Influenza and Pneumococcal Vaccination Demand Responses to Changes in Infectious Disease Mortality

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Objective. To test the hypothesis that individuals are more likely to receive a vaccination against influenza or pneumonia as the perceived disease threat increases.

Data Sources. This study uses two different national datasets. Individual-level information about the vaccination rates of 38,768 elderly persons are from the Behavioral Risk Factor Surveillance System, 1993–1998. Information on the combined influenza and pneumonia state mortality rates are measured from the Compressed Mortality File.

Study Design. Using both cross-sectional and state fixed-effects panel data estimators, we model an individual's probability of having an influenza or pneumococcal vaccination as a function of the lagged state mortality rate. Multiyear lags are specified in order to estimate the duration of the effect of disease mortality on individual vaccination behavior.

Principal Findings. Results support our hypothesis that influenza vaccination behavior responds positively to disease mortality, even after a one-year lag. We further find that cross-sectional estimators used in previous work yield downward-biased estimates, although even for our preferred panel data models, the estimated effects are small.

Conclusions. The findings indicate that behavioral demand responses can help to limit infectious disease epidemics, and suggest further research on how public awareness campaigns can mediate this disease threat responsiveness behavior.

Key Words. Vaccination, influenza, pneumonia, mortality

Pneumonia and influenza are infectious diseases with severe health consequences for the general population, and for the elderly in particular. Based on recent reports from the Centers for Disease Control and Prevention (CDC), pneumonia and influenza are still the sixth leading cause of deaths for the general population and the fifth leading cause of deaths for elderly persons in the United States. Among total deaths due to pneumonia and influenza, about 90 percent are elderly persons (Hoyert, Kochanek, and Murphy 1999; Janes et al. 1999; Murphy 2000; Hoyert et al. 2001; Anderson 2002). In addition, approximately 48,000 of the pneumonia and influenza hospitalizations per year occur among elderly persons who are at highest risk for influenza-related complications (Centers for Disease Control and Prevention 2000). The risk of being hospitalized due to pneumonia and influenza increases two- to threefold when a person aged 65 years or older has one or more chronic diseases (Honkanen, Keistinen, and Kivelä 1997). Medicare costs for influenza-related hospitalizations can reach one billion dollars each year (Fedson 1994; Houck, Lowery, and Prela 1997).

Clinical preventive services can reduce morbidity and mortality. Influenza immunization is associated with fewer hospitalizations and lower risk of death for both pneumonia and influenza during the influenza season. It is also associated with fewer outpatient visits for pneumonia and influenza and all respiratory conditions (Nichol, Baken, and Nelson 1999). Influenza and pneumococcal immunizations are cost-effective (Fedson 1994; Sisk et al. 1997; Finger and Francis 1998).

Despite recommendations from national organizations and scientific evidence for their effectiveness, vaccination rates remain low. The Advisory Committee on Immunization Practices recommends that persons aged 65 or older receive annual influenza immunization and at least one lifetime dose of pneumococcal immunization (Houck, Lowery, and Prela 1997). The American College of Physicians suggests that persons who received pneumococcal vaccine before age 65 be reimmunized at 65 if more than six years have passed since the initial vaccine (Goldberg and Chavin 1997). In this study we investigate the determinants of vaccine demand by elderly persons. In particular, we test the hypothesis that individual vaccine demand is partly determined by the perceived seriousness of the influenza and pneumonia threat (Philipson 2000).

Testing the empirical validity of this threat-responsiveness hypothesis is important both for understanding the limitations of access-related interventions aimed at increasing vaccination levels during nonepidemic periods, and for understanding the potential power of public information campaigns in helping to raise vaccination levels during epidemics. The hypothesis has been supported by tests in a handful of populations with different diseases,

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including HIV prevention for young men (Ahituv, Hotz, and Philipson 1996), measles immunization for children (Philipson 1996; Goldstein et al. 1996), and influenza vaccinations for working age and elderly persons (Mullahy 1999).

In addition to further testing the hypothesis in a different setting, our paper contributes to this literature in two other ways. First, in contrast to previous work examining influenza vaccination behavior, we control for a variety of potentially unobserved confounding variables through the use of panel data techniques. If persistently higher disease prevalence areas always have higher vaccination rates for systemic reasons, then cross-sectional approaches may yield upwardly biased estimates of short-run behavioral responses to epidemics. Or conversely, if some areas have persistently low demand for vaccination due to unobserved factors such as regional access to care, then the low demand would endogenously cause persistently high disease prevalence, implying that the cross-sectional approaches could underestimate the true threat-responsiveness.

