Does academic collaboration equally benefit impact of research across topics? The case of agricultural, resource, environmental and ecological economics

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Abstract:

In this paper, we analyse the effects of different types of formal collaboration and research topics on research impact of academic articles in the area of agricultural, resource, environmental, and ecological economics. The research impact is measured by the number of times an article has been cited each year since publication. The topics within the area of research are modelled using latent semantic analysis. We distinguish between the effect of institutional, national, and international collaboration. We use statistical models for count data and control for the impacts of journals, publication year, and years since publication. We find that, holding other factors constant, collaboration in the form of co-authorship increases research impact. The effect of inter-institutional collaboration within same country is similar to the effect of collaboration within same institution. However, international collaboration results in additional increase in impact. We find that the topic of a paper substantially influences number of citations and identified which topics are associated with greater impact. The effects of different types of collaboration on citations also vary across topics.

Keywords:

International collaboration; Citation; Co-authorship; Latent semantic analysis;
Topic modelling; Negative Binomial;

Introduction

Research is a complex enterprise, and its outputs depend on a number of factors. It is important for individual researchers to identify factors which could improve the quality of their outputs and enhance academic and real world impact of their research. It is also important for research administrators and funders to design mechanisms that encourage effective models of research. Collaborative research model, especially involving international collaboration is often considered beneficial for quality of research outputs. Recognising the potential benefits, collaboration is actively encouraged by the academic administrators or funders in different countries (Sergi et al. 2014).

A challenge of measuring the impact of collaboration, however, is to select the right metric because quality or impact of research output is not easily observable and measurable. A number of indicators are used to quantify quality and impact, including number of grants and awards, as well as number of downloads or citations to academic articles (Thelwall and Kousha 2015; Brorsen 2009). Among these indicators, citation counts are often readily available to be used as a proxy of the research impact (Azoulay et al. 2013). As a result, citation analysis has become a popular quantitative tool to assess and rank individual researchers, institutions, and journals (Hoepner et al. 2012; Burton and Phimister 1996; Rousseau et al. 2009; Kolstad et al. 2011), as well as to analyse factors that determine quality of research (Vanclay 2013; Hilmer and Lusk 2009; Tahamtan et al. 2016).

It had been documented that academic collaboration reflected in co-authorship of scholarly articles leads to higher number of citations (Laband and Piette 1995). Impact of collaboration on citation numbers depends on the type of collaboration, e.g., impact of international collaboration may differ from impact of collaboration within one country, with international collaboration often resulting in greater citations numbers (Pan et al. 2012). However, this

additional positive impact of international collaboration may depend on country and research field. For example, this impact was not observed in ecology and biochemistry for the researchers from the US (Sud and Thelwall 2016; Leimu and Koricheva 2005). Most often citation analyses were performed at the level of field of research within a discipline, and it is known that impact of international collaboration is different in different fields (Didegah and Thelwall 2013). However, there was no attempt to look at the variability of citation by research topic within a research field, and to examine whether impact of different types of collaboration differ for topics within a field and also determine which topics have greater impact. In this paper, we contribute to this gap.

In this paper, we focus on agricultural, resource, environmental, and ecological (AREE) economics (code Q of the *Journal of Economics Literature* classification), which is an area of research within the field of economics that applies economic theory to agriculture, natural and life sciences. Similar to economics and other social sciences, it does not require large capital investments, therefore it is characterised by the idea- and theory-driven collaboration (Wagner 2005). It also features links and collaborations with agricultural and natural sciences, resulting in diversity of research topics. Unlike mainstream economics, it is less dominated by researchers from the US (Albarrán et al. 2017), which makes it more suitable to study impact of international collaboration. Finally, there have been no study analysing determinants of citations in the area of AREE economics. It is not known whether international collaboration actually generates relatively higher citation rates in this field as it is commonly observed in other fields. Answering this question will provide some indications to individual researchers working in various fields within AREE economics of the trade-offs involved in different types of collaboration activities.

The goal of this study is to analyse (i) which types of collaboration results in higher impact research, especially whether international collaboration has relatively higher impact; (ii)

whether research topics within an area of research are associated with different research impact; and (iii) whether different types of collaboration have different influence on research impact for different research topics. While question (i) has been addressed for a number of research fields, no study has been done for AREE economics so far. There is only one study addressing question (ii). Finally, question (iii) has not been addressed in the peer reviewed literature at all.

To answer these questions, first, we use a text mining technique called latent semantic analysis (Furnas et al. 1988; Deerwester et al. 1990) to discover research topics in the papers published by the journals within the field of AREE economics. Then, we apply a regression model for count data to analyse impact of different types of collaboration, research topics, and other factors on citation counts. We use data from the 19 journals in the field of AREE economics published from 2001 to 2010 and utilise citations from the year of publication to 2015.

After this brief introduction, we present a summary of literature on the impact of collaboration patterns and topic selection on citation counts and develop research hypotheses. Then we present the data and analysis techniques, followed by results and discussion.

