An analysis of the intellectual structure of research on the financial economics of precious metals

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Abstract

We examine the literature on the financial economics of precious metals from a bibliometric and scientometric perspective. We surface the main trends and authors in the area over the last two decades, and provide estimates of the density of the networks of both researchers and research. Clear evidence is provided of an area dominated by a number of high output researchers, with distinct and clear areas of research with little overlap. A probabilistic topic modelling approach is further applied to determine the main topics of research in the area. We conclude that there are significant areas of potential synergy as yet unexploited in this research domain. We also highlight the current topics that can be a particularly important focus for these synergy efforts.

Keywords: Gold, silver, platinum, palladium, bibliometrics, topic modelling

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1. Introduction

What is the intellectual structure of financial economics research on precious metals? Over the last two decades we have seen a significant growth in research interest on these commodities, in parallel with increasing usage of them as financialised commodities. From a few dozen papers per annum in the 1990s to hundreds of papers now, research on this area has shown major growth, with little evidence of it slowing down. As will be seen, this research is global in scale of location of authors and many of the main papers attract hundreds of citations. Moreover, it researches a asset class[1] which is very large indeed in nominal terms. As of end 2018 industry sources suggest (WGC [2019], Appendix 1) a market size approximating for gold alone that of the FTSE100 and a global trade (liquidity) of similar dimensions to that of the UK gilt market. The general industry rule of thumb is that the gold market accounts for 50% of the precious metal market. Scaling up then we see a market which is, arguably, of a similar size to that of the TOPIX or the Chinese bond market and as liquid as the us Agency and Muni market. This is not a niche nor a trivial market.

However, the issue of *what* is being researched *by whom* remains unclear. This paper attempts to begin to unpick this, surfacing some stylised facts on the area. We do this by using traditional bibliometric and scientometric analyses, and augmenting this with the emerging approach of Topic Modelling.

Bibliometrics, the analysis of citation and author networks, as well as its close relative scientometrics, have had significant traction in areas outside finance. In the life sciences, medicine and nursing especially, Cochrane Reviews, deep systemic reviews of an area incorporating meta analyses and bibliometrics, are seen as the gold standard for evidence. A search for "bibliometrics or scientometrics" in Scopus will show that close to a quarter of all papers in this area are in Medicine. The next largest lies in Library and Archival science. In the UK the 2021 Research Evaluation Framework reference documents suggest that bibliometrics will be a major and indeed enhanced component in both suggested submission strategies and in how the review panels form jusgements[2] More critically, Jappe et al. [2018] provides a (Scoiologically focused) overview of the influence of bibliometrics and scientometrics on research evaluation and funding bodies.

[1] Arguably...there is research such as Batten and Lucey [2010] suggests perhaps that we might not consider all four precious metals as a single asset class. Nonetheless, it is the norm to deal with them as such

[2] See https://thebibliomagician.wordpress.com/2018/08/13/metrics-in-latest-ref-documents/ for a discussion and further linkages

After conducting a thorough scientometric analysis it is clear that the broad field of research on the financial economics of precious metals is quite splintered and broadly spread. The output of articles has also been observed to increase substantially year on year. *Hammoudeh* and *Lucey* remain the most dominant authors, even after adjustment for co-authorship. Analysing journal output, *Resources Policy* is found to be a central journal in the field, presenting evidence of the broad scattering of research of precious metals due to this journal's place outside of mainstream financial economics.

Several major clusters are evident when separated by nation, with the US being the most prevalent. Controlled for clusters of coauthorship, two distinct groupings are observed, namely Baur and Lucey; and Pierdoz and Hammoudeh. Accounting for all three measures of centrality presents evidence of Hammoudeh, Gupta, Bacilar and Tiwari presenting as central nodes. Analysing cooccurance networks which use text mining coupled with network modelling, we find that six key clusters of research are identified in which four clusters account for over 95% of the terms analysed. Further, using an LDA topic modelling algorithm we observe that the topics chosen within the context of the domain are of importance, while the growth of the topic at large is sensible there is evidence of selecting out in some journals, where there are distinct clusters of topics within each journal and subset of journal's domains.

The structure of the remainder of the paper is as follows: Section 2 provides a very concise literature review analysing the financial economics underpinning precious metals, while Section 3 describes the data and methodology employed. Section 4 discusses the results, starting with descriptive statistics, then bibliometrics as segregated by coauthorship networks, citation networks, cooccurance networks, bibliometric coupling networks and forward citations. We also extract the key topics in the area in Section 4 and run analytics on these topics. Throughout we examine also the network structure of the networks of papers and authors we surface.

2. The financial economics of precious metals: A very short review

Precious metals, generally taken as being gold, silver, platinum and palladium, have been used as monetary and investment assets from their earliest times. As of 2018 the estimated size of these markets places them amongst the largest of all financial assets. World Gold Council estimates of the size of the gold market place at approx US$3trn, comparable to the size of the UK government debt market. Sizes for the other assets are smaller, but are taken typically as being in total for all

three at the size of the gold market. And yet, so far as we can ascertain there has been no published research on the intellectual structure of this field of research. There have been few comprehensive literature reviews and no formal bibliometric evaluation.

One recent comprehensive review on the literature published on gold is provided by O'Connor et al. [2015] and thus, the literature review here on gold is kept short. For white precious metals, a thorough review is contained in Vigne et al. [2017]. In summary, these papers summarize a large body of research, in a traditional literature survey approach. Gold has been heavily researched for its relationship with inflation, as a hedge against equity and bond portfolios, as a potential "safe haven" asset, and in relation to how it interacts with other assets. There have been many studies of the price and volatility dynamics, and a significant amount of research has investigated the role of gold in historical contexts. Much of this latter has examined its function as a monetary asset. From the economics perspective relatively little attention was paid on ecological or industrial economics, perhaps down to the focus of these researchers on the financial and investment elements. A key takeaway from the gold research is that it has evolved over three main phases. In the 1980s's papers such as Abken [1980] begin the analysis of the post Bretton Woods gold market, focusing on the dynamics of the price. Throughout the 1980's studies such as Rockoff [1984] built on the pioneering work of Machlup [1969] on on the supply-demand relationships of gold. A foundation work in relation to gold as an investment asset is Jaffe [1989], updated by Hillier et al. [2006]. By the 1990s work had begun to look in more detail at the role of gold as an inflation hedge, with works such as Mahdavi and Zhou [1997] and Levin and Wright [2006] examining this, and Bampinas and Panagiotidis [2015] taking a very long perspective, challenged by Lucey et al. [2016] and Conlon et al. [2018]. Gold has also been examined in the context of a possible "safe haven" , with the foundation works being Baur and Lucey [2010] Baur and McDermott [2010] and Ciner et al. [2013].Gold has also had its efficiency examined in many papers, starting with Tschoegl [1980] and Solt and Swanson [1981] onto papers such as Pierdzioch et al. [2014]. Issues about what might be the fundemental price of gold, if any, are well summarized in papers such as Erb and Harvey [2013]

Relatively speaking, less research has been undertaken on the "white" precious metals. Of these by far the largest amount of research is on silver. Much as for gold so also has there been a widespread range of topics investigated. As noted in Vigne et al. [2017] research on platinum and palladium, as investment assets, is scanter again. As we will see in the remainder of this paper,

this focus on gold and on the investment elements is characteristic. Much early research, from the 1980's, examined the hypothesised long run relationship between Gold and Silver. Solt and Swanson [1981] investigated this but perhaps the most impactful papers are Escribano and Granger [1998], Ciner [2001] and Lucey and Tully [2006]. Silver and the other metals have also been examined as possible hedges, with this research summarized in Li and Lucey [2017] which shows that over many periods the white precious metals can be a more effective hedge or safe haven against equity and bond movements than can gold. In terms of its investment potential, exemplar papers would include Hillier et al. [2006] and Charles et al. [2015]. Efficiency issues in the white precious metal markets has mainly been examined in conjunction with gold, but papers such as Aggarwal and Sundararaghavan [1987] and Goss [1983] have examined the market alone.

A large body of literature has also grown up in more recent times on the microstructure of the precious metals markets, sparked by the spread of both databases and products. Studies such as Adrangi et al. [2000], Batten et al. [2013] and Hauptfleisch et al. [2016] examine the highh frequency dynamics of price diffusion and discovery. Papers such as Batten et al. [2018] and Batten et al. [2017] uncover the high frequency stylized facts of gold and silver. The way in which news announcements affects these markets has been examined in Christie-David et al. [2000] and more recently in Mei-Se et al. [2018].

Overall these markets have attracted a wide and growing body of literature. As noted, there exist comprehensive (as of publication) surveys of the literature to which more detailed study should be focused. The remainder of this paper takes the research, highlighted here, and analyses it in a rigerous and scientific manner.

3. Data Selection and Methods

A key aspect of any bibliometric exercise is the selection of the database. The advantage of using Scopus is sourced within its broad and inclusive nature, while it still allows for the extraction of references, institutional and national affiliations among other key characteristics. While Google Scholar (GS henceforth) would provide greater depth, such data are not available in a GS download. Web of Science is also narrower than Scopus. There is a long running discussion in bibliometric research on the comparative merits of these platforms - see as examples, Levine-Clark and Gil [2008],Vieira and Gomes [2009], Franceschet [2010] and Mongeon and Paul-Hus [2016a] - which concludes that each has advantages but all should, ideally, be used. Considerable data cleaning

would be required however to create a blended database of all. In addition, not all meta data are present in all three data bases, in particular Google Scholar [3]. For the analysis in this paper all data are sourced from Scopus, as this captures the widest range of papers with complete reference sets and author/institution metadata in a consistent form. From the authors knowledge of the area we are confident that no significant academic source of papers was omitted. We chose 1990 as a starting point for the research as the further back in any bibliometric database one goes the more scant becomes the coverage. This issue is discussed in Michels and Schmoch [2012] and in Harzing and Alakangas [2016]. Finally, all citation measures, unless otherwise noted, are inclusive of self citation. Waltman [2016], S5.3, contains an extensive discussion of self citation and its effects on scientometric measures and analyses. The conclusion of this section is that in large scale analyses self citation does not overly bias or distort findings. Nor is there any clear finding that for authors, as opposed to say countries or institutions, self citation should pose a problem for scientometric analysis, overall. Core bibliometric approaches involve surfacing the linkages between papers or articles. Here we use, unless otherwise indicated, the number of articles to weight collaboration and linkage. Thus linkages are stronger when say two authors collaborate with each other on 10 papers than would be the case where another two authors collaborate on 5. These linkages lend themselves nicely to graphical presentation, being in essence network models. Graphic models rely on nodes and edges (See Kosnik [2018]) where the nodes here are determined by the individual units of analysis (authors, countries etc) and the edges the linkages between them. In all cases we apply fractional counting, whereby authorship or nationality among other characteristics are scaled to the number of occurrences. Therefore an author appearing in a paper with five others has their linkages weighted $\frac{1}{6}$. Linkages are, unless otherwise noted, based on number of documents. The thicker the connecting lines in the networks the higher the weight. The package VosViewer was used for this analysis, supplemented by Gephi[4] and the R package Bibliometrix[5] (Aria and Cuccurullo [2017].