A second contribution of our work is to further examine the role of *perceptions* in affecting threat-responsiveness behavior. The theory as presented by Philipson (2000) predicts that rational and well-informed individuals will respond to current infectious disease threats by demanding efficacious vaccines. We test this prediction in two ways. First, because the pneumococcal vaccine is not considered efficacious against the form of pneumonia that increases during influenza epidemics, the theory would predict that increased threats should lead to increased influenza vaccination, but not increased pneumococcal vaccination. If pneumococcal vaccination also responds, this would be indirect evidence consistent with the role of misperceptions in affecting vaccination demand. The second way in which we test the role of perceptions is by examining responsiveness to *past threats*, as opposed to Philipson's tests of responsiveness to current threats. Given that the rapid mutation of influenza viruses causes there to be little relationship between epidemic levels from one year to the next, the canonical theory predicts zero responsiveness to the previous year's influenza disease threats. This prediction is at odds, however, with the responsiveness found by Mullahy (1999) to the previous year's influenza epidemic level. Mullahy hypothesizes that lagged prevalence could affect behavior by changing subjective expectations of the probability and severity of infection. We estimate disease threat-responsiveness for one-, two-, and three-year prevalence lags, in order to better test Mullahy's hypothesis against omitted variables explanations, and to better understand the duration of such perception effects on behavior.

CONCEPTUAL FRAMEWORK

The demand for vaccinations depends on the perceived costs and benefits of the vaccinations, under uncertainty (Mullahy 1999). Part of the uncertainty comes from not knowing whether the individual will be infected—with or without the vaccine—and if infected, then for how long and at what severity. People will be more likely to get vaccinated if they think they will get the disease, and if they think the vaccine will be effective.

In terms of cost, Medicare now provides free influenza and pneumococcal vaccines for elderly persons. Free Medicare coverage was extended to pneumococcal vaccines in 1981 and to influenza vaccines in 1993 (Carrasquillo, Lantigua, and Shea 2001). However, free vaccines are not sufficient to ensure a high vaccination rate (Honkanen, Keistinen, and Kivelä 1997; Rhodes, Arday, and Arday 1997). One CDC study indicated that in 1997, 65.5 percent of elderly persons reported receiving an influenza vaccination during the preceding year and 45.4 percent of elderly have ever had a pneumococcal vaccination, but with great variations across states (Centers for Disease Control and Prevention 1998). Even with no out-of-pocket cost for the vaccine itself, individuals still face a time cost and office visit copayment when getting vaccinated. The time cost is lower for those who live close to their physician, have frequent interaction with the medical care system, are retired, and live in an area with frequent public vaccination days. Socioeconomic status and local health care markets may also affect demand via the time cost.

The benefits of vaccination arise from improved health status. A variety of individual characteristics may affect these benefits. For example, those in poor health status, especially those with weak pulmonary systems (such as smokers), may demand vaccinations because of greater susceptibility to disease. Socioeconomic variables and local health care markets may also influence demand via this health status pathway, by affecting both the actual and perceived benefits of vaccination.

Of particular interest for our analysis, we hypothesize that vaccination demand depends positively on the contemporaneous disease threat, because the benefits of vaccination are greater when the chance of catching the disease is higher. Philipson (2000) defines the *infection elasticity for vaccine-preventable diseases* to be the increase in the vaccination rate induced by each increase in the infection rate. While biological epidemiology assumes that this elasticity is zero, meaning no behavioral response, the threat-responsiveness hypothesis recognizes that individuals change their behavior when disease threat rises. As the probability of infection rises, a person will be more likely to take preventive action. For example, to prevent influenza, a person might get vaccinated, avoid contact with other infected persons, dress warmly, and eat a healthy diet.

Health belief models also predict that individual *perceptions* of susceptibility to disease and severity of disease affect the probability of taking preventive action (Rosenstock 1966; Becker, Drachman, and Kirscht 1974), but they consider a wider range of influences on such perceptions besides the objective risk. Following this literature, as well as Mullahy (1999), we hypothesize that perceptions of the current disease prevalence and severity may be influenced by the lagged disease threat. These perceptions may be formed via a variety of pathways, such as recent infectious experiences by individuals and their acquaintances, recollection of information from their physician or media reports from CDC surveillance. The extent to which this lagged disease threat actually affects behavior, and the speed with which such effects decay with time from epidemics, are matters for empirical investigation.

One final determinant of vaccination behavior that is important for our analysis is the perceived vaccine efficacy. Because the pneumococcal vaccine primarily reduces pneumococcal disease such as bacteremia, but not the pneumonia that causes most deaths after influenza complications (Centers for Disease Control and Prevention 2003), fluctuations in influenza threat levels should not affect pneumococcal vaccination demand. We hypothesize that pneumococcal vaccination is responsive to influenza threat levels, however, due to the common public misperception that this vaccine can reduce the pneumonia complications arising from influenza.

In summary, the demand for vaccinations depends on the perceived risk and severity of infection, perceived vaccine efficacy, health status, socioeconomic status, environmental factors, and vaccine costs. Based on the conceptual framework, we posit three hypotheses regarding the effects of disease threats on elderly vaccination behaviors.

