Current Draft: January 2024

Effect of Vaccine Recommendations on Consumer and Firm Behavior*

Abstract

We provide novel evidence on how firms and patients respond to vaccine recommendations. In 2014, the Advisory Committee on Immunization Practices recommended that elderly adults receive the pneumococcal vaccine Prevnar 13. Using a difference-in-differences strategy, we first show that, following the recommendation, the manufacturer (Pfizer) increased direct-to-consumer advertising. We then document increased Prevnar 13-related information-seeking behavior, and we show that targeted adults were more likely to have received a pneumococcal vaccine and were more connected to the health care system. Overall, the recommendation increased both Medicare Part B drug expenditures and Pfizer sales by approximately $1 billion annually, with little to no observable health benefits.

JEL Codes: I18; I12; L15
Key words: immunization; pneumonia; aging; advertising

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We thank Alice Chen (the editor), two anonymous referees, Naoki Aizawa, Kitt Carpenter, Debbie Freund, Analisa Packham, Tamar Oostrom, Brad Shapiro, Aparna Soni, Lucy Xiaolu Wang, Coady Wing for helpful comments on earlier versions of this manuscript. We also thank conference participants at APPAM 2022, ASHEcon 2022 and NBER SI 2022, as well as seminar participants at Cal State Fullerton, Fordham University, SUNY Buffalo, University of Georgia, University of Massachusetts Amherst, University of Memphis, University of Washington, and Vanderbilt University. We are especially grateful to Helen Keipp Talbot – a voting member of the Advisory Committee on Immunization Practices – for her institutional insights and invaluable feedback. Some of the results in this paper are based on restricted-use and/or proprietary data. Readers interested in obtaining access can contact the authors. All interpretations, errors, and omissions are our own. The authors have no conflicts to disclose.

INTRODUCTION

Immunization is a canonical example of a market failure, as vaccines provide social benefits that are not fully internalized by consumers. Aiming to correct this market imperfection and increase vaccination rates to socially optimal levels, vaccination recommendations are often the first-line policy choice. In the United States, these vaccine recommendations are issued by the Advisory Committee on Immunization Practices (ACIP) – a federal advisory committee consisting of 15 medical and public health experts. Although ACIP has currently released 26 vaccine-specific recommendations, little is known about their impacts on consumer or firm behavior.

This paper provides new evidence on the market-wide effects of an ACIP pneumococcal vaccine recommendation targeted towards elderly adults. Pneumococcal vaccines offer protection against streptococcus pneumoniae – a bacterial infection causing over 500,000 cases of pneumonia in the United States annually (Morrill et al., 2014).[1] Pneumonia is the seventh leading cause of death in the US, and pneumonia-related hospitalizations cost an estimated $9 billion each year (Dion and Ashurst, 2021).

In 2011, the US Food and Drug Administration approved the pneumococcal conjugate vaccine (PCV13) – sold by Pfizer under the tradename Prevnar 13 – for adults aged 50 or older. Shortly afterwards, at their February 2012 meeting, ACIP

[1] Other common causes of pneumonia in the US include influenza, respiratory syncytial virus, and SARS-CoV-2 (CDC 2020).

considered recommending routine use of Prevnar 13 among older adults. At that time, however, the committee decided to defer the recommendation, stating that the "available evidence is insufficient" and that "critical data elements needed to make a recommendation are not available at this time."[2] ACIP revisited the recommendation in 2014, following the release of new randomized control trial evidence on the efficacy of the vaccine in preventing community-acquired pneumococcal disease in adults.[3] At their August 2014 meeting, ACIP ultimately decided to recommend adults aged 65 or older routinely receive Prevnar 13.[4]

We utilize this August 2014 recommendation change as a natural experiment to study how firms and consumers respond to changes in vaccine recommendations. While ACIP vaccine recommendations are common, little is known about how they affect vaccine uptake among adults, as existing evidence has largely focused on their impacts among children and adolescents (Lawler, 2017, 2020). Given differences in health care utilization and access to care for adults and children, it is unclear the extent to which findings from studies of children will apply to adults. Moreover, how pharmaceutical firms respond to and benefit from

[2] Advisory Committee on Immunization Practice's February 2012 Meeting Summary Statement: https://www.cdc.gov/vaccines/acip/meetings/downloads/min-archive/min-feb12.pdf.