Background and research hypotheses

Academic collaboration and co-authorship

Although collaboration does not necessarily result in co-authorship of academic papers, it is probably the best available measure of academic collaboration (Laudel 2002). A number of explanations are available on why researches collaborate and co-author academic papers (Nowell and Grijalva 2011; Laband and Tollison 2000). Development of communication technology has facilitated collaborative research by making communication among

researcher easy (Cainelli et al. 2015). In many institutes, publication number is used as a criterion of performance, which creates strong incentive to collaborate to increase the number of publications (Chung et al. 2009). Further, working on several papers as a team member allows diversifying research effort and avoiding risk of single paper being not published (Laband and Piette 1995). Finally, specialisation creates the necessity for researchers with unique but different skills to work together on a project. This can improve the quality of research, reflected in greater impact and increased numbers of citation of academic papers (Laband and Piette 1995; Franceschet and Costantini 2010; Didegah and Thelwall 2013; Pan et al. 2012).

Collaboration could be happening at multiple levels: institutional collaboration where researchers are collaborating with researchers from the same institute, national collaboration where researchers are working with other researchers outside of their institution but within the same country, and international collaboration where researchers from different countries are working together. There have been several studies analysing impact of different types of collaborations on the citation count of academic papers (Didegah and Thelwall 2013; Gazni and Didegah 2011; Pan et al. 2012). Their results have generally shown that international collaboration has positive effect on citation counts. For example, Sin (2011) showed that citation was higher for papers written through international collaboration, Northern European authors, and authors in high-income nations. Similar findings have been made by Aksnes (2003), Hanssen and Jørgensen (2014) and Katz and Hicks (1997).

It had been suggested that citations could be higher for papers with international collaboration due to increased visibility of the papers as researchers from different countries may attract readers from different networks (Glänzel 2001; Hanssen and Jørgensen 2014; Hara et al. 2003). On the other hand, due to transaction costs of collaboration, authors would only collaborate if the inherent quality of the work (articles) could be improved (e.g., using

data from different sources or replicating studies in different countries to test robustness of the results). However, Leimu and Koricheva (2005) showed that international collaboration in ecology had no effect on the citation rates of ecological papers. This suggests that the influence of collaboration types could be discipline-specific. However, no study has looked at the impact of different types of collaboration in the field of AREE economics, which have many overlapping features with economics and environmental sciences. It should be noted that while analysing impact of different types of collaboration, we do not make an attempt to attribute this impact to specific factors related to collaboration, such as article quality or visibility.

Based on the above discussion, we derive the following hypotheses:

H1. Collaboration has a positive effect on the number of times an article is cited.

More specifically, (H1a) articles co-authored by multiple authors are cited more often than single authored articles; (H1b) articles co-authored by teams involving multiple institutions are cited more often than single authored articles; and (H1c) articles co-authored by teams involving multiple countries are cited more often than single authored articles; and (H1d) number of co-authors positively impacts number of times an article is cited.

H2. National collaboration has a positive effect on the number of times an article is cited. Specifically, (H2a) articles co-authored by teams of researchers affiliated with multiple institutions are cited more often than articles co-authored by teams of researchers affiliated with single institution; and (H2b) the number of institutions involved in collaboration increases the number of times an article is cited.

H3. International collaboration has a positive effect on the number of times an article is cited. Specifically, (H3a) articles co-authored by researchers from multiple

countries are cited more often than articles co-authored by researchers from single country; and (H3b) the number of countries involved in collaboration increases the number of times an article is cited.

Research topics

We are interested in the variation of the impact of collaboration between topics. Topical or thematic structure and dynamics of individual journals and fields of research had been analysed using keywords (Costanza et al. 2016; Brookshire and Scrogin 2000; Debertin and Pagoulatos 1992) or topic modelling (Polyakov et al. 2016; Sidorova et al. 2008; Winson-Geideman and Evangelopoulos 2013). It is well known that citation counts differ across fields of research and type of collaboration has different impact on citation in different fields of research (Didegah and Thelwall 2013). For examples, topics have been classified as ‘cold’ or ‘hot’ in terms of changes in numbers of published papers (Westgate et al. 2015; Griffiths and Steyvers 2004). It could be expected that ‘hot’ topics would attract higher number of citations. Moreover, citation rates of a topic could be influenced by whether research on this topic takes place within many or few countries or institutions (i.e., evenness of the contribution of countries or institutions).

It had been observed that research topics could influence citation number of academic papers in the field of environmental modelling. Robson and Mousquès (2016) analysed the impact of topics on the average number of citations per year using regression models and found that there are substantial variations in citation rates among the topics. However, similar analyses have not been attempted in other fields of research, specifically in economics. Further, it is not known whether collaboration would influence citations of papers written on different topics within the field of ecological, environmental and resource economics. Therefore, we develop the following hypotheses:

H4: Citations differ for topics within the field of AREE economics.

H5: Types of collaboration has different impact on citations for different topics.

