

Prediction Markets: A Systematic Review and Meta-Analysis

(Full Paper)

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ABSTRACT

Prediction markets (PM) have drawn considerable attention in recent years as a tool for forecasting events. Studies surveying and examining relevant the trends of PM using traditional approaches have been reported in the literature. However, research using meta-analysis to review Prediction markets systems is very limited in Management Information System (MIS). This paper aimed to fill this gap by using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method to study Prediction markets trends over the past decades. Our results are as follows. First, we find that shows that more than 64% of academic studies on Prediction markets are published in top journals such as Journal of the Association for Information Systems, Journal of Consumer Research and Information Systems Research. Second, we showed that Prediction markets applications can be divided into two groups: internal use PMS and general public usage. Finally, our significant meta-analysis result show that on average prediction markets is 79% more accurate than alternative forecast methods based.

Keywords: Prediction markets, systematic literature review, meta-analysis.

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INTRODUCTION

Throughout history, people have always sought to predict the future of events. Among well-known forecasting methods, markets for information aggregation, such as prediction markets, have attracted the attention of several researchers in the literature. In general, prediction markets are an electronic platform where participants can interact with each other and exchange their beliefs. To measure and reward success, participants receive a payoff either in play money or real money if a certain outcome occurs. Given the growing importance of markets, we wonder how to survey scholarly sources on prediction markets. Most popular types of literature reviews in business studies include: narrative review, argumentative review, theoretical review and systematic review. (Ridley, 2012). Our research purpose is an attempt to systematically review previous academics works related to Prediction Markets (PM) using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method. Coined and first applied by Glass (1976), meta-analysis, warmly embraced in experimental fields such as medicine, education and psychology, is a quantitative technique that uses specific measures (e.g., an effect size) to indicate the strength of variable relationships for the studies included in the analysis. The technique emphasizes results across multiple studies as opposed to results from a single investigation.

Prior studies surveyed and examined relevant existing literature on Prediction markets and its trends. Zhao *et al.* (2008) present an analysis of Prediction Market research relevant to Information Systems (IS) from 1985 to 2007. They classified their results in two different ways. On the one side, they develop categories related to the publication outlet based on outlet name and outlet description. On the other side, they assign the articles to research themes. Tziralis and Tatsiopoulou (2007) presented an "Extended Literature Review" on Prediction markets on which they examined journal articles, conference proceedings papers, books and book chapters, master's theses, doctoral dissertations as well as other unpublished academic working papers and reports that were referring to the concept of Prediction Markets. As a result, they identified 155 relevant article to their study, published between 1990 and 2006. Those publications are often served as references literature reviews on prediction markets.

However, reviews of studies on Prediction markets based on meta-analysis are very limited in MIS. Therefore, we plan to fill this gap by using a systematic review and meta-analysis to study Prediction markets trends over the past decades. We calculate a statistic, namely "Effect Estimate" (or effect size) that provides an estimate of the comparison effect for each study. Then we select a meta-analytic effect estimate to synthesize the effect sizes across the studies. Test of heterogeneity will be also performed in order to assesses whether observed differences in results are compatible with chance alone. In relation with the motivation, our analysis contributes to several literatures. First, we relate to an emerging literature studying Prediction markets, its applications and trends. Second, by adapting a method generally used in medical sciences, we show evidence that paradigms are not totally disparate and it is possible to build bridges across blurred paradigm boundaries (Goia and Pitre, 1990).

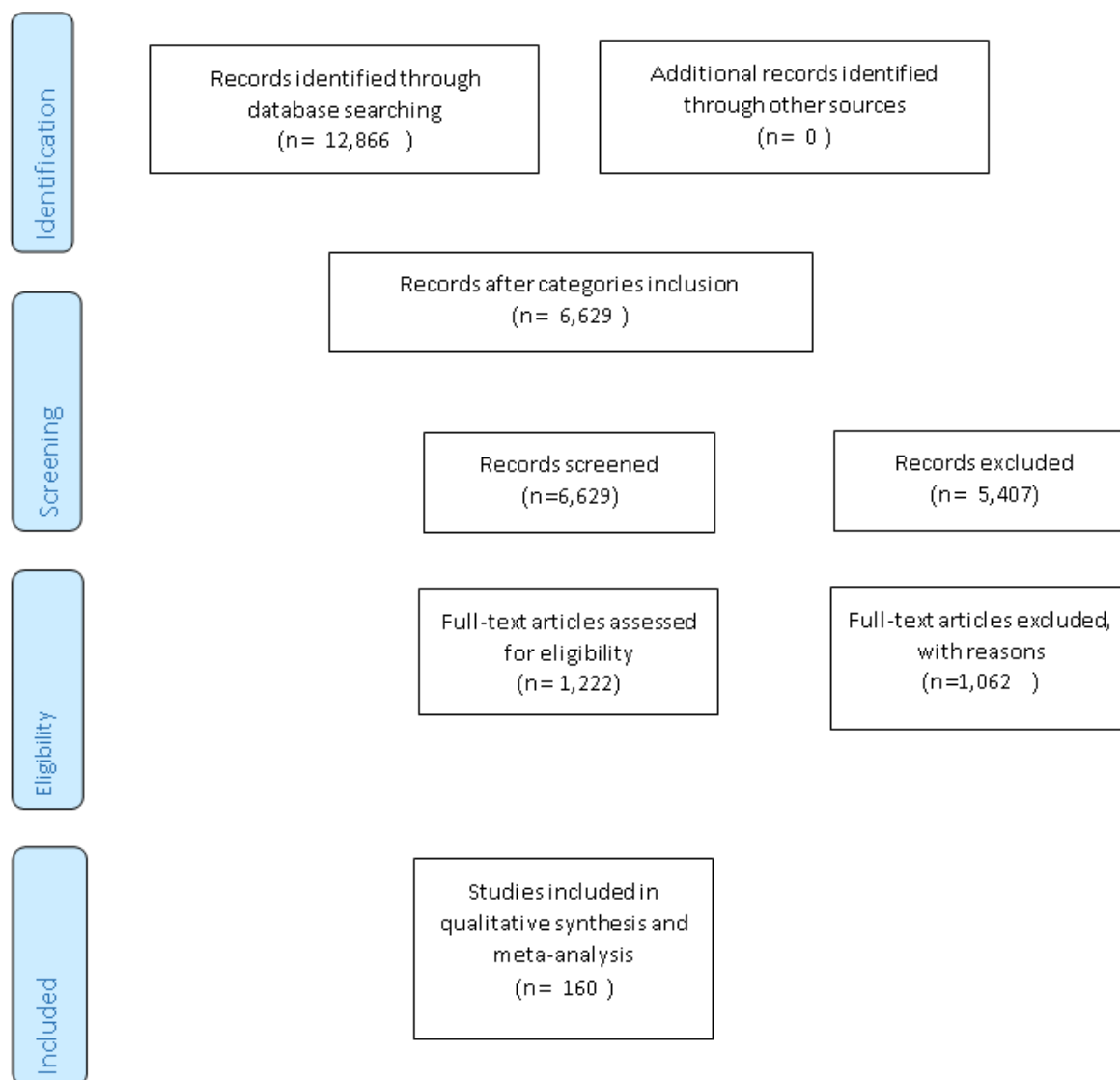
The remainder of the paper is structured as follows. Section 2 details the methodology used including data selection and effect size calculation. Section 3 presents the results and discussion. The final Section 4 concludes the analysis while elaborating on limitations of the paper.

