First, we illuminate how the incidence and extent of co-authorship have developed in *JEEM*. We then discuss

[4] See Acedo et al. (2006) for management and organizational studies and Hilmer and Hilmer (2005) for agricultural economics. Hollis (2001) uses a panel of 339 economists in order to evaluate the relationship between co-authorship and output, and Acedo et al. (2006) investigate co-authorship in management and organizational studies using network analysis.

[5] Piette and Ross (1992) investigate the 15 leading economic journals between 1984 and 1986 and find general evidence that co-authorship in economics depends on the field of specialization. In their probit estimation, the effect for "natural resources" was the most influential. Laband and Tollison (2000) have also estimated a probit model for the timespan from 1885 to 1995 using the old *Journal of Economic Literature* (JEL) classification. The marginal effect for the "JEL 700—Agriculture and natural resources" variable was both statistically highly significant and most influential (with a marginal effect of 0.0885).

trends in articles' quantitative content in relation to the status of co-authorship. Finally, stylized facts about acknowledgements, geographically distant collaboration, author gender, and external funding are addressed before we turn to our empirical analysis.

Data and variables

Our sample is a set of 1,436 articles, published in the *Journal of Environmental Economics and Management* between 1974 and 2010. The source is the *Social Science Citations Index* (SSCI), provided by Thomson Reuters. The SSCI offers a range of information about each article, including the number of authors, the number of pages, and how many times the article has been cited. For some characteristics, however, we had to collect data by hand. We gathered data on a number of content-related characteristics, including the number of equations, tables, figures, and appendices contained in each article. We then used this information to classify each article as purely qualitative, theoretical, quantitative, or both theoretical and empirical. We also gathered information on author gender and his or her institutional location. We counted the number of acknowledged colleagues and checked whether an article had acknowledged external funding or not. We will present a more detailed discussion of the variables when they are employed in a particular empirical model. This information allowed us to set up various empirical models in order to identify potential drivers of the decision to collaborate with another author.

Some descriptive evidence

Incidence and extent of co-authorship

When investigating the pattern of co-authorship, we specifically examine two different characteristics. First, changes in the *incidence* of co-authorship, which designates the fraction of articles with more than one author, and second, the *extent* of co-authorship, that is, the average number of authors in co-authored papers (Laband and Tollison 2000). The evolution of the incidence and extent of co-authorship is depicted in Figs. 1 and 2, where we compare trends at *JEEM* to six major economic journals ("core journals").[6]

A few interesting facts emerge from this comparison: In the initial two volumes of *JEEM*, the fraction of sole-author papers was remarkably low compared to our reference group of the core journals (≈38 % in 1974). After the first two volumes, this fraction subsequently increased, fluctuating between 50–70 % until the end of the 1980s. The fraction of single-authored articles reached a peak of ≈72 % in 1988, before dropping rapidly and continuously to only 15 % in 2008.[7] With regard to the core journals, we find no sideways trend between 1974 and 1988. The fraction of single-author papers decreased constantly, dropping from 75 % in 1974 to 25 % in 2010. In this way, the incidence of co-authorship for articles published in *JEEM* and the core journals increased significantly during the period under examination.

[6] According to Kalaitzidakis et al. (2003, p. 1349), *The American Economic Review, Econometrica, The Journal of Political Economy, Journal of Economic Theory, and The Quarterly Journal of Economics*. To keep a balance between US and European journals we have also included the British *Economic Journal*.

[7] Similar to Hudson (1996) we conduct a linear spline analysis for the average fraction of single-authored papers for each year in order to figure out whether trends were more or less steady or spasmodic. We find that the slope of the timeseries changes significantly at the 5 percent level in 1977, 1989, and 1999 (see Appendix 2 for the estimation and a graphic representation).

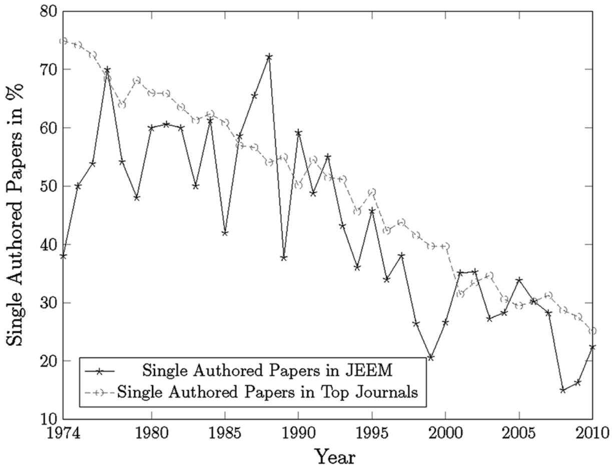


Fig. 1 Single authored papers in %

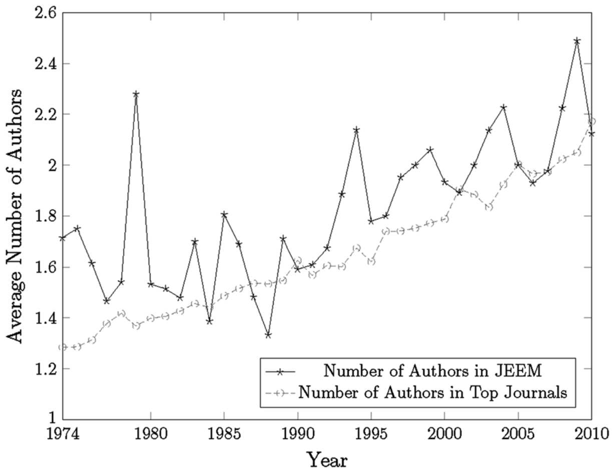


Fig. 2 Average number of authors

An average article in *JEEM* was written by 1.71 authors in 1974. Logically, the same trend that applies to the fraction of single-authored papers is also observable for the growth in total number of authors between 1974 and 1988. After 1988, the average number of authors increased steadily, reaching approximately 2.5 in 2009. The trend at the core journals was very similar, although the overall number of authors was lower. The average number of authors in the core journals rose from 1.28 in 1974 to 2.17 in 2010. We thus find that the extent of co-authorship has increased for both *JEEM* and the core journals.[8]

[8] However, the magnitude for articles published in *JEEM* was significantly higher. A standard mean-comparison test over the whole sample period revealed a t value of -9.96. In this way, the mean number of authors was statistically significantly higher for *JEEM* than for the core journals.

Quantitative content

Hudson (1996) and Laband and Tollison (2000) have argued that the rising quantitative content and associated increasing complexity of the field of economics could be an important explanatory factor for the rising incidence of co-authorship. Hudson (1996) compares general economic journals (such as *The Economic Journal* or *The Quarterly Journal of Economics*) with quantitatively oriented journals (such as *The Review of Economics and Statistics*). He finds evidence that the probability of co-authorship is higher in quantitatively oriented journals. In order to determine whether the quantitative content has an influence on the pattern of co-authorship in *JEEM* we have counted the equations, figures, tables, and appendices in each of the 1,436 published articles between 1974 and 2010. Table 1 provides a statistical overview of the different forms of authorship. We then studied whether the means differed significantly. While the two-group mean comparison tests for appendices are inconclusive, the tests for the number of equations and number of tables indicate strong support for structural differences, rejecting the null of equal means at the 1 % significance level and for figures at the 10 % significance level. The logical consequence is thus to investigate how quantitative content influences the incidence and extent of co-authorship. We do this in our empirical model later in the paper.

