PREDICTION MARKETS: Theory, Evidence and Applications.

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A convenient definition of a prediction market is a judgment-based market that is created or employed for the purpose of making predictions. The theoretical underpinning derives from the efficient market hypothesis, and from the view that relevant information concerning the likelihood of future events that is dispersed among many people can be aggregated effectively via market mechanisms in order to help forecast event outcomes. Prediction markets of various types have been employed for forecasting outcomes ranging from open and closed-door election outcomes (Rhode & Strumpf, 2013; Vaughan Williams & Paton, 2015; Vaughan Williams & Reade, 2015) to the box office success of movies (Court, Gillen, McKenzie, and Plott, 2018; Escoffier & McKelvey, 2015), the forecasting of infectious disease activity (Farrow, Brooks, Hyun, Tibshirani, Burke, & Rosenfeld, 2017; Polgreen, Nelson, & Newmann, 2007), and the probability of meeting project deadlines (Cowgill & Zitzewitz, 2015; Leigh & Wolfers, 2007).

The potential for these markets to be used for forecasting event outcomes has generated significant interest among social scientists and the business community, while corporations use prediction as a decision support tool (O’Leary, 2015; Spears, LaComb, Interrante, Barnet, & Senturk-Dogonaskoy, 2009). Prediction markets also have many potentially valuable applications for both public policy (Paton, Siegel, & Vaughan Williams, 2010; Tetlock, Mellers, & Scoblic, 2017) and economic forecasting (Snowberg, Wolfers, & Zitzewitz, 2013). A separate focus of attention has been the design of the market mechanisms used in prediction markets (Chen, 2011; Klingert & Meyer, 2018; Spann & Skiera, 2003). There has also been growing interest over recent years in the idea of combining forecasts from a range of different forecasting methodologies (Graefe, Armstrong, Jones, & Cuzan, 2014; Pathak, Rothschild, & Dudik, 2015; Rothschild, 2015), and some have questioned aspects of the performances of markets relative to other forecasting methodologies (Atanasov, Rescober, Stone, Swift, Servan-Schreiber, Tetlock, Ungar, & Mellers, 2017; Erikson & Wlezien, 2008; Fry & Brint, 2017). Others have examined how these markets might be influenced by attempts at market manipulation (Buckley & O’Brien, 2017; Hanson & Oprea, 2009). Forecasts from prediction markets have also been examined for systematic biases (Cowgill, Wolfers, & Zitzewitz, 2009; Ma, Tang, McGroarty, Sung, & Johnson, 2016; Restocchi, McGroarty, & Gerding, 2018), and the way in which new information is incorporated into market prices has likewise been investigated (Sung, McDonald, Johnson, Tai, & Cheah, 2019; Vaughan Williams & Reade, 2016). This work complements related research into the efficiency of wagering markets and other forecasting methodologies (Croxson & Reade, 2014; Vaughan Williams, Sung, Fraser-Mackenzie, Peirson, & Johnson, 2016; Vaughan Williams & Stekler, 2010).

The papers in this special issue address such topics and more. The remainder of this introductory essay provides focused summaries of the papers chosen for inclusion, draws some conclusions about the overall state of research in this area, and points out challenges for the future.

PAPERS IN THIS SPECIAL ISSUE

1. ***Joyce E. Berg and Thomas A. Rietz ‑ Longshots, Overconfidence and Efficiency on the Iowa Electronic Market***