METHODOLOGY

This research is an attempt to systematically review previous academics works related to Prediction Markets (PM). This systematic review was conducted by following the reporting checklist of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method (Liberati *et al.*, 2009). For the purpose of this study, a comprehensive literature search was undertaken online through Web of Science which is one the top electronic libraries and academic databases. More specifically, we developed a protocol to document the analysis method and inclusion criteria. More specifically, all academic works related to prediction markets published from 1975 to 2020 on web of science database as well as those in the Australian Business Deans Council (ABDC) journal quality list were searched for systematic review papers. We choose the ABDC list because it is more comprehensive than other journal ranking lists, such as social sciences citation index (SSCI), Association of Business Schools (ABS), and Scopus (Rainer & Miller, 2005).

Inclusion and exclusion criteria

- Keyword and Timespan: Using the database of ISI Web of Knowledge and typing the keyword “Prediction market” 12,866 papers were identified sorting by “Relevance” from 1975 to 2020.
 - Web of Science Categories: Using “Economics”, “Business Finance”, “Management”, “Business”, “Computer Science Information Systems”, “Multidisciplinary Sciences” “Information Science Library Science” and “Social Sciences Interdisciplinary” as inclusion categories, the number of papers was reduced to 6,629.
 - Open Access and Language: Selecting “English” as a language and “Open Access” as a filter reduced the number to 1,222. Out of which 160 relevant academic works concerning prediction markets were studied.
- For the purpose of our study, we consider 160 relevant researches concerning prediction markets. The title, journal name, and year of publication of the identified records were reported in Appendix.



Source: This study.

Figure 1: The PRISMA flow diagram (adapted from Liberati *et al.*, 2009).

Meta-analysis

The focus of this section is to present the steps in undertaking our meta-analysis. The first step is deciding upon the scope of the review in terms of outcomes that will be included. The scope of our illustrative review is to analyze the prediction accuracy comparison between PM and other forecasting models. The purpose here is to randomly examine studies in which the outcome is to compare the forecast accuracy between prediction markets and well-known methods such as polls and experts. Based on this specific criteria, 24 studies have been considered to perform the meta-analysis.

Effect sizes

Once the studies have been extracted, the second step is to find and calculate a statistic, namely “Effect Estimate” (or effect size) that provides an estimate of the comparison effect for each study (Fritz *et al.*, 2012). Given the fact that the set of studies included in our review all assessed the same outcome which is the forecast accuracy of Prediction markets but used different methodologies, settings and population sizes we consider the accuracy ratio or winning ratio as our effect estimate and random effect model as our analysis model. The random effects model can be presented mathematically using the equation of Wang and Griswold (2016):

$$r_i = r_i' + \theta_i + \varepsilon_i \tag{1}$$

where r_i , the study effect estimate (Accuracy ratio in our case), is equal to the average comparison effect (r_i') plus a random term θ , which denotes methodological and setting specificities of study i , and a term ε , which represents error in estimating and calculating the study’s true effect.

The accuracy ratio for Prediction markets or alternative forecast methods is adapted from the approach of Khoshelham (2011):

$$Accuracy\ ratio = r = E_w/E_T \tag{2}$$

An approximate standard error of the accuracy ratio of a particular study i is given by:

$$SE_i = \sqrt{\frac{1}{E_w} + \frac{1}{E_A}} \tag{3}$$

In case, the standard deviation or variance are provided we calculate the standard error as follows:

$$SE_i = \frac{\sigma}{\sqrt{n}} \tag{4}$$

Where E_w is the average number of events won or correctly predicted events in average, E_A average number of events not predicted by prediction markets systems or correctly predicted by alternative forecast methods and E_T total number of predictions. σ is the standard deviation and n the sample size.

In most cases, the accuracy ratio is provided in the included studies. Otherwise, we compute this ratio based on the method and information available. For instance, if studies used Mean average error (MAE) or Brier score, we follow Tung *et al.* (2011) to calculate the accuracy ratio.

$$Accuracy = 1-MAE = 1-Brier\ score \tag{5}$$

Table 1 presents the information about the included studies as well as methods used. A detailed information about how we compute the effect estimate of those studies can be found in Appendix.