We further estimate the applicability of Lotka's Law (Chung and Cox [1990]) to the dataset. Lotka's law suggests that the number of publication by authors is best described as an inverse square law. Lotka's Law is formulated as $A = K/X^n$, where K and n are constants. Usually

[3]One issue with all databases, discussed in Mongeon and Paul-Hus [2016b] is that they tend to have an over representation of English language journals at the expense of others.

[4]for analysis of centrality measures and checking of the consistency of the graphs generated from Vosviewer

[5]for preliminary data analysis and measures of author and country dominance

$n = 2$ is the number of authors publishing n papers and X represents the number publishing one paper. This implies that the number of authors publishing X number of articles is a fixed ratio, 2, to the number of authors publishing a single article. We used the R package Bibliometrix (Aria and Cuccurullo [2017] for this analysis. **aaa**

The search strategy used was:

```
(TITLE-ABS-KEY(gold OR silver OR platinum OR palladium)
AND NOT TITLE-ABS-KEY("gold standard"))
AND PUBYEAR >1989
AND(EXCLUDE(PUBYEAR,2019))
AND(EXCLUDE(PUBYEAR,2018))                                    (1)
AND(LIMIT-TO(DOCTYPE,"ar"))
AND(LIMIT-TO (SUBJAREA,"ECON"))
AND(EXCLUDE(EXACTSRCTITLE,"Economist United Kingdom"))
AND(EXCLUDE(PREFNAMEAUID,"UndefinedUndefined"))
```

The last two exclusions were required due to large numbers of papers being returned which were opinion or reportage from The Economist Newspaper, classified as articles by Scopus. All data were downloaded as both CSV and as plaintext, where all information was selected. This allows for the analysis of inward and outward citations, of abstracts and of a wide variety of other bibliometric areas. In total this yielded 1,437 articles.

4. Results

We move now to the main element of the paper, a scientometric analysis of these papers. In summary our findings are that the field is rather splintered. There is clear evidence of disconnected research endeavours, across thematic and national boundaries.

4.1. Descriptive statistics

Shown in Table 1 are some stylized facts. Over the period we have seen 1,437 articles, which have generated 15,093 forward citations from 4,765 individual sources. The papers have been very widely spread, with 427 individual sources represented. In total 3,067 authors have contributed, with 405 of these single authors. The preponderance of articles are multi-authored, with only 405 being

single authored. Such multi-authoring is increasingly common in economics. Card and DellaVigna [2013] finds, for the top 5 journals that the mean number of coauthors stands at 2.2, somewhat more than that identified in our research where the average number of authors per article is 1.75. The clear growth in the number of publications on an annual basis is evident from Figure 1. This perhaps more reflects increasing coverage by Scopus than an increase in topic interest, although it is not possible to ascertain if this is actually the case. An interesting possibility is that the growth in articles published broadly parallels the growth of the gold price (measured on an annual average basis). Perhaps the growth in importance of gold as an asset is a driver of researcher interest. This feedback loop has not been investigated. A qualitative analysis and review of motivation towards research topics might pay dividends here.

The top ten authors are listed in Table 2, with two, Hammoudeh and Lucey, clearly dominant. What is striking is that these authors have not collaborated, to date of publication. When we adjust for co-authorships, this remains the same. However, in the context of the number of papers overall we do not see an overwhelming dominance. Although there are bibliometric methods available to calculate the importance of authors (Kumar and Kumar [2008]) these typically rely on the notion that author order is meaningful. In economics and finance, author order is not generally an issue, with the preponderance of papers being alphabetically ordered (Kuld and O'Hagan [2018]). Thus we cannot easily say, beyond citation counts, which author or set are "more important" than others. It is also interesting that only one, Lucey, appears as an author of a "top ten cited papers" as we see in Table 2.

Output is more concentrated, as we can see in Table 3. One journal, *Resources Policy* is very much the locale of choice for publications in this field with almost 50% of the articles in the top 10 outlets being from Resources Policy. As Resources Policy is not a mainstream finance journal, this gives our first suggestion that the financial economics of precious metals is an area that is somewhat scattered, in terms of publication and the locale of choice for publication. Again, this concentration is at odds with the findings of Table 2.

Shown in Table 6 are the most cited papers in the field. There is a very eclectic mix of sources in this set, from mainstream finance journals through field journals. What is interesting is that the first five papers might be considered tangential to the main thrust of the discussion of the financial economics of precious metals. It is only when we come to the papers on safe haven status that we move directly into the issues of what the financial aspects might be. This paper set have been very

heavily cited, with compound year on year increases in citation counts of 20% and more [6].

4.2. Bibliometric analysis

The theoretical and empirical Lotka's law plots are shown in Figure 3. Empirical analysis suggests that there is perhaps a distinct difference, especially in the tails, and this is as evident from the visual overall[7]. Lotka's Law *appears* to hold in this literature, at the conventional 5% level of significance. Such a finding is similar to that found in a variety of fields such as risk management, [Chun-Hao and Jian-Min, 2012], entrepreneurship, [Lopes and Leite, 2016], business ethics , [Talukdar, 2015] or marketing [Vieira and Brito, 2015]. However, and importantly, there exists clearly a large tail of authors who have published a single paper, compared with what one might expect. It seems to suggest that authors may "dip into" this domain but not concentrate on it as a field of endeavour. The concentrated nature of the field therefore suggests that those working in the area exercise vigilance to ensure that group-think is minimised.

4.2.1. Coauthorship networks

A key aspect of uncovering the latent intellectual structure of a corpus is to evaluate the degree to which different elements work together. First, we evaluate co-authorship networks. To evaluate the most impactful trends and to limit the amount of visual clutter, we limit the analysis, in general, to authors who have published 5 or more papers. In Figure 4, we observe coauthorship across countries. Several major clusters are evident. The largest cluster of coauthorship is centred around the USA, with several other groups nearly as large. Recall from the clusters of authors we saw two main clusterings, around Hammoudeh and Lucey. Hammoudeh is based in the USA, which perhaps explains this cluster. The others however are less self explanatory. We show in Table 7 the membership of the clusters. Meanwhile, Figure 5 shows the coauthorship patterns across individuals, with the threshold set again at a minimum of 5 publications. We see a very sparse network here, with only 25 authors represented. Clearly this is an area where there is a high concentration of authors. We focus in Figures 6 and 7 on the two main groupings, with the cluster members noted in Table 8. Here it is clear that even within this sparse network we see two very distinct groupings: a cluster revolving around Baur and Lucey; and one around Pierdoz and

[6] Based on authors calculations. sourced from Scopus April 2019

[7] A formal test, gives a β coefficient of 2.5138, and based on a Kolomogorov-Smirnov test, a p-value of 0.07. We thus suggest that there is no difference between the theoretical and empirical distribution.

Hammoudeh. Baur and Lucey clusters are linked with the Safe Haven paper while both authors also have separate clusters, Baur with Beckmann and Czudag, a german originating cluster, although on closer examination this is a "chain" formed of two separate links, Beckmann and Czudaj and then Baur and Beckmann. Lucey-Batten-Ciner (Ireland, Australia and USA) form a closer knit set of relationships. We can see these two types of identified clusters in the other main grouping. Hammoudeh has close links with Reboredo and also with Nguyen, but these two are not directly linked. Meanwhile Gupta-Shabaz-Balcilar-Tiwawi all share links with each other.

Such author networks can be termed "social networks". A social network consists of a set of nodes, where authors and the connections between these nodes are observed. The density and number of a nodes' ties (direct connections via coauthorships) is its node's degree. Here a scholar's degree centrality in effect measures the number of people who have coauthored a paper with this scholar. Andrikopoulos and Economou [2015] note the different measures of centrality which have been proposed. A node can be important by standing on the path between two nodes; a measure called *betweenness centrality* which measures the number of shortest paths which pass through a given node, normalized for the network size. A node can also be central in the sense that it is itself connected to nodes that are themselves degree-central; this is termed *eigenvector centrality*. Shown in Table 9 are these measures of centrality. Four authors: Hammoudeh, Gupta, Bacilar, and Tiwari appear in all three measures. We note here that these four all consist however of one cluster grouping, which consists of two subclusters and which links to a third (Risse etc). Mathematically therefore it is inevitable that authors from these clusters would show strongly in these measures. It also shows the difficulty in drawing deep meaning from these metrics alone, absent an analysis of the underlying geography of the clusters.

A takeaway from this set of analysis is clear however - there is great scope for futher co-authorship and cross national collaboration.

4.2.2. Citation networks

A citation network is a graphical representation of how often elements of the graph cite each other. We show this in Figure 8 for sources and Figure 9 for countries, and the tables showing cluster memberships are shown in Tables 10 and 8. The source citation network is dominated by *Resources Policy* and the nation by the USA. Cluster 2 in the source citation network can be characterised as being the core financial and economic journals, such as *Journal of Banking and*

Finance, *Journal of Empirical Finance* and *International Review of Financial Analysis* ; Cluster 3 is also finance, but also economics and commodity related; Cluster 1 is dominated by *Resources Policy* and consists also of industrial, ecological and history journals. Again, we can conclude that there are reasonably distinct islands, wherein members of the islands cite within the cluster but less so outside. This also suggests a scope for further cross disciplinary and cross idea research.

4.2.3. Co-occurance networks

An interesting approach in bibliometrics is to couple network modelling with text mining. To do this we create networks of terms, again on the same conceptual basis as before. In the case of material exported from Scopus it is possible to use some or all of the Author Keywords, the publisher created Index Keywords, and the Abstract. As we feel that the authors of a paper should be the ones that have the best feel as to what areas are spoken to by the paper, we used the Author Keywords and Abstract. Shown in Figure 13 is the outcome of this process for Keywords and in Figure 11 are the results for the abstract. We further show detailed analyses for the main clusters of the keywords, in Figure 14. Six clusters are identified. The four main clusters are the largest, accounting for in excess of 95% of the terms. These clusters are for the most part quite distinct which suggests an opportunity for papers to bridge this gap. The *financial cluster* revolves around the price dynamics, financial asset aspects of precious metals, looking at material such as portfolio analyses, safe haven issues and the role of gold in relation to other assets. The *ecological cluster* examines issues around mining economics, sustainability and the commodity-currency nexus. The *industrial economics* cluster examines some aspects of the environmental area but also mining economics and the role of precious metals in industrial and commercial processes. Finally a cluster around *monetary issues* emerges, despite that we had excluded the gold standard as a topic. This cluster overlaps economic history and the role of modern central bank reserves in gold prices, and also clusters with the determination of adornment and collectible precious metal holdings.

For the abstracts we have, as might be imagined, a very large number of terms - in excess of 22,500. We limit, as is our convention, to terms that have more than 5 appearances, which reduces this to 1,210 and it is on this that we perform our analyses. We see from Figure 11, four distinct clusters. These clusters are for the most part quite distinct which suggests an opportunity for papers to bridge this gap. The financial cluster revolves around the price dynamics, financial asset aspects of precious metals, looking at material such as portfolio analyses, safe haven issues and the role of

gold in relation to other assets. The *ecological cluster* examines issues around mining economics, sustainability and the commodity-currency nexus. The industrial economics cluster examines some aspects of the environmental area but also mining economics and the role of precious metals in industrial and commercial processes. Finally a cluster around monetary issues emerges, despite that we had excluded the gold standard as a topic. This cluster overlaps economic history and the role of modern central bank reserves in gold prices, and also clusters with the determination of adornment and collectible precious metal holdings. This is further refined in Figure 12 where we increase the threshold to 10 occurrences. We now see a very clear split, one cluster primarily orientated towards an economic and financial perspective, the other, very starkly separate, examining what we might call the industrial and ecological aspect. It would seem clear from this that there is a gap, and thus an opportunity, for research which spans this area. Why there is so little crossover is intriguing. It may be down to the lack of cross fertilisation of economics and ecology in the great majority of undergraduate and graduate training. Economics PhD's overwhelmingly study macroeconomic, financial or labour areas[8]. in addition, Angrist et al. [2017] examines the evolution of economics research over a lengthy period. Development economics, where students would be exposed mostly to this area, accounts for $< 10\%$ of research and half that when we weight by top journals. Thus, there is an arguable lack of exposure, leading to a lack of opportunity to cite and possible consequent lack of overlap.