Berg and Rietz analyse the forecasting efficiency of binary prediction markets.  Such markets predict the probabilities of discrete outcomes, and have become quite popular.  However, researchers generally cite measures of the forecasting efficiency based on linear prediction markets, which forecast the level of an outcome, meaning that the efficiency can be measured by comparing the forecasts to the actual outcomes directly.  This differs from binary markets, where one must compare the forecast outcome probabilities to the actual outcome frequencies under repeated, essentially identical, conditions.   The authors use a unique set of repeated, binary prediction markets to study the efficiency using frequency and logistic analysis.  While they document a pricing bias at intermediate horizons, the bias disappears before the forecasted events occur.  The observed bias conflicts with static models of bias based on the longshot bias, the overweighting of low probability events, prospect theory, and other models that predict the over-pricing of low-probability events.  The bias observed is transitory, affects only very high and very low prices, and follows a pattern predicted by the information-based, over-reaction story of Daniel, Hirshleifer and Subrahmanyam (1998).  Early in a market, when there is little information, the prices appear unbiased.  As traders observe information, the prices respond, leading to a transitory overpricing of high probability events (and an underpricing of low probability events).  As the event approaches and more information is reflected in the prices, this bias fades, and ultimately disappears.  The paper makes two observations that are important in interpreting binary market prices:  (1) Prices are forecast probabilities and cannot be compared to outcomes directly.  (2) Prediction markets may appear overconfident (i.e., over-pricing very high probability events and under-pricing very low probability events) at intermediate horizons.

1. ***Alasdair Brown and Fuyu Yang ‑ The Wisdom of Large and Small Crowds: Evidence from Repeated Natural Experiments in Sports Betting***

Brown and Yang analyse the role that the crowd size plays in the accuracy of prediction/betting market prices. They ask whether large markets with high participation rates provide more accurate forecasts than smaller markets. There are conflicting theoretical predictions in this area. On the one hand, a large market populated with noise traders (De Long, Shleifer, Summers, & Waldmann, 1990) may produce biased prices. On the other hand, large markets create incentives for information acquisition, as the returns from informed trading are higher. Indeed, information may actually be dispersed amongst the crowd (Galton, 1907), and therefore a larger crowd will produce more accurate predictions, as long as the forecast errors are not correlated. The authors examine repeated natural experiments in tennis betting, where the Queen's Club tennis tournament clashed with a major soccer tournament every other year. Importantly, these clashing tournaments exogenously reduced the rate of participation in tennis betting. They found that larger markets (without the clashing soccer tournament) produced more accurate predictions. This result is of considerable practical importance, as prediction market designers can often set rules or incentives which determine whether the prediction market will be large or small. In this case, bigger is better.

1. ***Chung-Ching Tai, Hung-Wen Lin, Bin-Tzong Chie and Chen-Yuan Tung ‑ Predicting the Failures of Prediction Markets: A Procedure of Decision Making Using Classification Models***

Tai, Lin, Chie, and Tung provide a decision-support framework for helping policy or decision makers who rely on forecasts from prediction markets. Regardless of the accuracy of prediction markets in general, failures in their predictions will sometimes put decision makers’ stakes at risk. Thus, rather than relying on markets’ predictions blindly, this paper offers a systematic way of assessing the predictions’ credibility. On the basis of previous studies about factors that influence the efficiency of prediction markets, the authors incorporated a list of variables into statistical models and machine learning algorithms in order to explore the underlying (and possibly nonlinear) relationships between these factors and the prediction results. More specifically, four classification models were used to classify the credibility of prediction market forecasts. They then used a combined forecasting technique to integrate the classification results from these four models. This enabled them to provide a judgment about a specific prediction market’s forecast prior to the predicted event. A large dataset involving 650 markets was used to train and test their combined forecasting framework. The results indicate that the method was able to discover models that were capable of predicting the failures of prediction markets according to different criteria. Most interesting is the flexibility of the proposed framework, which allows decision makers to build their own models with different sets of variables, classification models, and decision objectives.

