

# Using Prediction Markets to Forecast Trends in Infectious Diseases

Prediction markets provide a means for collecting, analyzing expert opinions to forecast infectious disease outbreaks

**Philip M. Polgreen, Forrest D. Nelson, George R. Neumann**

**P**ublic health agencies conduct surveillance for a number of infectious diseases and related phenomena. Typically, the collected information is used to help public health officials, researchers, and health care professionals cope with and plan for future disease activity. In many cases, however, such information is no longer particularly relevant for clinical purposes when it becomes widely available. For example, influenza surveillance data are usually at least one to two weeks old by the time this information is available at the state and regional levels.

For sexually transmitted and other infectious diseases, the information lag often is much longer because it is published on a quarterly or yearly basis. Some data may not be disseminated until after scientific manuscripts are published, typically months after manuscripts are submitted.

Prediction markets provide an alternative approach for gathering and analyzing infectious disease-related information, including informed opinions, for the purpose of spotting trends. Such “markets” predict events and trends by using information contained in prices that are part of either real or simulated transactions.

Operators construct prediction markets by defining specific financial instruments or contracts that are based on some particular event of interest, such as “Will there be a documented case of human-to-human transmission of H5N1 influenza in North America by January 2008?” Findings are presented in an easy-to-interpret graphical format.

Although prediction markets will never replace traditional disease-surveillance systems, they can serve as a useful supplement. Importantly, these markets can be used to generate data that are useful for improving existing surveillance systems and for determining how microbiologists and medical professionals respond to new findings as they identify and then cope with specific disease outbreaks. By recording every trade and retrospectively determining who knew what and when during the early stages of outbreaks, we can use such systems to help the medical and microbiology communities build more sensitive conventional surveillance systems.

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## Summary

- Prediction markets predict events and trends by generating prices from trades occurring between participants. These prices contain information useful for forecasting purposes.
- Such “markets” aggregate information from all participants, providing each of them incentives and feedback to reveal knowledge to other participants.
- In a pilot study, health care professionals, including clinical microbiologists, who participated through a prediction market forecast influenza activity 2–4 weeks in advance with greater accuracy than was achieved using historical data.
- The three requirements for a market are disparate information, uncertainty, and an outcome against which to base a contract; once established for a particular infectious disease, such markets can be quickly adapted to analyze other diseases.



## The Value of Expert Opinions in Predicting Infectious Disease Trends

Clinical microbiologists generate useful data about infectious diseases that some surveillance systems tap into directly. For instance, in some cases, microbiology labs report numbers of positive tests to public health agencies routinely, while in others they send the agencies clinical isolates for further study. Meanwhile, many additional microbiologists possess information that could be used to predict particular infectious disease trends.

In the specific case of influenza, the World Health Organization (WHO) collaborates with 122 institutions in 83 countries to identify and collect new strains of the influenza virus. These efforts form the basis for WHO recommendations for which influenza strains to use when formulating vaccines for the next season. On a local basis, clinical microbiologists are often among the first to know that influenza is circulating in a particular community when they see that diverse physicians are ordering diagnostic tests and then determine that respiratory cultures are turning positive for influenza. Thus, clinical microbiologists often can provide short-range estimates of influenza activity in their respective communities.

Microbiologists also have special insights into likely trends for a wide range of other infectious disease-related subjects, including sexually transmitted diseases and antibiotic resistance. Moreover, many microbiologists have informed opinions as to the incidence and prevalence of diseases and drug resistances in their communities. In some cases, these opinions are based on direct observations and, in others, on scientific knowledge or past experiences dealing with these issues.

### How Can One Effectively Collect Opinions from Microbiologists?

Because of their disparate nature, the opinions of clinical and research microbiologists cannot be readily aggregated by using standard research and statistical methods. Furthermore, the subjective nature of this information also makes it difficult to analyze and interpret. However, the business sector routinely uses focus groups and surveys to collect and then analyze similar types of subjective information from customers and

front-line employees. This analyzed information is then routinely used to forecast sales figures, spot industry trends, and improve business decisions related to adjusted expectations.