> **H**1: The influenza vaccination rate depends positively on the lagged influenza threat.
>
> **H**2: The pneumococcal vaccination rate also depends positively on the lagged influenza threat, due to misperceptions of vaccine efficacy.
>
> **H**3: Threat-responsiveness behavior diminishes with the length of lag since the threat.

METHODS

Data

This study uses two different national datasets. The dependent variables—individual-level influenza and pneumococcal vaccination status—and individual-level explanatory variables are from the 1993 to 1998 Behavioral Risk Factor Surveillance System survey data (BRFSS). The key explanatory variables—the combined influenza and pneumonia mortality rates, which are consistent with CDC reports—are measured from the Compressed Mortality File. All of the key explanatory variables use data from 1990 to 1997 in order to test the effect of lagged disease mortality, as discussed above. The study population includes people aged 65 and older living in the community. There are 38,768 individual observations in the final dataset.

The BRFSS is an ongoing data collection program to monitor state-level prevalence of the major behavioral risks associated with premature morbidity and mortality among adults. The CDC developed a core questionnaire for states to collect data on actual behavior, rather than on attitudes or knowledge, that would be especially useful for planning, initiating, supporting, and evaluating health promotion and disease prevention programs. By 1994, all states, the District of Columbia, and three territories were participating in the BRFSS.

The BRFSS does not conduct the questionnaires of influenza and pneumococcal vaccination on each state in every year. In 1993, 1995, and 1997, nearly all 50 states included the vaccination questions in the survey. In 1994, 1996, and 1998, however, only 9 states, 15 states, and 13 states in each year, respectively, collected such vaccination information. This study combines all of these six years' data into one repeated cross-section dataset. Robustness tests indicate that results do not significantly differ when the even years with partial state participation are excluded. This is consistent with the fact that states choose questionnaire modules years in advance, and thus there is unlikely to be any systematic selection bias associated with whether a state collects vaccination data in a given year.

Dependent Variables

This study evaluates two clinical preventive services by elderly persons—influenza vaccination and pneumococcal vaccination. The outcome variables are generated from the vaccination module in the BRFSS, which asks respondents: "During the past 12 months, have you had a flu shot?" and "Have you ever had a pneumonia vaccination?" Two binary variables were created to indicate the influenza vaccination and pneumococcal vaccination status for individual respondents for each year. During the study period, on average, 60 percent of the respondents had received influenza vaccination in the past year, and 39 percent of the respondents had ever had a pneumococcal vaccination (Table 1). Both average vaccination rates are lower than the

Table 1: Summary Statistics for the Study Variables

Variables	*Mean*	*Standard Deviation*	*Minimum*	*Maximum*
Dependent Variables				
Influenza vaccination	.60	.49	0	1
Pneumococcal vaccination	.39	.49	0	1
Explanatory Variables				
State mortality (per 10,000) for both influenza and pneumonia combined	3.29	.60	1.90	4.80
Individual characteristics				
Age (splines)	71.15	3.22	65	74
65–74	2.28	3.45	0	10
75–84	.28	1.27	0	15
85 and older	.35	.48	0	1
Male				
Race				
White non-Hispanic	.90	.30	0	1
Black non-Hispanic	.06	.24	0	1
Hispanic	.02	.15	0	1
Other	.02	.14	0	1
Education				
No education or kindergarten	.008	.089	0	1
Elementary	.14	.35	0	1
Some high school	.14	.35	0	1
High school graduate	.34	.48	0	1
Some college or technical school	.21	.41	0	1
College graduate	.16	.36	0	1
Self-reported health status				
Excellent	.12	.33	0	1
Very good	.25	.43	0	1
Good	.33	.47	0	1
Fair	.10	.29	0	1
Poor	.20	.40	0	1
Living status				
Numbers of extra adults at home in addition to a spouse	.13	.43	0	8
Access to care				
Cost problem of seeking needed care	.05	.22	0	1

continued

Table 1: *Continued*

Variables	*Mean*	*Standard Deviation*	*Minimum*	*Maximum*
Smoking status				
Current smoker	.19	.39	0	1
Former smoker	.39	.49	0	1
Never a smoker	.43	.49	0	1
Year				
1993	.21	.41	0	1
1994	.05	.21	0	1
1995	.28	.45	0	1
1996	.10	.30	0	1
1997	.31	.46	0	1
1998	.05	.22	0	1

1. The data of the dependent variables and the individual characteristics are from 1993 to 1998 of Behavioral Risk Factor Surveillance System.
2. State mortality rate is the overall average of county mortalities in each state, by different year, from 1992 to 1997 of the Compressed Mortality File.
3. Years are dummy variables indicating from which data year each observation is drawn. The mean values indicate the proportion of the study sample drawn from that specific year.
4. There are 38,768 observations.

Healthy People 2000 goal of 65 percent of the elderly receiving the vaccination, and far lower than the *Healthy People 2010* goal of 90 percent.

