Other recent projects include [2, 3], both are education platforms and not research tools. In [2], several concepts such as the iterated game, computer tournaments and evolutionary dynamics are introduced through a user interface game. Project [3] offers a big collection of strategies and allows the user to try several match and tournaments configurations. Such as noise.

In [69], the authors claim that they have managed to re-run the first tournament that Axelrod performed. They tried to push his work further by altering aspects such as, the format of the tournament, the objective and the population. One of the authors claimed to have been a contributor to the first tournaments, which would explain how it was managed to reproduce the tournament.

2.6.1 Biological Applications

- [78] uses evolutionary game theory to study the spread of virus.
- [33] a shout for his work, using tit for tat to study cells.

3 Data Analysis

In this section we will focus on the analysis of the study of the prisoner's dilemma using a large dataset of articles. This data set will be used to ascertain the level of collaborative nature of the field and identify influencers. This will be done relative to:

- Other sub fields of game theory: auction games [52] and the price of anarchy [71].
- A temporal analysis.

3.1 Data Collection

Before analysing our data in this subsection we will describe the data collection process.

Academic articles are accessible through scholarly databases and collections of academic journals. Several databases and collections today offer access through an open application protocol interface (API). An API allows users to query directly a journal's database and skip the user interface side of the journal. Interacting with an API has two phases:

1. requesting;
2. receiving;

The request phase includes composing a url with the request. Figure 11 demonstrates an example request. The first part of the request is the address of the API we are querying. In this example the address is that of the arXiv API. The second part of the request contains the search arguments. In our example we are requesting for a single article that the word 'prisoners dilemma' exists within it's title. The format of the request message is different from API to API.

The receive phase includes receiving a number of raw metadata of articles that satisfied the request message. The raw metadata are commonly received in a xml or a json format [65]. Similarly to the request message, the structure of the received data differs from journal to journal.

```
http://export.arxiv.org/api/query?search_query=abs:prisoner's dilemma&max_results=1
```

Figure 11: A request message for the arXiv API.

The data collection is crucial to this study, to ensure that this study can be reproduced all code used to query the different APIs has been packaged and is available online [57]. The software could be used for any type of project similar to the one described here, documentation for it is available at: `http://arcas.readthedocs.io/en/latest/`.

The following sources were used to collect data,

1. arXiv [51];
2. PLOS [30];
3. IEEE;
4. Nature;
5. Springer.

These are four prominent journals in the field, as well as the arXiv [51] pre print server. In the case of an article being both in a journal and the arXiv, only the journal version was considered.

For each article [57] collects a list of the features, shown in Table 4. Note that the plain text of the article is not collected, just the metadata. The data is archived and available at. In this work only the features of Table 5 are used.

	Result name	Explanation
1	Abstract	The abstract of the article.
2	Author	A single entity of an author from the list of authors of the respective article.
3	Date	Year of publication.
4	Journal	Journal of publication.
5	Key	A generated key containing an authors name and publication year (ex. Glynatsi2017).
6	Keyword	A single entity of a keyword assigned to the article by the given journal.
7	Labels	A single entity of labels assigned to the article manual by us.
8	Pages	Pages of publication.
9	Provenance	Scholarly database for where the article was collected.
10	Score	Score given to article by the given journal.
11	Title	Title of article.
12	Unique key	A unique key.

Table 4: Metadata for each entry/article.

	Result name	Explanation
1	Abstract	The abstract of the article.
2	Author	A single entity of an author from the list of authors of the respective article.
3	Date	Year of publication.
4	Journal	Journal of publication.
5	Provenance	Scholarly database for where the article was collected.
6	Title	Title of article.

Table 5: Structure of data set. Contained results.

In the work described here, a series of keywords were used to identify relevant articles. Articles for which these keywords were in the title or the abstract are included in the analysis. A list of the keywords that were used are shown in Table 6.

Similarly, for collecting data on auction games and the price of anarchy the following keywords respectively for each topic,

- key: auction game theory;
- key: price of anarchy.

	Keywords
1	prisoner's dilemma
2	prisoners dilemma
3	prisoners evolution
4	prisoner game theory
5	R Axelrod
6	memory one strategy
7	tit-for-tat
8	tit for tata
9	zero determinant strategies

Table 6: Keywords used in searching for articles.