Recently, both academic researchers and corporate entities such as Hewlett Packard, Google, and Eli Lilly have begun using prediction markets as an alternative means for forecasting business trends or other kinds of developments. We think that prediction markets can be adapted to forecast the activity of a wide variety of infectious diseases and related phenomena. The accuracy of these forecasts will be enhanced over other methods because prediction markets can effectively tap into aggregated expert opinions of microbiologists.

### Prediction Markets Use Pricing Trends To Chart Expert Opinions

While the idea that prices convey information is well established, research that uses markets and pricing data to analyze aggregate opinions and to forecast trends or events originated at the University of Iowa in 1988. That research soon was incorporated into a continuing project, called the Iowa Electronic Market (IEM). As part of its educational mission, the IEM system has been used by more than 15,000 students in more than 100 colleges and universities throughout the world as a means for simulating financial markets.

During the past 18 years, IEM also has conducted more than 300 prediction market-based analyses to forecast various events, including elections and legislative vote outcomes, decisions by the Federal Reserve to adjust interest rates, shifts in currency and stock prices, movie box office receipts, values for initial public stock offerings, and sales of Harry Potter books. Its prediction record has proved substantially superior to alternative mechanisms such as opinion polls. For example, in forecasting U.S. presidential elections, the average prediction error across 6 elections was less than 1.5%, compared to opinion polls for those same elections at about 2.5% (Fig. 1).

During the past decade, prediction markets patterned after the IEM have been used successfully in both academic and commercial settings. For example, Eli Lilly and Company has used this approach to help predict which developmental drugs have the best chance of advancing

## Polgreen Taps Economics To Predict Infectious Disease Trends

When Philip Polgreen went to college, he anticipated becoming an economist. During his senior year, however, he read an article about using mathematics to predict the spread of smallpox, and it changed his career goal. “I knew what I wanted to do—study infectious diseases,” he says. “I finished my majors in mathematics and economics and went to medical school instead of graduate school. Given my lack of biology classes, the first two years of medical school were difficult, but I caught up.”

Since then, he found an unorthodox way of combining his interests in economics and infectious diseases. A few years ago during the severe acquired respiratory syndrome (SARS) epidemic, he met the economists Forrest Nelson and George Neumann, who developed “prediction markets” as a way of forecasting outcomes for disparate events, including elections and the Academy Awards.

“Together, we decided to use these markets to help predict future infectious disease activity,” Polgreen says. “At first, most people thought we were crazy, and some of them still do—but trying to apply new methods to old problems often leads to solutions. Forrest and George have been terrific mentors over the past few years, and thanks to the Robert Wood Johnson Foundation’s pioneer fund we have been able to pursue this research.”

“In medical school, I got interested in viruses,” he recalls. “Because of this interest, I decided to try to start a career in a basic sci-

ence laboratory. However, during the final year of my infectious disease research fellowship, I had run into lots of dead ends. My primary project was to find the receptor for a virus on lymphocytes. The project was hampered by a lack of commercial reagents and unreliable growth of the virus in cell culture.”

Despite so many frustrations, Polgreen regards his stint doing laboratory research as a valuable experience. “Although I was unable to demonstrate anything conclusively, my laboratory experience was a great success from an educational perspective,” he says. “The research provided me with valuable experience in generating and testing hypotheses, choosing appropriate experimental controls, and understanding the strengths and limitations of various laboratory techniques. Most importantly, I learned a great deal about my own research interests. At the end of my third year of fellowship, I evaluated my strengths and interests, and decided to pursue the more quantitative areas of research that I had begun to explore in college.”

Polgreen, 37, a native of Rockford, Ill., graduated in 1992 from Beloit College in Beloit, Wis., and from medical school at the University of Cincinnati in 1997. He expects to receive a M.P.H. in epidemiology this year from the University of Iowa. His wife, Linnea, is an economist, and they are the parents of two-year-old twins.