4.2.4. Bibliometric coupling networks

Bibliometric coupling is a situation where two articles or other domains share common reference sets. We show in Figure 18 a bibliometric coupling for sources. Typically, bibliometric coupling for authors and nations tend to be very similar to those for citation networks. We find that of all the sources, when we impose a 5 article cutoff we resolve to 64 sources, the largest connected component of these being a mere 57. Shown in Table 11 are the cluster members. *Resources Policy* is again clearly at the center of the reference set typically used in this discipline. It clusters with environmental and industrial journals, primarily. There is a significant dispersion in this cluster, with three elements: the Resources Policy cluster; one on economic history; and one on ecology and conservation. The second cluster, centered around *International Review of Financial Analysis*

[8]https://80000hours.org/career-reviews/economics-phd/

and *Journal of Futures Markets* is clearly a financial economics cluster while there is also a evident cluster on commodities with *Energy Economics*, *Journal of Commodity Markets* (a relatively new journal) and *Economic Modelling* dominating. The takeaway from this is clear, there are pockets of research that draw from distinctly different research streams. It is also clear that the new Journal of Commodity Markets has already made a clear impact.

4.2.5. Forward citations

Forward citations are citations to articles in the reference set, whether these are also in the reference set or elsewhere. We find 15,093 forward citations to our reference set, from a total of 4,765 individual sources. The top forward citing sources are given in Table 12. Again we see the dominance of *Research Policy*. What is perhaps surprising is the strong pickup of papers in *Energy Economics*, recalling that Energy Economics is not in the top output sources, nor is the next journal, *Journal of Cleaner Production* nor the next again, *Ecological Economics*. The papers cited in Energy Economics and Journal of Cleaner Production tend to be papers on the price dynamics of precious metals, cited in the context of analogies and counterpoints to issues in energy related commodities. This suggests that the growth in research in the precious metals domain has allowed broader commodity researchers to draw on this research in relation to their own research, placing this area clearly at an intersection of financial and commodity research.

4.3. Topic modelling

Topic modelling involves grouping similar documents within a corpus to identify the sub-topics around which the documents of that corpus cluster. The most popular approach is Latent Dirichlet Allocation (LDA) following the development work of Blei et al. [2003] and as outlined in Blei [2012].

A first step is atomizing the documents in a corpus. In our case we have abstracts for all articles in the dataset. The abstracts then are the documents, and atomizing them separates them into vectors of individual words (terms). We then have an initial matrix of document-terms. From these document terms we remove stop words (common words such as 'and', 'of', 'the'). We then stem the remaining words to reduce the unique count further - with stemming we pair words back to a common stem, so for example finance, finances, and financing, might be all reduced down to a term 'financ'. The document-term matrix (DTM) values are now a count of occurrences of stemmed words per document. The last step is to remove very rare words across the matrix that are unlikely to identify a broad topic. We remove words mentioned in five or less documents. We also remove

very frequent words using a process called TF-IDF (Term Frequency - Inverse Document Frequency) (Salton and Buckley [1988]), on the grounds that very frequent words are too broadly used to be able to identify individual topics. Standard practice is to remove about 10% of the highest TF-IDF terms and this in our DTM removes words such as 'research', 'testing', as well as very common precious metals works.

With the DTM now suitably reduced, we proceed to the LDA topic extraction. Following Blei et al. [2003] we commence a probabilistic optimization process to attach topics to words and topics to documents. The assumption is that each document consists of a range of topics and this is determined by the topics of words. The intuition behind this is that research normally consists of blending together a number of topics - thus e.g. an article on Indian gold pricing might be 20% Indian topic context, 30% gold topic context, and 50% methodologies of pricing mechanisms - and words chosen reflect that topic mix. The LDA approach to topic modelling is so called because it uses Dirichlet priors to start the estimation of word allocation to topics and topic allocation to documents. A Dirichlet distribution is a distribution that can create probability vectors, in our case it is the starting point for determining how to map words and documents across topics. We use Bayesian updating after initial Dirichlet allocation with a variational inference to infer from the model the appropriate topics. This process is well-described in Boyd-Graber et al. [2017].

LDA topic modelling is widely used in Computer Science and expert systems, and in engineering. It is less prominent in social sciences, economics or business. [9]. Recent applications in economics include Ambrosino et al. [2018] examining a very large corpus of JSTOR papers, surfacing topics in economics over the 1845-2013 period; Wehrheim [2018] applying topic modelling to the corpus of the Journal of Economic History. Outside of economics, Liu et al. [2018] surfaces the topics of the field of Business Ethics, while Wang et al. [2015] mines the corpus of papers published in the Journal of Consumer Research.

While there do exist formal methods to aid in the selection of the number of topics, the number of topics is usually chosen ex-ante based on an assessment of topic keywords as a preference. We experimented from small (3, 5) to larger (10, 12, 15) numbers of topics. 10 topics seemed, based on the judgment of the authors, to provide a balance between too coarse a set of topics (vague

[9] Of approx 4300 papers on Topic Modelling in Scopus as of late 2018, fully half were in CS while 15% were in engineering and only 258 papers were in business and economics disciplines

topics) and too fine-grained (overlapping topics). The LDA algorithm allocates sets of words to the topics and we have labelled these into meaningful topic names. See Table 13 for a mapping of the actual words chosen to the topic names. Shown in Fig 15 are the evolution of topics over time, and in Fig 16 topic distribution over the top 10 journals. Shown in Fig 17 is the breakdown of topic distribution as between the top 10 journals and other journals.

A number of points emerge from this analysis. First, the topics chosen are meaningful and sensible within the context of the domain. Second, the evolution of the topics over time is sensible. We see for example a large increase in papers looking at risk and return post 2008. This reflects the general increase in risk related research post the onset of the GFC and also the rise in gold prices (See O'Connor [2015] for a discussion of the contemporaneous evolution of gold prices and gold related research). Perhaps a surprise is the relative importance of Silver as a topic, and how it has declined markedly over time. Third, we see some selecting out in journals. Figure 16 suggests that CSR and sustainability is very much the domain of Resources Policy, Med. Journal of Social Sciences, and Ecological Economics, with very little in the more mainstream finance and economics journals. Within these, Applied Financial Economics, Applied Economics Letters and Journal of Futures Markets are heavily populated with volatility studies. Economic Modelling, International Review of Financial Analysis and Finance Research Letters contain large elements of papers examining FX and Inflation. Authors who are seeking a journal to which to submit should find such a clarification of the observed topics useful in considering where to place. Finally, from Figure 17 we note that the topic distribution is uneven as between the top 10 journals and the rest. There is very little in the way of silver research in the top 10, while well over half of Engineering Economics (albeit mainly confined to the journal Resources, Conservation and Recycling) is within the top 10.

5. Discussion and conclusions

We have surfaced the intellectual framework of precious metals research in economics. The field is dominated by a few researchers, and is characterised by a number of distinct research agendae. There is significant international collaboration. Research on the economic aspects of gold is overwhelmingly the approach, with white precious metals being significantly less researched. After conducting a thorough scientometric analysis, one key result is clear. The broad field of research on the financial economics of precious metals is quite splintered and broadly spread with

3,067 authors contributing and the average number of authors per article is less than that of the top 5 journals at 1.75. The output of articles has also been observed to increase substantially year on year. *Hammoudeh* and *Lucey* remain the most dominant authors, even after adjustment for co-authorship. Analysing journal output, *Research Policy* is found to be the central journal in the field, presenting evidence of the broad scattering of research of precious metals due to this journal's place outside of mainstream financial economics. Analysing the bibliometrics of broad papers within the field through coauthorship networks, citation network and cooccurance networks presents further results of note. Several major clusters are evident when separated by nation, with the US being the most prevalent. Controlled for clusters of coauthorship, two distinct groupings are observed, namely Baur and Lucey; and Pierdoz and Hammoudeh. Accounting for all three measures of centrality presents evidence of Hammoudeh, Gupta, Bacilar and Tiwari presenting as central nodes.

Analysing cooccurance networks which use text mining coupled with network modelling, we find that six key clusters of research are identified in which four clusters account for over 95% of the terms analysed. The financial cluster based on precious metals focuses on areas of price dynamics financial asset aspects of precious metals, portfolio analyses, safe haven issues and the role of gold in relation to other assets. While ecological and industrial clusters focus on issues such as mining and environmental issues respectively, a final cluster based on monetary issues focuses specifically on the gold standard as a topic which incorporates economic history and the role of gold in central banking. Conducting a similar analysis on over 22,500 identified abstracts produces similar results. Using an LDA algorithm we present evidence of the evolution of research on precious metals over time and the development of the topic within the top journals. This leads to a number of observations, namely the topics chosen within the context of the domain are of importance, while the growth of the topic at large is sensible, there is evidence of selecting out in some journals, where there are distinct clusters of topics within each journal and subset of journal's domains. Further, authors who are considering submission in the broad field of precious metals should strongly consider these latter results to identify such a clarification of the observed topics.

From the perspective of researchers in the field, a key finding here is that the field is fractured. Thus there is great opportunity for researchers who reach across the fractures. One major gap exists in the split between the industrial/ecological area and the financial economics area. Editors and conference organisers who wish to make impact might consider soliciting papers and research

which aims explicitly to bridge this gap. Equally industry might seek to promote such research. One context in which the two areas can be housed is along the achievement of the Sustainable Development Goals, such as emerging in the research on 'green finance'.

A second set of gaps relates to the researchers, with two clear sets of related researchers operating in isolation each from the other. Both sets, it is interesting to note, are active in the financial economics area.

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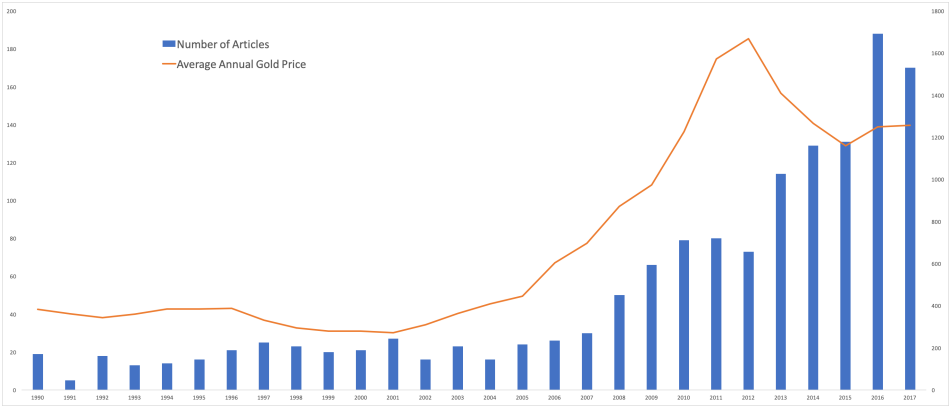
Figure 1: Publications Per Annum



Note: The above bars represents the number of articles published per year as calculated using Scopus. The line represents the average monthly price of gold.