3.2 Preliminary Analysis

A total of three data sets are explored in this work. A summary of each data is presented in this section. these three data sets are,

- the main data set, which contains information on the prisoner's dilemma, []
- a data set containing data on auction games [] and
- a data set containing data on price of anarchy [].

The prisoner's dilemma data set.

The main data set and the main focus of this analysis. The data set [] consists of 1150 articles, where 1145 have unique titles. This is because a total of 5 articles have been collected from both a journal and arXiv. All duplicates from arXiv are dropped, thus hereupon we consider 1145 unique article entries.

There are a number of 41 articles that have not been collected from the aforementioned APIs. These articles were manually added to the dataset throughout the writing of Section 2. A more detailed summary of the articles' provenance is given by Table 7.

Provenance	Number of articles
IEEE	241
Manual	41
Nature	23
PLOS	63
Springer	312
arXiv	470

Table 7: Keywords used in searching for articles.

The oldest article was published in 1944 and the most recent one in 2017. Note that the last data collection was on December 2017. The overall rate and the rates of publication for each journal have been calculated. The rate is estimated as the ratio of total articles and the years of publication. Thus:

$$\text{rate} = \frac{\text{number of articles}}{\text{years of publication}}$$

Table 8 summarises these rates. The overall rate is 21 articles per year. The most significant contribution to this appears to be from arXiv with 19 articles per year, followed by IEEE with 8 articles.

	rates
Overall	21.167
IEEE	8.926
Nature	1.769
PLOS	5.727
Springer	6.889
arXiv	19.375

Table 8: Publication rates.

Auction games and the price of anarchy data sets. A summary of the two data set is given by Table 9. A total of 296 unique articles have been collected on price of anarchy. The earliest entry being in 2003 and a total of 668 unique authors have written about the topic. In comparison, a total of 2103 articles are examined for auction games. Auction games are a well studied topic for several years with the earliest entry going back to 1974. Finally, 3860 different names are examined. The frequency of the prisoner's dilemma, for both articles and authors, lies between the frequencies of these two topics. In Figure 12 a timeplot for each topic is displayed and is exhibited that both topics have an increasing trend over the years. Though price of anarchy is clearly a new topic compared to auction games.

	Price of anarchy	Auction games
Unique articles	296	2103
Unique authors	668	3860
Min publication year	2003	1974
Max publication year	2017	2017

Table 9: Data sets summary.

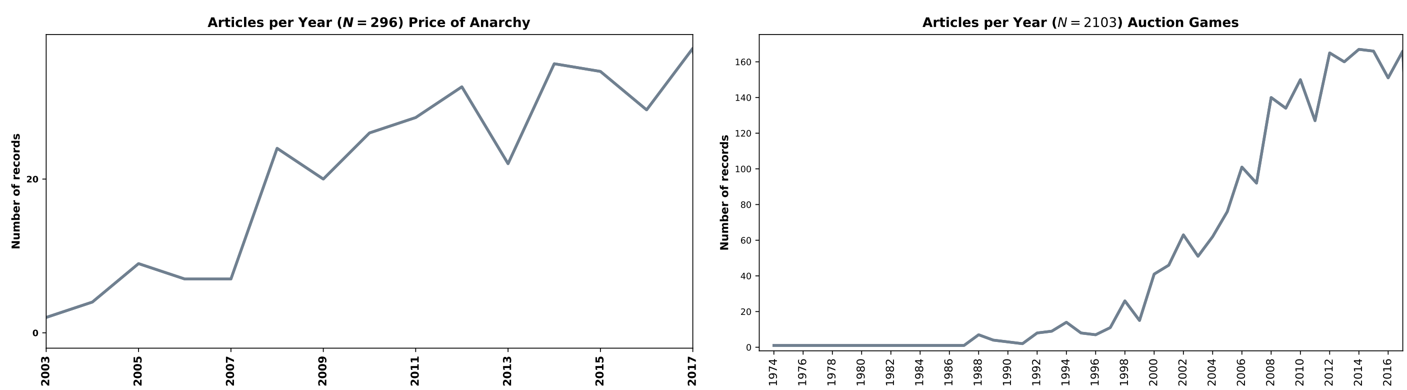


Figure 12: Timeplots.