Polgreen is assistant professor of infectious diseases at the University of Iowa in Iowa City, and director of the Infectious Diseases Society of

America’s emerging infections network, a sentinel group of about 1,000 specialists funded by the Centers for Disease Control and Prevention. Their goal is to help detect emerging infectious disease trends. (See EIN at URL [http://www.idsociety.org/Content/NavigationMenu/Resources/Emerging\\_Infections\\_Network/About\\_EIN/About\\_the\\_Emerging\\_Infections\\_Network.htm](http://www.idsociety.org/Content/NavigationMenu/Resources/Emerging_Infections_Network/About_EIN/About_the_Emerging_Infections_Network.htm).)

“I am interested in gathering information about infectious diseases from different people in different places and transforming it into a form that can be used to help prevent and treat infectious diseases,” he says. “Microbiologists, as well as health care workers, have a great deal of information—and someone needs to figure out how to use it to better prepare for the future; currently there are no infectious disease forecasts.”

“My colleagues and I hope to help members of the network communicate and share information about infectious diseases . . . in an attempt to make infectious disease forecasts available to microbiologists, clinicians, and public health workers in as close to real time as possible,” he adds. “In the last decade, numerous technological advances have taken place. We would like to help the field of infectious diseases capitalize and incorporate some of these advances in their discipline and daily routine.”

### Marlene Cimons

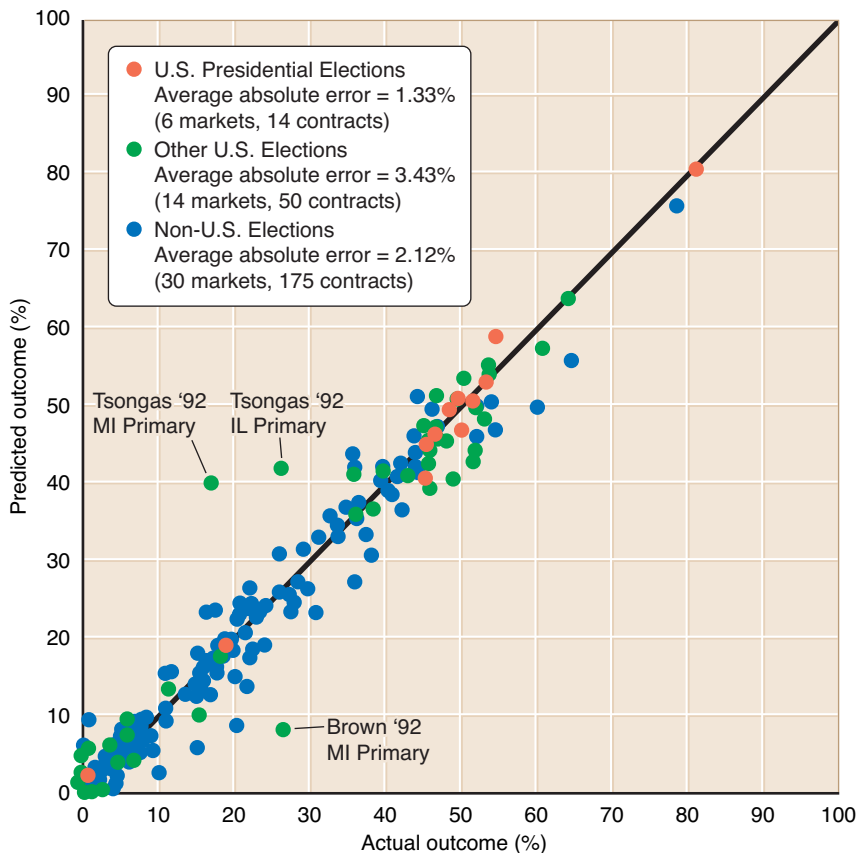
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though clinical trials. And when Hewlett-Packard (HP) used such markets to forecast sales of its printers, they outperformed statistical sales

forecasts. Similarly, the Hollywood Stock Exchange accurately predicts Oscar nominees and opening-weekend box-office receipts more accu-



FIGURE 1



Political futures market predicted versus actual outcomes for vote-share and seat-share markets. Vote-share market predictions are for percentages of votes received by parties or candidates. Seat-share market predictions are for percentages of seats in congress or parliament held by parties. Predictions are based on normalized (to sum to 100%), last-trade prices as of midnight the night before each election. The 45-degree line represents perfect accuracy.

rately than do other analysts working for the movie industry, and the Foresight Exchange is designed to predict other types of events, such as whether specific scientific conjectures will be proved correct or false.