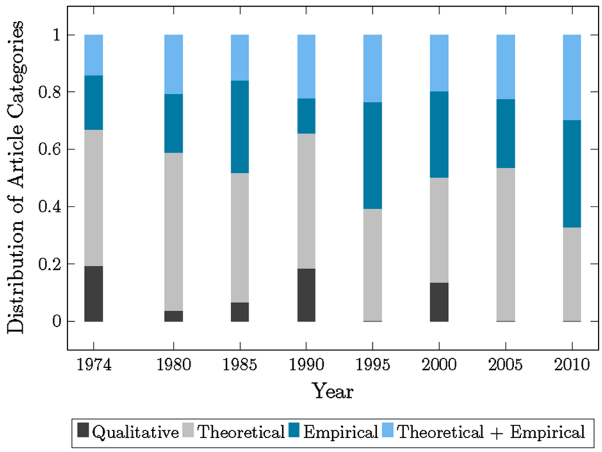
Type of articles

We used the information about quantitative content to categorize the articles as qualitative, theoretical, quantitative, or both theoretical and quantitative in nature. Of course, how an article should be categorized is often a subjective matter. We follow Figlio (1994) in our categorization approach. A paper is considered "qualitative" if it is a survey, a case study without empirical analysis, or a commentary piece. An article is defined as "quantitative" if it is purely empirical and when almost no theoretical models serve as a basis for estimation. We also classify articles as empirical if real, as opposed to artificial, data are used. Theoretical articles are purely theoretical discussions or papers that utilize techniques for simulation with artificial data. And, finally, we have classified articles as "theoretical and empirical" when they include substantial theoretical and empirical components (e.g. the derivation of reduced form estimation equations from a theoretical model and their testing in an econometric framework). To validate our categorization we have performed probit estimations for the type of article. The results are summarized in Appendix 3. Figure 3 summarizes the evolution of the different types of article categories in *JEEM*. We find that articles in the journal have become substantially more empirical in the last few decades. While purely qualitative articles have vanished after 2000 and the share of purely theoretical articles has declined in the past three decades, empirical work has gained more and more importance. As we will show in the empirical part of the paper, this has impacted patterns of co-authorship in the journal.

Table 1 Quantitative content in single- and multi-authored articles in *JEEM*

	Observations	Equations	Tables	Figures	Appendix
Single-authored articles	589	8,743	894	1,078	0.33
Multi-authored articles	847	10,626	2,274	1,704	0.37

Fig. 3 Distribution of article categories



Acknowledgments, geographically distant collaboration, females, and external funding

What are possible additional motive factors behind collaboration? To answer this question, we not only investigated forms of formal co-authorship but also informal intellectual collaboration. To this end, we counted the acknowledgments mentioned in each article. As an author usually benefits from the comments of a colleague, the least he or she can do to thank is to offer a "thank you" in the acknowledgments. Such acknowledgment may represent an incentive for the collaborating individual to provide input when time constraints would otherwise limit more extensive collaboration and elevation to co-author status. An alternative interpretation could be that the pressure to publish has increased over time and journal submissions became more important over time and way more strategic. Authors could therefore think that acknowledgements have a signaling value so that if many important scholars in the field are mentioned this might be a quality indicator for the editor.[9] Hence there could exist a trade-off between acknowledgments and co-authorship status (Barnett et al. 1988). We also investigated whether patterns of collaboration between geographically distant individuals have changed over the past 36 years. In light of the decreasing cost of transportation and the advent of internet and e-mail, one could speculate that the spatially separated collaboration has intensified. While only 16 % of the multi-authored articles written in 1975 were written by geographically distant authors, this share increased to 77 % by 2006. Another interesting aspect previously investigated by Laband and Tollison (2000) is whether the probability of an article being co-authored changes when one of the authors is female. They find that an author being female has the largest positive marginal effect on the probability of co-authorship. Surprisingly, female gender reduces the chances of co-authorship when the authors are geographically distant (Laband and Tollison 2000, p. 644). We analyzed all *JEEM* articles written under participation of a female researcher (whether as a single-author or co-author).[10] Finally, we investigated each

[9] We are thankful for this comment provided by an anonymous referee. In practice, however, it is hard to distinguish between the different effects acknowledgements could measure.

[10] Unfortunately, 31 articles could not be analyzed, since we could not determine the gender of the author(s) because only the surname and the first initial were given.

article with regard to whether external funding was acknowledged or not. There is a significant difference between single- and multi-authored articles in terms of the frequency with which external funding is acknowledged. While approximatively 34 % of single-authored papers contained thanks for external funding, the corresponding share among multi-authored articles was roughly 55 %. The average number of authors was 2.09 for articles that mentioned external funding and 1.66 for those that didn't. A mean-comparison test indicates a strong difference between single-authored papers and multi-authored articles. Furthermore, in contrast to the findings of Laband and Tollison (2000), we also discovered variation in the pattern of external funding for multi-authored papers. Looking only at multi-authored articles (848 papers), the average number of authors who did not mention financial support was about 2.32, while the number of article authors that

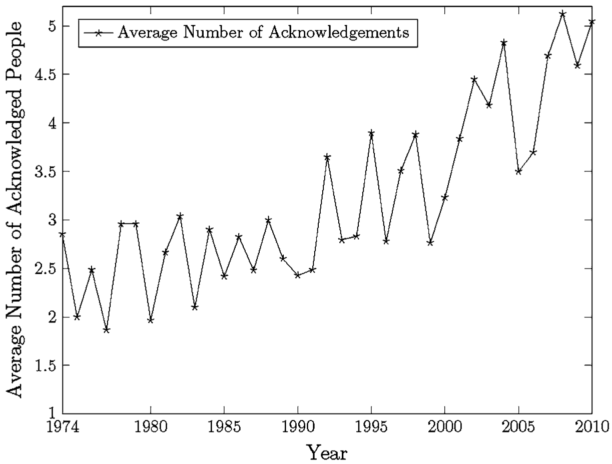


Fig. 4 Average number of acknowledgements

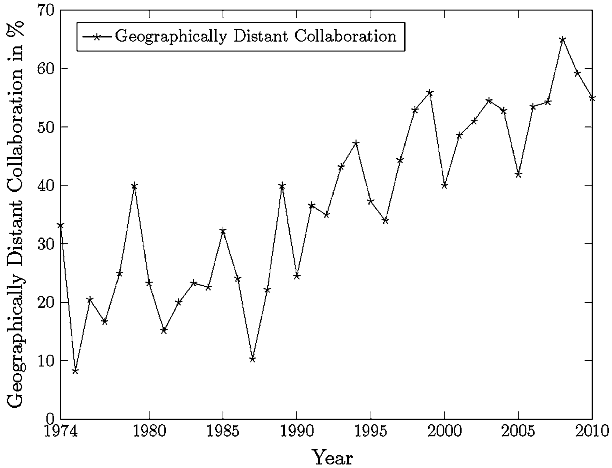


Fig. 5 Geographically distant collaboration in %

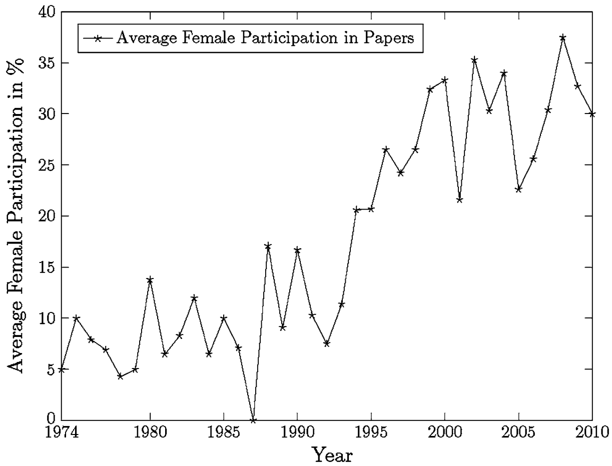


Fig. 6 Average female participation in %

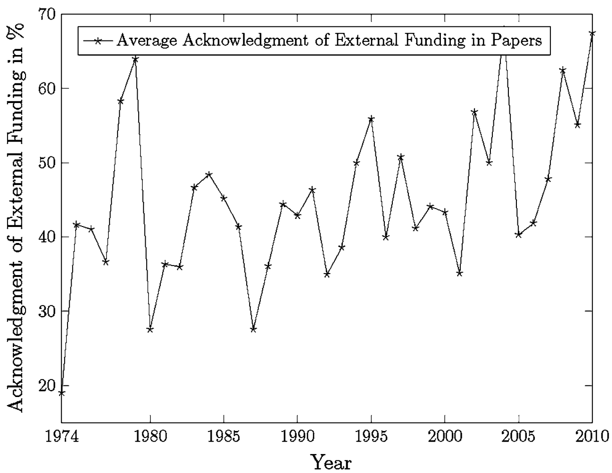


Fig. 7 Average acknowledgement of external funding in %

mentioned financial support was around 2.56. A mean comparison test once again provided statistical evidence for a significant difference. Later in this paper, we examine the impact of external funding on the number of article authors (Figs. 4, 5, 6 and 7).