Data and Methods

Bibliographic data

The data were collected in January 2016 from Scopus database. We included journals in the areas of AREE economics (including land, forest, energy, and marine economics) published and indexed by Scopus between 2001 and 2010. Only documents classified as “article” were used, furthermore documents that were classified as article but were comment, reply or corrigendum were removed from the sample. This resulted in selection of 8,850 articles from 19 journals, listed in Table 1. The data for every article include title, abstract, list of keywords, list of authors and their affiliations, year of publication, volume, issue, number of pages, references, and number of times the article was cited every year from the year of publication to 2015.

The affiliation data were processed using regular expression also known as search patterns (*prxchange* function in SAS v 9.3) to extract country, institution, and address of the affiliation for each co-author. For the co-authors with several affiliations, only the affiliation listed first was considered. For each paper, number of co-authors, number of institutions, and number of countries were calculated. Furthermore, using author names, number of individual authors in each institution and each country were calculated. These variables were used as proxies for “sizes” of respective institution and countries. Descriptive statistics of the variables are presented in Table 2.

Table 1. Journal titles, impact factors, and number of documents

Journal title	Abbreviation	IF 2014	Number of articles
Agricultural Economics	AE	1.19	447
American Journal of Agricultural Economics	AJAE	1.33	990
Australian Journal of Agricultural and Resource Economics	AJARE	1.07	251
Canadian Journal of Agricultural Economics	CJAE	0.86	275
Ecological Economics	EcE	2.72	1767
Energy Economics	EnE	2.71	795
Energy Journal	EJ	1.77	343
Environment and Development Economics	EDE	1.17	326
European Review of Agricultural Economics	ERAE	1.27	166
Environmental and Resource Economics	ERE	1.43	679
Forest Policy and Economics	FPE	1.86	480
Indian Journal of Agricultural Economics	IJAE	-	343
Journal of Agricultural Economics	JAE	1.28	273
Journal of Agricultural and Resource Economics	JARE	0.53	305
Journal of Environmental Economics and Management	JEEM	2.39	439
Journal of Forest Economics	JFE	1.14	140
Land Economics	LE	1.34	383
Marine Resource Economics	MRE	2.07	225
Resource and Energy Economics	REE	1.33	223
Total			8850

Table 2. Descriptive statistics of variables

Variable	Number of observations	Mean	Standard Deviation	Minimum	1st Quartile	Median	3rd Quartile	Maximum
Institutional collaboration (1 if institutional collaboration, 0 otherwise)	8850	0.28	0.45	0	0	0	1	1
National collaboration (1 if national collaboration, 0 otherwise)	8850	0.26	0.44	0	0	0	1	1
International collaboration (1 if international collaboration, 0 otherwise)	8850	0.21	0.41	0	0	0	0	1
Number of authors	8850	2.33	1.28	1	2	2	3	29
Number of institutions	8850	1.65	0.87	1	1	1	2	22
Number of countries	8850	1.25	0.55	1	1	1	1	13
Average number of authors in an institution	8850	26	26	1	6	18	39	131
Average number of institutions in a country	8850	451	375	1	123	214	945	945
Adjusted number of pages	8850	11.5	3.9	1	9	11	14	35
Number of references	8850	31.95	18.52	0	20	29	40	313
Question sign in title	8850	0.09	0.29	0	0	0	0	1
Colon in title	8850	0.41	0.49	0	0	0	1	1
Number of citation in 2015	8850	15.50	23.20	0	4	9	18	717
Number of citations 5 years after publications	8850	12.29	18.48	0	3	7	15	471
Annual number of citations	87605	2.40	4.55	0	0	1	3	176

Topic modelling

There are a number of approaches used to classify documents into topics. Academic publications are often supplied with keywords and classification codes. However, they tend to be subjective and are not necessarily available for all documents. There are a number of topic modelling methods based on text mining techniques, namely latent Dirichlet allocation (LDA) (Blei et al. 2003) and latent semantic analysis (LSA) (Furnas et al. 1988; Deerwester et al. 1990). In this study we model topics of the articles using LSA.

The assumption behind LSA is that words, which are close or similar in meaning, occur in similar pieces of text. LSA collects all of the contexts within which words appear and establishes common factors that represent underlying concepts (Sidorova et al. 2008). This method overcomes the problems of polysemy and synonymy (Priam et al. 2007) which are inherent to any method using non-processed keywords for classification by topics. Similar to principal component analysis, LSA reduces dimensionality of original data through singular value decomposition (SVD), producing simultaneous principal components for two sets of variables: the terms and the documents. The number of factors has to be predefined by the researcher, which allows regulation of the level of aggregation at which topics are identified. The SVD results include a set of factor loadings for the terms and a set of factor loadings for the documents. Each latent semantic factor, representing a topic or a theme, is associated with a set of terms and a set of documents with high loadings (Sidorova et al. 2008).

To prepare data for LSA, we used article titles, keywords and abstracts to construct a vector space model using package “tm” in R statistical software (Feinerer et al. 2008). For consistency, words that may have different spelling were converted to American English. Common words like “the”, “and”, “or” were removed. Words were stemmed by keeping roots. For example, “environment”, “environments”, “environmental” were all represented by “environment”. We included words with three and more characters occurring at least twice

to construct 9522×8850 term-document matrix $\mathbf{X}$ consisting of the frequency counts of 9,522 stemmed words in the titles, keywords, and abstracts of 8,850 articles. The term frequencies were transformed using term frequency-inverse document frequency (TF-IDF) transformation (Salton and Buckley 1988) to promote weight of rare terms and discount the influence of common terms.