In the following section we explore the authors of the papers and their connections to one another.

3.3 Analyse co authorship

Measuring academic collaborations and influences is not always trivial. Many academics tend to consider citations as a measure of how good a research project is. According to a blog post [58] written by Nature in 2017, depending on citation

	rates
Overall	58.973
IEEE	15.050
Nature	1.000
PLOS	3.000
Springer	38.622
arXiv	27.250

	rates
Overall	19.812
IEEE	8.733
Springer	5.571
arXiv	9.818

Table 10: Publication rates for auction games and the price of anarchy.

could be misleading. This is because:

- The true number of citations can not be known. Citations can be missed due data entry errors or typos in a journal.
- Academics are influenced by many more papers than they actually cite.
- Several citations are superficial.

For this reasons in this work we consider other measures. Initially, we construct a network of co authorship. Then using several network measures, which will be explained in details in the following sections, we study how collaborative the field is and which authors have more influence.

3.3.1 Constructing the networks

The first step in constructing the network includes getting all the unique authors from the data set. There are several different ways of writing an author's name that difference sources use. For example the authors name can be written in several ways, such as:

- Nikoleta Glynatsi
- Nikoleta E. Glynatsi
- Nikoleta Evdokia Glynatsi

Consequently, several different entries of the same author existed within the data set. To address the problem the Levenshtein Distance [54] was used. The Levenshtein Distance is a metric for measuring the difference between two sequences. The Levenshtein distance between two strings is defined as the minimum number of edits needed to transform one string into the other, with the allowable edit operations:

1. insertion;
2. deletion;
3. substitution of a single character.

The Levenshtein distance of all possible pairs of authors in the data set was computed. If the distance was between 85 and 99 the entries were highlighted. The highlighted entries were manually checked to assure that there were indeed the same authors and then one of them was replaced by the other.

For example all entries with author name as 1 were replaced by 2.

1. Y. Moreno

2. Yamir Moreno

The manual check is performed because not all highlighted entries are actually the same author. For example:

1. Zhen Yang and
2. Zhen Wang

are two individual authors. Once the names were cleaned the total number of unique authors over the 1145 articles is 2101 .

The co authorship network is defined as the undirected graph G of of vertices V and edges E. There are 2101 vertices representing each unique author. The vertices are joined by 3174 edges. An edge connects two authors if and only if those authors have written together. No weight has been applied to the edges or the nodes. The network is shown in Figure 13.

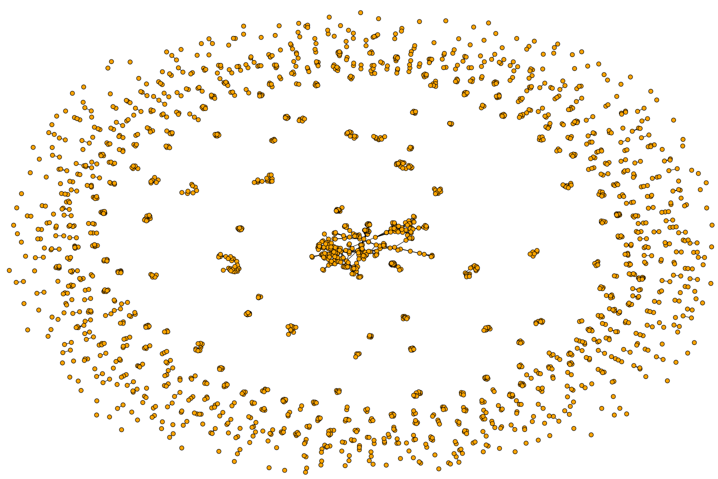


Figure 13: Co-authorship network.

Now that the network has been defined in the following sections the collaborative trend of the field and the influencers are explored.

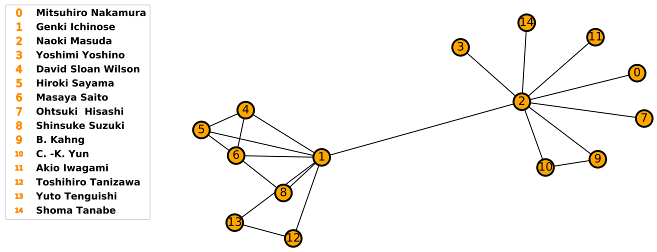
3.3.2 Collaborative behaviour

In this section we ascertain the level of collaborative nature of the field using several measures such as, number of connected components, clustering coefficients and degree distribution. To explain the notion of some measures we will be using several sub graphs of the network G.