Summary

To summarize, we have identified a number of interesting trends. We have shown that the incident and extent of co-authorship increased significantly between 1974 and 2010. Furthermore, empirical research has gained increasing prevalence over time, and the number of acknowledged persons has increased. The fraction of articles in which a woman participated has risen from almost 0 % to more than 30 %. In addition, while only 16 % of co-authored articles were written by geographically distant authors in 1975, this share increased to 75 by 2010. In the following second part of this paper, we employ various empirical models to identify the most important drivers of collaboration.

Searching for empirical evidence

Co-authorship

The model

What are the motive forces behind these trends? To explain the findings described in the previous section, we need to test for several hypotheses with regard to the co-authorship structure of papers (Barnett et al. 1988). Can these trends perhaps be explained by Adam Smith's observation that an increasing market size leads to more specialization [*the division of labor hypothesis*, McDowell and Melvin (1983)]? Barnett et al. (1988) were the first to highlight and explain the carrot-and-stick argument (*the opportunity cost of time hypothesis*): They claim that the opportunity cost of time in the profession has increased and that this increase has affected the market for the production of publishable articles. Yet alongside the increase in the volume of publications that has been witnessed in recent decades, there also appears to have been an increase in research complexity and specialization. This, in turn, has fostered a need for increased collaboration, as has been noted by Barnett et al. (1988) for other fields of economic research (i.e. *the quality hypothesis*). We investigate whether this finding holds true for environmental and resource economics, a field that also deals with climate change. "Given that the problem scope of climate change is broader than any single discipline, the scientific community must draw on extensive knowledge from various scientific disciplines" (Bjurström and Polk 2011, pp. 1–2). As research has become more demanding in terms of both skill and financial expense, a critical mass of expertise and reputation is now necessary in order to obtain external funding. We therefore use our data to test a fourth hypothesis which states that the acknowledgment of external funding has a positive influence on the number of authors (*the competition for external funding hypothesis*). Again, we want to emphasize, that theses four hypotheses are only the starting ground for further estimations we employ later in the paper. To test which hypotheses are valid in the case of environmental and resource economics, we employ the following empirical model with our dataset:

$$
\begin{aligned}
\mathrm{NO}_i = {} & \beta_0 + \underbrace{\beta_1 \cdot \mathrm{PAGES}_i + \beta_2 \cdot \mathrm{THEOR}_i + \beta_3 \cdot \mathrm{QUANTI}_i + \beta_4 \cdot \mathrm{QUANTITHEOR}_i}_{\text{Division of Labor Hypothesis}} \\
& + \underbrace{\beta_5 \cdot \mathrm{ACKNOWLEDGE}_i}_{\text{Opportunity Cost Hypothesis}} + \underbrace{\beta_6 \cdot \mathrm{TOP10CITED}_i + \beta_7 \cdot \mathrm{TOPINSTITUTION}}_{\text{Quality Hypothesis}} \\
& + \underbrace{\beta_8 \cdot \mathrm{EXTERNALFUND}_i}_{\text{External Funding Hypothesis}} \\
& + \beta_{9-45} \cdot \mathrm{YEAR}_i + \varepsilon_i
\end{aligned}
\tag{1}
$$

The variables are: NO is number of authors, PAGES is number of adjusted pages, [QUALI] is dummy variable for a qualitative article (= reference category), THEOR is dummy variable for a theoretical article, QUANTI is dummy variable for a quantitative article, QUANTITHEOR is dummy variable equal to one for papers that are both quantitative as well as theoretical, ACKNOWLEDGE is number of researchers in the acknowledgements, TOP10CITED is leading articles, TOPINSTITUTION is dummy variable if one of the authors is located at a top institution, EXTERNALFUND is dummy variable for the acknowledgment of external funding, YEAR is year dummy variables.

Variables

A few words on the variables. NO is self-explanatory. We had to employ a page-adjustment procedure in order to take into account several layout changes over the 36 years. In this regard, we randomly picked three articles for each year and counted the words on a page solely filled with text (no graphs, tables, etc.). Then we took the mean and indexed the value to construct 1974-page equivalents.[11] PAGES therefore represents the adjusted number of pages. As mentioned in the previous section, we classified the articles by type. QUALI is a dummy variable indicating purely qualitative articles (e.g. surveys or case studies without empirical work). QUALI serves as our reference category for the type of article and the three other categories are to be interpreted as relative to QUALI. THEOR is the dummy for purely theoretical work or papers that utilize techniques such as simulation to artificial data.[12] QUANTI is a dummy variable for purely empirical papers in which almost no theoretical models serve as a basis for estimation. Another condition for classifying an article as empirical is the use of real data. QUANTITHEOR designates articles that include both substantial theoretical and empirical components (e.g. the derivation of reduced form estimation equations from a theoretical model and their testing in an econometric framework). As mentioned, we also counted the number of people that were acknowledged at the outset of each article (excluding the thanks to the two or three anonymous referees). This number is reflected by the ACKNOWLEDGE variable. We also constructed a TOP10CITED variable, which indicates the leading articles in terms of citations.[13] The TOP10CITED variable is constructed in terms of citations received in the subsequent 3 years after the publication. This guarantees an equal treatment of the articles. However, when running our regressions with alternative measures of lead articles, the results change neither qualitatively nor quantitatively.[14] Citations are not a pure quality indicator but they tell also something about the diffusion of knowledge. Co-authored articles are likely to show a different diffusion pattern. However, the diffusion of knowledge is beyond the scope of this paper. The variable TOPINSTITUTION is a dummy and equals one if an author is located at a top institution [according to the top ten institutions in Shogren and Durden (1991)]. EXTERNALFUNDING is a dummy variable that equals one if external funding was acknowledged in the article. YEAR are year dummy

[11] While the mean for 1974 was $\approx$570 words per page, this number has risen to $\approx$1,050 words per page in 2010. If we did not take into account these layout changes the coefficient for pages would be significantly biased downwards.

[12] Due to the fact that programming of bootstrapping routines or simulation studies require demanding computer skills and hence fosters potential collaboration, the coefficient on THEORY would be even higher if we were to treat artificial data and simulation methods as quantitative work.

[13] Of course citations are only one possible alternative for measuring impact or influence. But as Medoff (2007) aptly writes about the findings of Leibowitz and Palmer (1983), "if an article (or an economist) with few citations is considered to be a significant scientific contribution, then why has it not generated more citations?" (Medoff 2007, p. 305).

[14] Alternative measures include the ordinal inclusion of citations or interpreting the articles as "TOP" that were cited by a core journal at least once ($\approx$10 %). In an older version of the paper, we have considered the 10 % of the most cited articles as being the leading publications. This approach favored older articles. We are thankful to a referee for this comment.

variables. In terms of our regression equation, the four hypotheses can be interpreted as follows.