Meta-analytic effect estimate

At this stage, we selected a meta-analytic effect estimate to synthesize the effect sizes across the studies:

$$\Phi = \frac{\sum \omega_i r_i}{\sum \omega_i} = \frac{\omega_1 r_1 + \omega_2 r_2 + \dots + \omega_n r_n}{\omega_1 + \omega_2 + \dots + \omega_n} \tag{6}$$

Φ is the meta-analytic estimate of all studies; r_i is the study effect estimate (accuracy ratio) of study i ; ω_i is the weight of a particular study i .

The weight can be derived by applying inverse-variance weighting method (Marin-Martinez and Sanchez-Meca, 2010):

$$\omega_i = \frac{1}{SE_i^2} \tag{7}$$

The standard error of the meta-analytic effect estimate is used to provides a measure of the precision surrounding the meta-analytic effect estimate (Borenstein *et al.*, 2011). It is calculated as the square root of the reciprocal of the sum of the weights:

$$SE(\Phi) = \sqrt{\frac{1}{\sum \omega_i}} \tag{8}$$

The 95% confidence interval (CI) for the effect estimate would be computed as

$$Lower\ Limit = r_i - 1.96 \times SE_i(r_i)$$

$$Upper\ Limit = r_i + 1.96 \times SE_i(r_i)$$

Finally, the Z-value could be computed using:

$$Z = \frac{\Phi}{SE(\Phi)} \tag{9}$$

and the two-tailed p-value by: $p = 2[1 - \mathcal{N}(|Z|)]$ Where \mathcal{N} is the standard normal cumulative distribution function.

Table 1: Considerations on methodologies and data used by studies on Meta-analysis

Study	Data and methodology			Considerations
	<i>E_w</i>	<i>SD</i>	<i>n</i>	
<i>Atanasov et al. 2017</i>	na	Provided	Provided	<i>Authors used Brier score to compute the forecast accuracy. We only consider results from Experiment 1.</i>
<i>Berg et al. 2008</i>	Provided	n.a.	n.a.	<i>Binomial tests are used for the relative accuracy of the market.</i>
<i>Bohm and Sonneggard 1999</i>	Estimated*	Estimated*	Provided	<i>Authors used time series data to investigate the performance of the market. Here we only consider the YES outcome predicted by the market from 11/11 to 12/11</i>
<i>Brüggelambert 2004</i>	n.a.	Estimated*	Provided	<i>Mean absolute error (MAE) is considered by the authors to report the political market accuracy. We only consider the results for GEM 94 which is the largest market assed by their study.</i>
<i>Chen et al. 2003</i>	n.a.	Provided	Provided	<i>This paper proposed a relative performance (Kullback-Leibler measures). We only consider the results from Excerpt 1a.</i>
<i>Cowgill and Zitzewitz 2015</i>	n.a.	Provided	Provided	<i>We only consider results from Markets versus experts for Google.</i>
<i>Dana et al. 2019</i>	n.a.	Provided	Provided	<i>We consider the Brier scores for prices and beliefs presented in this study.</i>
<i>Graefe 2019</i>	n.a.	Estimated*	Provided	<i>This study uses the mean absolute error (MAE) to review the accuracy of four methods to forecast German federal elections. We consider combined markets and combined polls for our research.</i>
<i>Karniouchina 2011</i>	n.a.	Estimated*	Provided	<i>This study considered Virtual Stock Markets to assess the forecast of movie HSX forecasts</i>
<i>Leigh and Wolfers 2006</i>	Provided	Provided	Estimate d*	<i>We used an average of predicted probability of Howard victory for Prediction markets and Polls.</i>
<i>Li et al. 2016</i>	Provided	n.a.	Provided	<i>The authors studied a prediction market system to forecast infectious diseases in Taiwan</i>
<i>Matzler et al. 2013</i>	n.a.	Estimated*	Provided	<i>This research used MAE to test whether online consumer communities. Here, we consider race skis which has the lowest MAE.</i>
<i>Polgreen et al. 2007</i>	n.a.	Estimated*	Provided	<i>This research used prediction markets to tracking and forecasting emerging infectious diseases such as SARS. We consider results for 0 Weeks in advance.</i>
<i>Prokesch et al. 2015</i>	n.a.	Estimated*	Estimate d*	<i>Authors introduced an electronic combination of a prediction market and Delphi methodology. We consider MAPE for Prediction market on April+May+June.</i>
<i>Rieg and Schoder 2010</i>	Provided	Estimated*	Provided	<i>This experimental study compared forecast accuracy between prediction markets and a simple survey. We only consider the results from Simplified Prediction Market Design and Survey 1 which have the lowest variance.</i>
<i>Rothschild 2015</i>	n.a.	Provided	Provided	<i>This research paper combined the forecasts of victory with a probit of the inverse normal of their probabilities. Here we consider the coefficients for the probability of victory for Prediction markets.</i>
<i>Slamka et al. 2012</i>	n.a.	Provided	Provided	<i>This study conceptually and empirically compares the forecasting accuracy of Second-Generation prediction markets (G2). Here we consider Mean absolute errors across all topics.</i>
<i>Song et al. 2007</i>	Provided	n.a.	n.a.	<i>This paper compares the forecasts of the outcomes of NFL games made by statistical models, experts and markets. Here, we consider the proportion of game winners that were correctly predicted by markets and Experts.</i>
<i>Spann and Skiera 2003</i>	Provided	n.a.	n.a.	<i>We consider the Mean Absolute Percentage Error (MAPE) for HSX enhanced model.</i>
<i>Spann and Skiera 2009</i>	Provided	n.a.	n.a.	<i>This article compares the forecast accuracy of different methods, namely prediction markets, tipsters and betting odds,</i>
<i>Teschner et al. 2011</i>	Estimated*	n.a.	n.a.	<i>This paper design a market for economic derivatives that aggregates macro-economic information. We only consider results from Exports section</i>
<i>Tung et al. 2011</i>	Provided	Estimated*	Provided	<i>This paper devises a methodology to compare the accuracy of prediction markets and polls for Taiwan elections. We only consider the results for 2008 presidential election.</i>
<i>Tung et al. 2015</i>	Provided	n.a.	n.a.	<i>The author designed and built the Epidemic Prediction Markets (EPM) system.</i>
<i>Van Bruggen et al. 2010</i>	n.a.	Provided	Provided	<i>This paper used the mean absolute percentage error (MAPE) to scrutinize the forecast accuracy.</i>

Provided: means that the study directly mentioned this statistic; *Estimated**: We use information and data provided by the study to calculate the statistic; *n.a.*: non-available data. *E_w*: correctly predicted events by the Prediction market systems; *SD*: Standard deviation; *n*: number of participants.