We used package “RSpectra” in R (Qiu 2016) to perform SVD of the term-document frequency matrix $\mathbf{X} = \mathbf{TSD}^T$ where $\mathbf{T}$ and $\mathbf{D}$ are, respectively, the term and document eigenvectors, and $\mathbf{S}$ is the diagonal matrix of singular values. These matrices can be combined to produce factor loadings for terms $\mathbf{TS}$ and factor loadings for documents $\mathbf{DS}$ (Evangelopoulos et al. 2012). To reduce number of dimensions of factor loadings matrices, we use truncated version of the diagonal matrix $\mathbf{S}_k$ where k is the number of dimensions determined using scree plot (Cattell 1966). To achieve interpretable factor loadings we performed *varimax* rotation of the term loadings $\mathbf{TS}_k$ followed by rotation of the document loadings $\mathbf{DS}_k$ using the same rotation matrix (Sidorova et al. 2008; Visinescu and Evangelopoulos 2014). Because factor loadings are not normalised, their regression coefficients would be difficult to interpret. Therefore, they were converted to binary values by assigning 1 to the topics with the highest loading for each article, in other words, each article was assigned a single topic.

Topic characteristics

Griffiths and Steyvers (2004) noted that topics in a scientific discipline not only generate different amounts of interest, but the level of interest can rise (“hot topics”) or fall (“cold topics”). To analyse dynamics of topics popularity, we follow Polyakov et al. (2017) and estimated a linear mixed model:

$$\bar{p}_{z,t} = \alpha + (\beta + v_z)t + u_z,$$

where $\bar{p}_{z,t}$ is average proportion of topic z among the papers published in year t , α and β are fixed intercept and slope, v_z and u_z are random intercept and slope. Year t is measured relative to the median year. Topics with positive random intercepts can be interpreted as having higher than average contribution to the body of literature, while positive random slopes indicate those topics growing at above average rates ('hot' topics). It is expected that 'hot' topics would attract higher citations.

Another important characteristic of a research topic (or a research field) is evenness of the contribution of countries or institutions to a research topic (or research field). To measure evenness, we used evenness index (Pielou 1966) defined as

$$J' = H' / H'_{\max},$$

where H' is Shannon diversity index and $H'_{\max}$ is maximum possible value of Shannon diversity index. Shannon index is calculated as:

$$H' = -\sum_{i=1}^N s_i \ln(s_i),$$

where N is number of countries or institution and s_i is the fraction of contribution of i -s country or institution to a topic. Evenness index can be viewed as normalised diversity index taking values between zero and one. When all contribution to a topic comes from one country (institution), evenness index is equal to zero, while when every country or institution contributes equally, evenness is equal to one. To calculate contribution of countries or institutions to a topic, we aggregated contributions to this topic of all authors affiliated with respective country or institution, weighted by inverse number of authors in each article. Greater evenness (or lower concentration) of contribution to a topic across countries and

institutions may mean that this topic is of interest to a broader research community.

Therefore, we expect that topics with higher evenness of countries' and institutions' contributions would be cited more.

Citation analysis

We assume that the number of citation of an article depends on the article quality and its exposure. It had been suggested that due to increasing complexity and specialisation of science, researchers collaborate to increase the quality of research output (Schymura and Löscherl 2014). Another factor that may increase quality and therefore number of citations is strength of the institution, which can be proxied by its size or number of affiliated researchers. Furthermore, quality could be reflected in article characteristics such as number of pages and references. In addition to quality, collaboration impacts exposure of the article through the collaboration networks. Greater networks are created by collaboration across institutional and international borders. Exposure is also impacted by the field of research and topic within the field of research. Larger and more interdisciplinary fields and topics provide greater opportunity of the article to be cited. Research fields and topics may impact citation counts through different citation traditions and habits. Exposure of the article is also impacted by the year of publication (the numbers of journals and articles rises with time, increasing the opportunity to be cited) and by time since publication.

The number of citations to an article is a count data, which is appropriately modelled using statistical models with discrete conditional distribution of the response such Poisson or Negative Binominal (NB) (Didegah and Thelwall 2013; Sud and Thelwall 2016). In this study, we use Generalised Linear Model with NB conditional distribution of the response and a log link function. NB distribution allows modelling over-dispersion common in citation data. Log link function accounts for non-linearity in the relationship between citations and their determinants. Furthermore, we log-transformed continuous explanatory variables, which

made the functional form equivalent to allometric or power law. The articles in our sample were published over a period of ten years resulting in large variation of cumulative citation numbers due to different time passed since publication. One approach to control for these factors is using age adjusted number of citations (Hoepner et al. 2012), however number of citations is nonlinearly related to the time since publication (Hilmer and Lusk 2009). We model number of citations received by an article every year since its publication, controlling both for the year of publication and for the number of years from publication to citation. The drawback of using this approach is that repeated observations of citations to same article over time are correlated. The correlation between repeated observations of an article is controlled by using article specific random effects. The model can be written as

$$c_{i,d,t} \sim \text{NB}(\mathbf{x}_i'\boldsymbol{\beta} + \mathbf{y}_i'\boldsymbol{\gamma} + \delta_d + \tau_t + \eta_i + \varepsilon_{i,t})$$