Because of differences in wording between the influenza and pneumococcal vaccine questions, magnitudes of effects on these dependent variables will not be directly compared. The influenza question asks about the annual vaccination rate, but the pneumococcal question asks about the cumulative rate since only one pneumococcal vaccination is recommended after age 65. Because the survey is a set of repeated cross-sections, rather than a true panel, we cannot identify exactly which individuals received the pneumococcal vaccination in the previous year. This is not a limitation for our analyses, however, since we can still analyze whether the pneumococcal vaccination *rates* increase in response to lagged influenza threat levels.

Interview Date Restriction

The timing of the survey recall period relative to the influenza season leads to a further complication. The BRFSS survey asked respondents "During the past 12 months, have you had a flu shot?" During the past 19 influenza seasons in the United States, the months with the heaviest influenza activity occurred in December four times, in January five times, in February seven times, and in March three times (Centers for Disease Control and Prevention 2002).

A respondent interviewed during the first quarter of 1995 would respond to two different influenza seasons—the first quarter of 1994 and the fourth quarter of 1994. To evaluate the respondents' vaccination behavior responding to a specific single influenza season, this study restricts the sample to those interviewed in the second and third quarters of each year. Similarly, Mullahy (1999) restricted his sample to individuals responding to the survey in the first three quarters of 1991, but this would still allow people to answer questions about two influenza seasons in the same survey. For consistency, we also use the second and third quarter's sample population for pneumococcal vaccination analysis.

Independent Variables

The key explanatory construct of interest is the influenza disease threat. There are multiple potential ways to measure this threat. Because direct measures of incidence and prevalence are incomplete at the required level of detail, we have chosen an alternative measure that we argue yields the most precise indicator of the actual threat in each state, the influenza and pneumonia mortality rate. Although case fatality is low, the incidence rate is high, making influenza and pneumonia leading causes of death for elderly. Furthermore, both have a short infection period, and case-fatality does not differ greatly from year to year. To the extent that case fatality does differ depending on the adequacy of that year's vaccine, this should vary uniformly nationwide, and will not affect the appropriateness of using the state mortality rate as a proxy for the state threat level in our analysis.

Following the standard practice in reports from CDC, the cause-of-death is measured as combined influenza (*ICD-9* Code: 487) and pneumonia (*ICD-9* Codes: 480–486) together; this measure primarily reflects mortality from influenza-related complications. The county-level cause-specific mortality rates are derived from the National Center for Health Statistics' Compressed Mortality File, which includes data on deaths and population by county, age, and underlying cause-of-death. These county mortality rates then are combined to generate state average mortality rates, weighted by county representativeness in our microdata from the BRFSS. From 1992 to 1997, the average state mortality rate due to influenza and pneumonia was 3.29 per 10,000 population for all ages (range is from 1.90 to 4.80).

The individual characteristics in our empirical model include age, gender, race, education, marital status, self-reported health status, living status, access to care, and smoking behavior. The individual information comes from the BRFSS, 1993 to 1998.

Age may have a nonlinear effect on the vaccination rate. Age is specified as a piecewise linear function to generate three age groups—65–74, 75–84, and 85 and older. About a third of the sample is male. The racial composition is 90 percent white, 6 percent black non-Hispanic, 2 percent Hispanic, and 2 percent other race. Education levels are categorized from no education or only kindergarten to elementary, some high school, high school graduate, some college or technical school, and college graduate. High school graduate is the most common group (34 percent). Self-reported health status includes five binary variables—excellent, very good, good, fair, and poor. Most of the study sample reported to be in very good or good health status (total 58 percent). However, 30 percent of the sample reported with fair or poor health status.

Elderly persons living with other people might be less interested in receiving prevention because they might think they could get someone to take care of them if needed, or more interested because the risk of infectious disease is larger when in close contact with more people. This factor may become stronger when the elderly persons live with other adults in addition to their spouses. Such co-residence may also decrease time costs. We generated a variable equal to the number of adults at home in addition to spouses. The range of this variable is from 0 to 8 and has mean of 0.13.

People with less access to the health care system are expected to receive less prevention. We generated a dummy variable indicating whether the respondent reported cost as a barrier to getting needed care in the past year (5 percent said “yes”).

Smoking is both a proxy measurement of health prevention behavior, and an indicator of susceptibility of illness. Current smokers are expected to be less interested in health prevention services than nonsmokers. However, current smokers may also be more vulnerable to respiratory disease, which would increase their demand for vaccination. Binary variables were generated to indicate current smoker (19 percent), former smoker (39 percent), and never smoker (43 percent, the reference group).

BASIC MODEL

The basic model, developed in the conceptual framework section, models the probability of vaccination as a function of the previous year’s state influenza and pneumonia mortality rate and individual characteristics

$$\begin{aligned}\Pr\ (\text{Vaccination}) = f\ (&\text{lagged state mortality rate, individual characteristics,}\\ &\text{unobserved individual and state factors})\end{aligned}$$

The model is run separately for influenza and for pneumococcal vaccination. Because the dependent variable is dichotomous, we estimate a logit model.