Source: This study.

Heterogeneity

It is important to consider to what extent the results of studies are consistent. In our present research, we only consider statistical test which are chi-squared (χ^2 , or Chi2) test and I2 statistic to identify heterogeneity. It assesses whether observed differences in results are compatible with chance alone. A large chi-squared statistic relative to its degree of freedom provides evidence of heterogeneity of intervention effects (Higgins *et al.*, 2003).

$$\chi^2 = \sum \frac{(O - E)^2}{E} \quad (10)$$

Where O is the observed value in a study, E is its expected value

In addition to chi-squared, I^2 statistic describes the percentage of the total variability in effect estimates that is due to heterogeneity rather than within study variation. A value of 0% indicates no observed heterogeneity, and larger values show increasing heterogeneity. A value below 50% is often considered as moderate heterogeneity in a random effect model. Following Higgins and Thompson (2002), this statistic can be written as:

$$I^2 = \left(\frac{Q - df}{Q} \right) \times 100 \quad (11)$$

where Q is the chi-squared statistic and df (Number studies – 1) is its degrees of freedom.

Forest plot

To take all the relevant studies asking the same question, identify a common statistic in said papers and then to displays them on a certain way, we used RevMan 5, a software developed by Cochrane Collaboration. Forest plot is extracted to present the analysis of our study. Forest plot compare directly what the studies show and the quality of that result all in one place. The forest plot horizontal axis represents the accuracy ratio (relative statistic) the studies being profiled show while the vertical line is known as the “line of null effect” where there is no accuracy difference between Prediction markets and other alternative forecast methods. A point estimate of the study result represented by a red box. The bigger the box, the more important is the size of the study. Moreover, a horizontal line representing the 95% confidence intervals of the study result, with each end of the line representing the boundaries of the confidence interval.

RESULTS AND DISCUSSIONS

Prediction markets trends

Table 2 represents study of databases as well as journals/publishers for the review. The database that most commonly featured papers in Prediction markets is Elsevier containing 51 articles accounted for 32% of academic works published in journals such as European Journal of Operational Research, Journal of Banking & Finance, Decision Support Systems, Journal of Business Research, Journal of Forecasting and Business Horizons.

Databases such as Springer International Publishing and the Institute for Operations Research and the Management Sciences (INFORMS) account for 18% of academic publication. Springer International publishing 15 articles (9%) in journal such as Economic Theory, Information Systems Frontiers; Group Decision and Negotiation; Information Systems Frontiers while INFORMS publishing 14 articles (9%) in journal like Information Systems Research, Management science, Marketing Science, Operations Research and Decision Analysis. In addition, Institute of Electrical and Electronics Engineers (IEEE) published a total of 12 articles (7%) in IEEE Transactions on Engineering Management and International conferences such as International Workshop on Database and Expert Systems Applications; International Conference on Information Management, Innovation Management and Industrial Engineering; SICE Annual Conference.

Results also show that 21.88% Journals considered for the analysis have A* ranking in ABDC. And 43.75% of Journals considered here for analysis have A ranking in ABDC. A* and A Journals such as Journal of the Association for Information Systems, Decision Support Systems, Management science and others from different disciplines have been considered to provide an interdisciplinary approach to the study. Hence, it appears that top journals (A* and A ranking) are the preferred outcome for Prediction markets.

Table 2: Classification of academic works on prediction markets

Database	ABDC ranking	Journal/Publisher	#
Academica SINICA	n.a.	Journal of Information Science and Engineering	1
American Economic Association	A*	Journal of Economic Perspectives	2
Association for Computing Machinery	n.a.	ACM Transactions on Intelligent Systems and Technology	1
Association for Information Systems (AIS)	A*	Journal of the Association for Information Systems	1
Cambridge University Press	n.a.	Political Analysis; Political Science & Politics	2
Columbia Law Review Association	n.a.	The Columbia Science and Technology Law Review	1
Editura ASE	n.a.	Amfiteatru Economic Journal	1
Elsevier	A*	European Journal of Operational Research; Journal of Banking & Finance; Decision Support Systems; Energy Economics	11
	A	Finance Research Letters; International Journal of Accounting Information Systems; Technological Forecasting and Social Change; Economic Letters; International Journal of Forecasting; International Journal of Medical Informatics; Journal of Business Research; Journal of Forecasting	36
	B	Business Horizons	2
	n.a.	Physica A-Statistical Mechanics and its Applications; Electoral Studies	2
Emerald	A	Internet Research	2
	C	Foresight	3
Euromoney Institutional Investor	n.a.	The Journal of Investing	1
Google Scholar	n.a.	IGI Global	1
Harvard Business Publishing	A	Harvard Business Review	1
IEEE	A	IEEE Transactions on Engineering Management	1
	n.a.	International Workshop on Database and Expert Systems Applications; Conference on Technologies and Applications of Artificial Intelligence; Hawaii International Conference on System Sciences; IEEE International Conference on Innovations in Intelligent Systems and Applications; IEEE/WIC/ACM International Conferences on Web Intelligence and Intelligent Agent Technology; International Conference on Computers & Industrial Engineering; International Conference on Information Management, Innovation Management and Industrial Engineering; SICE Annual Conference; IEEE Intelligent Systems; IEEE Access	11
Inderscience	n.a.	International Journal of Electronic Business	1
INFORMS	A*	Information Systems Research; Management science; Marketing Science; Operations Research	11
	A	Decision Analysis	3
International Institute of Applied Informatics	n.a.	International Congress on Advanced Applied Informatics	1
MIT Press	A	MIT Sloan Management Review	1
Oxford University Press	A*	Journal of Consumer Research; Review of Economic Studies	3
	n.a.	Economic Journal; Public Opinion Quarterly; Clinical Infectious Diseases	4
Poznan School of Logistics	n.a.	LogForum	1
Sage Publications	A	California Management Review; Strategic Organization	3
	n.a.	Simulation & Gaming; Social Science Computer Review	2
Society for Judgment and Decision Making	A	Judgment and Decision Making	2
Southern Economic Association	n.a.	Southern Economics	1
Springer	n.a.	International Joint Conference on e-Business and Telecommunications	1
Springer Heidelberg	n.a.	Review of Economic Design	1
Springer International Publishing	A*	Economic Theory	1
	A	Information Systems Frontiers; Group Decision and Negotiation; Information Systems Frontiers	9
	B	Computational Economics; Information Systems and e-Business Management	2
	C	Ethics and Information Technology	1
Springer Nature	A	Electronic Markets	2
	n.a.	BMC Public Health	1
Taylor & Francis Online	A*	European Journal of Information Systems; Journal of Management Information Systems	3
	A	Applied Economics; Australian Journal of Political Science; International Journal of Electronic Commerce; Quantitative Finance	5
Taylor and Francis	n.a.	Journal of Political Science Education; Social Epistemology	2
University of Buckingham Press	B	The Journal of Prediction Markets	9
University of Minnesota Press	A*	MIS Quarterly	2
Washington University School of Law	n.a.	Washington University Law Review	1
Wiley-Blackwell Publishing	A*	Journal of Product Innovation Management	2
	A	Journal of Economic Surveys; R&D Management; Scandinavian Journal of Economics; The Economic Record	4
World Scientific Publishing Co.	A*	New Mathematics and Natural Computation	1
Total			160