Hypotheses

The *division of labor hypothesis* posits that the division of labor is bounded by the size of a market, and that increased specialization is necessary. This arguments holds not only for efficient pin production but also for the scientific profession. As we have descriptively shown above, the number of articles and pages written in the field of environmental and resource economics has considerably grown over the past two decades. With the growth of the field, pressures have arisen for researchers to specialize in niche areas, not least to improve chances of publication. This pressure to specialize, while impacting all fields of economics, has been particularly acute in environmental and resource economics, due to its interdisciplinary nature. Moreover, we expect that this specialization process has become more intense as a result of increasing computational resources, the availability of powerful software applications, and the expansion of the internet. The attendant decrease in transaction costs for knowledge generation and its worldwide exchange could be one of the reasons for the observed increase in co-authored articles. For example, if one researcher is a predominantly theoretical economist trying to investigate empirically the effects of, say, the implementation of a carbon tax and its impacts on an industrial sector, he will try to collaborate with another researcher who is skilled in econometric modeling and simulation analysis. Such a combination of two or more authors may help or even be necessary to make a valuable scientific contribution. We thus hypothesize an increasing incidence of co-authorship over time:

Hypothesis 1 The *division of labor hypothesis* implies $\frac{\delta NO}{\delta PAGES} > 0, \frac{\delta NO}{\delta THEOR} = 0, \frac{\delta NO}{\delta QUANTI}$ and $\frac{\delta NO}{\delta QUANTITHEORY} > 0$

We therefore argue that the number of authors increases in tandem with number of pages, that purely qualitative articles and theoretical papers are written more often by a single author, that quantitative articles increase the need for additional authors, and that articles that are both theoretical as well as empirical also increase the number of authors.

The *opportunity cost of time hypothesis* attempts to capture the increasing pressures on economists to publish. The decreasing costs of transportation and the eased communication offered by the internet have made knowledge exchange very easy. Nevertheless, science has become more complicated and a single economist may have to discuss his or her topic of interest with other colleagues. Furthermore, the "opportunity cost of time of the typical member of the profession has increased" (Barnett et al. 1988, p. 540). Accordingly, we posit that these time pressures have led acknowledgement to become increasingly common, as contributors lack the time to provide the substantial feedback that would merit co-author status. There is thus of trade-off of sorts for contributors between providing some input (to receive acknowledgement) or extensive input (to receive co-author status). We test this trade-off between the number of articles and the number of acknowledged people:

Hypothesis 2 The *opportunity cost of time hypothesis* implies $\frac{\delta NO}{\delta ACKNOWLEDGE} < 0$

The *quality hypothesis* is a mixture of the *division of labor* and *opportunity cost of time hypotheses*. Economic research has become increasingly complex over the past century indicated by the rise in quantitative content and empirical approaches. Even the bias of leading economic journals against empirical analysis in the 1960s has disappeared. A combination of skills thus tends to be necessary nowadays to maintain a certain quality level (Figlio 1994). Additionally, the number of economists over time has grown faster than journal space, so that the competition for journal space has intensified. In this way, if the quality of an article as measured by citations is improved by additional collaborators and if the competition for journal space has intensified, we expect leading articles to have been written by more than one author:

Hypothesis 3 The quality hypothesis implies $\frac{\delta NO}{\delta TOP10CITED} > 0$ and $\frac{\delta NO}{\delta TOPINSTITUTION} > 0$

The *competition for external funding hypothesis* stems from the *division of labor*, the *opportunity cost of time* and *quality hypotheses* and has been previously examined only rudimentarily.[15] As research has become more demanding in terms of both skill and financial expense, a critical mass of expertise and reputation is now necessary in order to obtain external funding. Bjurström and Polk (2011), for example, argue that environmental and resource economics are characterized by a high degree of interdisciplinary research. Thus, two effects are likely: First, a funding institution will give money only to a group of people. This can have potentially an effect on the number of authors. Second, research is conducted in teams, which results in a higher number of authors. Hence, there are two possible effects: External funding may enable to hire additional researchers (i.e. potential co-authors) and larger consortia may be better eligible to raise external funding resulting in more potential authors.[16] This leads us to our last hypothesis:

Hypothesis 4 The *Competition for External Funding Hypothesis* implies $\frac{\delta NO}{\delta EXTERNALFUND} > 0$

Estimation and results

We excluded two outliers (<0.01 %) from our sample. These were the articles by Howe et al. (1994), written by nine authors and Loehman et al. (1979), written by 12 authors. We then started our estimation with an ordinary least squares estimation [1], being aware of the discrete nature of the dependent variable. Hence we expect heteroscedastic disturbance and unbiased but inefficient estimators. Subsequently, we employed a count data model (Poisson)[17] [2] for the number of authors to ensure consistent and asymptotically efficient estimates. As all tests for heteroscedasticity suggest evidence for heteroscedasticity in the framework of non-robust OLS estimation.[18], we also used a feasible generalized least squares estimation [3] procedure (Wooldridge 2002). As OLS is not the most efficient estimator in the presence of heteroscedasticity we can gain precision in least-squares estimates by weighting observations with lower variance more heavily than those with higher variance. The intuition is that we weight the estimator so that it places greater emphasis on observations for which the observable explanatory variables perform better in

[15] Laband and Tollison (2000) investigate a sub-sample of 439 articles published in *The American Economic Review, the Journal of Political Economy*, and *The Quarterly Journal of Economics* and compare it to articles in three biology journals. They find that "in both disciplines, the presence of funding increases the average number of coauthors by 0.3, which implies that there is *some* relationship between funding and co-authorship" (Laband and Tollison 2000, p. 637).

[16] However, distinguishing between both effects is not possible with our dataset.

[17] As our data is significantly underdispersed we have chosen the Poisson count data model (Cameron and Trivaldi 2013).

[18] We obtain a χ^2 of 216.96 in a Breusch-Pagan test (p = 0.00).

explaining the dependent variable. Finally, we estimated a probit model to determine which factors affect the probability of an article being co-authored or not.

The estimation results for the ordinary least squares, the count data model, and the FGLS estimates are summarized in Table 2. The obtained results for all of the models are qualitatively similar. While the overall explanatory power in terms of the R^2 is sufficiently satisfactory, the individual coefficient estimates are all statistically significant at the 1 % level with the exception of PAGES (10 % level) and the TOP10CITED variable (insignificant in all models). We find strong support for three of our four hypotheses and mixed evidence for the *Quality Hypothesis*. The *Division of Labor Hypothesis* is founded by the coefficient estimates for PAGES, THEOR, QUANTI, and QUANTITHEOR. While rather qualitative or theoretical papers are mainly written by a single author (the hypothesis that the coefficient on THEOR equals zero results in a p value of 0.69), there is statistical evidence that the number of authors increases with the amount of pages, if an article is empirical in nature, or if a paper contains both theoretical as well as quantitative analysis. The coefficient that tests the *Opportunity Cost of Time Hypothesis*, ACKNOWLEDGE, also has the expected sign and is statistically significant. The *Competition for External Funding Hypothesis* is supported by the positive coefficient estimate for EXTERNALFUNDING. However, there is only mixed evidence for the *Quality Hypothesis*. While the estimate for the TOP10CITED variable is not significant, the TOPINSTITUTION variable adds a lot of explanatory power. Nevertheless, we cannot confirm nor reject the *Quality Hypothesis*. To provide an example: Our ordinary least square model predicts that a paper consisting of 20 pages, carrying out empirical and theoretical analysis, and acknowledging financial support will be, ceteris paribus, written by 2.3 authors.