1. ***Andrew Grant, David Johnstone and Oh Kang Kwon ‑ The Cost of Capital in a Prediction Market***

Grant, Johnstone and Kwon treat the contracts in prediction markets as financial assets. Contracts are “priced” from the traders’ subjective perspectives using utility theory or the finance expression of utility theory known as the capital asset pricing model (CAPM). The contract's price implies its discount rate, or required rate of return. By exploring the price-implied discount rates of binary contracts, the authors clarify how a trader's rational required expected return reacts to the trader’s subjective probability of winning. The general finding is that a trader who is more confident of the contract expiring in the money requires a lower expected return on that contract. The expected return required of a typical prediction market contract that pays either zero or one is found to increase linearly in its ratio of ex ante perceived subjective payoff variance to payoff mean.  A surprising but immediate conclusion is that the natural risk-aversion of well-informed traders induces a favourite-longshot bias in prediction markets, where longshot contracts cost more than they should relative to their low chance of winning and favourites are relatively too cheap. This bias is explained not by errors in traders' probability assessments, but by the posted bids and asks of traders whose probability assessments are accurate but who are risk-averse.

1. ***Luis Felipe Costa Sperb, Ming-Chien Sung, Tiejun Ma and Johnnie Johnson ‑ Keeping a Weather Eye on Prediction Markets: Improving Forecasts by Accounting for Environmental Conditions***

Costa Sperb, Sung, Johnson and Ma investigate the influence of environmental factors on the calibration of probabilistic estimates derived from prediction market prices. The literature suggests that environmental factors, such as weather and atmospheric conditions, can affect the information processing and cognitive abilities of decision-makers, leading to sub-optimal estimations about uncertain events. This, in turn, has the potential to impair the effectiveness of prediction markets as a means of appropriately aggregating and weighting relevant information that is dispersed in the public. In the context of horserace betting markets, the authors found that the accuracy of the probabilities derived from market prices is affected systematically by the prevailing weather and atmospheric conditions, even after the effects of these conditions on the performances of the contestants (horses and jockeys) have been discounted. They showed that significantly better forecasts can be derived from prediction market prices by correcting for this phenomenon, and that these improvements have substantial economic value. Importantly, the results of this paper suggest that when the purpose of a prediction market is to derive accurate probabilistic estimates from final contract prices, the forecast accuracy can be improved greatly by identifying and correcting for conditions where prediction markets systematically underperform.

1. ***J. James Reade and Leighton Vaughan Williams ‑ Polls to Probabilities: Comparing Prediction Markets and Opinion Polls***

Reade and Vaughan Williams consider the forecast performance of prediction markets alongside that of opinion polls in the context of US election outcomes. The first contribution of this paper is to evaluate a much wider range of prediction markets than previous studies have been able to, most notably considering the large commercial prediction markets Intrade and Betfair. Prediction market forecasts are probabilistic in terms of which candidate will win, whereas opinion polling outputs tend to be reported in terms of vote shares. This makes it difficult to compare how close the different types of forecasts were to being the most efficient, where efficiency is measured in terms of the information incorporated at the time when the forecast was made. Although these two variables are related, their correspondence requires a set of assumptions, either theoretical or statistical. Page (2008) provides theoretical assumptions, and the second contribution of this paper is to use the related statistical assumptions to develop an empirical conversion between probabilities and vote shares. As both opinion polls and prediction market forecasts can be corrected for bias, it is more informative to think about the precision of forecasts. On this metric, prediction market forecasts of election outcomes perform better than opinion polls.

1. ***Chen Di, Stanko Dimitrov and Qi-Ming He ‑ Incentive Compatibility in Prediction Markets: Costly Actions and External Incentives***

Di, Dimitrov, and He consider the effects of external incentives on prediction markets’ abilities to aggregate information. Most papers on external incentives show that when external incentives exist, it is likely that prediction markets will not always capture all agents’ private information accurately. However, papers which consider external incentives tend to assume that agents’ costs external to the prediction market are symmetric. The authors show that even when agents are in a position to take actions external to the prediction market that influence the outcome of the traded event, prediction markets may indeed capture all agents’ private information if the actions external to the prediction market are present. In particular, prediction markets do not incentivise undesirable actions as long as the desired external action is rewarded more than the undesired action. This insight hopefully addresses the concerns that some managers may have in using prediction markets in the workplace due to potentially providing an incentive for undesirable actions.