Source: This study.

Prediction market application

Table 3 shows the classification of the studies according to prediction markets (PM) application. PM can be divided into two groups: internal use PMS and general public usage.

Internal use PMS

By internal use, we mean application of Prediction Markets not intended for the general public usage but specifically built for trading within companies or organizations. In the business world, prediction markets systems such as Satoshi, Dice230, BitBet and Iowa Electronic Markets Google IPO Markets have been already established internally to trade on strategically important objectives or key performance indicators, such as input prices, sales and project completion dates (Wolfram 2015; Teschner and Gimpel 2018; Chen *et al.* 2003; Othman and Sandholm 2013; Brito *et al.* 2014). Wolfram (2019) demonstrated that with clearly mandated goodwill from the top, Prediction markets can succeed as a forecasting methodology for companies. Berg *et al.* (2009) analyzing prediction markets systems intended to predict the post-IPO value of Google found that the markets were relatively accurate far in advance of the IPO.

General public usage PMS

Prediction Markets are also applied outside companies and organizations in areas such as politics, sport and entertainment industry, economic forecasting and healthcare sector.

- Politics

Research using markets for the sole purpose of aggregating beliefs regarding a future event was first developed at the University of Iowa in 1988. Commonly named as Iowa Electronic Markets (IEM), this prediction market system was built to forecast US presidential and state elections (Berg & Rietz, 2003; Berg *et al.*, 2008; Erikson & Wlezien, 2008; Graefe *et al.* 2014; Khan & Lieli 2018). Later, IEM-like platforms were used to run political stock markets on elections in Australia (Leigh & Wolfers, 2006), Germany (Brüggelambert, 2004), Sweden (Bohm & Sonnegard, 1999) and in Taiwan (Lin *et al.*, 2013; Tung *et al.*, 2011). Interesting fact about those systems is that forecasts derived from PM trading prices have been more accurate than their natural benchmark, namely polls, although traders exhibit biases (Atanasov *et al.*, 2017; Dana *et al.*, 2019). Moreover, trading prices react extremely quickly to new information (Berg & Rietz, 2019).

- Sport and entertainment industry

Servan-Schreiber *et al.* (2004) showed how prediction markets are widely used in sports and entertainment. These markets focus on forecasting the outcome of sports games and events such as baseball, soccer, football, hockey, basketball, tennis, and horse racing. Betfair.com, the World Sports Exchange, NewsFutures and TradeSports are among the most popular prediction market systems used in that field. Prediction Markets are even applied in the movie industry to predict box-office results (Sripawatakul & Sutivong, 2010). Two popular examples are the Hollywood Stock Exchange (HSX) and CMXX.com, prediction market where traders forecast box office success of movies. Results on show that these markets are considered as accurate predictions as experts (Blume *et al.*, 2010; Brown & Yang, 2019; Strumbelj 2014; Boulu-Reshef *et al.* 2016). In accordance with the efficient market hypothesis game events are quickly resulting in changes of trading prices.

- Economic forecasting

Another interesting field of PM application is the prediction of economic data such as retail sales, GDP, international trade balance, and the growth in payrolls. For this purpose, a market called “Economic Derivatives 20” was launched in 2002. A first analysis shows that the expectations reflected in trading prices are similar to survey based predictions (Kloker *et al.*, 2018; Teschner *et al.* 2011). Teschner *et al.* (2015) showed that those PMS can quickly incorporate new information, are largely efficient, and are impervious to manipulation. Also, they can be used to both uncover the economic model behind forecasts, as well as test existing economic models.

- Healthcare sector

Works related to the use of Prediction markets in the healthcare sector have also been reported in the literature. In 2007, Polgreen, Nelson and Neumann proposed a prediction market –the Iowa Influenza Market (IIM)– for tracking and forecasting emerging infectious diseases, such as severe acute respiratory syndrome and avian influenza, by aggregating expert opinion (Polgreen *et al.*, 2007). Later, Tung, Chou and Lin built a successful Epidemic Prediction Market System (EPMS) in Taiwan in 2010. But unlike the IIM, the Taiwan EPMS shown a superior performance in terms of duration, space, the number of diseases, and the method of trading transaction (Li *et al.*, 2016).