We also employed a probit estimation model [4] in order to determine the marginal effects of the explanatory variables. The dependent variable in this case equals one if an article was co-authored, and zero otherwise. All variables aside from the TOP10 variable and the PAGES variable are statistically significant at the 1 % level. We will now focus on the most important marginal effects (evaluated at the sample mean using the standard delta method). Ceteris paribus, if an article is quantitative or contains quantitative and theoretical work, the probability that it was written by more than one author is higher by approximatively 28 and 24 %, respectively. The effects of a top institution and the acknowledgement of external funding have also a large impact on the probability with $\approx + 24$ and $\approx + 14$ %, respectively. Hence, the probit model also supports three out of the four stated hypotheses.

Impact of quantitative content on co-authorship

The model

Our strong support for the *division of labor hypothesis* and the *opportunity cost of time hypothesis* could indicate, on the one hand, that the economics profession has become more technical, or, on the other hand, that collaboration between different types of economists has become more necessary as the market has grown. However, we want to extend our analysis beyond the five hypotheses from the previous section. We now investigate the impact of quantitative content on co-authorship. We analyzed all 1,436 articles for various measures of quantitative content. Due to the results obtained above, we expect the probability of co-authorship to be an increasing function of its quantitative content (Laband and Tollison 2000).

Table 2 OLS, count data model, FGLS and probit estimates for number of authors/coauthored articles

Dependent variable	OLS [1]		Count data model [2]		FGLS [3]		Probit [4]		
No. of authors [1]–[3]/coauthored [4]	Coef.	t	Coef.	z	Coef.	t	Coef.	z	ME
PAGES	0.008* (0.004)	1.93	0.004* (0.002)	1.83	0.010*** (0.004)	2.69	0.009 (0.007)	1.15	0.003 (0.002)
THEOR	0.033 (0.084)	0.40	0.045 (0.057)	0.78	−0.017 (0.081)	−0.21	0.187 (0.192)	0.97	0.059 (0.060)
QUANTI	0.568*** (0.097)	5.85	0.332*** (0.061)	5.46	0.516*** (0.095)	5.44	0.883*** (0.203)	4.35	0.277*** (0.063)
QUANTITHEOR	0.438*** (0.098)	4.47	0.271*** (0.061)	4.40	0.390*** (0.094)	4.13	0.772*** (0.206)	3.75	0.242*** (0.064)
ACKNOWLEDGE	−0.037*** (0.007)	−5.05	−0.020*** (0.004)	−4.93	−0.038*** (0.007)	−5.71	−0.077*** (0.012)	−6.53	−0.024*** (0.004)
TOP10CITED	0.127 (0.087)	1.45	0.049 (0.038)	1.28	0.126 (0.087)	1.45	0.144 (0.134)	1.08	0.045 (0.040)
TOPINSTITUTION	0.351*** (0.062)	5.66	0.170*** (0.029)	5.95	0.341*** (0.056)	6.06	0.775*** (0.108)	7.18	0.243*** (0.033)
EXTERNALFUND	0.261*** (0.045)	5.74	0.141*** (0.024)	5.89	0.257*** (0.044)	5.88	0.435*** (0.077)	5.66	0.137*** (0.023)
Model summary and tests									
Observations	1,434		1,434		1,434		1,434		
Year dummies	Yes		Yes		Yes		Yes		
F-statistic	9.95				11.41				
R^2	0.230				0.242				
Root MSE	.806				0.755				
Wald-χ^2			512.59				317.61		
Pseudo-R^2			0.04				0.181		
Log-pseudolikelihood			−1,975.039				−795.307		

Table 2 continued

Dependent variable	OLS [1]		Count data model [2]		FGLS [3]		Probit [4]		
No. of authors [1]–[3]/coauthored [4]	Coef.	t	Coef.	z	Coef.	t	Coef.	z	ME
RESET test p value	0.487				0.799				

ME marginal effects

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; robust standard errors appear in parentheses; a constant is included in all regressions

Our estimation strategy consists of two steps: First, we estimate a simple probit model, with co-authorship status as the dependent variable, major explanatory variables and several control variables as explanatory factors. Finally, we restrict our sample to the 825 co-authored articles to check the robustness of our results and to include the information, if two authors were geographically distant. Our first model is:

$$\begin{aligned}
\mathrm{CO}_i = {} & \beta_0 + \beta_1 \cdot \mathrm{PAGES}_i + \beta_2 \cdot \mathrm{FEMALE}_i + \beta_3 \cdot \mathrm{EQUAT}_i \\
& + \beta_4 \cdot \mathrm{TABLES}_i + \beta_5 \cdot \mathrm{FIGURES}_i + \beta_6 \cdot \mathrm{APPENDIX}_i \\
& + \delta_7 \cdot \mathrm{THEOR}_i + \delta_8 \cdot \mathrm{QUANTI}_i + +\delta_9 \cdot \mathrm{QUANTITHEOR}_i \\
& + \delta_{10} \cdot \mathrm{ACKNOWLEDGE}_i + \delta_{11} \cdot \mathrm{TOP10CITED}_i \\
& + \delta_{12} \cdot \mathrm{TOPINSTITUTION}_i + \delta_{13} \cdot \mathrm{EXTERNALFUND}_i \\
& + \delta_{14-50} \cdot \mathit{YEAR}_i \\
& + \gamma_i \\
& \text{with } \beta \text{ as major variables and } \delta \text{ as controls.}
\end{aligned} \tag{2}$$

The additional variables used in this subsection are: CO is dummy equal to one if article is co-authored, otherwise 0, FEMALE is dummy equal to one if a woman is involved in writing the article, otherwise 0, EQUAT is number of equations in the article, TABLES is number of tables in the article, FIGURES is number of figures in the article, APPENDIX is dummy equal to one if article has an appendix, otherwise 0

Variables

Again, some words on the variables. The dependent variable is the status of co-authorship and equals one if an article was co-authored and zero if not. FEMALE is a control variable for the gender of an author (Laband and Tollison 2000). EQUAT is the number of (numbered) equations in an article.[19] TABLES and FIGURES are the number of tables and figures in the article, and APPENDIX a dummy variable for whether a paper had an appendix or not. Since we know whether each of these articles was written by more than one author and we have collected information about the quantitative content of each article published in *JEEM*, we were able to investigate the statistical significance of the relationship between the quantitative content of a paper and the probability of co-authorship.

Estimation and results

Table 3 summarizes the estimation results for five different alternatives of model 2. We have included a "female author involved dummy" as well as the number of adjusted pages in every model, following Laband and Tollison (2000). Table 3 also reports the additional control variables. Our models A to D estimate the separate effect of equations, tables, figures, and appendices on the probability that an article is co-authored or not. While equations have a negative influence on the probability of co-authorship—significant at the 5 % (equations) level—the impact of tables and appendices is positive but not significant (1 % level). Model E evaluates the joint impact of quantitative content on the relevant probability. The coefficients and marginal effects remain almost unaltered and hence are robust across all model specifications with the exception, that the coefficient on figures becomes significant. The marginal effects for the additional controls remain stable across

[19] We have chosen to use only the numbered equations in order to ensure comparability between articles.