Where $c_{i,d,t}$ is the number of citation received in year t by article i published in year d , $\mathbf{x}_i$ is a vector of the characteristics of co-authorship and collaboration, $\mathbf{y}_i$ is a vector of article characteristics (such as, number of pages and number of references), $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$ are vectors of parameters to be estimated, δ_d are publication years fixed effects, τ_t are citation years fixed effects, η_i are article specific random effects, and $\varepsilon_{i,t}$ is the error term.

We employ two approaches to model effect of collaboration. One approach is to use a set of dummy variables indicating whether there is international, national, institutional collaboration, or no collaboration. Another approach, which accounts not only for the type, but also for the extent of collaboration, is to use number of authors, number of institutions, and number of countries. Number of authors accounts for the effect of incidence and extent of collaboration. Number of institutions indicates whether there is an additional effect of the incidence and the extent of inter-institutional collaboration. Number of countries accounts for

the effect of international collaboration additional to the effect of collaboration and inter-institutional collaboration.

In addition to collaboration, we test the impact of the size of research groups and size of research communities, because they may be related to informal collaboration and dissemination of research. The number of unique authors found in our dataset in each institution serves as a proxy for the size of a research group (institution), and the number of institutions in a country serves as a proxy for the size of a research community (in a country). We calculate average number of authors in institution and average number of institutions in a country for each article to avoid double accounting of number of co-authors and institutions contributed to each article. We use natural logs of continuous variables to account for diminishing effects of the factors these variables represent.

It had been shown that the number of citation received by a paper depends on the discipline (Najman and Hewitt 2003), but no studies looked whether it also depends on the topic within a discipline. To explore the impact of topics within a research on citations, we included a set of variables representing research topics within the field. To test whether impact of collaboration on citation numbers vary with research topics, we estimated two additional models where variables representing collaboration were interacted with topics.

To isolate the impact of collaboration and topics in regression models we have included several additional factors that have been identified by other studies to influence citation counts. Article characteristics used as explanatory variables include number of pages, number of references, presence of question sign and colon in title, journal dummy variables, and topic dummies. Numbers of pages were normalised to number of pages in *Ecological Economics* (the journal with most articles in the dataset) using average number of words on a typical page for each of the journals in our dataset. We use natural logs of number of pages and

number of references to account for diminishing effects of these factors. Dummy variables indicating presence of question mark and presence of colon in the article title were included to account for “catchy” title, which had been shown to impact number of downloads and number of citation an article attracts (Jamali and Nikzad 2011). In addition, we use journal specific dummy variables to control for unobservable journal characteristics such as reputation.

Results and Discussion

Topic modelling

To select the number of topics for the analysis we used Scree plot (Figure 1). We identified 7, 10 and 21 as candidate numbers of topics. After inspecting words and articles with high loading in each topic of candidate classifications, we selected 10-topic solution. The names were assigned to topics by inspecting words and articles in each topic with highest loading.

Figure 1. Scree plot for the selection of number of topics.

Table 3 presents the number of articles in each topic, as well as proportions of collaboration types and average numbers of co-authors, institutions, and countries in each topic. The proportions of articles in our dataset assigned to different topics, which we call popularity, vary from 4% (Water Economics) to 18% (Agricultural Economics).

In Figure 2, the measures of level and changes in a topic's popularity are presented. The popularity (X axis) provides information on the allocation of total research effort to individual topics, while the changes in popularity (Y axis) can be used to assess which topics show growth ("hot" topics) or decline ("cold" topics) (Griffiths and Steyvers 2004). It could be observed that Climate change, Ecosystem services and Commodity markets topics are "hot". On the other hand, Fishery economics, Environmental Economics, or Agricultural economics are relatively "cold" as their popularity has declined. We anticipate that these measures could be related to citations of the articles representing topics. Specifically, we expect that articles representing more popular or "hot" topics, would be cited more often, while the articles representing less popular or "cold" topics, would be cited less often. That is, we expect citations to increase from bottom left to top right corner of the graph in Figure 2.