Forecast accuracy

Underneath the included studies are two statistics: heterogeneity and overall effect. The heterogeneity tests aim to determine if there are variations between the included studies. The Chi-squared statistic $\chi^2 = 42.90$ with a p-value of 0.007 translating presence of heterogeneity among our studies. The degree of heterogeneity is given by I2 test which is $46\% < 50\%$. That indicates a moderate and acceptable level of heterogeneity. Therefore, we conclude that there is an inferential reason to conduct further analysis.

Table 3: Main application of prediction markets

Purpose	System	Focus	Industry or area	Relevant literature
Internal use PMS	Hewlett-Packard, Corporate prediction market (CPM), Mechanical Turk; Gates Hillman prediction market (GHPM); Satoshi, Dice230 and BitBet; Iowa Electronic Markets Google IPO Markets	<ul style="list-style-type: none"> • Project management • Idea generation • Product development 	Business area	Wolfram 2015; Wolfram 2019; Teschner and Gimpel 2018; Chen <i>et al.</i> 2003; Othman and Sandholm 2013; Brito <i>et al.</i> 2014; Berg <i>et al.</i> 2009; Matzler <i>et al.</i> 2013; Gruca <i>et al.</i> 2003; O'Leary 2013; Karniouchina 2011; Spann and Skiera 2003
General public usage PMS	Iowa Electronic Markets (IEM); xFuture; PredictIt Kavanaugh Market, PKM; G1 and G2 markets; PollyVote; New York betting markets, Wall Street betting market; Centrebet; Foresight software; POSGI prediction market; PredictIt; Swedish EU-Referendum Political Stock Market	Political stock markets on elections	Political arena	Slamka <i>et al.</i> 2012; Brüggelambert 2004; Berg and Rietz 2003; Berg <i>et al.</i> 2008; Erikson and Wlezien 2012; Graefe <i>et al.</i> 2014; Jones 2008; Khan and Lieli 2018; Kou and Sobel 2004; Brown <i>et al.</i> 2019; Rothschild 2015; Rothschild and Sethi 2016; Strijbis and Arnesen 2019; Lin <i>et al.</i> 2013; Tai <i>et al.</i> 2019; Tung <i>et al.</i> 2011; Graefe 2019; Rhode and Strumpf 2004; Williams and Reade 2016; Berg and Chambers 2019; Groeger 2016; Bohm and Sonnégard 1999; Leigh and Wolfers 2006; LaComb <i>et al.</i> 2007; Jumadinova and Dasgupta 2015; Wolfers and Zitzewitz 2004; Vaughan Williams <i>et al.</i> 2019; Reade and Williams 2019
	<ul style="list-style-type: none"> • Betfair.com, Sports Exchange, PIM Sports, STOC CER; NewsFutures and TradeSport • Hollywood Stock Exchange (HSX) and CMXX.com; IEM Movie Box Office Market; TradeSports.com; NewsFutures.com; FreeMarket; Intrade, Betfair 	<ul style="list-style-type: none"> • Sports games • Success of movies 	Sport and entertainment industry	Servan-Schreiber <i>et al.</i> 2004; Sripawatakul and Sutivong 2010; Sung <i>et al.</i> 2019; Blume <i>et al.</i> 2010; Brown and Yang 2019; Strumbelj 2014; Boulu-Reshef <i>et al.</i> 2016; Vlastakis <i>et al.</i> 2009; Restocchi <i>et al.</i> 2019; McHugh and Jackson 2012; Song <i>et al.</i> 2007
	Economic Derivatives 20; Continuous artificial prediction market (c-APM); Economic Indicator Exchange (EIX); Clean Energy Exchange	Retail sales, GDP, international trade balance, etc.	Economic forecasting	Jahedpari <i>et al.</i> 2017; Kloker <i>et al.</i> 2018; Teschner <i>et al.</i> 2015; Teschner <i>et al.</i> 2011; Borison and Hamm 2010; Gangur and Plevny 2014
	Iowa Influenza Market (IIM); Epidemic Prediction Market System (EPMS); Flu Market; Taipex	Emerging infectious diseases	Healthcare sector	Polgreen <i>et al.</i> 2007; Li <i>et al.</i> 2015; Li <i>et al.</i> 2016; Tung <i>et al.</i> 2015; Wang <i>et al.</i> 2006
<ul style="list-style-type: none"> • IBET • Hyperledger Composer • Prediction markets on terrorism (PMsoT) 	<ul style="list-style-type: none"> • Blockchain • Social network • Terrorism 	Others	Carvalho 2020; Dubin 2019; Qiu <i>et al.</i> 2013; Qiu and Kumar 2017; Weijers and Richardson 2014	

Source: This study.

Next to the list of the included studies, are results on the studies effect estimates. In our study, the effect estimate measured were the Accuracy ratio. In addition, we presented the standard error (SE), the study weight as well as the 95% confidence intervals (CIs). The study weight is the power of the study. Studies such as Slamka *et al.* (2012) with a weight of 20.0% and an effect size of 0.82 (95% CI: [0.81, 0.83]), Cowgill and Zitzewitz (2015) with a weight of 17.2% and an effect size of 0.82 (95% CI: [0.80, 0.84]), Van Bruggen *et al.* (2010) with a weight of 15.4% and an effect size of 0.81 (95% CI: [0.79, 0.84]) and Dana *et al.* (2019) with a weight of 14.2% and an effect size of 0.79 (95% CI: [0.76, 0.82]) have lower variation, i.e. tighter 95% CIs, smaller horizontal line but bigger red box, higher weight and more influence on the overall effect. A possible explanation is that those studies mostly focus on the transparency of the payoff mechanisms while analyzing the accuracy of the different forecast methods. In their experimental design, the authors explain how the participants saw the same information when making trades. This may open onto a heightened level of trust in the process and the experience as a whole. In addition, those studies carefully recruited forecasters from professional societies, research centers and so on based on effective participant recruitment techniques. Those techniques lead to participant's retention as well as the enhancement of the whole experience. For example, authors reported that participants competed for social rewards, including a place on the leaderboard and the chance to join an elite group of "super-forecasters".