Table 3 Estimation results for the impact of quantitative content on co-authorship

Dependent variable	Probit models									
Article is coauthored	Model A	ME	Model B	ME	Model C	ME	Model D	ME	Model E	ME
Major variables										
PAGES	0.011 (0.008)	0.036	0.006 (0.008)	0.002	0.011 (0.008)	0.003	0.007 (0.008)	0.002	0.018* (0.010)	0.005
FEMALE	0.262** (0.103)	0.082**	0.265*** (0.102)	0.083***	0.262** (0.102)	0.082**	0.266*** (0.102)	0.084***	0.259** (0.102)	0.081**
EQUAT	−0.007* (0.004)	−0.021*							−0.007* (0.004)	−0.002*
TABLES			0.007 (0.022)	0.002					−0.010 (0.023)	−0.004
FIGURES					−0.028 (0.017)	−0.009			−0.032* (0.018)	−0.010*
APPENDIX							0.005 (0.086)	0.015	−0.011 (0.086)	−0.004
Additional controls										
THEOR	0.269 (0.200)	0.084	0.174 (0.192)	0.055	0.193 (0.193)	0.060	0.167 (0.192)	0.053	0.305 (0.203)	0.095
QUANTI	0.809*** (0.204)	0.254***	0.795*** (0.214)	0.250***	0.834*** (0.204)	0.262***	0.815*** (0.204)	0.260***	0.858*** (0.218)	0.268***
QUANTITHEOR	0.778*** (0.211)	0.244***	0.695*** (0.211)	0.218***	0.732*** (0.207)	0.229***	0.708*** (0.206)	0.222***	0.833*** (0.220)	0.260***
ACKNOWLEDGE	−0.078*** (0.012)	−0.024***	−0.075*** (0.012)	−0.024***	−0.077*** (0.012)	−0.024***	−0.075*** (0.012)	−0.024***	−0.079*** (0.012)	−0.025***
TOP10CITED	0.153 (0.135)	0.048	0.165 (0.135)	0.052	0.163 (0.135)	0.051	0.163 (0.135)	0.051	0.148 (0.136)	0.046
TOPINSTITUTION	0.758*** (0.109)	0.238***	0.764*** (0.109)	0.240***	0.770*** (0.110)	0.241***	0.764*** (0.109)	0.240***	0.762*** (0.109)	0.238***

Table 3 continued

Dependent variable	Probit models									
Article is coauthored	Model A	ME	Model B	ME	Model C	ME	Model D	ME	Model E	ME
EXTERNALFUND	0.430*** (0.078)	0.135***	0.440*** (0.078)	0.138***	0.440*** (0.078)	0.138***	0.440*** (0.078)	0.138***	0.429*** (0.078)	0.134***
Model summary										
Observations	1,404		1,404		1,404		1,404		1,404	
Year dummies	Yes		Yes		Yes		Yes		Yes	
Wald-χ^2	309.59		311.25		312.48		311.35		310.83	
Pseudo-R^2	0.183		0.182		0.183		0.182		0.185	
Log-pseudolikelihood	−777.15		−778.67		−777.32		−778.72		−775.42	

ME marginal effects

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; robust standard errors appear in parentheses

the models and are significant with the exception of the theoretical dummy variable and the TOP10CITED variable.

Geographical separation

Our final empirical exercise investigates the subsample of the 826 co-authored articles. This allows us to include a new factor to control for: whether two (or more) authors were geographically separated or not (the DIFFERENT_ INSTITUTION variable).[20] Our criterion for declaring two authors to be geographically separated was not institutional affiliation but the geographic distance (>100 miles). So, if one authors was, say, at Harvard University and the other author at Boston University, the article was not declared as written by geographically distant authors. We use the following estimation model:

$$\begin{aligned}\mathrm{NO}_i =&\beta_0 + \beta_1 \cdot \mathrm{PAGES}_i + \beta_2 \cdot \mathrm{FEMALE}_i + \beta_3 \cdot \mathrm{EQUAT} + \beta_4 \cdot \mathrm{TABLES}_i \\ &+ \beta_5 \cdot \mathrm{FIGURES}_i + \beta_6 \cdot \mathrm{APPENDIX}_i + \beta_7 \cdot \mathrm{THEOR}_i + \beta_8 \cdot \mathrm{QUANTI}_i \\ &+ \beta_9 \cdot \mathrm{QUANTITHEOR}_i + \beta_{10} \cdot \mathrm{ACKNOWLEDGE}_i + \beta_{11} \cdot \mathrm{TOP10CITED} \\ &+ \beta_{12} \cdot \mathrm{TOPINSTITUTION} + \beta_{13} \cdot \mathrm{EXTERNALFUND} \\ &+ \beta_{14} \cdot \mathrm{DIFFERENT\_INSTITUTION} \\ &+ \beta_{15-51} \cdot \mathrm{YEAR}_i + \chi_i\end{aligned} \tag{3}$$

Again, it turns out that after controlling for article type, the quantitative content does little to explain the number of authors. Other factors play a much larger role, such as whether a female was involved or external funding was acknowledged. Our estimations also reveal that the geographic separation of authors has a positive and statistically significant influence on the number of authors, much more than the quantitative content (Table 4).

Endogeneity issues

However, there are three fundamental problems with models 1, 2 and 3. According to Wooldridge (2002) there exist three theoretical causes for endogeneity problems. First, it might be not correctly specified, i.e. by ignoring important variables or unobserved heterogeneity. Second, there could be a simultaneity problem where two variables are codetermined, with each affecting the other. And third, endogeneity issues could potentially arise with our measures of quantitative content and the decision to co-author. To cope with endogeneity, we use the following strategy. First, we identify the potential cause of endogeneity. Relying on our OLS estimates from model 1, we can exclude omitted variable bias as a source of endogenity. The null hypothesis that the model has no omitted variables cannot be rejected (p value 0.49). We exclude simultaneity as a potential source of endogeneity since an author chooses the type of an article and not the number of equations, tables or figures. However, measurement error could be a potential source of endogeneity. We have counted or observed all relevant characteristics of the articles, so we expect that a measurement error is rather unlikely. A potential problem could arise with our article classification variables (QUALI, THEOR, QUANTI, QUANTITHEOR). We ran instrumental variable regressions and tested all variables, beside QUALI, for their exogeneity. Our instruments for the article category were the number of equations, tables, figures and

[20] An inclusion of this variable for all 1,426 articles would not have made any sense, since this variable can only be 1 if the article is co-authored. An inclusion would have resulted in multicollinearity.

Table 4 Estimates for number of authors (OLS, count data model and FGLS), spatial separation included

Dependent variable	OLS [1]		Count data model [2]		FGLS [3]	
No. of authors [1]–[3]	Coef.	*t*	Coef.	*z*	Coef.	*t*
PAGES	0.005 (0.006)	0.83	0.002 (0.002)	0.88	0.002 (0.006)	0.40
FEMALE	0.187*** (0.064)	2.90	0.074*** (0.024)	3.04	0.204*** (0.068)	3.02
EQUAT	−0.004 (0.002)	−1.47	−0.002 (0.001)	−1.51	−0.004 (0.002)	−1.46
TABLES	0.026* (0.014)	1.85	0.010* (0.005)	1.93	0.024* (0.014)	1.71
FIGURES	0.011 (0.011)	1.04	0.004 (0.004)	1.04	0.007 (0.010)	0.67
APPENDIX	−0.046 (0.057)	−0.81	−0.018 (0.022)	−0.79	−0.033 (0.055)	−0.61
THEOR	−0.025 (0.112)	−0.22	−0.010 (0.048)	−0.20	−0.050 (0.127)	−0.40
QUANTI	0.154 (0.117)	1.32	0.065 (0.049)	1.33	0.159 (0.132)	1.20
QUANTITHEOR	0.123 (0.125)	0.98	0.056 (0.052)	1.07	0.102 (0.138)	0.74
ACKNOWLEDGE	−0.010 (0.009)	−1.09	−0.004 (0.003)	−1.12	−0.013 (0.009)	−1.42
TOP10CITED	0.095 (0.091)	1.04	0.037 (0.033)	1.10	0.122 (0.101)	1.20
TOPINSTITUTION	0.008 (0.065)	0.12	0.002 (0.025)	0.09	0.002 (0.059)	0.04
EXTERNALFUND	0.111** (0.050)	2.21	0.046** (0.020)	2.30	0.095* (0.052)	1.83