1. ***Thomas Auld and Oliver B. Linton ‑ The Behaviour of Betting and Currency Markets on the night of the EU Referendum***

Auld and Linton identify the night of the 2016 UK EU Referendum as providing a unique natural experiment for studying the degree to which information was discounted in two parallel forms of prediction markets: financial and betting markets. In particular, they explore the behaviours of both the sterling dollar exchange rate and binary contracts listed on Betfair that pay out according to the outcome of the Referendum. The authors argue that the *sole* determinant of prices in these assets for those few hours overnight was the flow of information provided by the results of the vote. Using public information, they construct an ex-ante joint prior distribution for the vote-share of each constituency that announced that night. Using a Bayesian methodology, they update this prior as the results arrive and compute a dynamic probability that the UK would vote to leave the EU. They find that although both markets are slow to price the information contained in the results (by around two to three hours), the betting market is less inefficient than the financial market. Furthermore, by constructing a theoretical model that links the prices of these contracts, independent of the outcome of the vote, they show that there were violations of weak market efficiency. There were apparently very profitable arbitrage opportunities available by selling the pound and placing hedging bets on Betfair that would pay out whether or not the UK voted to leave the EU.

1. ***Christoph Lohrmann and Pasi Luukka ‑ Classification of Intraday S&P500 Returns with a Random Forest***

Lohrmann and Luukka link stock markets to prediction markets and analyse the prediction of S&P500 intraday returns. In contrast to much of the existing literature, this is set up as a four-class problem rather than a regression or binary classification problem. Premised on these four return classes, four trading strategies are tested against a simple buy-and-hold strategy. All of the suggested trading strategies conduct buy- and sell-decisions based only on certain predicted classes. The research indicates that the four classes differ in their contributions to the returns on the strategies. In particular, the two extreme classes with ‘strong positive’ and ‘strong negative’ predicted returns lead to higher mean returns overall than the ‘slightly positive’ and ‘slightly negative’ return classes. This result holds true even when misclassified returns are included in the averages. Thus, using strategies that act only on a subset of the predicted classes (such as the extreme predictions) can generate higher profits than following all of the predictions.

1. ***Oliver Strijbis and Sveinung Arnesen ‑ Explaining Variance in the Accuracy of Prediction Markets***

Strijbis and Arnesen go beyond the current focus of the prediction market literature by combining observational and experimental analyses of prediction market errors. They investigate the prediction errors of a real money prediction market using a logarithmic market scoring rule for 65 direct democratic votes in Switzerland. The authors distinguish between prediction market errors that are due to the set-up of the market, the features of the event to be predicted, and the participants involved. They find that the prediction market accuracy primarily varies according to the set-up of the market, while the features of the event and in particular the composition of the participant sample hardly matter. Hence, those applying prediction markets should consider the specific configuration of their market carefully, but can remain more relaxed about the composition of their sample of traders.

1. ***Alasdair Brown, J. James Reade and Leighton Vaughan Williams ‑ When Are Prediction Market Prices Most Informative?***

Brown, Reade and Vaughan Williams consider the informativeness of prediction market prices. How do market prices react in the aftermath of information events? This is naturally an important question, as prediction markets are used extensively for eliciting forecasts about uncertain future events. The paper uses the Intrade exchange and the release of opinion polling data. In particular, it investigates what happens in prediction markets in the immediate aftermath of opinion polling releases. Such releases are significant news events, and, in the case of Gallup polls, occur on a regular schedule, at 1pm Eastern Time on most days during the 2012 presidential campaigns in the US. The authors find that there is an increase in trading activity in the immediate aftermath of a poll release. However, much of this activity involves relatively inexperienced traders, and as a result, market efficiency declines in those moments. Once more experienced traders return in the following hours, though, price efficiency recovers. These findings are of practical importance, as they give a sense of the extent to which prediction market prices might be able to be relied upon for accurate forecasts in the aftermath of significant news events.