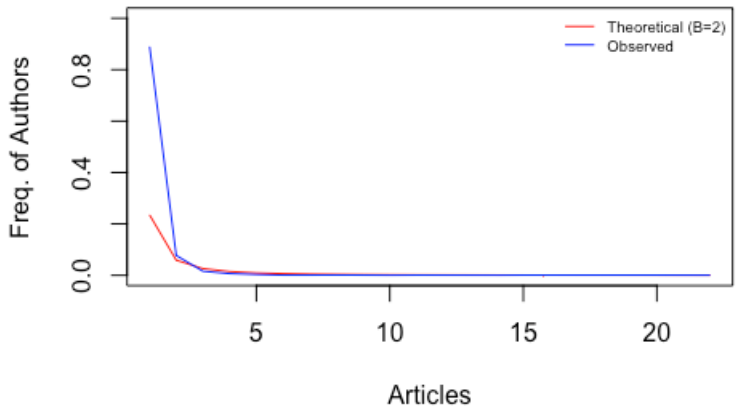
Figure 2: Associated Wordclouds for Abstracts and Keywords

(a) Abstract Wordcloud

(b) Keyword Wordcloud

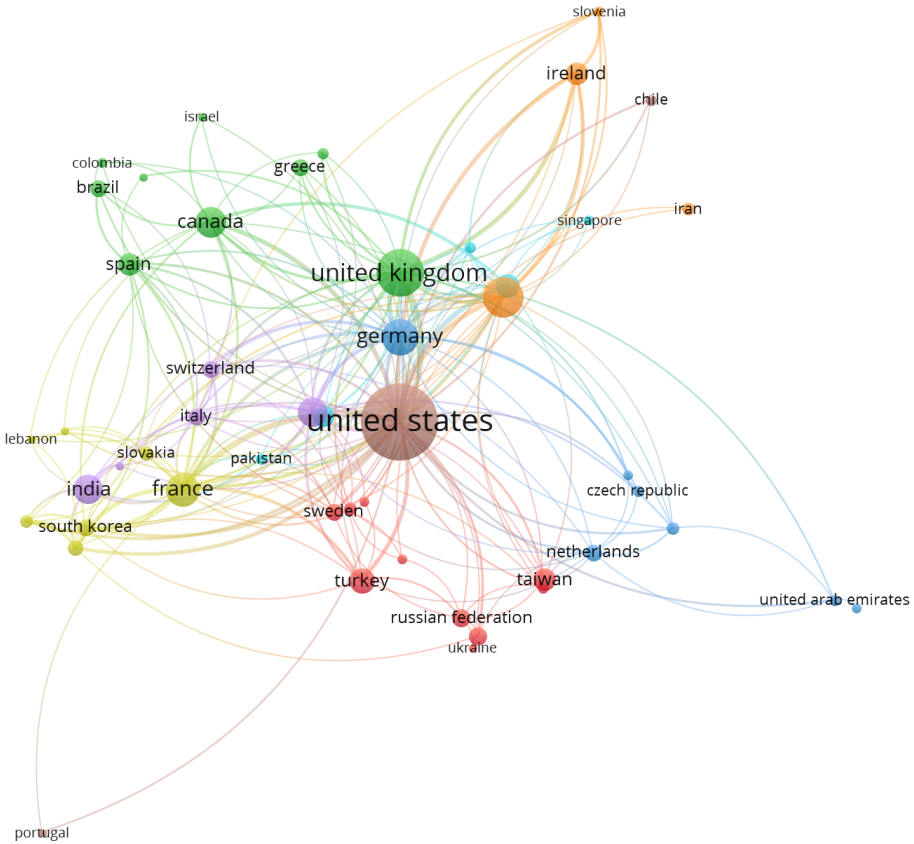
Note: The above wordclouds represent a visualization of the key words typically associated with the abstracts and keywords of the analysed research publications.

Figure 3: Lotka's Law



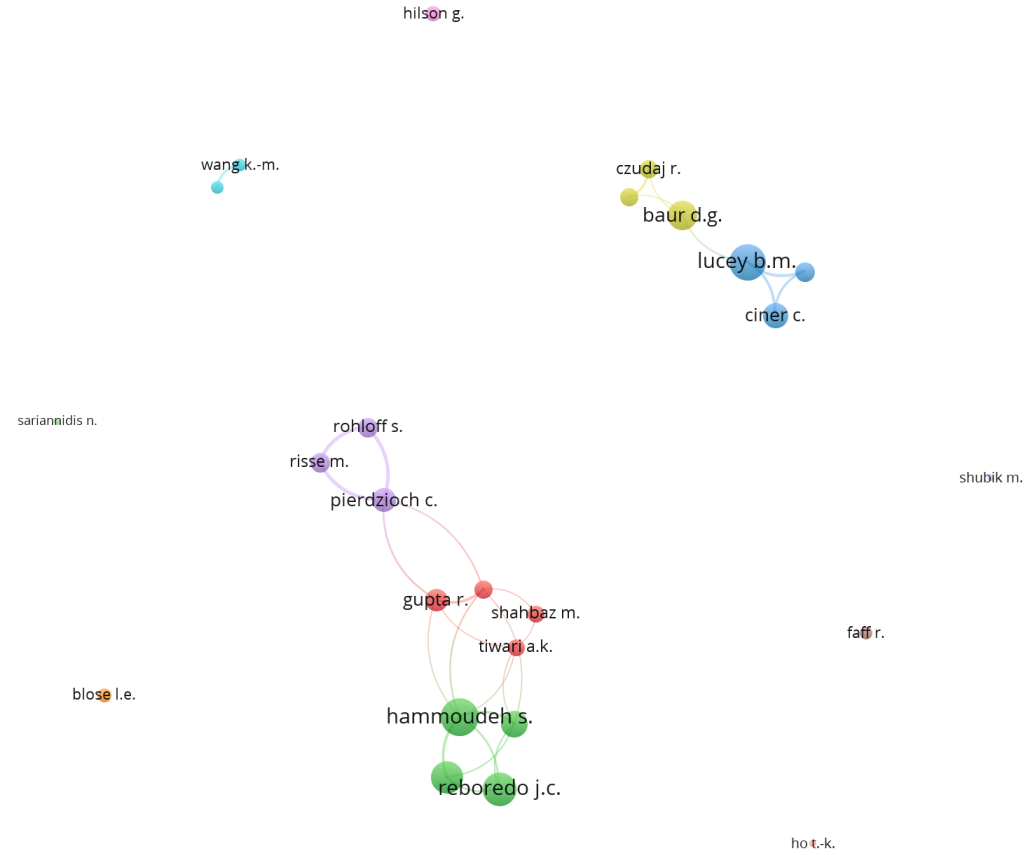
Note: Lotka's law suggests that the number of publication by authors is best described as an inverse square law. Lotka's Law is formulated as $A = K/X^n$, K and n are constants, usually n=2, A is the number of authors publishing n papers and X the number publishing one paper. This implies that the number of authors publishing X number of articles is a fixed ratio, 2, to the number of authors publishing a single article. We used the R package Bibliometrix (Aria and Cuccurullo [2017] for this analysis.

Figure 4: Coauthorship Patterns across countries



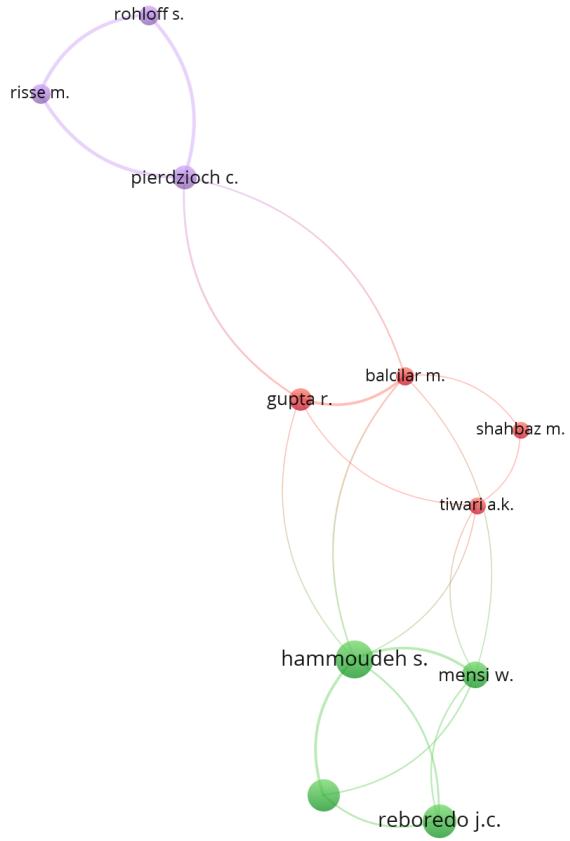
Note: To evaluate the most impactful trends and to limit the amount of visual clutter, we limit the analysis to authors who have published 5 or more papers. In the above figure we see the coauthorship across countries. The above figure is prepared using VOSviewer which is a software tool for constructing and visualizing bibliometric networks.

Figure 5: Coauthorship Patterns across Authors



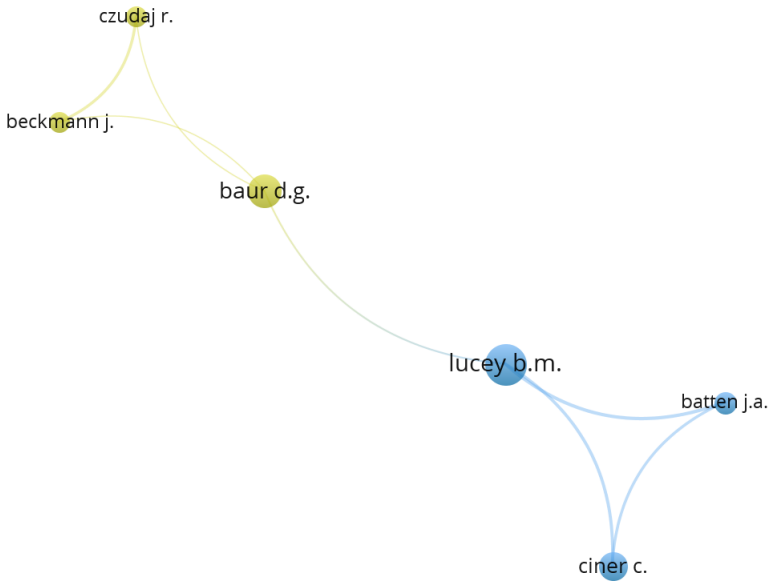
Note: In the above figure we see the coauthorship as analysed using clusters of the main authors in the field. The above figure is prepared using VOSviewer which is a software tool for constructing and visualizing bibliometric networks.

Figure 6: Coauthorship Patterns across Authors - Component 1



Note: In the above figure we see the coauthorship across countries. The main groupings, with the cluster members, are noted in Table 8 The above figure is prepared using VOSviewer which is a software tool for constructing and visualizing bibliometric networks.