### How Prediction Markets Work

While conventional markets allocate resources, prediction markets are virtual exercises that are conducted solely to forecast events by exploiting information that is “contained” in prices. Prices of artificial financial instruments or contracts are based on some future event of interest. The ultimate value of such a contract is contingent upon the outcome of that event. In the context of forecasting infectious disease-related devel-

opments, we might ask: “Does the influenza vaccine currently being produced include the appropriate dominant strain of virus that will circulate next season?”

In such a prediction market-based analysis, interested participants—typically, experts in the topic—are invited to buy and sell contracts designated “yes” and “no.” Trading continues until the end of the influenza season when the outcome is revealed by a previously specified official source—for example, data collected and published by the World Health Organization (WHO). At that point the market closes and contracts are liquidated with values determined by the event outcome. During the course of the market, clinical microbiologists and other experts, who are the traders in this virtual market, use their own information about the unfolding event to guide their transactions in the market as they seek to maximize their simulated “profits.” These participant traders typically buy contracts that are, according to their own information-based opinions, undervalued and sell those that they consider to be overvalued. The prices at which the contracts trade reflect an aggregate, consensus belief about their future values and, thus, can be used to make a prediction.

Providing participants with incentives to trade is critical for making prediction markets work. The transactions that traders make to maximize their profits effectively reveal their private information to the marketplace. However, because money transactions of this sort may not be appropriate in health care settings, participants who trade in our virtual health-related markets use imaginary instead of actual money.

Even so, when the virtual markets close at the end of the analysis period, individually held account balances are converted into small monetary rewards that are donated to participants for the purpose of buying reference books, paying for journal subscriptions, or covering conference fees and travel costs. The money involved is small and compares to amounts individuals would receive for completing mar-

keting surveys. Moreover, the monetary awards are restricted for uses that enhance the professional development of individual participants. In our most recent market to predict influenza activity in the state of Iowa, for example, each of the 86 participating traders began with a virtual sum of \$100; the final grants to them ranged from \$28.79 to \$301.86.

When clinical microbiologists or other experts participate in prediction market analysis exercises, they find new opportunities to share knowledge but also to compete with peers or other professional groups, and such friendly competitions provide additional incentives to participate. Although prediction markets prove accurate without the use of money, other evidence suggests that cash incentive payments decrease the variance about the mean without affecting the mean probability assessment of such analyses.

### **Advantages of Prediction Markets over Surveys**

Prediction markets offer a number of advantages over surveys, the more conventional method for aggregating expert opinions to forecast events. For instance, prediction markets sample participant opinions on a continuous and ongoing basis, allowing unusual trends or abrupt shifts in opinion to be identified sooner and with greater ease. While profits and losses in the market are not tallied until the market closes, transaction prices are observable throughout the operation of the market, and it is those prices which convey the aggregate beliefs regarding the future outcome of the event. While some surveys offer small incentives to participants, traders in a prediction market have incentives that increase in proportion to the quality of information that they provide. A properly designed market provides a direct and easily interpreted measure of the event being predicted. Unlike surveys, an interactive market environment provides immediate feedback to participants, allowing them opportunities to reassess their own information, respond to feedback, and refine their opinions.