Table 4 continued

Dependent variable	OLS [1]		Count data model [2]		FGLS [3]	
No. of authors [1]–[3]	Coef.	*t*	Coef.	*z*	Coef.	*t*
DIFFERENT_ INSTITUTION	0.184*** (0.049)	3.74	0.077*** (0.020)	3.82	0.181*** (0.047)	3.90
Model summary and tests						
Observations	825		825		825	
Year dummies	Yes		Yes		Yes	
F-Statistic	3.42				3.49	
R^2	0.155				0.155	
Root MSE	.691				.672	
Wald-χ^2			216.68			
Pseudo-R^2			0.01			
Log-pseudolikelihood			−1203.29			

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; robust standard errors appear in parentheses; a constant is included in all regressions

appendices. From a theoretical point of view we expect that the type of an article is highly correlated with the article characteristics and uncorrelated with the error term.[21] We ran GMM instrumental variable regressions and tested the instrumented variables for exogeneity. It turned out that we cannot reject exogeneity for the QUANTI and QUANTI-THEOR variables (with p values of 0.7733 and 0.1170). The robustified Durbin-Wu-Hausman test for THEOR leads to a rejection of the null hypothesis that THEOR is exogenous (p value of 0.0053). The test of the overidentifying restriction (Hansen's J test) cannot reject the null hypothesis and we conclude that our overidentifying restriction is valid (p value of 0.8990). Using the F-statistic (17.60) or the minimum eigenvalue of 39.98 we reject the null of weak instruments, the relative bias of the coefficient is less than 10 %. The results from the IV regression are presented in column two of Table 5. In a next step we employ a structural-model approach to cope with the endogeneity in a count-data model framework. We apply a two-step estimation procedure to the Poisson model for the number of authors with the modification that THEOR is now treated as an endogenous variable. The four excluded variables used as instruments for THEOR are similar to our IV estimation. The first step produces residuals from a linear probability regression of THEOR on the regressors and instruments. All instruments beside TABLES are highly statistically significant. The second step fits a Poisson model on regressors that also include the first-step residual. The z statistic for the coefficient of the first-step residual serves as a basis for a robustified Wald test of exogeneity. The p value is 0.001 and hence we can reject the exogeneity. To adjust the variance-covariance matrix we employ a bootstrap method to correct the standard errors. The results are summarized in column three of Table 5. Finally, we use an instrumental variable probit model to determine the factors influencing the probability to coauthor.

Comparison of the endogenous estimates (column 1) and instrumental variables estimates shows the lower efficiency of the estimators, as the standard errors are slightly larger. After controlling for potential endogeneity issues and other potentially influential factors, we find the instrumental variable models predominantly capture the type of an article rather than the quantitative content. Hence, in the endogenous model, the impact of quantitative content is overestimated and the coefficients are biased upwards. All models find a stable relationship between gender, the presence of external funding, if the author was at a top institution and the status of co-authorship.

Limitations of our study

There are some limitations in our study. First, our chosen methodology can be used in a limited way to observe how the four hypotheses evolved over time. In a different model setup we have not only used year dummies but interacted the variables also with a time trend variable. Our results suggest that e.g. the *External Funding Hypothesis* became more important over time.[22] But the inclusion of additional interaction variables reduced the degrees of freedom and made it difficult to ensure a robust inference. However, we feel that the estimates are good enough to give us an indication of how some trends evolved over time. Second, our variable to measure the quality of articles (TOP10CITED) could also be an indicator for the diffusion of knowledge. Citations are not a pure quality indicator but they tell also something about this diffusion pattern. Co-authored articles are likely to show

[21] The partial correlations for e.g. a theoretical article and the number of equations was 0.43 and −0.63 for the number of tables.

[22] The results are available upon request.

Table 5 OLS and instrumental variable estimates for instrumented THEOR (IV, structural model and IV-Probit)

Dependent variable	OLS [1]		IV [2]		Structural model [3]		IV-Probit [4]	
No. of authors [1]–[3]/coauthored [4]	Coef.	*t*	Coef.	*z*	Coef.	*z*	ME	*z*
First-stage results (main): THEOR as dependent								
EQUAT			0.057*** (0.000)	8.13	0.057*** (0.000)	8.13	0.006*** (0.001)	8.27
TABLES			−0.000 (0.003)	−0.13	−0.000 (0.003)	−0.13	−0.000 (0.003)	−0.06
FIGURES			0.007*** (0.011)	3.62	0.007*** (0.011)	3.62	0.008*** (0.002)	3.98
APPENDIX			0.048***(0.009)	4.89	0.048*** (0.009)	4.89	0.047*** (0.010)	4.86
Summary and tests								
Exogeneity (*p* value)			0.0053		0.0053		0.0356	
Overidentification(*p* value)			0.8990					
First-stage *F*			17.605					
Second-stage results								
THEOR	0.031 (0.084)	0.37	−0.773** (0.323)	−2.39	−0.449** (0.209)	−2.16	−0.970* (0.573)	−1.69
PAGES	0.006 (0.004)	1.45	0.011** (0.005)	2.21	0.005** (0.003)	2.01	0.014* (0.008)	1.70
FEMALE	0.235*** (0.063)	3.73	0.236*** (0.063)	3.78	0.130*** (0.032)	4.05	0.267*** (0.100)	2.66
QUANTI	0.524*** (0.098)	5.35	−0.235 (0.306)	−0.77	−0.153 (0.198)	−0.77	−0.268 (0.562)	−0.48
QUANTITHEOR	0.400*** (0.099)	4.06	−0.355 (0.308)	−1.15	−0.199 (0.052)	−1.01	−0.377 (0.562)	−0.67
ACKNOWLEDGE	−0.036*** (0.007)	−4.84	−0.036*** (0.007)	−4.92	−0.020*** (0.003)	−4.88	−0.074*** (0.012)	−6.27
TOP10CITED	0.141 (0.088)	1.61	0.118 (0.088)	1.34	0.035 (0.041)	0.84	0.120 (0.135)	0.89

Table 5 continued

Dependent variable	OLS [1]		IV [2]		Structural model [3]		IV-Probit [4]	
No. of authors [1]–[3]/coauthored [4]	Coef.	t	Coef.	z	Coef.	z	ME	z
TOPINSTITUTION	0.322*** (0.061)	5.26	0.336*** (0.061)	5.53	0.162*** (0.030)	5.39	0.761*** (0.107)	7.09
EXTERNALFUND	0.258*** (0.046)	5.68	0.272*** (0.046)	5.96	0.155*** (0.024)	6.46	0.447*** (0.077)	5.80
First-stage residual					0.556** (0.218)	2.55		
Model summary and tests								
Observations	1,404		1,404		1,404		1,404	
Year dummies	Yes		Yes		Yes		Yes	
R^2	0.236		0.206					
Root MSE	.797		.799					
F-statistic	9.59		426.72		499.90		327.18	
Wald-χ^2			426.72		499.90		327.18	
Pseudo-R^2					0.04			
Log-pseudolikelihood					−1933.64		−384.62	

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; robust standard errors appear in parentheses; a constant is included in all regressions

a different diffusion pattern. In ongoing work we rely on a knowledge diffusion model by Fok and Fransens (2007) to determine characteristics of the knowledge diffusion process as e.g. the relation between key characteristics of the diffusion process and features of the articles. Third, Barnett et al. (1988) have stated another hypothesis, the *diversification hypothesis*. This hypothesis attempts to capture a risk-bearing behavior of academic scholars, who are exposed to uncertainties with respect to publication. As the field has become more complex and the workload of referees and editors has increased, there could be a tendency toward more collaboration to minimize the random variance effect of the publication process. We have investigated the number of submissions to *JEEM* each year and compared it to the papers accepted.[23] The lack of data on submissions prior to 2000 made it impossible to investigate this hypothesis. A much better way to test the *diversification hypothesis* would be to include a variable that measures the spread of submissions per author to different journals, but this approach was beyond the scope of this paper.[24]