Figure 7: Coauthorship Patterns across Authors - Component 2

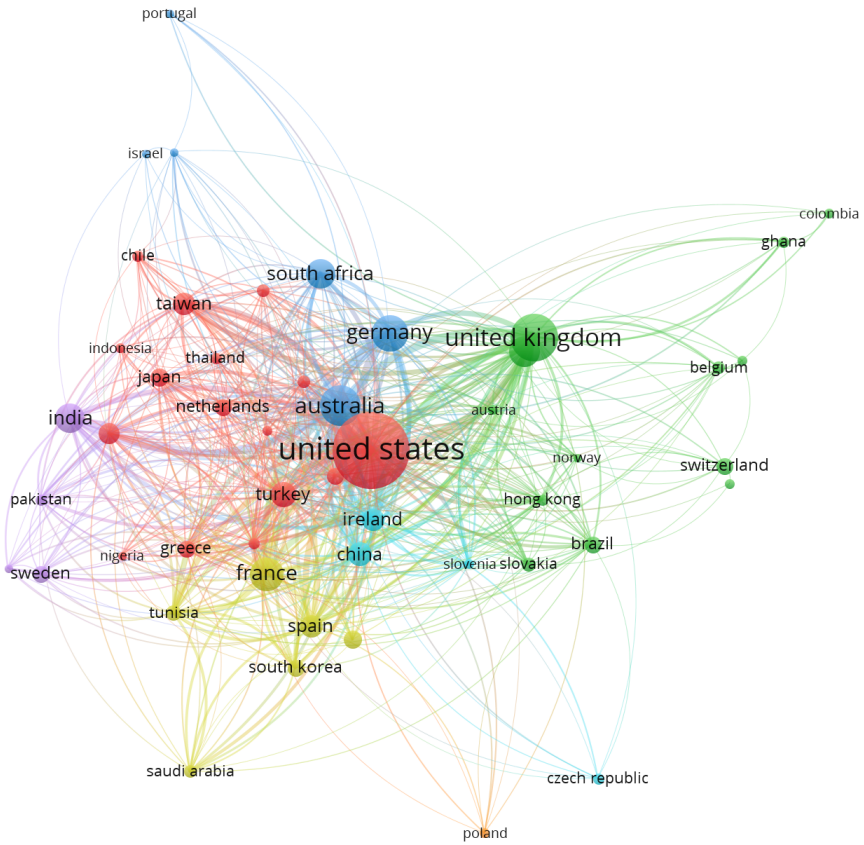


Note:In the above figure we see the coauthorship across countries. The main groupings, with the cluster members, are noted in Table 8 The above figure is prepared using VOSviewer which is a software tool for constructing and visualizing bibliometric networks.

Figure 8: Citation Pattern across Sources

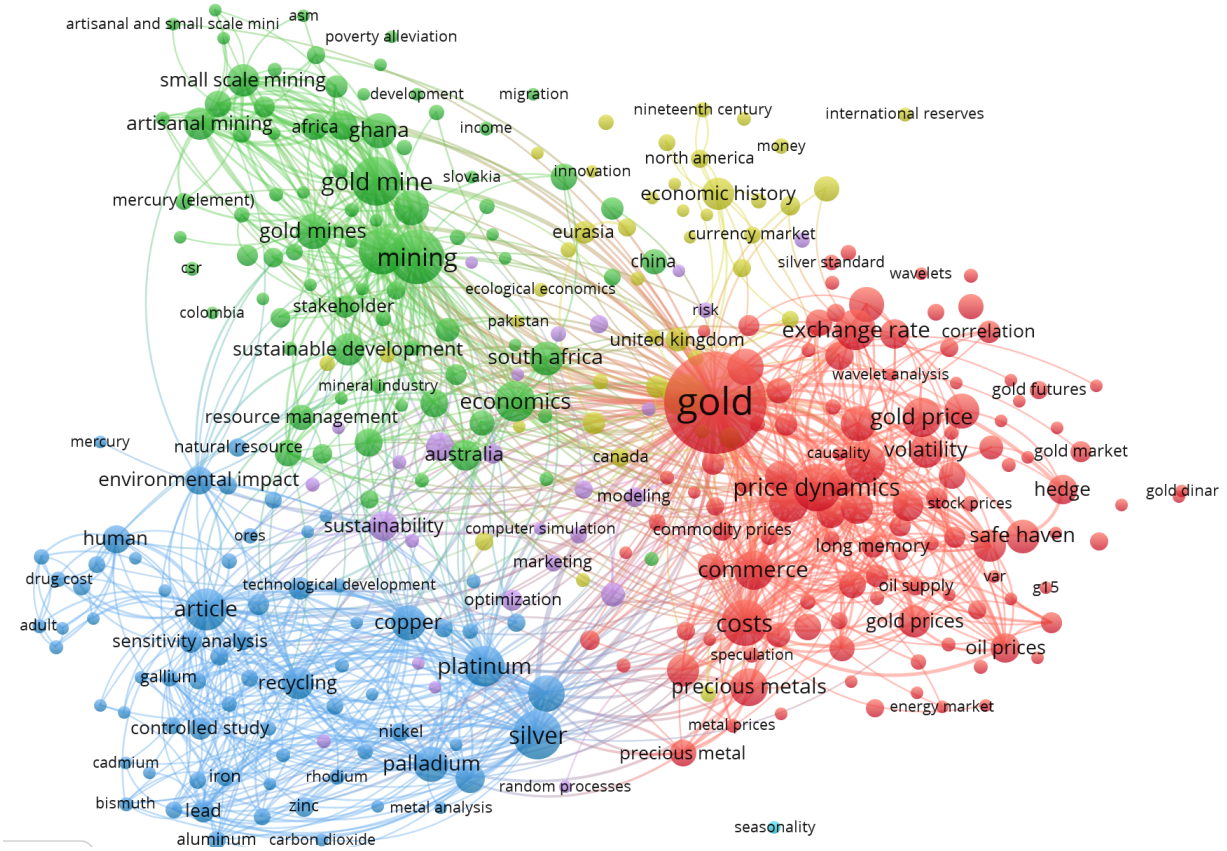
Note: A citation network is a graphical representation of how often elements of the graph cite each other. We show this in the above figure for sources, and the table showing cluster memberships are shown in Table 8. The above figure is prepared using VOSviewer which is a software tool for constructing and visualizing bibliometric networks.

Figure 9: Citation Pattern across Countries



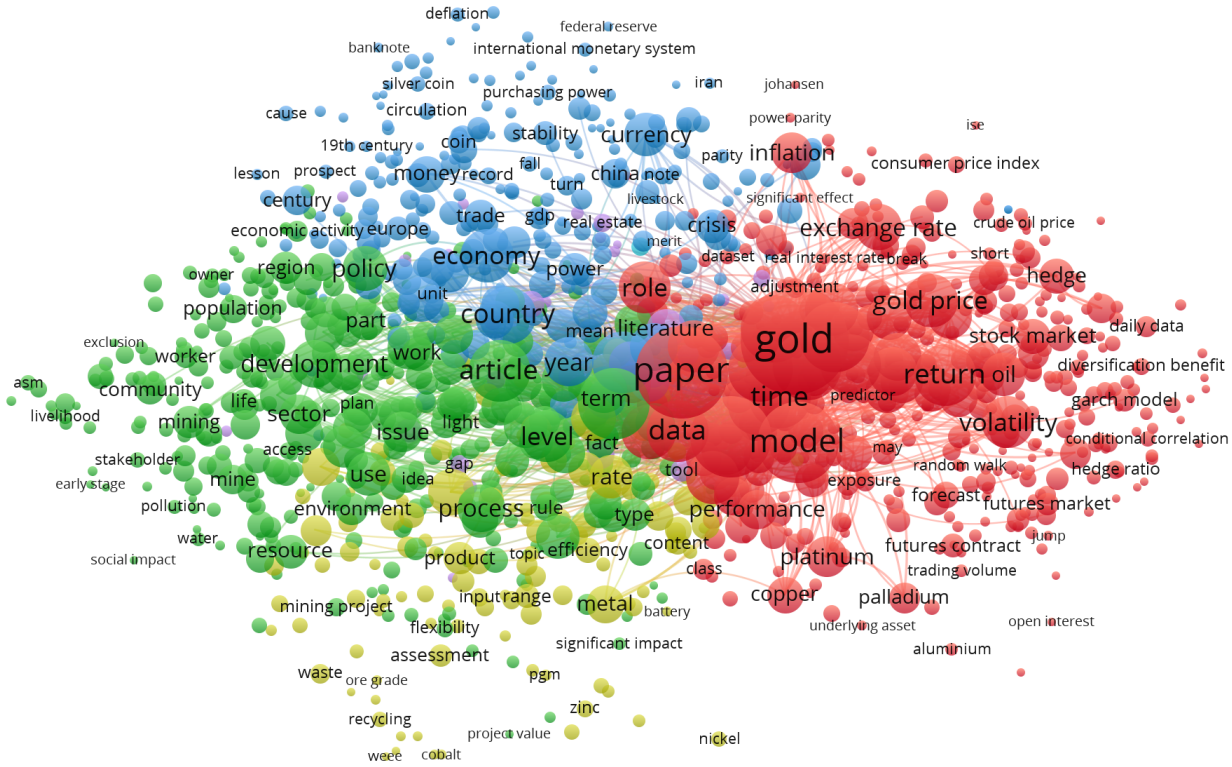
Note: A citation network is a graphical representation of how often elements of the graph cite each other. We show this in the above figure for countries, and the tables showing cluster memberships are shown in Table 8. The above figure is prepared using VOSviewer which is a software tool for constructing and visualizing bibliometric networks.

Figure 10: Keyword Cooccurance



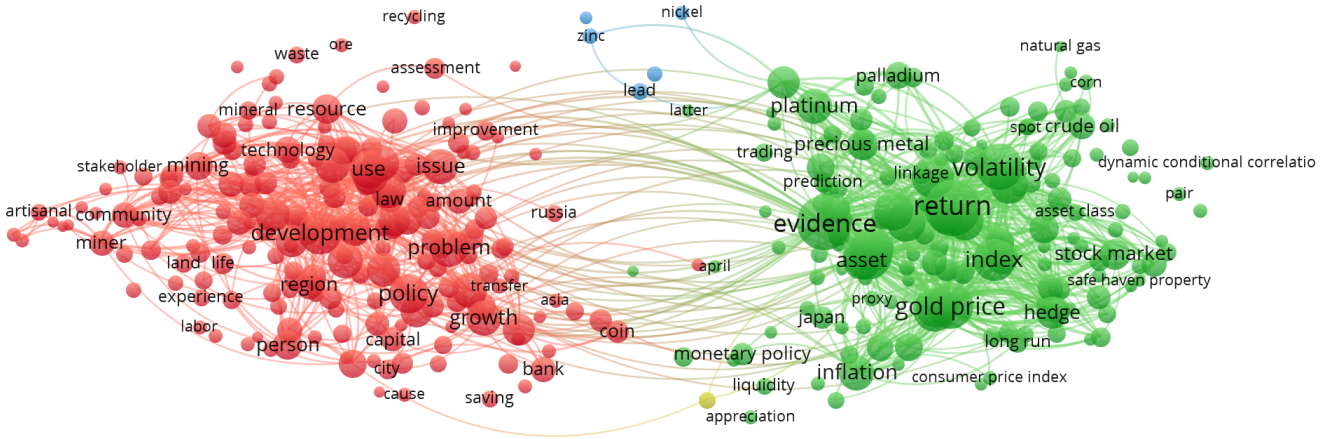
Note: In the above figure we create networks of terms. In the case of material exported from Scopus it is possible to use some or all of the Author Keywords, the publisher created Index Keywords, and the Abstract. The above figure is prepared using VOSviewer which is a software tool for constructing and visualizing bibliometric networks.