Table 3. Numbers of articles and collaboration metrics by topics

Topics	Number of articles	Proportions of articles by type of collaboration				Average number of		
		Single author	Institutional	National	International	Authors	Institutions	Countries
Environmental economics	1003	33%	24%	24%	18%	1.98	1.52	1.20
Forest economics	724	19%	31%	28%	21%	2.60	1.75	1.27
Commodity markets	1167	24%	31%	25%	20%	2.23	1.58	1.22
Energy economics	537	28%	28%	25%	20%	2.18	1.58	1.24
Agricultural economics	1610	22%	31%	23%	24%	2.40	1.66	1.29
Nonmarket valuation	1192	18%	24%	35%	23%	2.49	1.81	1.26
Water economics	367	22%	31%	26%	22%	2.57	1.70	1.25
Fishery economics	523	27%	19%	32%	22%	2.25	1.74	1.27
Climate change	650	25%	31%	24%	20%	2.37	1.60	1.22
Ecosystem services	1077	32%	28%	21%	19%	2.34	1.59	1.25

Figure 2. Topics popularity, “hot” and “cold” topics.

Figure 3. Evenness of contributions to topics.

The topics vary by extent of collaboration types. The highest proportion of articles with international collaboration is observed in Agricultural Economics (24%) and Nonmarket Valuation (23%). This may reflect multidisciplinary and empirical nature of the topics that require collaboration among economists, ecologists and agricultural scientists. On the other hand, Nonmarket Valuation has the lowest proportion of single authored articles. The lowest proportion of international collaboration and the highest proportions of single authored articles are observed in Environmental Economics and Ecosystem Services. Forest Economics, a multidisciplinary and empirical topic, also has low proportion of single authored articles and the highest proportions of articles with national collaboration.

Another important characteristic of topic is its distribution across institutions and countries. The scatterplot of the evenness of countries' and institutions' contributions to each topic is shown on Figure 3. We can observe that Ecosystem services, Energy economics and environmental economics are more evenly distributed than any other topic, whereas, Water economics and Fishery economics are highly concentrated. We anticipate that the citation counts of articles assigned to topics will increase from lower left corner (low evenness) to upper right corner (high evenness) of this plot.

Citation analysis

Table 4 presents results of the estimation of two citation counts models with alternative collaboration metrics. To measure collaboration, Model 1 uses dummy variables for international, national, and institutional collaboration, while Model 2 uses number of authors, number of institutions, and number of countries. The magnitude and significance of dispersion coefficients suggest over-dispersion. Therefore, the NB is appropriate model for these data. In the NB model, coefficient of an untransformed explanatory variable can be interpreted as proportion change in the dependent variable due to unit change in an

explanatory variable, while coefficient of a log transformed variable can be interpreted as elasticity indicating percent change in the dependent variable due to percent change in an explanatory variable.

Impact of collaboration

The coefficients of binary variables representing type of collaboration in Model 1 suggest that collaboration has a positive impact on citation counts. Papers written with any form of collaboration have received significantly more citations compared to single-authored papers (H1a, H1b, H1c are supported). The coefficient for the log number of authors in Model 2 is statistically significant and indicates that this variable positively affects number of times a paper is cited (H1d is supported). It suggests that changing number of authors from 1 to 2 (100% increase) increases citation counts by 27%. Because this coefficient can be interpreted as elasticity, it also suggests that adding one more author (changing from 2 to 3 or by 50%) would increase number of citations by 13.5%.

In Model 1, coefficients for institutional collaboration and national collaboration are of similar magnitude and the null hypothesis of equality of the coefficients is not rejected, not supporting H2b. This indicates that a paper co-authored by researchers within one institution or among multiple institutions from the same country attracts approximately 25% more citations than a similar single authored paper. In Model 2, the coefficient for log number of institution is not significantly different from zero, which does not support H2a.

Judging from the coefficient of international collaboration dummy in Model 1, an internationally co-authored paper attracts 36% more citations than a single authored paper. This coefficient is greater than the coefficient for institutional collaboration and the coefficient for national collaboration (the null hypothesis of equality of the coefficients is rejected, $F=12.46$, $p<0.001$ and $F=8.01$, $p<0.005$, respectively), which supports hypothesis

H3a. More specifically, an article with international collaboration attracts approximately 11% more citations than a similar article with other types of collaboration. Further, the coefficient of log number of countries is significant, supporting hypothesis H3b, and indicates that two-country collaboration increases citation counts by 9% in comparison with collaboration within one country, which is, again, consistent with the results of Model 1. These results show clear benefit of international collaboration. While Models 1 and 2 show consistent results, Model 2 demonstrates better fit because it accounts for both incidence and extent of different types of collaboration.

To control effect of collaboration, we also included average number of authors in institution and average number of institution in a country. The average size of research institutions (as measured by the number of authors in an institution averaged over co-authors) has positive impact on citations (Table 4). This can be attributed to both increase of quality of research output because of mentoring, training and opportunities of informal collaboration in larger research groups, but also to increased exposure to the research of colleagues. On the other hand, number of institution in a country does not have measurable impact on citations. Sud and Thelwall (2016) have found that impact of international collaboration differs by country, however our result suggests that this is not attributable to country size as measured by number of institutions in a country.