Lagged Information Approach and Fixed-Effects Model

Although we expect to find a positive correlation between the area mortality rate and the vaccination rates, there are several econometric issues that complicate this simple model. One potential problem is that the individual's vaccination status and cause-specific mortality rate may be determined simultaneously. In order to avoid this potential endogeneity problem, we use a lagged information approach to estimate vaccination status as a function of the one-year lagged mortality rate. The individual characteristics are based on the same years' information as the dependent variables.

The main empirical model, therefore, is as follows

$$V_{ist} = \beta_0 + \beta_1 M_{st-1} + \beta_2 X_i + \beta_3 Y_t + \beta_4 S_s + \varepsilon_{ist}$$

where V is the individual propensity of vaccination utilization, M indicates the state influenza and pneumonia mortality rate, X indicates a vector of individual characteristics (e.g., age, gender, race, education, marital status, health status, and health behavior), Y is a vector of year-specific dummies, S is a vector of state fixed-effects dummy variables, and ε is the error term. The subscript i represents individual, s indicates state, t indicates the year, $t-1$ indicates the year prior to the observation of the dependent variables.

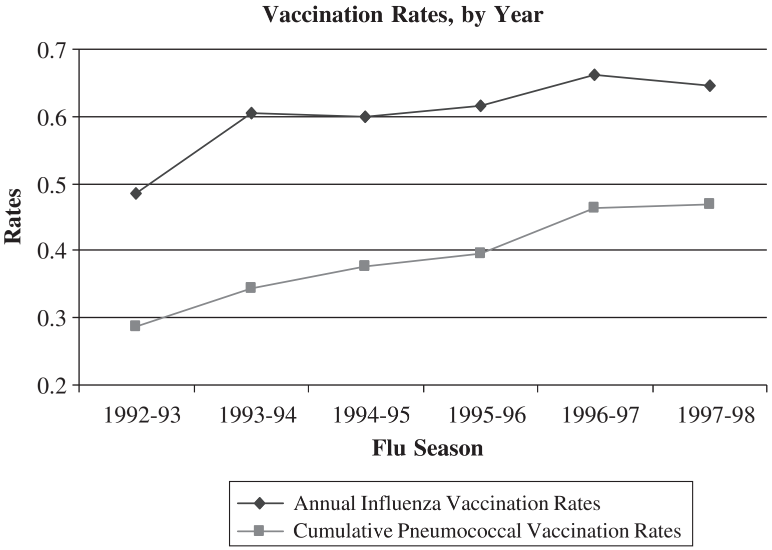
We first estimate a pooled cross-sectional model, omitting the fixed effects by constraining $\beta_4 = 0$. This is more efficient than the fixed-effects model, but could lead to bias if there are omitted state variables such as norms or access to care. Therefore, we also estimated a state fixed-effects model. A Hausman test rejected the null hypothesis of random effects in favor of fixed effects for both vaccination analyses ($p<.01$ for influenza vaccination, and $p<.05$ for pneumococcal vaccination). Finally, we reran the fixed-effects models using increasing mortality lags of up to three years, in order to test the rate at which the mortality-responsiveness declines.

RESULTS

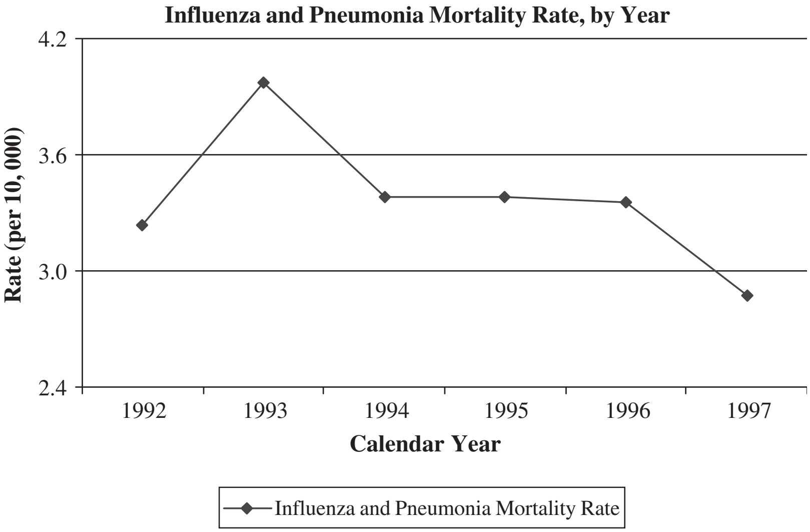
The influenza vaccination rates and pneumococcal vaccination rates increased nearly every year during the study period (Figure 1). Influenza vaccination rates are higher than pneumococcal vaccination rates each year by about 20 percentage points. Unlike the vaccination rates, the mortality rates do not