[3] The clinical trial was conducted by Pfizer as a post-approval condition of licensure and took place between September 2008 and October 2013 (Bonten et al., 2015). Results from the trial were publicly released in February and March 2014 and were presented to ACIP at their June 2014 meeting (Pfizer, 2014).

[4] As we later discuss, there are two pneumococcal vaccines available in the United States. The first, sold by Merck under the tradename Pneumovax 23 (PPSV23), has been available and recommended for adults aged 65 or older in the United States for decades. Prevnar 13 (PCV13) was recommended to be routinely administered in series with PPSV23 for adults aged 65 or older from 2014-2019.

these recommendations has not previously been examined. Yet with the US vaccine market currently valued at nearly $30 billion and projected to grow dramatically over the next decade, these supply-side considerations can offer critical insights into how ACIP's recommendations contribute to social welfare.

We first examine whether the manufacturer of Prevnar 13 (Pfizer) responded strategically to the recommendation by changing its direct-to-consumer advertising expenditure.[5] Direct-to-consumer advertising is a key way through which pharmaceutical firms communicate with consumers, accounting for approximately $6 billion in spending in 2016 (Schwartz & Woloshin, 2019). If pharmaceutical firms view ACIP's recommendations as a substitute for direct-to-consumer advertising, we may expect private firm advertising expenditure to decrease in the post-recommendation period. On the other hand, firms may believe that the recommendations increase the return to private advertising, and therefore may respond by increasing advertising expenditure. Thus, the effect of ACIP's recommendation on private advertising is an empirical question.

To answer this question, we use a difference-in-differences identification strategy comparing changes in Prevnar 13 advertising expenditures to the associated changes for 100 comparison pharmaceuticals over the 2011-2019 period. Our results show that there were large increases in direct-to-consumer advertising

[5] The manufacturer may also have increased marketing to physicians, for example through journal advertisements or physician detailing. As we later discuss, we focus on direct-to-consumer advertising due to data availability.

in the post-recommendation period. There is no evidence that Prevnar advertising was differentially trending during the pre-recommendation period, and a series of placebo tests indicate that the post-period increase was unlikely to have occurred by chance.

Another way in which Pfizer may have strategically responded to the recommendation is by changing physician detailing for Prevnar 13. Notably, prior evidence indicates both that physician detailing impacts provider behavior (Ching & Ishihara 2010; Datta & Dave, 2016; Shapiro, 2018) and that physician recommendations play an important role in vaccination decisions (Gargano et al., 2013; Moghtaderi & Adams, 2016). While data limitations prevent us from rigorously examining changes in this form of pharmaceutical marketing, we provide descriptive trends that suggest that Pfizer may have also increased direct-to-physician advertising.

Next, we consider the effects of the recommendation and the subsequent marketing response on two dimensions of consumer behavior: information-seeking behavior and vaccine take-up. Using 2011-2019 Google Trends data, we show that during the post-period consumers significantly increased their internet search intensity for the term 'Prevnar,' relative to searches for the comparison pharmaceuticals. To examine changes in pneumococcal vaccination among elderly adults, we use both 2011-2019 National Health Interview Survey data and 2012-2019 Medicare Part B claims public use files. The descriptive trends, shown in

Figure 1, show visual increases in pneumococcal vaccination following ACIP's recommendation.

Using difference-in-differences strategies comparing (i) changes in pneumococcal vaccination for adults targeted by the recommendation (aged 65 or older) to changes for younger adults and (ii) changes in Medicare claims for Prevnar 13 to changes for other vaccines covered by Medicare Part B, we find that elderly adults were 5.6-7.9 percentage points more likely to be vaccinated against pneumococcal disease in the post-recommendation period. We are unable to disentangle the extent to which this increase was driven by ACIP's recommendation versus Pfizer's advertising, as existing evidence indicates that direct-to-consumer advertising increases pharmaceutical take-up (Alpert et al., 2023; Lakdawalla et al., 2013; Shapiro, 2022; Sinkinson & Starc 2019). In our context, private firm marketing may be an important mechanism driving the increase in vaccination.

Additionally, we document broader spillovers to other dimensions of health care. After the recommendation, adults aged 65 or older were significantly more likely to report having visited a health care provider in the past two weeks and having received another vaccine routinely recommended for older adults (herpes zoster vaccine). This latter result suggests that policymakers and clinicians looking to broadly increase vaccine take-up should look for opportunities to administer multiple vaccines during a single health care visit.