Figure 11: Abstract Cooccurance



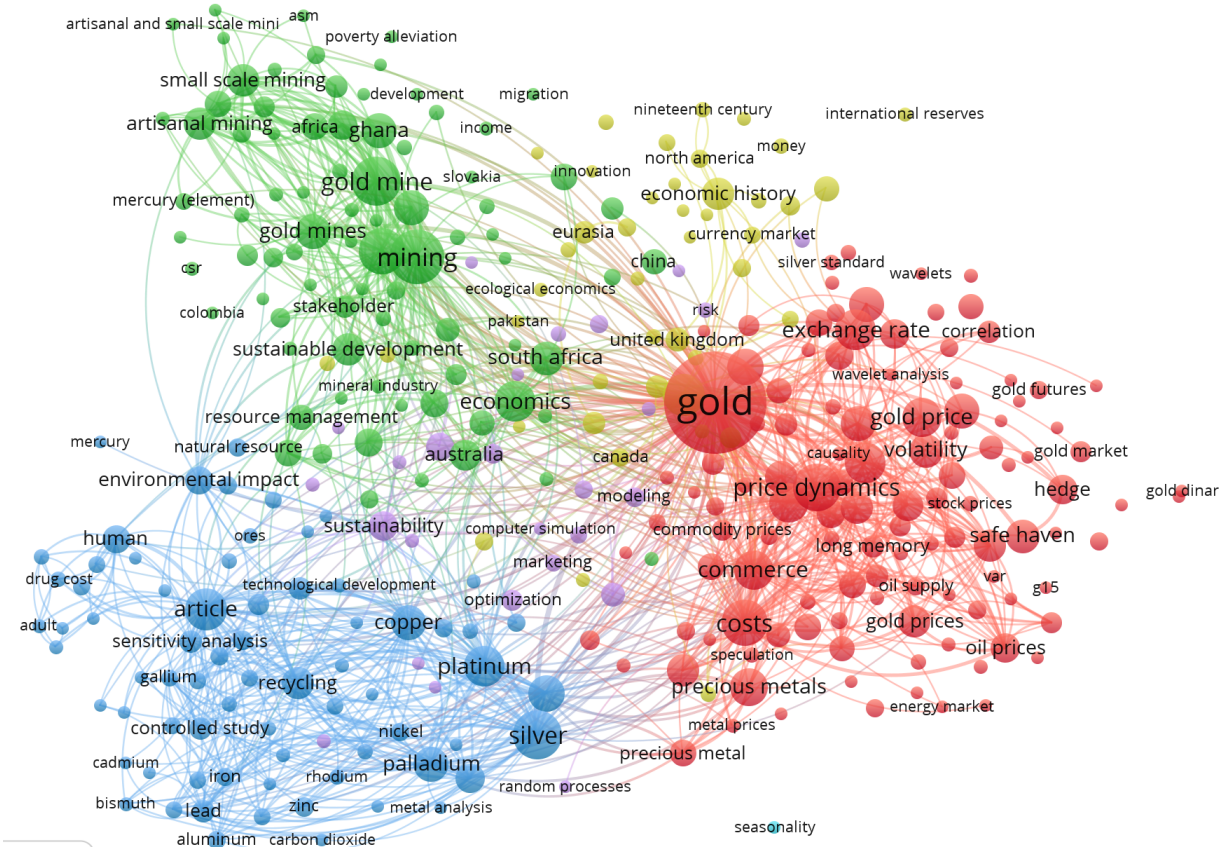
Note: In the above figure we create networks of terms. In the case of material exported from Scopus it is possible to use some or all of the Author Keywords, the publisher created Index Keywords, and the Abstract. The above figure is prepared using VOSviewer which is a software tool for constructing and visualizing bibliometric networks.

Figure 12: Abstract Text Mining



The above figure is prepared using VOSviewer which is a software tool for constructing and visualizing bibliometric networks.

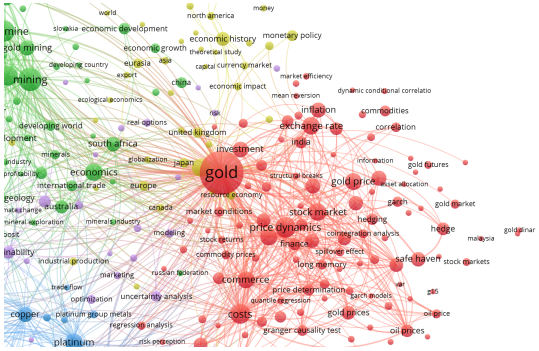
Figure 13: Keyword Cooccurance - Overall



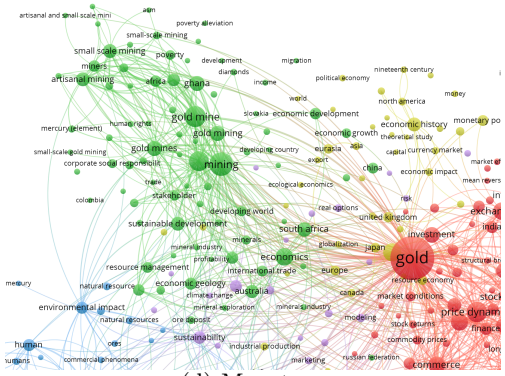
Note: In the above figure we create networks of terms. In the case of material exported from Scopus it is possible to use some or all of the Author Keywords, the publisher created Index Keywords, and the Abstract. The above figure is prepared using VOSviewer which is a software tool for constructing and visualizing bibliometric networks.