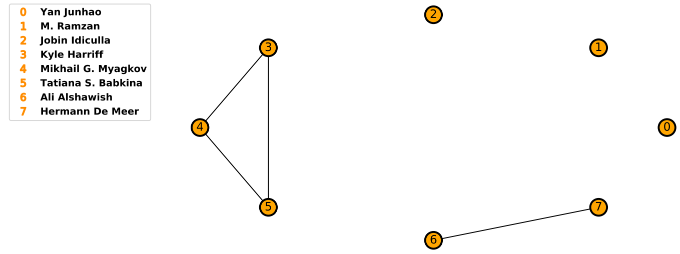
Number of connected components.

The first measure of connectivity is the number of connected components. A connected component, in graph theory, of an undirected graph is a sub graph in which any two vertices are connected to each other by paths. Let us consider two sub graphs of G, Z and H. Sub graph Z is a connected graph where H is not.

There are in total 529 connected components within graph G. Thus there are least 529 team of authors within the field that are connected, through authorship.



(a) Sub graph Z.



(b) Sub graph H.

Figure 14: Connected components examples.

Clustering coefficients.

Another measure is the clustering coefficients. It is a measure of the degree to which nodes in a graph tend to cluster together. Thus is measure of cliqueness. There are two types of clustering coefficient of a graph. The local and the global measure. The local measure, measures the clustering coefficients of a specific node. The local clustering coefficient is calculated as, $\frac{2 Number of edges between neighbours}{Node degree (Node degree - 1)}$.

The global version of the measure can be calculating by averaging all the local coefficients of the graph. The clustering coefficient ranges between values of 1 and 0. The closer to 1 indicates that the graph is getting closer to a complete graph where the closer to 0 indicates being a star.

Consider the following three sub graphs as examples:

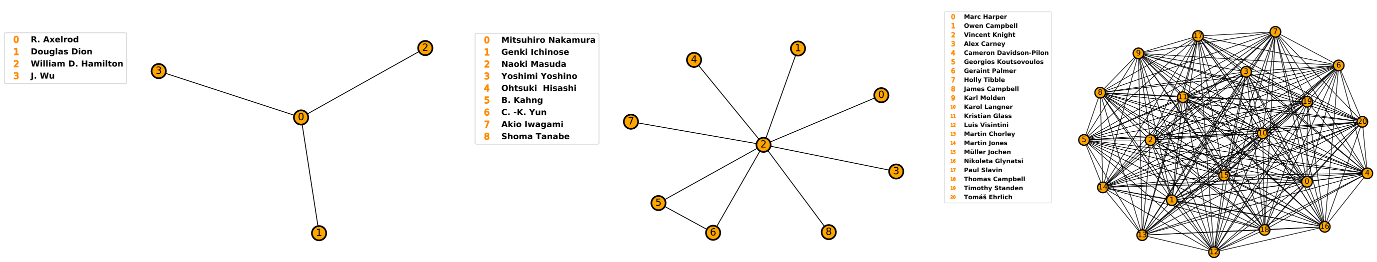


Figure 15: Clustering coefficients examples.

Sub graph one has a $cc = 0$ and the third case has a cc of 1. The middle case appears to be in the middle with a cc of 0.23. In our work having a high clustering coefficient indicates that people tend to have authorship connections but only because the collaborate with only specific people. Thus there is no a larger connection to the graph other than the clique of authors that worked together.

The prisoners' dilemma graph, G, has a cc of 0.68.

Degree distribution.

Degree shows the number of connections a node has. The histogram of the the degree distribution is given by Figure16. The most frequent degree appears to be that of 2 degrees.