With prediction markets, the most successful participants are those with the best information, and those are the very individuals who are most likely to thrive in the market. With surveys, this

### **Current or Planned Infectious Disease Prediction Markets:**

- Iowa Influenza Activity Market 2006–2007
- North Carolina Influenza Activity Market 2006–2007
- Vaccine Effectiveness Market (North America) 2006–2007
- Mumps Reappearance Market (U.S.) Spring 2007
- H5N1 Prediction Market 2006

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process would introduce a selection bias, but with markets the incentive structure tends to make the forecasts more accurate. Another advantage is that prediction markets typically cost much less to administer than surveys, in part because the required number of participants is much smaller. For example, although the minimal number of traders for a successful prediction market is an open research question, markets with as few as 20 or 30 active traders can yield accurate results. However, accuracy tends to improve as the number of traders increases. In general, election-based prediction markets produce more accurate results than do national surveys or polls with 10 times the number of participants. Also, because whether such markets are cleared on a daily, weekly, or continuous basis is a design parameter, information may be aggregated at any desired frequency without incurring extra costs. With surveys, however, participants typically need to be revisited at each designated time period.

### **Prediction Markets for Microbiologists**

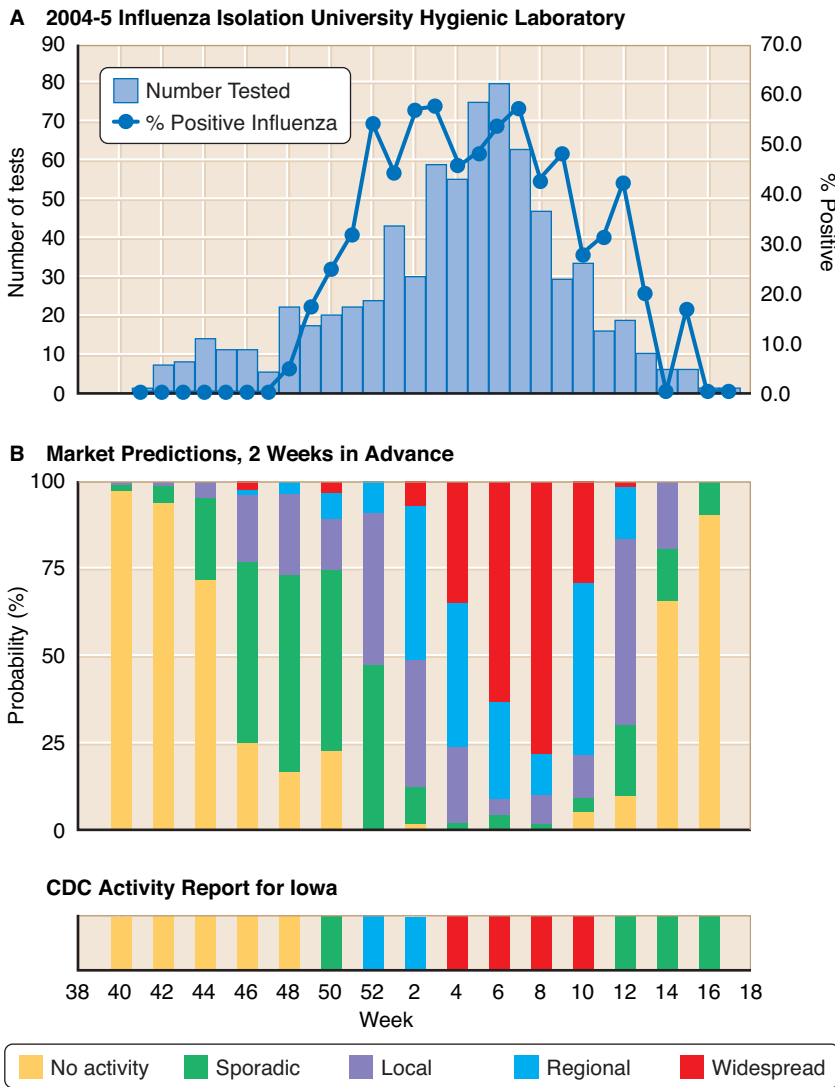
For several issues revolving around emerging infectious diseases, microbiologists in different geographic regions doing basic research or working in clinical settings possess special information that could prove useful in predicting the occurrence, rate of increase, the peak, and rate of decline for particular outbreaks. Prediction markets could provide an opportunity for them to extract and distill that information. A thorough test of this concept for infectious diseases remains to be done.