Figure 14: Four Main Clusters of Keywords

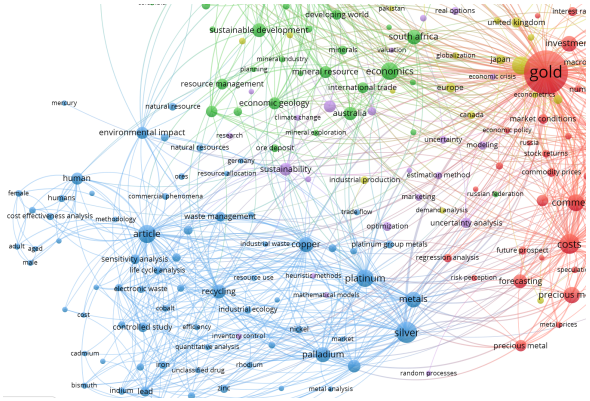
(a) Financial



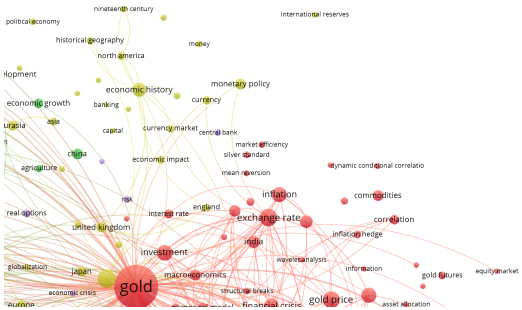
(b) Environmental



(c) Ecological

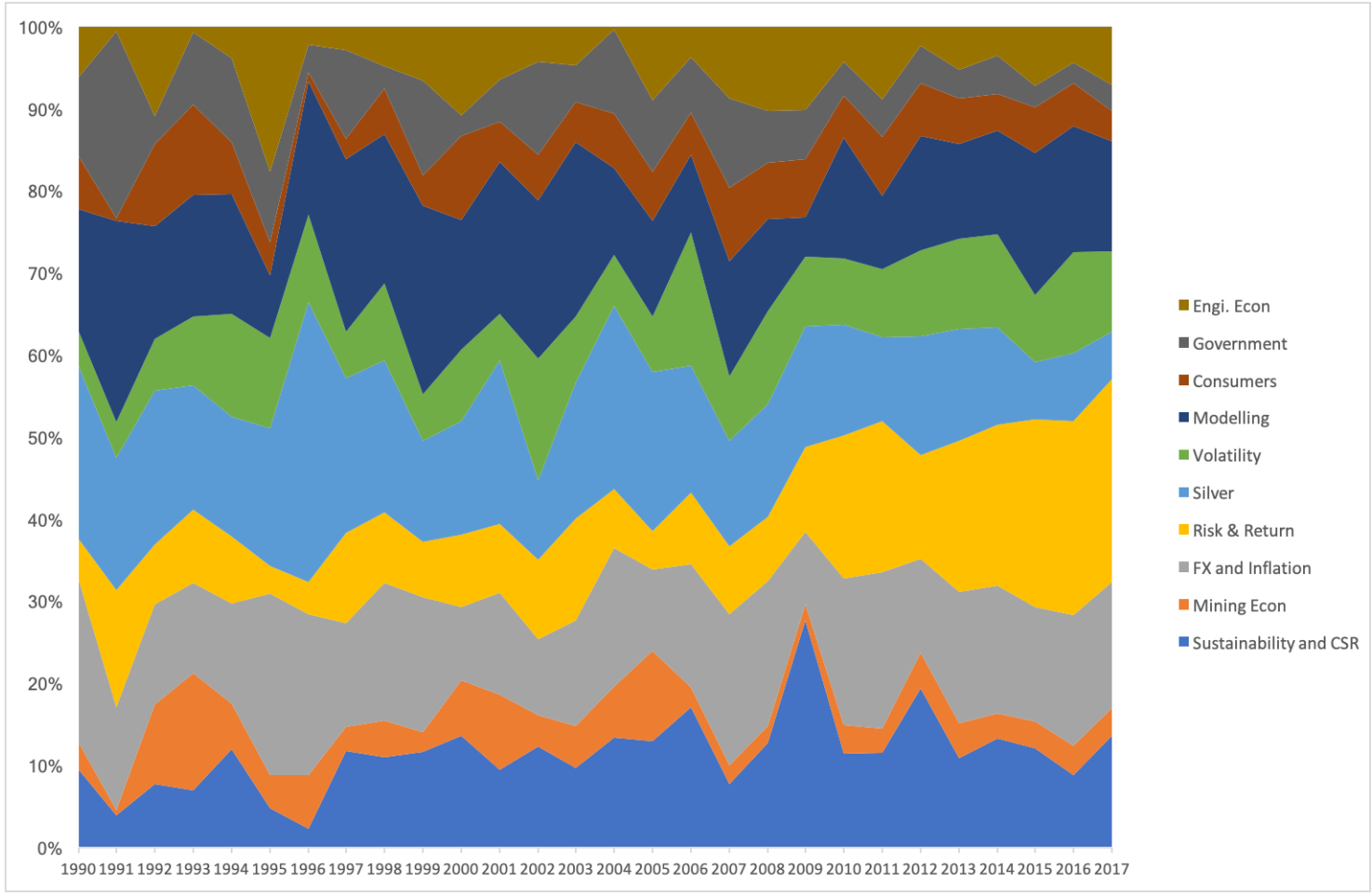


(d) Monetary



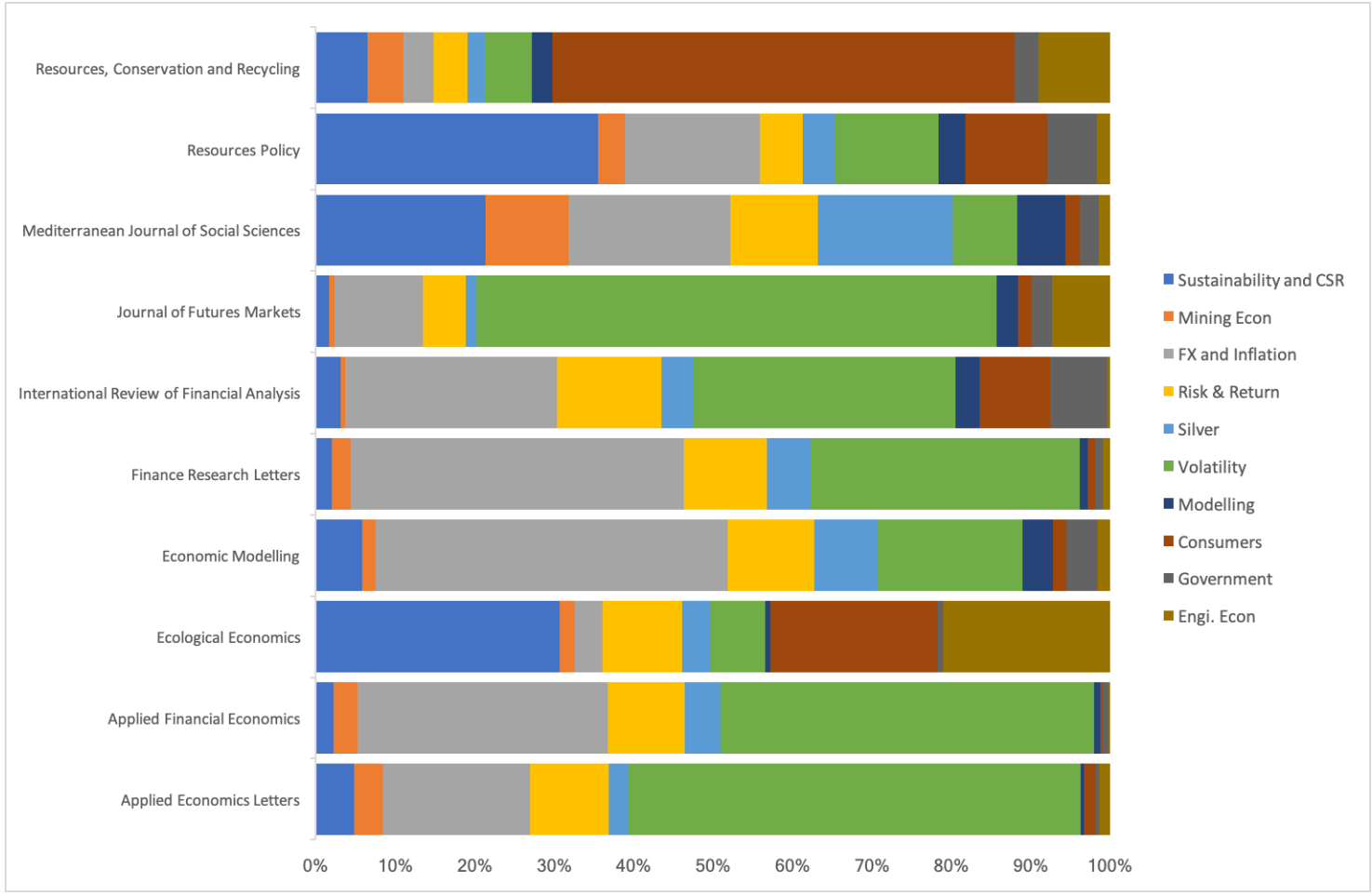
The above figure is prepared using VOSviewer which is a software tool for constructing and visualizing bibliometric networks.

Figure 15: LDA Topic Modelling : Evolution of topics over time



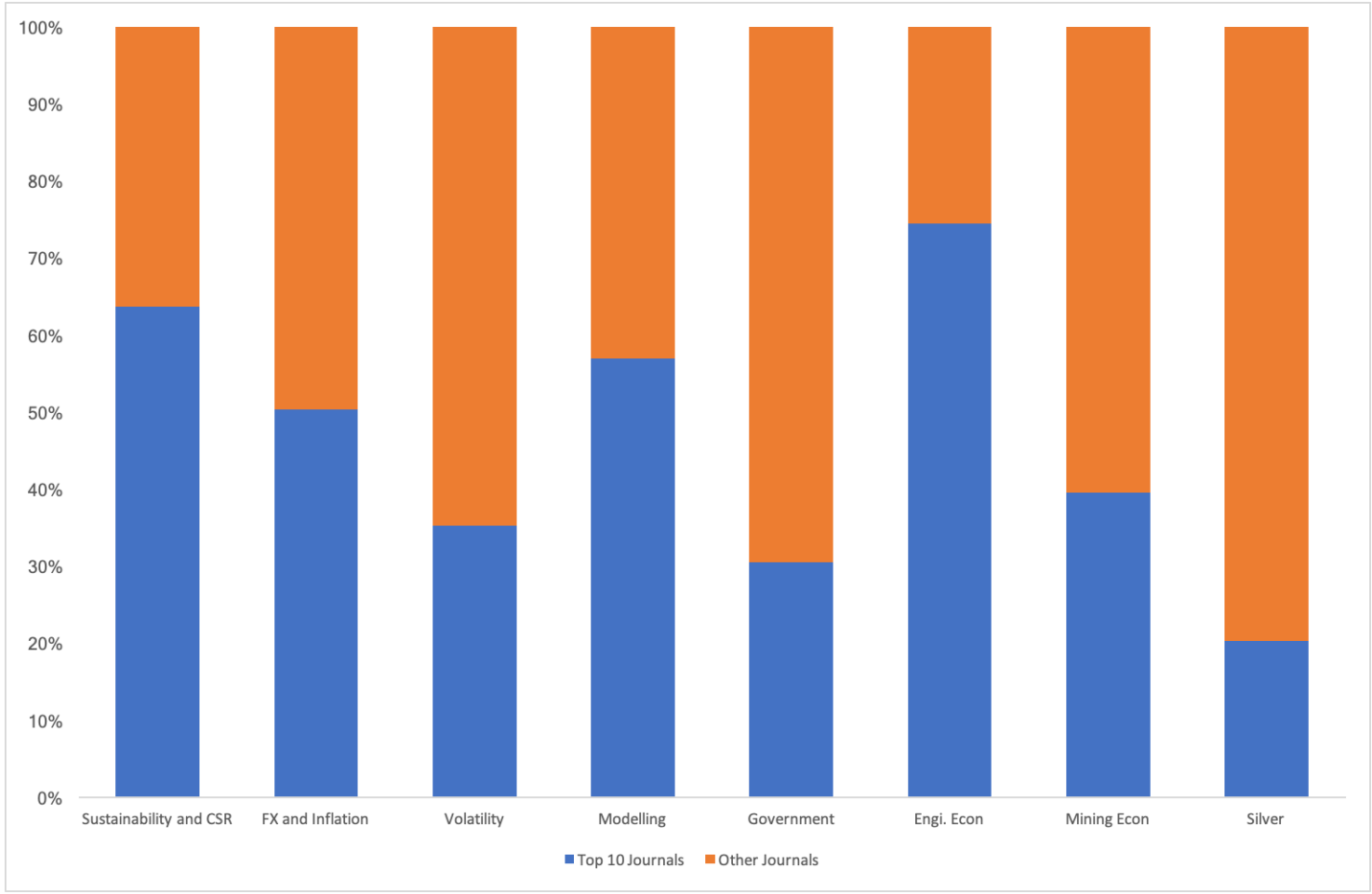
Note: Here we see the evolution, on an annual basis, of the modelled topics from the LDA analysis, each topic as a % of the total.

Figure 16: LDA Topic Modelling : Distribution of topics by Journal



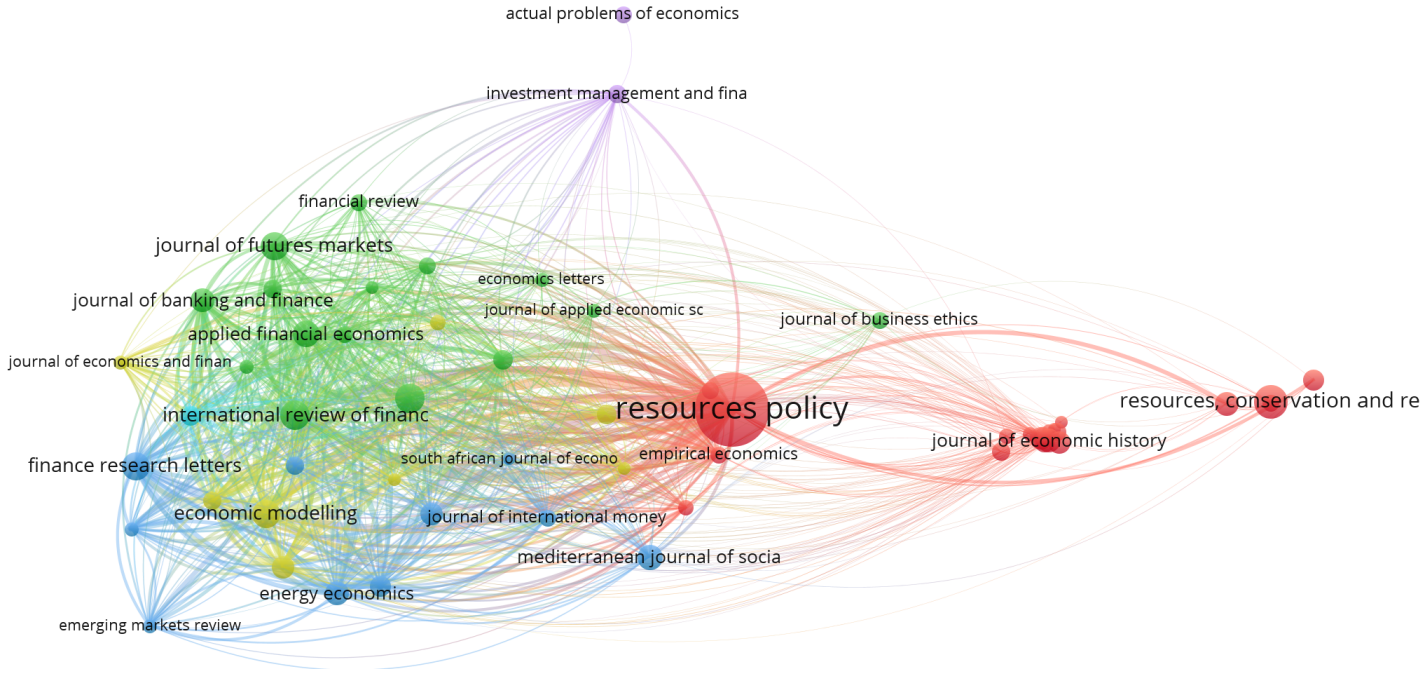
Note: Here we see the evolution, on an journal by journal basis, of the modelled topics from the LDA analysis, each topic as a % of the total.

Figure 17: LDA Topic Modelling : Distribution of topics by Journal Type



Note: This shows the % of each topic which appears in documents in the top 10 journals, by total output, and the remaining journals.