Finally, we estimate the effect of ACIP's recommendation on Medicare expenditures and Prevnar 13 sales using Medicare Part B public use claims files and data collected from pharmaceutical companies' financial statements. We estimate that ACIP's 2014 recommendation, in conjunction with Pfizer's subsequent advertising campaign, increased Medicare Part B Fee-For-Service (FFS) spending on Prevnar 13 by $14.40 per beneficiary, or approximately $483 million annually.[6] Assuming a similar increase for all Medicare beneficiaries (including Medicare Advantage), our result implies over $839 million in new Medicare spending. Using financial statement data, we document a corresponding $1 billion annual increase in Pfizer-reported sales revenue for Prevnar 13 following ACIP's recommendation, compared to the associated changes for the comparison group pharmaceuticals. This increase is evident from the descriptive trends shown in Figure 2 (Panel A). Importantly, the sales increase was limited to the US (Panel B), even though the clinical trial information was known and discussed in other countries. These patterns suggest that the increase in Prevnar 13 sales was driven by ACIP's recommendation and Pfizer's advertising response and not the clinical trial performance, which is consistent with comments made by Pfizer's then-CEO attributing increased Prevnar 13 take-up and sales performance to ACIP's

[6] While the average sales price of Prevnar 13 was increasing over our sample period, the average price per dose in 2013 was approximately $143.

recommendation (Pfizer 2015). Overall, our findings highlight the value that private firms may gain from vaccine recommendations.

This paper contributes to several notable bodies of literature. First, by providing the first quasi-experimental evidence on the firm marketing response to ACIP vaccine recommendations, we build on existing work examining the relationship between government health policies and strategic firm decisions (Acemoglu et al., 2006; Duggan & Scott Morton, 2006; Duggan & Scott Morton, 2010; Finkelstein, 2004; Freedman et al., 2015; Kyle, 2007; Lakdawalla & Yin, 2015; Starc & Swanson, 2021). By exploring how Pfizer's marketing changed in response to ACIP's recommendation, we also add to the body of work analyzing the strategic role of advertising (Ambrus et al., 2016; Anderson & Renault, 2006; Kaldor, 1950; Zinman & Zitzewitz, 2016). Notably, regulating direct-to-consumer advertising of pharmaceuticals is an ongoing policy priority due to widespread belief that advertising increases inappropriate prescribing and unnecessary health care costs.[7] While recent work has shown that direct-to-consumer pharmaceutical advertising can significantly increase take-up of prescription drugs (Alpert et al., 2023; Lakdawalla et al., 2013; Shapiro, 2022; Sinkinson & Starc, 2019) and health

[7] Some advocacy groups, such as the American Medical Association, have called for a ban on direct-to-consumer advertising of prescription drugs (AMA, 2015), and over the past decade numerous pieces of legislation have been introduced aiming to regulate this form of pharmaceutical marketing. For example, in 2020 the *Responsibility in Drug Advertising Act* was introduced in the Senate, which proposed prohibiting direct-to-consumer advertising of drugs for the first three years following drug approval. In 2021, Senate Bill 2304 was introduced that aimed to require the disclosure of price information in all direct-to-consumer advertisements of prescription drugs.

insurance coverage (Aizawa & Kim, 2018, 2021), little is known about how pharmaceutical firms' advertising responds to positive information shocks resulting from government action (Lawler & Skira, 2022). Our results suggest that Pfizer's increased advertising was likely an important mechanism for increasing vaccination rates and helping ACIP achieve its public policy goal.[8]

By documenting a plausibly causal positive relationship between ACIP's age-targeted recommendation and vaccine take-up, we also build on work examining the determinants of vaccination. This literature has shown that vaccine mandates for school attendance (Abrevaya & Mulligan, 2011; Carpenter & Lawler, 2019; Churchill, 2021a) and ACIP vaccine recommendations (Lawler, 2017, 2020) significantly increase childhood and adolescent vaccination rates. There is comparably less work on how to increase adult vaccination rates and, as previously noted, given differences in health care utilization and access to care for adults and children, it is unclear the extent to which findings from studies of children will apply to adults. Recent evidence suggests that promotional campaigns (Bouckaert et al., 2020; Ward, 2014), lowering costs (Churchill & Henkhaus, 2023), and