***CONCLUSION***

In summary, the papers presented in this issue demonstrate that there are several factors, such as the natural risk aversion of well-informed traders and the trading behaviour observed immediately after the release of new information, which can induce biases in prediction market forecasts. Equally, they show that certain prediction classes (such as extreme predictions) can be under- or over-priced. In addition, the papers demonstrate that the accuracy and precision of the forecasts derived from prediction markets can be affected by a range of factors, including environmental factors, the size of the market, the set-up of the market, the external incentives provided and the point in the market cycle at which predictions are observed.

However, evidence is also presented that, despite *a priori* expectations, some aspects of prediction markets do not influence their accuracy, such as features of the event and the composition of the participants. In addition, provided that markets are given sufficient time, the accuracy of prediction market forecasts increases and the forecasts derived from these markets outperform those from other forecasting mechanisms such as opinion polls and financial markets on key metrics.

As a consequence, the evidence presented here should provide comfort to potential users of prediction market forecasts. Taken together, the papers suggest that prediction markets can become a powerful source of forecasting ability by thinking carefully about their design, setting up procedures for adjusting forecasts to account for known biases, and planning carefully when such forecasts should be used,.

These findings reflect a notable increase in interest in the applications to which prediction markets can be put, as well as in the broader body of evidence which suggests that these markets might produce better forecasts than alternative forecasting mechanisms. The insights gained have also been shown to have potentially valuable applications for policy, not least when accurate forecasts are required in relation to quantifiable targets. The findings also reflect a wider interest in the best way of designing and implementing prediction markets.

Even so, some have questioned the extent to which prediction markets can outperform other forecasting methods, or whether they are at best a supplement to more traditional forecasting methodologies. These doubts have attracted added focus in very recent years following some high-profile forecasting failures in the context of major political event outcomes. In particular, the 2016 EU referendum in the UK and the 2016 US presidential election produced results that were a surprise not only to the great majority of pollsters, but also to followers of the prediction markets. There are various theories as to why the markets failed in these big votes. One theory looks to the basic laws of probability. An 80% favourite can be expected to lose one time in five, if the odds are correct. According to this explanation, things should even out in the long run. A second theory to explain the surprise results is that something fundamental has changed in the way in which the information contained in political prediction markets is perceived and processed. One interpretation is that the hitherto widespread success of these markets in forecasting election outcomes, and the publicity that was given to this, turned them into something of an accepted measure of the state of a race, creating a perception which was difficult to shift in response to new information. This is a form of ‘anchoring’. Linked to this is a herding hypothesis, which is that because the prediction markets had become so firmly entrenched in conventional wisdom as an accurate forecasting tool by 2016, people herded around the forecasts, propelling the implied probabilities of favoured outcomes upwards. A third theory is that conventional patterns of voting broke down in 2016, due primarily to unprecedented differential voter turnout patterns across key demographics, which were not modelled correctly in most of the polling and were missed by political pundits, political scientists, politicians and those trading in the prediction markets. Finally, there has been widespread discussion of the impact of manipulation, not only of the markets themselves, but also of the distribution of information and misinformation.

Future research into the uses and applications of prediction markets might focus on what can potentially be learned from recent forecasting failures in order to improve the efficiency of the forecasts derived from prediction markets, as well as to identify when markets are likely to be most informative. The ways in which market forecasts can be adjusted to allow for systematic biases are also likely to attract the continued interest of researchers. In addition to comparing the efficiency of prediction markets with those of other forecasting methodologies, there is a growing interest in the idea of combining forecasts derived from the different methodologies in order to generate improved forecasts. Increasing attention is also being paid to the design and incentive structure of markets and the contribution they can make as a corporate and policy decision support tool.

The papers selected for this special issue of the *International Journal of Forecasting* reflect this diverse research agenda, and offer an exceptionally strong contribution to the existing literature on prediction markets. Importantly, they also provide a valuable framework upon which future work can build. It is with no little anticipation that those interested in theory, evidence and applications relating to prediction markets look forward to the outputs of further research in this area.

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