Conclusion

In this paper we investigated *JEEM*, the leading journal in the field of environmental and resource economics, with respect to the development of intellectual collaboration between the authors of published articles. First, we presented a descriptive analysis of important characteristics. We then analyzed the influence of these characteristics on the status of co-authorship. We tested four interesting hypotheses concerning co-authorship using our sample of all 1,436 articles published in *JEEM* between 1974 and 2010. We found support for the *division of labor hypothesis*, the *opportunity cost of time hypothesis*, and the *external funding hypothesis*. We could reject the *quality hypothesis*. In contrast to previous studies (e.g. Laband and Tollison 2000), we found substantial differences in the pattern of external funding for single-authored and co-authored articles. We conjecture that these differences in external funding could be due to the interdisciplinary nature of environmental and resource economics (Bjurström and Polk 2011). This can have potentially an effect on the number of authors. Research in environmental and resource economics is conducted in teams, which results in a higher number of authors. External funding may enable to hire additional researchers (i.e. potential co-authors) and larger consortia may be better eligible to raise external funding resulting in more potential authors. We could also demonstrate that collaboration between geographically distinct authors increased over time.

However, there are some limitations that offer possible fields for future research. We have applied our citations measure as a quality indicator of an article. But it is also possible to interpret citations as a measure of knowledge diffusion. This interpretation allows the analysis of other potential motive factors behind scientific collaboration. Does the extent of co-authorship increase the diffusion of scientific articles and what does this imply for the patterns of co-authorship? It is reasonable to conjecture that a higher number of authors in co-authored papers allows for a faster and broader diffusion of scientific knowledge. Diffusion patterns might be also driven by research trends in publications about specific topics. An increasing share of articles about topics like climate change or sustainability

[23] We thank Dan Phaneuf, the editor of *JEEM*, for the delivered data on paper submissions for the period from 2000 to 2010. Unfortunately, this results in a restricted sample of 517 articles and the empirical analysis loses some meaning and explanatory power. However, the results are available upon request.

[24] We are thankful to a referee for pointing this out.

might have an effect on the degree of interdisciplinarity of an article. Which fields in economics adapted ideas developed in environmental and resource economics? Did generated knowledge diffuse in other areas of research? These further characteristics could help to explain even better an author's decision to cooperate with another peer. Yet a final question remains that was not tested empirically within the scope of this paper: Why all the effort? The answer appears to be simple: scientific curiosity of two collaborating environmental economists.

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Appendix 1: Summary statistics

See Table 6.

Table 6 Descriptive statistics of important variables

Variable	Mean	SD	Min	Max
Number of authors	1.857242	0.9611748	1	12
Qualitative articles dummy (QUALI)	0.0445682	0.2064258	0	1
Theoretical articles dummy (THEOR)	0.454039	0.4980566	0	1
Empirical articles dummy (QUANTI)	0.2597493	0.4386497	0	1
Empirical and theoretical articles dummy (QUANTITHEOR)	0.2416435	0.4282284	0	1
Pages	15.83844	5.782017	2	41
Adjusted pages	16.94372	6.44433	2.006761	41.94704
External funding dummy	0.4610028	0.4986506	0	1
Acknowledgments	3.370474	3.427386	0	22
Spatially separated collaboration dummy	0.3938761	0.488778	0	1
Woman participated in article dummy	0.1992883	0.3996074	0	1
Equations	13.48816	12.51928	0	95
Appendix dummy	0.3551532	0.4787264	0	1
Tables	2.206128	2.579062	0	14
Figures	1.937326	2.416027	0	23

Unrestricted sample: as described in the article, two outliers have been excluded from the analysis

Appendix 2: Linear spline analysis

See Table 7 and Fig. 8.

Table 7 Linear spline regression for single-authored papers

Dependent variable	Linear spline analysis	
Average fraction of single-authored papers	Coefficients	*t*-Statistic
Year1974–1977	0.0584313** (0.0259054)	2.26
Year1978–1988	−0.0591268** (0.0288935)	−2.05
Year1989–1999	−0.0244146** (0.0085566)	−2.85
Year2000–2010	0.0184761** (0.0087409)	2.11
Intercept	−114.9354** (51.19172)	−2.25
Model summary		
Observations	37	
F-statistic	29.05	
R^2	0.7841	
Root-MSE	0.07609	

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, robust standard errors appear in parentheses

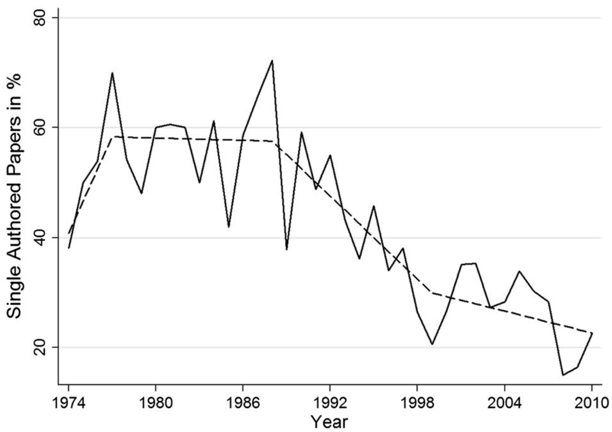

Fig. 8 Linear spline regression

Appendix 3: Classification of articles

To validate our classification we estimate three similar probit models j with the type of article as the dependent variables ($j \in (THEOR, QUALI, QUANTI, QUANTITHEOR)$) and our variables for quantitative content and other potentially relevant characteristics as regressors.

$$\begin{aligned}\text{Probit}_{ji} = {} & \beta_0 + \beta_1 \cdot \text{PAGES}_i + \beta_2 \cdot \text{FEMALE}_i + \beta_3 \cdot \text{EXTERNALFUND}_i \\ & + \beta_4 \cdot \text{EQUAT}_i + \beta_5 \cdot \text{TABLES}_i + \beta_6 \cdot \text{FIGURES}_i + \beta_7 \cdot \text{APPENDIX}_i \\ & + \gamma_i \\ & \text{with } j \in (THEOR, QUALI, QUANTI, QUANTITHEOR)\end{aligned}$$

See Table 8.

Table 8 Probit estimates for article category

Dependent variable	THEOR		QUALI		QUANTI		QUANTITHEOR	
Type of article	Coef.	z	Coef.	z	Coef.	z	Coef.	z
PAGES	−0.015	−1.46	−0.000	−0.02	0.009	0.82	0.014*	1.71
FEMALE	−0.080	−0.65	−0.940***	−2.91	0.346***	2.91	−0.152	−1.49
EXTERNALFUND	−0.112	−1.18	−0.564***	−2.94	0.383***	3.52	0.038	0.47
EQUAT	0.048***	8.34	−0.363***	−3.12	−0.177***	−11.60	0.024***	7.01
TABLES	−0.564***	−10.57	−0.281***	−1.02	0.270***	8.14	0.183***	9.85
FIGURES	−0.026	−1.22	−0.431***	−5.53	0.060**	2.72	0.033**	2.04
APPENDIX	0.317***	2.99	−0.321	−0.93	0.042	0.34	−0.103	−1.19
Intercept	0.412***	3.38	0.723***	3.39	−0.585***	−4.54	−1.777***	−14.76
Model summary								
Observations	1,405		1,405		1,405		1,405	
Wald-χ^2	212.28		74.77		174.62		177.22	
Pseudo-R^2	0.4904		0.6425		0.5356		0.1229	
Log-pseudolikelihood	−493.404		−93.013		−373.247		−678.885	

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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