Comparison with other topics authorship

number of connected components. 162

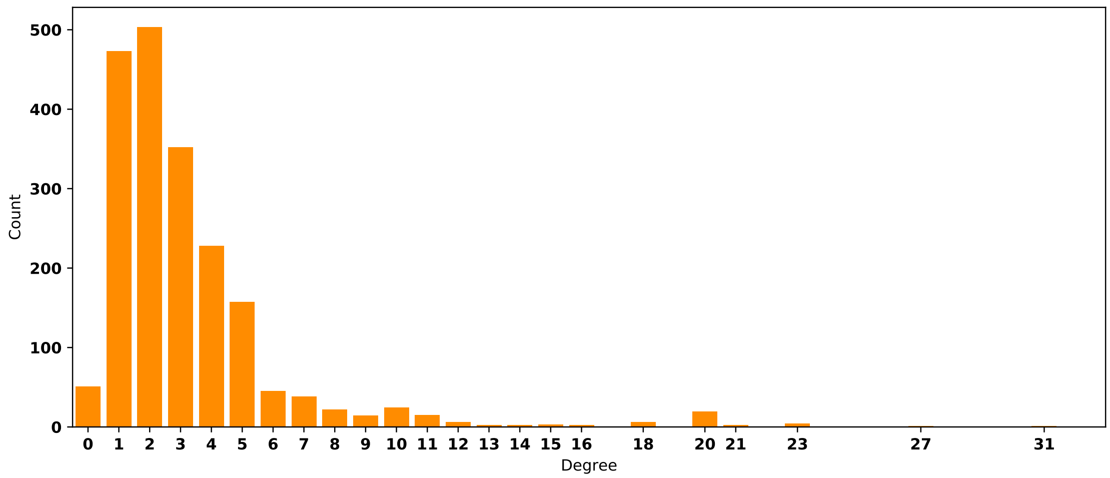


Figure 16: Degree Histogram. Co-authors network of prisoner's dilemma data.

Global clustering coefficient. 0.712470749205443

number of connected components. 797

Global clustering coefficient. 0.677346124933566

To further examined the differences or the similarities of these networks we consider the degree distributions. The normalised distributions of all three networks are given in Figure 17. They have been normalised such that the frequencies sum to one. The distributions appear to be similar but to validate the hypothesis a statistical test will be used. None of the distributions is normally distributed thus the non parametric test Kruskal-Wallis is used [?]. Kruskal-Wallis allow us to compare the medians of two or more distributions. The test returns a p-value of 0.29. Thus, there is no significant difference in the degree distributions of the three networks.

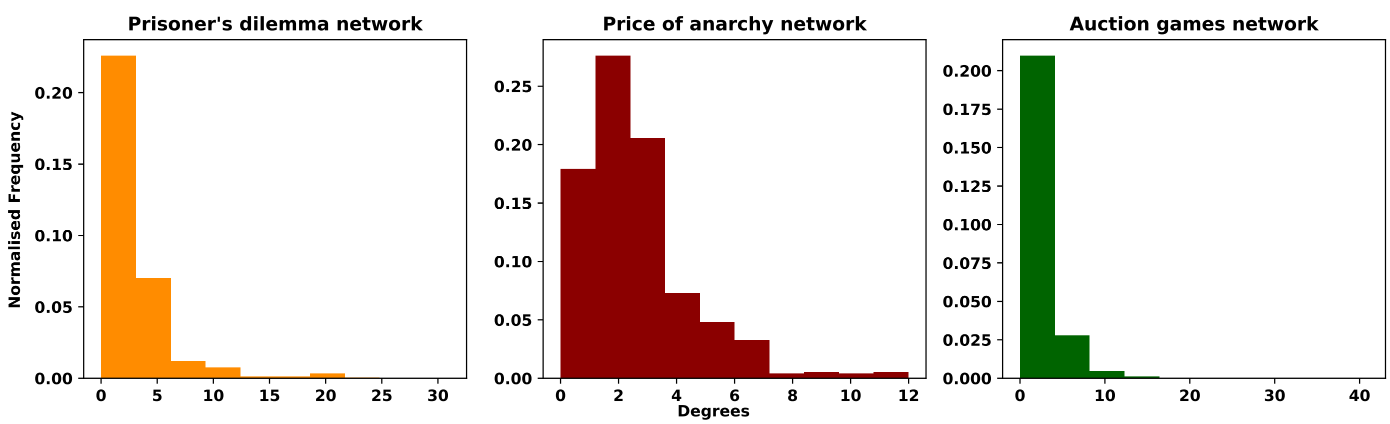


Figure 17: Degree distributions for all three networks.

3.3.3 Influencers

Betweenness centrality

Closeness centrality