[8] Much of the work on pharmaceutical firm marketing following positive information shocks has focused on the effect of clinical trial results on physician detailing (Azoulay, 2002; Ching & Ishihara 2010; Shapiro, 2018; Sood, et al. 2014). Lawler & Skira (2022) examine impacts on both direct-to-consumer advertising and physician receipt of transfers of value from pharmaceutical firms in the context of a different government action (removal of a black box warning on a drug label).

employer vaccine mandates (White, 2021) are potentially effective policy levers for the adult population.[9]

CLINICAL EVIDENCE AND POLICY HISTORY

Streptococcus pneumoniae is a bacterial infection that causes over 500,000 cases of pneumonia, 40,000 cases of invasive pneumococcal disease, and 4,000 associated deaths annually in the United States (Morrill et al., 2014).[10] There are two available vaccines that reduce the likelihood of contracting pneumococcal disease, especially the most severe 'invasive' infections (CDC, 2021). The pneumococcal polysaccharide vaccine (PPSV23) provides protection against 23 pneumococcal capsular types and has been available in the United States since 1983 under the tradename Pneumovax 23.[11] The Advisory Committee on Immunization Practices (ACIP) began recommending routine use of PPSV23 for adults aged 65 or older in 1989 (MMWR, 1989).

A new pneumococcal vaccine, Prevnar 13 (PCV13), was introduced by Pfizer in 2010 and approved by the FDA under the accelerated approval pathway in 2011 for adults aged 50 or older.[12] The accelerated approval process required

[9] A closely related literature examines the effects of recommendations for other forms of preventive care on uptake, selection, and health outcomes (Buchmueller & Goldzahl, 2017; Einav et al., 2020; Kadiyala & Strumpf, 2016; Stewart & Mumpower, 2003).
[10] These deaths are concentrated among the elderly. In 2019, the elderly streptococcus pneumoniae mortality rate was 3.27 per 100,000 individuals compared to 1.68 for adults aged 50-64, and 0.54 for those aged 35-49 (Active Bacterial Core Surveillance Report, 2019).
[11] A version that provided protection against 14 pneumococcal capsular types, PPSV14, was first introduced under the tradename Pneumovax in 1977 (NYT, 1977).
[12] Prevnar (PCV7) was introduced in 2000 exclusively for children (MMWR, 2000).

that the manufacturer conduct a randomized placebo-controlled trial of Prevnar 13 to verify the clinical benefits in elderly adults. The 'Community-Acquired Pneumonia Immunization Trial in Adults' (CAPiTA) was conducted from 2008-2013.[13] Pfizer released the top-line results of the CAPiTA trial in February 2014 with the full data released in March of that year (Pfizer, 2014). In June 2014, these data were presented to ACIP, and ACIP, after conducting cost-effectiveness analyses and reviewing all existing evidence on the efficacy of the vaccine, decided to recommend adults aged 65 or older receive Prevnar 13 in August 2014.[14]

ACIP recommendations, while publicly disseminated through CDC publications, are largely intended to provide guidance to vaccine providers (MMWR, 2002). The guidelines recommended that adults aged 65 or older who had already received PPSV23 return 12 months later to receive a Prevnar dose. Meanwhile, adults who had not received any pneumococcal vaccine doses were recommended to immediately receive Prevnar and return for Pneumovax after at least a year (MMWR, 2015).[15] If received on schedule, patients face no out-of-pocket costs for these vaccines. The Affordable Care Act's preventive services

[13] Participants were enrolled between September 2008 and January 2010, and the trial was completed in October 2013 (Bonten et al., 2015).

[14] These results indicated a 45.6 percent efficacy against vaccine-type pneumococcal pneumonia, a 45.0 percent efficacy against vaccine-type nonbacteremic pneumococcal pneumonia, and a 75.0 percent efficacy against vaccine-type invasive pneumococcal disease among elderly adults. Notably, in 2013 only 10 percent of community-acquired pneumonia cases in elderly adults were caused by PCV13 serotypes that would potentially be preventable with Prevnar 13.