Figure 18: Bibliographic Coupling - Sources



Note: The above figure presents a bibliometric coupling for sources. The above figure is prepared using VOSviewer which is a software tool for constructing and visualizing bibliometric networks.

Table 1: Descriptive Statistics

Measure	Count
Documents	1437
Sources (Journals, Books, etc.)	427
Period	1990 - 2017
Average citations per documents	15.09
Authors	2521
Author Appearances	3067
Authors of single authored documents	405
Authors of multi authored documents	2116
Documents per Author	0.57
Authors per Document	1.75
Co-Authors per Documents	2.13
Collaboration Index	2.3

Note: The above table presents some stylized facts relating to the data used in this analysis seperated by key characteristics.

Table 2: Top 10 Authors

Authors	Articles	Authors	Fractionalised
Lucey B.M.	22	Lucey B.M.	9.17
Hammoudeh S.	20	Baur D.G.	8.67
Gupta R.	15	Hammoudeh S.	6.40
Pierdzioch C.	15	Reboredo J.C.	5.70
Baur D.G.	15	Pierdzioch C.	4.83
Reboredo J.C.	14	Gupta R.	4.53
Risse M.	11	Hilson G.	4.00
Rohloff S.	11	Ciner C.	3.83
Balcilar M.	10	Risse M.	3.83
Nguyen D.K.	9	Blose L.E.	3.50

Note: The table here shows the most prolific authors, both in general terms and adjusted for co-authorship.

Table 3: Top Ten Output Sources

Journals	Articles
1 Resources Policy	155
2 Resources Conservation And Recycling	32
3 International Review Of Financial Analysis	26
4 Applied Economics Letters	25
5 Economic Modelling	24
6 Finance Research Letters	23
7 Journal Of Futures Markets	22
8 Applied Financial Economics	21
9 Mediterranean Journal Of Social Sciences	18
10 Ecological Economics	18

Table 4: Author Locations

Country	Items
USA	237
Germany	67
UK	61
China	53
France	46
Spain	40
Australia	35
Canada	33
Norway	25
Turkey	25

Note: The above table shows the most commonly represented countries in the author locations.

Table 5: Top 10 Citation Sources

Country	Total Citations	Average Citations Per Article
USA	5155	21.75
UK	1111	18.21
Germany	809	12.07
France	657	14.28
China	501	9.45
Spain	490	12.25
Canada	479	14.52
Netherlands	474	19.75
Norway	440	17.6
Italy	420	18.26

Note: The above shows the citation count for the leading nations identified in Table 2

Table 6: top 10 Cited Papers

Authors	Paper	Year	Journal	Citations
Engel S., Pagiola S., Wunder S.	Designing payments for environmental services in theory and practice: An overview of the issues	2008	Ecological Economics	967
Schwartz E.S.	The stochastic behavior of commodity prices: Implications for valuation and hedging	1997	Journal of Finance	878
Tufano P.	Who manages risk? An empirical examination of risk management practices in the gold mining industry	1996	Journal of Finance	497
Albert M.B., Avery D., Narin F., McAllister P.	Direct validation of citation counts as indicators of industrially important patents	1991	Research Policy	399
Melnik M.I., Alm J.	Does a seller's ecommerce reputation matter? Evidence from ebay auctions	2002	Journal of Industrial Economics	312
Baur D.G., McDermott T.K.	Is gold a safe haven? International evidence	2010	Journal of Banking and Finance	288
Baur D.G., Lucey B.M.	Is gold a hedge or a safe haven? An analysis of stocks, bonds and gold	2010	Financial Review	276
Riley J.G.	Silver signals: Twenty-five years of screening and signaling	2001	Journal of Economic Literature	261
Young A.	Gold into base metals: Productivity growth in the People's Republic of China during the reform period	2003	Journal of Political Economy	241
MÃijller U.A., Dacorogna M.M., Olsen R.B., Pictet O.V., Schwarz M., Morgenegg C.	Statistical study of foreign exchange rates, empirical evidence of a price change scaling law, and intraday analysis	1990	Journal of Banking and Finance	241

Table 7: Country Members of Coauthorship Clusters

Country	cluster	Country	cluster
Austria	1	France	4
Belgium	1	Lebanon	4
Finland	1	Norway	4
Japan	1	Saudi Arabia	4
Russian Federation	1	Slovakia	4
Sweden	1	South Korea	4
Taiwan	1	Tunisia	4
Thailand	1	India	5
Turkey	1	Italy	5
Ukraine	1	Romania	5
Brazil	2	South Africa	5
Canada	2	Switzerland	5
Colombia	2	China	6
Ghana	2	Hong Kong	6
Greece	2	Malaysia	6
Israel	2	Pakistan	6
Nigeria	2	Singapore	6
Spain	2	Australia	7
United Kingdom	2	Iran	7
Czech Republic	3	Ireland	7
Denmark	3	Slovenia	7
Germany	3	Chile	8
Indonesia	3	Portugal	8
Netherlands	3	United States	8
New Zealand	3		
United Arab Emirates	3		

Note: in Figure 4 we see the coauthorship across countries. Several major clusters are evident. The largest cluster of coauthorship is centred around the USA, with several other groups nearly as large. We show in the above table the membership of the clusters.

Table 8: Author Members of Coauthorship Clusters

Author	cluster	Author	cluster
Balcilar M.	1	Baur D.G.	4
Gupta R.	1	Beckmann J.	4
Shahbaz M.	1	Czudaj R.	4
Tiwari A.K.	1	Pierdzioch C.	5
Hammoudeh S.	2	Risse M.	5
Mensi W.	2	Rohloff S.	5
Nguyen D.K.	2	Lee Y.-M.	6
Reboredo J.C.	2	Wang K.-M.	6
Batten J.A.	3	Blose L.E.	7
Ciner C.	3	Faff R.	8
Lucey B.M.	3	Hilson G.	9
		Ho T.-K.	10
		Sariannidis N.	11
		Shubik M.	12

Note: The above show the membership of the various identified clusters of coauthorship.

Table 9: Centrality Measures for Authors

Rank	Degree Centrality	Eigenvector Centrality	Betweeness Centrality
1	Hammoudeh, S	Hammoudeh, S	Hammoudeh, S
2	Gupta, R	Gupta, R	Tiwari, A
3	Lucey, B	Bacilar, M	Gupta, R
4	Bacilar, M	Mensi, W	Jammazi, R
5	Tiwari, A	Nguyen, D	Bacilar, M
6	Graedel, T	Tiwari, A	Mensi, W
7	Nguyen, D	Rebodero, J	Lucey
8	Mensi, W	Kang, S	Shahbaz, M
9	Chouaid, C	Yoon, S-M	Pierdizoch, C
10	Shahbaz, M	Sensoy, A	Bouri, E

Note: The above shows three measures of influence for individual authors.

Table 10: Country Citation Network Cluster Members

Country	cluster	Country	cluster
Chile	1	Norway	2
Greece	1	Slovakia	2
Indonesia	1	Switzerland	2
Iran	1	United Kingdom	2
Italy	1	Australia	3
Japan	1	Germany	3
Malaysia	1	Israel	3
Netherlands	1	Portugal	3
New Zealand	1	Romania	3
Nigeria	1	South Africa	3
Singapore	1	France	4
Taiwan	1	Russian Federation	4
Thailand	1	Saudi Arabia	4
Turkey	1	South Korea	4
United Arab Emirates	1	Spain	4
United States	1	Tunisia	4
Austria	2	India	5
Belgium	2	Lebanon	5
Brazil	2	Pakistan	5
Canada	2	Sweden	5
Colombia	2	China	6
Denmark	2	Czech Republic	6
Finland	2	Ireland	6
Ghana	2	Slovenia	6
Hong Kong	2	Poland	7

Note: The above shows membership by country of the citation clusters identified.

Table 11: Bibliographic Clustering of Sources Cluster Members

Label	Cluster	Label	Cluster
Australian Economic History Review	1	Economics Bulletin	3
Cato Journal	1	Emerging Markets Review	3
Ecological Economics	1	Energy Economics	3
Economic And Political Weekly	1	Finance Research Letters	3
Economic History Review	1	International Journal Of Economics And Financial Issues	3
Empirical Economics	1	International Review Of Economics And Finance	3
European Journal Of The History Of Economic Thought	1	Journal Of Commodity Markets	3
European Review Of Economic History	1	Journal Of International Money And Finance	3
Explorations In Economic History	1	Mediterranean Journal Of Social Sciences	3
Finance A Uver - Czech Journal Of Economics And Finance	1	South African Journal Of Economics	3
Journal Of Consumer Research	1	Applied Economics	4
Journal Of Economic History	1	Economic Modelling	4
Journal Of Industrial Ecology	1	Int. Journal Of Applied Bus. & Economic Research	4
Journal Of Monetary Economics	1	Journal Of Economics And Finance	4
Journal Of The Economic & Social History Of The Orient	1	Journal Of Multinational Financial Management	4
Resources Policy	1	Journal Of Wealth Management	4
Resources, Conservation And Recycling	1	North American Journal Of Economics And Finance	4
Review Of Financial Economics	1	Studies In Economics And Finance	4
Revista De Economia Politica	1	Actual Problems Of Economics	5
Revista De Historia Economica	1	Investment Management And Financial Innovations	5
World Development	1	Quarterly Review Of Economics And Finance	6
Applied Economics Letters	2		
Applied Financial Economics	2		
Economics Letters	2		
European Journal Of Finance	2		
Financial Review	2		
International Review Of Financial Analysis	2		
Journal Of Applied Economic Sciences	2		
Journal Of Banking And Finance	2		
Journal Of Business Ethics	2		
Journal Of Economics And Business	2		
Journal Of Empirical Finance	2		
Journal Of Futures Markets	2		
Journal Of International Financial Markets, Institutions And Money	2		
Quantitative Finance	2		
Research In International Business And Finance	2		

Table 12: Top 20 Forward Citations

Journal	Citations	Journal	Citations
Resources Policy	338	Extractive Industries and Society	101
Energy Economics	248	Applied Economics	96
Journal of Cleaner Production	204	International Review of Economics and Finance	80
Ecological Economics	169	Finance Research Letters	77
Economic Modelling	143	Research in International Business and Finance	77
Resources, Conservation and Recycling	142	Energy Policy	75
Journal of Futures Markets	140	Quantitative Finance	74
Physica A: Statistical Mechanics and its Applications	138	Sustainability (Switzerland)	71
International Review of Financial Analysis	110	World Development	66
Journal of Banking and Finance	109	Ecosystem Services	63

Table 13: Topics and Words associated with them from LDA modelling

Topic Description	LDA allocated words
Sustainability & CSR	mining gold social development economic local sector paper industry scale
Mining Econ	costs mine time project results methods
FX and Inflation	gold price exchange rate inflation rates variables long dollar
Volatility	gold market stock markets returns volatility oil financial results risk
Silver	silver economic money monetary system currency world century countries gold
Risk-Return	investment gold risk study paper firms investors market analysis
Modelling	futures silver model price prices models metals gold volatility precious
Consumers	consumption consumers quality business status silver households information income effect
Government	government public revenue policy companies years tax private country australia
Engi. Econ	metals production resource resources waste mineral platinum recycling environmental

Note: The above shows the topics and words associated with them from LDA modelling