Figure 1: Trends of Vaccination Rates and Mortality Rates over Time

A. Vaccination Rates for Elderly Persons by Year.



B. Mortality Rates for All Ages by Year.



show a steady trend. The mortality rate increased from 1992 to 1993, then decreased in 1994. The rates were stable from 1994 to 1996 and decreased again in 1997. The standard errors on these rates are extremely small, implying that virtually all of the year-to-year changes are statistically significant. However, the variation across states is quite large, with the influenza and pneumococcal vaccination rates as high as 73 and 51 percent, respectively, in Wyoming and as low as 44 and 29 percent in Washington D.C. Similarly, the mean influenza and pneumonia mortality rates in our sample ranged from a high of 4.5 per 10,000 population in Massachusetts to a low of 2.3 per 10,000 population in Nevada. There are also substantial differences across states in the year to year mortality changes. At the individual level, the correlation between influenza and pneumococcal vaccination status is 0.42; because the latter is a measure of lifetime rather than the previous year's vaccination, however, we do not attempt to further analyze the relationships between these.

Cross-Sectional Analysis

In the pooled cross-sectional logit analyses, the mortality rate does not have a significant effect on the probability of an elderly person receiving influenza vaccination (see first column of Table 2). However, the mortality rates have a significantly *negative* estimated effect on elderly person's decision of receiving pneumococcal vaccination (see third column of Table 2), which may suggest misspecification due to omitted variables. This suspicion is corroborated by Hausman tests, which reject random-effects models in favor of state fixed effects, thus we next turn to the fixed-effects analysis.

Fixed-Effects Model

Our preferred model is the individual-level state fixed-effects regression that also controls for individual characteristics. Higher state pneumonia and influenza mortality rates induce more elderly persons to receive the vaccinations (see columns 2 and 4 in Table 2). The result is significant for the influenza vaccination model but not the pneumococcal vaccination model. These findings support hypothesis one but do not support hypothesis two.

Marginal Effects of Mortality on Vaccinations

Another way to describe the effect of mortality on vaccinations is to calculate the marginal effect of an increase in the combined influenza and pneumonia mortality variable, defined as deaths per 10,000 population, based on the

Table 2: The Effects of Mortality on the Probabilities of Receiving Vaccination by Elderly Persons—Model Comparisons

	Influenza Vaccination		*Pneumococcal Vaccination*	
	Pooled Model	*State FE Model*	*Pooled Model*	*State FE Model*
Constant	–4.94**	–5.62**	– 6.95**	–7.14**
	(.30)	(.35)	(.31)	(.36)
Key Independent Variable				
Mortality rate for influenza and pneumonia	–.012	.120*	–.060**	.048
	(.020)	(.049)	(.020)	(.048)
Control Variables				
Age (splines)				
65–74	.0710**	.0711**	.0864**	.0860**
	(.0041)	(.0041)	(.0043)	(.0043)
75–84	–.0022	–.0028	–.0065	–.0067
	(.0044)	(.0044)	(.0043)	(.0043)
85 and older	–.0368**	–.0369**	–.0445**	–.0442**
	(.0097)	(.0097)	(.0099)	(.0099)
Male	–.033	–.032	–.083**	–.083**
	(.023)	(.024)	(.024)	(.024)
Race				
Black non-Hispanic	–.667**	–.626**	–.714**	–.697**
	(.045)	(.047)	(.052)	(.054)
Hispanic	–.158*	–.175*	–.350**	–.408**
	(.070)	(.072)	(.075)	(.077)
Other nonwhite	–.084	–.159	.118	–.051
	(.077)	(.088)	(.077)	(.089)
Education				
None or kindergarten	–.44**	–.46**	–.27*	–.25
	(.12)	(.12)	(.13)	(.13)
Elementary	–.305**	–.300**	–.285**	–.259**
	(.034)	(.035)	(.036)	(.036)
Some high school	–.115**	–.112**	–.098**	–.089**
	(.034)	(.034)	(.035)	(.035)
Some college	.160**	.149**	.195**	.176**
	(.030)	(.030)	(.030)	(.030)
College	.412**	.400**	.318**	.305**
	(.034)	(.034)	(.033)	(.033)
Health Status				
Excellent	–.391**	–.396**	–.311**	–.319**
	(.035)	(.036)	(.037)	(.037)
Very good	–.119**	–.125**	–.087**	–.094**
	(.028)	(.028)	(.029)	(.029)
Fair	.315**	.324**	.428**	.448**
	(.041)	(.041)	(.040)	(.040)