[15] The initial guidelines from August 2014-June 2015 recommended that unvaccinated adults receive PCV13 and then return for PPSV23 after 6-12 months (MMWR, 2014).

provision requires health insurers to cover ACIP recommended vaccines without patient cost-sharing,[16] and in December 2014 the Centers for Medicare and Medicaid Services updated their guidance to cover both pneumococcal vaccines. Medicare Part B covers the first shot at any time and a second shot if given at least one year after the first shot (Medicare, 2022). Therefore, while over a longer time horizon the two pneumococcal vaccines may be viewed as complements, the recommendation and reimbursement schedules imply that the products serve as substitutes during a one-year window.

Notably, ACIP stopped recommending routine use of Prevnar 13 for elderly adults in June 2019, after concluding "that implementation of a PCV13 recommendation for all adults aged ≥ 65 in 2014 has had minimal impact on PCV13-type disease at the population level in this age group" (MMWR, 2019).[17] Consistent with their conclusion, Figure 3 does not reveal any visual change in PCV13-type pneumococcal incidence among the elderly following the recommendation. The 2019 ACIP update described Prevnar 13 as a safe and effective vaccine that could reduce risk for PCV13-type pneumococcal disease

[16] The provision requires that plans begin covering newly recommended vaccines by one year after the ACIP recommendation date (*Fed. Reg.* Vol. 80 No. 134 pg. 41318).

[17] At the time of the initial recommendation in 2014, ACIP indicated a need to 'reevaluate' the recommendation after several years because PCV13 serotypes accounted for a small proportion of community-acquired pneumonia cases in adults aged 65 or older (MMWR, 2014). The low incidence of PCV13 serotypes among the elderly was likely due to increased pneumococcal vaccination in children, as incidence rates fell dramatically after Prevnar 7 was approved for children in 2000 and Prevnar 13 in 2010 (MMWR, 2019).

among adults aged 65 or older, but no longer advised that it be included as part of routine care (MMWR, 2019). Table 1 summarizes these relevant policy dates.

For this article, we focus on the impacts of the initial 2014 ACIP recommendation that Prevnar 13 be routinely administered in series with Pneumovax 23 for adults aged 65 or older. At the time, executives at Pfizer expressed beliefs that ACIP's recommendation was good for business. For example, on a Q2 2012 quarterly earnings call, one Pfizer executive discussing Prevnar 13 stated that "in the vaccine business, it's CDC recommendations that are the real drivers." Speaking on the Q1 2015 quarterly earnings call, then-CEO Ian C. Read alluded to ACIP's recommendation driving "strong uptake" of Prevnar 13 in adults aged 65 or older. On that same call Albert Bourla – then-President of Pfizer's Global Vaccines, Oncology, and Consumer Healthcare business – stated that every year 4 million adults in the US turned 65-years-old, 27 million adults had received Pneumovax, and 20 million additional adults had never received a pneumococcal vaccine (Pfizer, 2015). A little over a year later, Read noted that 40 percent of these 47 million adults had been vaccinated (Pfizer, 2016). At approximately $200 per shot, this would imply approximately $3.8 billion in sales revenue during the six quarters following ACIP's recommendation.[18]

[18] Appendix Figure A1 suggests that financial markets viewed ACIP's recommendation as beneficial to Pfizer.

DATA AND METHODOLOGY

Advertising Behavior: Ad$pender

We explore whether Pfizer increased direct-to-consumer advertising in response to ACIP's Prevnar recommendation using Kantar Media's 2011-2019 Ad$pender database. These data contain advertising expenditure and occurrence information for over 3 million brands and 18 different media types.[19] The start of our sample period (2011) coincides with the approval of Prevnar 13 for use in adults aged 50 or older. To construct our comparison group, we sort non-Pfizer pharmaceutical products by advertising expenditure during the pre-ACIP recommendation period (2011-2013).[20] Prevnar 13 was the 60th most advertised product on this list; we therefore selected the remaining top 100 products as our comparison group.[21] In the Appendix, we further refine this comparison group and show that our results are robust to excluding (i) drugs with generic entry, (ii) drugs without advertising expenditure the year prior to our reference year, and (iii) both drugs with generic

[19] The full list of media types is available here: https://products.kantarmediana.com/documents/AdSpenderManual.pdf.