Table 4. Results of the estimation of Negative Binomial regressions for the annual number of citations

Variables	Model 1		Model 2	
	Estimate	Robust Error	Estimate	Robust Error
Intercept	-3.606‡	(0.162)	-3.570‡	(0.161)
Institutional collaboration	0.231‡	(0.035)		
National collaboration	0.255‡	(0.037)		
International collaboration	0.361‡	(0.040)		
log(number of authors)			0.271‡	(0.031)
log(number of institutions)			0.013	(0.041)
log(number of countries)			0.094†	(0.045)
log(average number of authors in an institution)	0.047‡	(0.012)	0.041‡	(0.012)
log(average number of institution in a country)	0.014	(0.011)	0.016	(0.011)
log(number of adjusted pages)	0.244‡	(0.044)	0.231‡	(0.045)
log(number of references)	0.363‡	(0.029)	0.364‡	(0.029)
Question sign in title	0.116‡	(0.041)	0.128‡	(0.042)
Colon in title	0.075‡	(0.026)	0.077‡	(0.025)
Topics (10) (F-value)	18.080‡		17.350‡	
Environmental economics	-0.354‡	(0.061)	-0.336‡	(0.060)
Forest economics	-0.187‡	(0.067)	-0.191‡	(0.066)
Commodity markets	-0.365‡	(0.065)	-0.352‡	(0.063)
Energy economics	0.091	(0.071)	0.106	(0.070)
Agricultural economics	-0.257‡	(0.063)	-0.253‡	(0.062)
Nonmarket valuation	-0.013	(0.059)	-0.019	(0.058)
Water economics	-0.049	(0.069)	-0.063	(0.068)
Fishery economics	-0.496‡	(0.073)	-0.489‡	(0.072)
Climate change	-0.091	(0.066)	-0.090	(0.065)
Ecosystem services (reference)	0.000		0.000	
Journals (19) (F-value)	91.430‡		92.380‡	
Publication year (10) (F-value)	20.960‡		20.180‡	
Year since publication (15) (F-value)	756.590‡		758.530‡	
Variance of articles random effects	1.042†		1.042†	
Dispersion	1.347†		1.330†	
-2 Log Pseudo-Likelihood	321,793		321,208	
Number of observations	87,605		87,605	

Significance levels: ‡ 1%; † 5%; * 10%

Impact of topics

Coefficients of topic dummies are similar in two models and indicate that there is substantial variation in citation counts attributed to topic. The effect of topics is statistically significant ($F=18.08$, $p < .001$ in Model 1 and $F= 17.35$, $P < .001$ in Model 2) supporting hypothesis H4. Energy Economics, Ecosystem Services, and Nonmarket Valuation attract relatively larger number of citations while Fishery Economics, Environmental Economics and Commodity Markets attract lower number of citations. This is consistent with our predictions based on topic popularity and its dynamics, as well as evenness of contribution of countries and institutions. It is not enough to look at these characteristics in isolation. For example, Energy Economics is one of the topics with lowest number of publications (low apparent popularity), however, it is a “hot” topic (Figure 2) with greater evenness of contributions by both countries and institutions (Figure 3). Therefore, it is not surprising that it has attracted the highest number of citations per article as evidenced by coefficient of the dummy.

Next, we test whether impact of collaboration differs across research topics. We extended Models 1 and 2 by adding interactions of topics variables with collaboration variables (new Models 3 and 4, respectively). Table 5 presents only coefficients of the interactions effects of Models 3 and 4. For example, the coefficient indicating the impact of institutional collaboration on citations of articles classified as Environmental Economics is presented in row 1 column 1 of Table 5. Our results indicate that there is variation in the impact of different types of collaboration across research topics, providing support for H5. The topics where magnitude of the impact of collaboration is greater than average are Ecosystem Services, Fishery Economics, and Nonmarket Valuation, while the magnitude of impact of collaboration is lower than average for Forest Economics, and Energy Economics.

Table 5. Results of the estimation of Negative Binomial regressions for the annual number of citations with interactions between topics variables and collaboration variables. Only interactions effects are presented.

Topics	Model 3			Model 4		
	Institutional collaboration	National collaboration	International collaboration	log(number of authors)	log(number of institutions)	log(number of countries)
Environmental economics	0.253‡	0.328‡	0.404‡	0.325‡	0.044	0.071
Forest economics	-0.035	-0.032	0.159	0.094	-0.004	0.185
Commodity markets	0.198†	0.135	0.116	0.247‡	-0.099	-0.038
Energy economics	0.062	0.232*	0.280*	0.063	0.246	-0.042
Agricultural economics	0.234‡	0.234‡	0.327‡	0.224‡	0.002	0.050
Nonmarket valuation	0.331‡	0.369‡	0.495‡	0.359‡	-0.006	0.162
Water economics	0.095	0.221*	0.118	0.227*	0.120	-0.200
Fishery economics	0.370‡	0.286†	0.190	0.331†	-0.108	-0.122
Climate change	0.138	0.161	0.332‡	0.225†	0.053	0.136
Ecosystem services	0.400‡	0.406‡	0.738‡	0.419‡	0.000	0.330†

Significance levels: ‡ 1%; † 5%; * 10%

There are several topics where the patterns of collaboration (that is relative importance of institutional, national, and international collaboration) are consistent with the patterns reported for the whole dataset. These topics are Environmental Economics, Agricultural Economics, Ecosystem Services, and Nonmarket Valuation. The positive effect of international collaboration is lower than that of national or institutional collaboration for Fishery Economics, Commodity Markets, and Water Economics. Note that all three topics have low measures of countries' evenness (Figure 3), i.e., most of the collaborative effort has been concentrated within few countries or institutions. In Forest Economics, there is no evidence of positive impact of institutional and national collaboration. For Fishery Economics, the greatest is positive impact of institutional collaboration, while for Water Economics, it is national collaboration.