continued

Table 2: *Continued*

	Influenza Vaccination		*Pneumococcal Vaccination*	
	Pooled Model	*State FE Model*	*Pooled Model*	*State FE Model*
Poor	.152**	.156**	.210**	.218**
	(.031)	(.031)	(.030)	(.031)
Extra adults at home	−.173**	−.166**	−.128**	−.123**
	(.025)	(.025)	(.026)	(.027)
Cost problem of care	−.203**	−.211**	−.186**	−.190**
	(.049)	(.049)	(.052)	(.052)
Smoking status				
Current smoker	−.208**	−.216**	.071*	.057
	(.034)	(.035)	(.035)	(.036)
Former smoker	.101**	.095**	.171**	.160**
	(.026)	(.027)	(.026)	(.026)
Year				
1994	.440**	.306**	.368**	.307**
	(.057)	(.065)	(.059)	(.067)
1995	.429**	.408**	.497**	.464**
	(.034)	(.035)	(.036)	(.037)
1996	.492**	.433**	.566**	.580**
	(.044)	(.048)	(.045)	(.049)
1997	.676**	.666**	.831**	.818**
	(.033)	(.034)	(.035)	(.035)
1998	.619**	.638**	.859**	.964**
	(.056)	(.059)	(.055)	(.059)

1. Reference groups include: year 1993, female, white, high school graduate, good health status, and nonsmoker.

2. *5% significance level,

**1% significance level.

3. Coefficients for each state in the state fixed-effects models are not reported.

fixed-effects results. The marginal effect of an increase in mortality by 1 per 10,000 on influenza vaccinations, holding other factors constant, is 2.7 percentage points when averaged over the entire sample. To help interpret this number, note that the CDC typically defines the influenza and pneumonia epidemic threshold as 1.645 standard deviations above baseline (Brammer et al. 2000). Given that the standard deviation of our mortality indicator is 0.6 (Table 1), a one-unit change in the mortality rate is equivalent to moving from the baseline to an epidemic level. Alternatively interpreted, the estimated elasticity is roughly .15. For pneumococcal vaccination the marginal effect of mortality is 1.1 percentage points, yielding an estimated elasticity of roughly

.09; this magnitude should not be directly compared to the influenza marginal effect because of the difference in question wording, but in any case this is not statistically different from zero.

Individual Characteristics

The individual characteristics in the fixed-effects model have very similar signs and magnitudes as the control variables in the cross-sectional model. This implies that the individual characteristics are largely uncorrelated with the state fixed effects.

The individual characteristics in both the fixed-effects and cross-sectional analyses are often statistically significant, and generally have the expected sign (Table 2). The probability of vaccination increases with age for those aged 65 to 74 ($p < .01$ for both vaccinations), is roughly flat for those aged 75 to 84, and negative for those over age 85 ($p < .01$ for both vaccinations). Men are significantly less likely to receive pneumococcal vaccinations than women ($p < .01$). Compared to whites, African American and Hispanic elderly persons are significantly less likely to receive either vaccination ($p < .01$). African Americans are far less likely than whites to receive vaccinations. Education is strongly positively associated with getting vaccinated.

Those in worse health are more likely to get vaccinated. Compared to the elderly persons with self-reported *good* health status, elderly persons with worse self-reported health status significantly increase the propensities to receive the vaccinations. Conversely, elderly persons with self-reported *very good* or *excellent* health status significantly reduce the probability of receiving vaccinations (all health status indicators for both vaccinations have $p < .01$). The results are reasonable because elderly persons who are in worse health status have more to gain from preventing a serious illness. They are also more likely to visit physicians, who in turn may be more likely to order vaccinations among the ill; these factors may independently increase the probability of vaccination, and this is one reason for including this variable as a control.

The number of extra adults at home in addition to a spouse is negatively associated with both influenza vaccination and pneumococcal vaccination ($p < .01$). This variable may be correlated with unmeasured low socioeconomic status, because those who live with others are generally less well off. Elderly persons who reported a problem with access to health care due to cost were also significantly less likely to receive either of the vaccinations (both with $p < .01$). Even though the costs of influenza vaccination and pneumococcal vaccination are fully covered by Medicare, the study results here imply

Table 3: Fixed-Effects Vaccination Logits with Higher-Order Mortality Lags

	Influenza Vaccination				*Pneumococcal Vaccination*			
Pneumonia and Influenza Mortality								
1-Year Lag	.120*			.113*	.048			.052
	(.049)			(.052)	(.048)			(.052)
2-Year Lag		.063		.009		.008		–.016
		(.051)		(.057)		(.051)		(.057)
3-Year Lag			.053	.037			.016	.014
			(.050)	(.052)			(.049)	(.051)

1. Control variables include all other variables in Table 2 regressions.
2. *5% significance level, **1% significance level.
3. Coefficients for each state in the state fixed-effects models are not reported.

that other cost factors associated with access to care (e.g., copayments for physician visits) might still influence vaccination decisions.

Current smokers are significantly less likely to receive influenza vaccination ($p < .01$) compared to nonsmoking elderly persons. In contrast, elderly persons who were former smokers but quit smoking now have significantly higher propensities of receiving influenza vaccination or pneumococcal vaccination (both vaccinations with $p < .01$) than nonsmoking elderly persons.