However, we conducted a pilot prediction market to predict influenza activity in the state





FIGURE 2



Information available publicly regarding influenza activity. The top panel illustrates the percentage of influenza cultures testing positive during the 2004–05 influenza season for the state of Iowa. For comparison, the “two-weeks-in-advance” forecasts from the market appear in panel two and the CDC’s activity levels appear in panel three.

of Iowa for each of the last two influenza seasons. Contracts in these markets were based on the Centers for Disease Control and Prevention (CDC) color-coded system for tracking national flu outbreaks, in which red indicates a widespread outbreak, blue means regional, purple is local, green is sporadic, and yellow indicates no flu activity. Traders bought and sold contracts based on their beliefs about future influenza activity and at prices reflecting their expectations.

The interaction of all these traders led to a consensus opinion about the probability that influenza activity would be at a particular level for a particular week. We found that a small group of health care professionals that included clinical microbiologists could predict influenza activity 2–4 weeks in advance with greater accuracy than could be achieved using historical data alone (Fig. 2).

We believe that prediction markets for microbiology and infectious disease have applications beyond predicting local seasonal influenza activity. For example, a market could be opened to predict the future dominant strain of influenza by aggregating information from microbiologists and virologists from around the world. This market could be opened months before officials decide what strains to include in annual vaccine lots. The Robert Wood Johnson Foundation is providing funds for such a market beginning with the 2007–08 influenza season. However, we plan to open a prelude to this market in the fall of 2006 to assess the effectiveness of the 2006–07 influenza vaccine.

Every season, the proportion of people who are vaccinated but still become sick from influenza provides an early indication of that vaccine’s effectiveness. If many vaccinated health care workers contract influenza, they provide an early indicator of a problematic vaccine. Thus, we plan to open a market that asks health care epidemiologists, microbiologists, and clinicians to predict whether the 2006–2007 influenza vaccine performs better, the same, or worse compared to the one from last season. The contracts for this market will be based on influenza vaccine effectiveness information generated by the Naval Health Research Center, which conducts population-based surveillance for febrile respiratory illness at U.S. military basic training centers.

Another possible prediction market of interest to microbiologists would be an avian influenza market to predict human-to-human transmissions of avian influenza in different geographic regions by particular dates. Addition-

ally, markets to forecast next season's supply and demand for influenza vaccine could help to reduce uncertainty regarding the future vaccine supply—thereby helping patients, health care workers, vaccine manufacturers, and public-health policy makers. Yet another market could be established to predict the reemergence of the mumps virus or to estimate the probability of better control of pertussis after the introduction of a new vaccine. Markets could also be conducted to predict the outcome of widely anticipated research results or ongoing clinical trials.

The three requirements for a market are disparate information, uncertainty, and an outcome against which to base a contract. While

short-term markets have advantages, prediction markets can effectively run for a year or more. One of the distinct advantages of markets over other forecasting techniques is that after a trader base has been established, new prediction markets can be created almost overnight to address emerging infectious diseases, even before a specific etiological agent is identified. For example, in the case of severe acquired respiratory syndrome, or SARS, outbreak in the spring of 2003, a prediction market could have quickly, accurately, and inexpensively aggregated expert opinion about this new infection. Such a prediction market would have been especially useful, given the absence of SARS surveillance systems at that time.

#### SUGGESTED READING

Giles, J. 2005. Wisdom of the crowd: decision makers, wrestling with thorny choices, are tapping into the collective foresight of ordinary people. *Nature* 438:281.

Forsythe, R., F. D. Nelson, G. R. Neumann, and J. Wright. 1992. Anatomy of an experimental political stock market. *Am. Econ. Rev.* 82:1142–1161.

Pennock, D. M., S. Lawrence, C. L. Giles, and F. A. Nielsen. 2001. The real power of artificial markets. *Science* 291:987–988.

Smith, V. L. 2003. Constructivist and ecological rationality in economics. *Am. Econ. Rev.* 93:465–508.

Surowiecki, J. 2004. *The wisdom of crowds: why the many are smarter than the few and how collective wisdom shapes business, economies, societies and nations.* Random House, Inc., New York.

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