The smaller the study, the wider the horizontal line and smaller the red box representing the point estimate because 95% confidence intervals will be much bigger. This means, studies such as Teschner *et al.* (2011) with a weight of 0.0% and an effect size of 0.58 (95% CI: [-0.57, 1.73]) and Brüggelambert (2004) with a weight of 0.1% and an effect size of 0.44 (95% CI: [-0.44, 1.32]) cross the line of null effect and therefore do not illustrate statistically significant results. Based on the effect size of those studies, the markets were relatively less accurate than other forecast methods. However, we cannot conclude anything given the fact that the tests reveal insignificant results. One possible reason is that those studies do not provide the accuracy ratio or appropriate data and information to compute those statistics. In this case, we calculate the effect estimate based on results of those studies. In addition, both papers highlighted the dissemination of information from informed insiders to less informed participants in German markets. That probably the reason why they couldn't disclose more information about accuracy and efficiency of the markets.

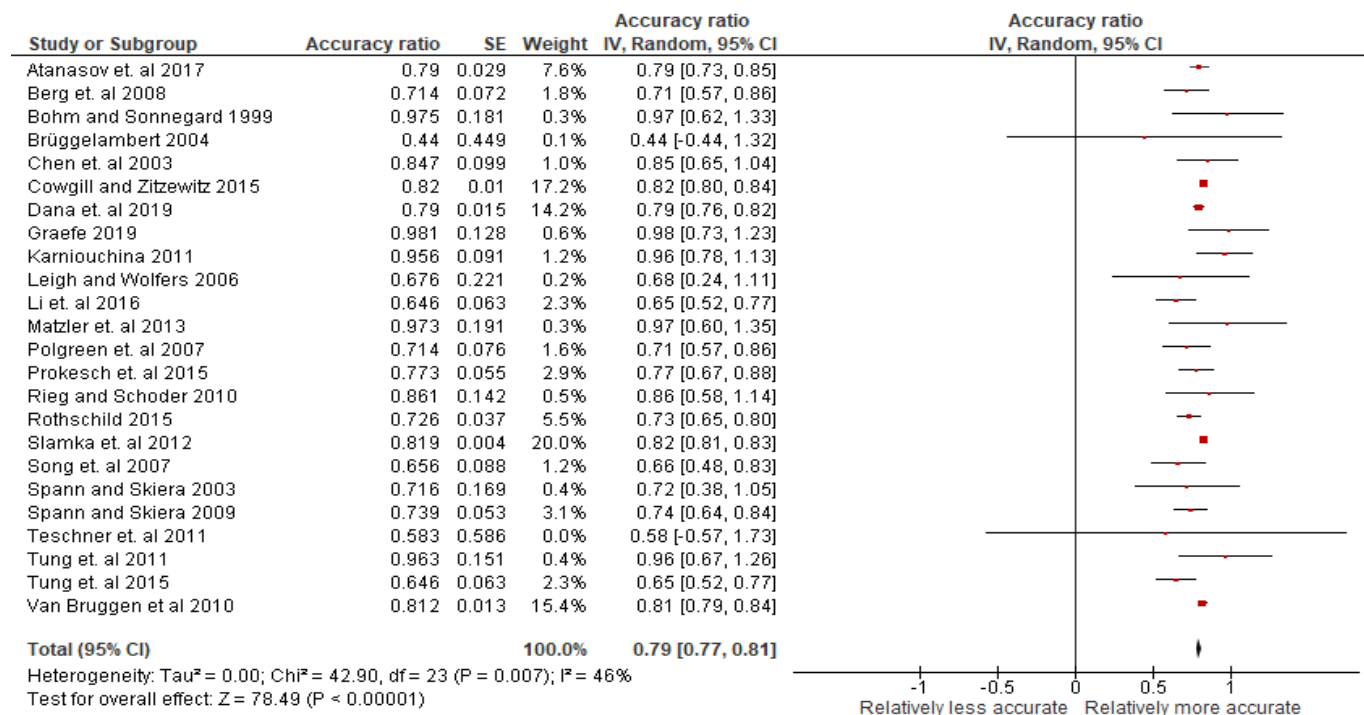
Studies such as Li *et al.* (2016) and Tung *et al.* (2015) share the same weight (2.30%) and same effect size of 0.65 (95% CI: [0.52, 0.77]). Like Polgreen *et al.* (2007) who proposed a prediction markets to track and forecast emerging infectious diseases, Li *et al.* (2016) and Tung *et al.* (2015) scrutinized the first Epidemic Prediction Markets (EPM) system in Taiwan showing that markets have a better prediction capability than historical average data in depicting the trend of epidemic diseases. They found that EPM was 65% more accurate than the traditional baseline of historical average for the target week. Similarly, studies like Bohm and Sonnégard (1999) and Matzler *et al.* (2013) present the same weight (0.30%) and the same effect size of 0.97 (95% CI: [0.60, 1.35]). Bohm and Sonnégard (1999) demonstrated how Prediction markets worked well in predicting the outcome of the Swedish EU referendum while Matzler *et al.* (2013) shows that prediction markets work well in forecasting new products using online communities.