[20] We exclude Pfizer's non-Prevnar pharmaceuticals, given the possibility that the firm responded to ACIP's PCV13 recommendation by shifting resources among its products. Appendix Figure A2 plots advertising expenditure (Panel A) and sales revenue (Panel B) for Pfizer's top products during the pre-recommendation period. There is no evidence that Pfizer shifted its advertising budget across products. Similarly, we drop the shingles (herpes zoster) vaccine, as it is the only other vaccine specifically targeted towards elderly adults and so we may expect the manufacturer to strategically respond to changes in Prevnar advertising. In results available upon request, we formally explored the relationships between advertising for these products and ACIP's PCV13 recommendation; we did not detect any significant or meaningful patterns.

[21] See Appendix Table A1 for the list of products. Pneumovax 23, the other pneumococcal vaccine, is outside this range and not included as a comparison product. We also explored whether ACIP's PCV13 recommendation led to changes in Pneumovax 23 advertising, though we did not detect a significant change.

entry and those without advertising expenditure in the year prior to our reference year.

As previously discussed, Pfizer may have responded to ACIP's Prevnar 13 recommendation by reducing advertising expenditure, if the recommendation was viewed as a substitute for private advertising, or by increasing advertising expenditure, if it was expected that returns to advertising would increase following ACIP's endorsement. Figure 4 descriptively shows a large increase in Prevnar 13-related advertising expenditures in the months following ACIP's recommendation (Panel A); anecdotal evidence also suggests that the content of these ads particularly targeted individuals aged 65 or older.[22] To test whether this increase was unique to Prevnar 13 or part of a broader trend in pharmaceutical advertising, we estimate the following difference-in-differences model comparing changes in Prevnar 13-related advertising expenditures to the changes in expenditures for the 100 other pharmaceutical products:

$$AD_{it} = \alpha + \sum_{j=-43,\, j\neq -1}^{65} \beta^{j} \cdot \mathbf{1}\{\text{Brand=Prevnar}\}_i \times \mathbf{1}\{\text{Month} = j\}_t + \rho_{it} + \rho^2_{it} + \theta_i + \tau_t + \varepsilon_{it} \quad (1)$$

[22] For example, the Prevnar 13 'One Step' commercial stated, "What if one stalk of broccoli could protect you from cancer? What if one pushup could prevent heart disease? Wishful thinking, right? *But there is one step adults 65 or older can take to prevent another serious disease*…" (Emphasis added) See: https://www.ispot.tv/ad/nUcJ/prevnar-13-one-step.

where the dependent variable, AD, is advertising expenditure for drug brand *i* in year-month *t*. To account for the fact that advertising expenditure likely varies over the product lifecycle, we control for a quadratic in the number of months since FDA approval, ρ.[23] We include a full set of time-invariant drug-specific fixed effects, θ, and drug-invariant year-month fixed effects, τ.

The coefficients on the independent variables of interest, β^j, measure how advertising expenditure changed *j* months away from ACIP's August 2014 Prevnar 13 recommendation. Equation (1) allows us to test (i) whether Prevnar 13-related advertising was differentially trending before ACIP's recommendation relative to the comparison pharmaceuticals; and (ii) whether the effect of ACIP's recommendation on advertising expenditure evolved over time. Because we have one treated pharmaceutical product, we conduct inference using a variant of Fisher's (1935) permutation test. We estimate equation (1) an additional 100 times, each time pretending as though one of the comparison group products was instead our treated drug (i.e., as if it had been recommended by ACIP in August 2014, instead of Prevnar 13). We save the resulting 100 sets of placebo coefficients, $\hat{\beta}^j_{Placebo}$, and compare the Prevnar event study coefficients, $\hat{\beta}^j_{Prevnar}$, to the respective 95 percent intervals generated from the placebo estimates (Buchmueller et al., 2011; Cunningham & Shah, 2018). If the Prevnar 13 coefficients are located within

[23] The results are essentially unchanged if we include higher order polynomial terms or exclude the term altogether.

(outside) the interval, it indicates that the results were likely (unlikely) to have been obtained by chance.

We also explored whether Pfizer changed how it interacted with physicians following ACIP's Prevnar 13 recommendation using the 2014-2019 CMS Open Payments Database.[24] These data contain information on all payments and gifts ("transfers of value") made to physicians by pharmaceutical manufacturers or their representatives, including the date of payment, the manufacturer providing the payment, and the drug(s) discussed during the visit.[25] While the descriptive trends – shown in Appendix Figure A3 – suggest an increase in Prevnar-related provider visits that included a transfer of value, the limited pre-period prohibits us from saying anything meaningful about the relationship.