Higher-Order Mortality Lags

To examine how quickly the effects of lagged mortality fade over time, we replaced the one-year lagged mortality rate with either two-year or three-year lags. The higher-order lags have substantially smaller effects than the one-year lag, and are not statistically significant (Table 3). A final specification includes all three lags in a single model, again confirming that only the one-year lag is significant (for influenza), and the two-year and three-year lags have smaller estimated effects. These results support our third hypothesis, that lagged disease threat should have a declining effect on the vaccination rate.

DISCUSSION

Our study has produced a number of interesting policy-relevant and methodological findings. Most important is our finding in support of the threat-responsiveness hypothesis. Higher mortality rates, which indicate more severe disease threats, induce people to change their behavior and get vaccinated, albeit with a lag. A greater perceived health threat leads to greater preventive behavior.

Second, the magnitude of the effect is modest, at least at mortality levels found in our data. For example, an elasticity of .15 for influenza vaccination implies that a 10 percent increase in last year's influenza and pneumonia mortality rate will lead to a 1.5 percent increase in this year's vaccination rate. Or alternatively stated, movement from baseline to epidemic thresholds only leads to a 2.7 percentage point increase in the influenza vaccination level. With a mean influenza vaccination rate of 60 percent, an extremely severe epidemic would be required before these self-limiting behavioral responses would have much effect. A potential limitation of our analysis that might lead to underestimated effects would be measurement error in the state mortality rate as our proxy for individual's information regarding epidemic severity. This should be a good proxy given that public information campaigns often rely on such aggregated epidemic surveillance, but future research will be required to better understand the determinants of epidemic level perceptions.

Third, we found mixed evidence on the role of (mis)perceptions. Threat-responsiveness appeared to occur even after a one-year lag following the end of the threat, but this effect had disappeared by the second year. Furthermore, higher influenza threats did not lead to significantly higher pneumococcal vaccination rates, as we had predicted would occur due to misperceptions. This lack of a relationship, despite the positive influenza effects, is intriguing because it also suggests that the extra health care contacts to receive the influenza vaccine were not exploited to improve pneumococcal vaccination rates. Although clinical practice guidelines do not recommend that physicians increase pneumococcal vaccination efforts in response to influenza epidemics, they do recommend taking advantage of primary care visits to increase pneumococcal vaccination levels. Given that many elderly in our data who received the influenza vaccination (presumably in part because of heightened awareness of vaccine preventable infectious disease) remained unvaccinated against pneumococcal pneumonia, awareness campaigns highlighting these missed opportunities may be effective at improving pneumococcal vaccination rates.

Finally, we also have produced important methodological findings. We have found that panel data methods are useful to control for state fixed effects that may be correlated with both the vaccination rate and the mortality rate, and that failure to control for these effects would have lead to downward bias. Specification tests suggest that simple cross-sectional models may be misspecified.

Our results point to the importance of further study of how public health interventions can exploit disease threat-responsive behavior to increase vaccination rates and hence lower future influenza and pneumonia mortality. What types of public information campaigns best inform the public about current and future infectious disease risk, in a way that will induce behavioral change? Three different standard approaches would include information through the media, information through providers, and increasing access in public venues. Any of these methods could remind people about recent epidemics, warn about the coming influenza season, and remind about the risks of having infectious disease. Our estimates of the rapid decay of lagged effects, however, suggests that continual ongoing interventions may be necessary in order to generate sustained behavioral changes.

This study has two important limitations. We do not have information on exactly how much elderly persons know about the actual mortality rate, for example from media, professional journals, workshops, Internet, friends, or senior centers. The amount of information will vary with the mortality rate, and by region. Our results inform how the actual mortality rate affects vaccination behavior, whereas another study might focus more on the effectiveness of particular kinds of information dissemination. Second, we do not have information on the exact date when people received their vaccinations. Fortunately, we have a large enough sample that we can limit our sample to those interviewed in the second and third quarters, which will minimize this potential bias.

An additional consideration is associated with the potential effects of provider behavior on elderly vaccination behavior. In general, the effects of disease mortality may have two major pathways to affect elderly vaccination behavior. One pathway directly affects elderly persons, and the other pathway indirectly affects the health care provider's behavior. For the pathway that goes through providers, health care providers may have better channels to know the disease epidemic than the general public, and then health care providers respond to it by encouraging more of their patients to receive cost-effective prevention. Future research will be needed to determine to what extent individual behavioral responses are driven by these provider behavioral responses. In addition, it would be important to explore which interventions would be most helpful in changing people's prevention behavior. Is it more cost-effective to invest in patient education activities (e.g., media, public health education programs) or to invest in professional adherence activities (e.g., clinical guidelines, performance evaluation)? A future analysis of this critical question would be valuable.

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