Studies such as Tung *et al.* (2011) and Spann and Skiera (2003) have the same weight (0.40%) but different effect size. With an effect size of 0.65 (95% CI: [0.52, 0.77]), Tung *et al.* (2011) devised a methodology to compare the accuracy of prediction markets and polls and shown that the prediction markets outperform the opinion polls in various indices of accuracy while Spann and Skiera (2003) whose effect size is 0.72 (95% CI: [0.38, 1.05]), show rather encouraging results for the applicability of Virtual Stock Markets (VSM) for business forecasting purposes. Similarly, Karniouchina (2011) having an effect size of 0.96 (95% CI: [0.78, 1.13]) share the same weight of 1.20% with Song *et al.* (2007) with an effect size of 0.66 (95% CI: [0.48, 0.83]). Karniouchina (2011) finds a good predictability of the Hollywood Stock Exchange (HSX) that is an online prediction market allowing people to trade movie and movie star stocks while Song *et al.* (2007) analyzing the betting line predictions found that prediction market was substantially superior to both experts and systems in predicting game winners.

Studies such as Leigh and Wolfers (2006), Graefe (2019), Berg *et al.* (2008), Chen *et al.* (2003) and Rieg and Schoder (2010) also have a weight lower than 2%. A possible explanation is based on study outcomes and experiment settings. Indeed, Leigh and Wolfers (2006) studying the efficacy of econometric models, public opinion polls and prediction markets in light of the 2004 Australian election found that markets provide a useful forecasting performance (0.68; 95% CI: [0.24, 1.11]) but data suggest a more reasonable degree of volatility (SD=0.221). Hence, the lower weight in our analysis. Graefe (2019) also reviewed the accuracy of multiple forecast methods in the context of elections. He found that on average across both elections, polls and prediction markets were both highly accurate (0.98; 95% CI: [0.73, 1.23]) but admitted that the accuracy of individual forecasts did not correlate across elections. Berg *et al.* (2008) with an effect size of 0.71 (95% CI: [0.57, 0.86]) compared prediction markets to polls over past presidential elections and found that the market significantly outperforms the polls in every election when forecasting more than 100 days in advance.

Chen *et al.* (2003) got an effect size of 0.85 (95% CI: [0.65, 1.04]) by introducing a novel methodology for predicting future outcomes that uses small numbers of individuals participating. Experiments show that this nonlinear aggregation mechanism vastly outperforms both the imperfect market and the best of the participants. Rieg and Schoder (2010) following Chen *et al.* (2003) designed a small-scale laboratory experiment and found no differences in accuracy when comparing markets and opinion polls. The experiments demonstrated that it is possible to gain highly accurate forecasts (0.86; 95% CI: [0.58, 1.14]) with a relatively small number of participants taking part continuously.

Finally, black diamond at the bottom of the forest plot shows the meta-analytic effect estimate Φ when all the individual studies are combined together and averaged. (Fig. 3). The meta-analytic effect estimate which is 0.79 (95% CI: [0.77, 0.81]) indicates that on average prediction markets is 79% more accurate than alternative forecast methods based on included studies. The overall effect, Z testing the overall effect significance when taking all the included studies together has a p-value lower than 0.00001, which indicates a very significant result.



Accuracy ratio Effect size) were calculated from random effects meta-analysis with inverse variance weighting (see Methodology, Meta-analysis). SE: Standard deviation; df: degree of freedom

Source: This study.

Figure 2: Effect sizes from studies comparing PMs forecast accuracy versus alternative prediction methods.

RESULTS AND DISCUSSIONS

Conclusions

By systematically review previous academics works related to Prediction Markets (PM), this paper found that PM can be classified internal use PM and general public usage. The first group refers to Prediction Market systems not intended for the general public usage but specifically built for trading within companies or organizations while General public usage PM applied outside companies and organizations in areas such as politics, sport and entertainment industry, economic forecasting and healthcare sector. Moreover, our paper shows that more than 64% of papers are published in top journals such as Journal of the Association for Information Systems, Decision Support Systems, Management science. It has been considered to provide an interdisciplinary approach to the study.

In terms of forecast accuracy, we conducted a meta-analysis. The test indicates a moderate and acceptable level of heterogeneity. Furthermore, we found that. Studies such as Slamka *et al.* (2012), Cowgill and Zitzewitz (2015), Van Bruggen *et al.* (2010) and Dana *et al.* (2019) have smaller horizontal line but bigger red box and more influence on the overall effect. A possible explanation is that those studies mostly focus on the transparency of the payoff mechanisms while analyzing the accuracy of the different forecast methods. In addition, we found that studies using small numbers of participants with inappropriate experiment settings share the lowest weight of the analysis.

Finally, our meta-analytic effect estimate indicates that on average prediction markets is 79% more accurate than alternative forecast methods based on included studies. The overall effect, Z testing the overall effect significance when taking all the included studies together has a p-value lower than 0.00001, which indicates a very significant result.

Limitations and future research

Although we have shown important contribution to the literature, it's crucial to notice some limitations that future research can consider. First, the compilation of 160 publications following the reporting checklist of the PRISMA framework was systematic, but our assessment of the inclusion criteria and studies quality is based on our subjective judgment. Therefore, some relevant articles may not have been included in this review.

Future work can extend this framework by considering other databases such as Scopus, Jstor and so on to perform systematic review on Prediction markets. In addition, subsequent research can consider different inclusion and exclusion criteria and other journal ranking lists like social sciences citation index (SSCI) or Association of Business Schools (ABS). Future researchers may also consider to review themes by describing in more comprehensive way the methodology, and types of data collected.

A second limitation is regarding the language and research trends. In the future, research reviews may include academic works published in languages other than English, opening new collaboration opportunities for joint research with Chinese, Russian, French, or Indian academics for example. An analysis of themes across the years may show the research trends and identify application areas. Additionally, an analysis of the co-authorship networks and citation counts may also be useful for the justification of studies on Prediction markets systems.

Lastly, we restricted our meta-analytic model in considering articles comparing forecast accuracy of prediction markets versus other forecast methods. Subsequent research can enlarge the total outcome by considering other variables. Moreover, we estimated some important statistics such as effect size based on available information and assumption. For the sake of transparency, we have disclosed all the computations we have made in this research in Appendix. Future papers can consider other models and effect estimates such as Standardized Mean Difference (SMD). These limitations can provide future research avenues and can step on the contributions established by this paper regarding a systematic review and meta-analysis on Prediction markets

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