To demonstrate the interactions between topic and collaboration we have presented predictions of citation counts for different topics and types of collaboration using coefficients of the Model 3 (Figure 4). The predictions of citations received in 2009 for the articles published in 2005 in *Ecological Economics*, with all other variables at the median of the sample. *Ecological Economics* is selected because it has the highest number of articles with all topics represented. The Figure re-iterates the patterns observed in Table 5 indicating that the benefit of international collaboration is higher for topics Climate Change, Ecosystem Services and Non-market valuation. A possible explanation could be that studies focusing on these topics often deal with issues spread over multiple countries or regions making exchange of effort and information through international collaboration more beneficial.

Figure 4. Number of citations by topic and type of collaboration with 95% confidence interval predicted for article published in *Ecological Economics* in 2005, 4 years since publication at the median of sample.

Other factors influencing citations counts

The main objective of this study was to investigate the influence of collaboration pattern and research topics on citation counts. We conducted this by testing a number of hypotheses. However, to make the analysis robust, we included a set of variables identified in previous research to influence citation counts. We found that year of publication, number of years since publication, and journal dummies explain significant proportion of the variation in citation counts. Coefficient for number of pages and number of references are positive and statistically significant, which is consistent with previous research (Laband and Tollison 2006; Hilmer and Lusk 2009; Didegah and Thelwall 2013). Catchy title as indicated by

question sign and colon in title positively influence citations counts. This suggests that the title play an important role in an article getting noticed and cited; therefore, formulation of the title deserves attention if authors would like to increase impact of research. However we would caution against the abuse of columns and question signs in the titles.

Conclusion

In this paper, we have investigated 19 academic journals in the field of AREE economics to understand the role different types of collaboration and research topics play in attracting citations. This is the first study of citation that uses automatically discovered research topic within a field of study to explain citation counts. To model the effect of various factors on citation rates, we used negative binomial model, however, unlike other citation studies, we model number of citations received by an article every year since its publication. This allowed us to pool citation data of articles published over ten years period without imposing assumption of citations dynamics since publication of an article. To classify body of literature into research topics, we used latent semantic analysis. The discovered topics differ by extent of collaboration, geographic distribution, popularity and trend of popularity. These differences suggest that there will be differences in articles' citations attributable to specific topics.

We found that, other factors being equal, collaboration has a positive impact on citation counts with different types of collaboration having different impacts. For example, national (inter-institutional) collaboration does not have additional positive impact on number of citations. At the same time, international collaboration increases citation counts. These results provide a justification for the promotion of international collaboration by many research funders. Assuming that citation count is an indicator of quality of academic papers,

encouraging greater collaboration and investing in international collaboration could be beneficial.

Our results also indicate that citation counts within the field of AREE economics are influenced by the research topic. We have shown that differences in citation rates across topics are related to the topics' level and dynamics of popularity, as well as to the evenness of countries and institutions contribution to specific research topic. Classification of topics according to their popularity can be of interest for the researches in the field of scientometrics. For example, knowing which specific topics are “hot” and have greater impact in any area, researchers can further study respective topics and participating institutions or research groups investigating their models of funding, profiles of the researchers, and practices of collaboration. These future findings can be useful to improve effectiveness of collaboration on other topics and areas.

We also found that different types of collaboration have different impact on citation of articles depending on the topic. Collaboration, as well as international collaboration has greater positive impact on citations of articles in Environmental Economics, Ecosystem Services, Fishery Economics, and Nonmarket Valuation topics. This may be related to the empirical and applied nature of these topics.

Because citations are impacted by the topic within a research area, citation counts and related metrics should be used as measures of performance with great caution, and in the context of a particular research topic. Likewise, caution should be exercised when using citation to determine priority areas as citations do not capture the impact of a research on social welfare. Effort should be spent on developing a measurable indicator to understand the impact on social welfare along with academic impact.

While our paper has generated some valuable insights on the impact of different types of collaborations on the citation rates of articles of different research topics, there is potential to improve the analysis further. First, our analysis reveal that international collaboration is beneficial to generate higher citation rates, however, these benefits should be weighed against cost of carrying out collaboration activities. For some topics or researchers, it may not be optimal to engage in international collaborations due to high transaction cost. Second, while we have found variation in impact of collaboration types on citations rates for different topics, it is important to understand the reasons behind it. Global surveys of researchers from various sub-fields could be conducted to enrich our understanding of the value of different types of collaborations. Finally, temporal dynamics of citations should be analysed more thoroughly as the impacts of different types of collaboration may vary with time.

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