Information Seeking Behavior: Google Trends

We use 2011-2019 Google Trends data to test whether ACIP's Prevnar 13 recommendation and the resulting marketing response affected Prevnar-related information-seeking behavior. For each month in the sample window, Google takes a random sample of all internet searches and divides the number of queries for a particular term, such as 'Prevnar,' by the total search volume. The month when this ratio is maximized is indexed to 100, and all subsequent indices are determined by

[24] Although these data began being collected in August 2013, there are documented inconsistencies prior to January 2014 (Cox, 2016; Ornstein, 2014a, 2014b).
[25] While this information is required to be reported under the Physician Payment Sunshine Act of 2010, the Open Payments data do not include information on encounters that did not involve a transfer of value.

dividing each month's ratio by the maximum ratio. While these data do not contain information on who is searching for the term, they have previously been used to examine changes in vaccine-related search intensity (Carpenter & Lawler, 2019; Churchill, 2021b; Oster, 2018).

Figure 4 shows how Google searches for 'Prevnar' evolved over time (Panel B). Consistent with the advertising trends, search intensity remained relatively flat during the pre-recommendation period and increased dramatically in the months following ACIP's August 2014 Prevnar 13 recommendation. We empirically assess the relationship between ACIP's recommendation and Prevnar 13-related information seeking behavior by comparing changes in search intensity for 'Prevnar' to the corresponding changes in search intensity for 100 other search terms using the same specification shown in equation (1). The terms in this comparison group identically match the pharmaceutical products used to analyze the Ad$pender data.

Vaccine Take-Up: National Health Interview Surveys & Medicare Claims

To test whether vaccine take-up changed during the post-recommendation period, we use data from two complementary sources: the 2011-2019 National Health Interview Surveys (NHIS) and publicly available 2012-2019 Medicare Part B claims data. The NHIS are nationally representative cross-sectional household surveys monitoring health outcomes and behaviors of the non-institutionalized civilian US population. For our analyses, we limit our sample to adults aged 50 or

older, as this is the primary adult population for which the pneumococcal vaccines are approved.

Our main outcome of interest in the NHIS is a measure of pneumococcal vaccination.[26] Unfortunately, during our sample period, the NHIS survey question about pneumococcal vaccination did not distinguish between receipt of Prevnar 13 (newly recommended by ACIP in 2014) and Pneumovax 23 (recommended by ACIP since 1989).[27] As such, we will not measure any vaccination increases among adults who had already received Pneumovax and then were induced by ACIP's recommendation to receive Prevnar. Instead, we will only be able to detect changes for adults who would have otherwise remained completely unvaccinated against pneumococcal disease in the absence of ACIP's 2014 recommendation. Furthermore, the NHIS question did not ask respondents about when they received the pneumonia vaccine. As a result, some of the individuals reporting that they had received the vaccine in the post-period data may have been vaccinated prior to the 2014 recommendation. Importantly, however, we would not expect the share of these individuals who were vaccinated prior to 2014 to differentially change for

[26] For supplemental analyses considering impacts on health care more broadly, we also examine measures of visits to health care providers, influenza vaccination, and shingles vaccination.

[27] Specifically, the survey question for 2011-2018 read, "Have you EVER had a pneumonia shot? This shot is usually given only once or twice in a person's lifetime and is different from the flu shot. It is also called the pneumococcal vaccine." In 2019 the questionnaire was redesigned and began distinguishing between the two vaccines. In results available upon request, we show the robustness of our conclusions to excluding the 2019 data.

individuals 65 or older relative to those aged 50-64 concurrent with the recommendation.

To overcome the limitations of the NHIS data, we also use publicly available summary tables of Medicare Part B claims, 2012-2019, provided at the state-year-service level. These data capture all Medicare claims and associated Medicare payments for beneficiaries with Part B Fee-For-Service (FFS) coverage – beneficiaries enrolled in Medicare Advantage plans are not included – and services are identified based on HCPCS codes.[28] Thus, we can separately identify (i) claims for Prevnar or Pneumovax and (ii) claims for Prevnar that occurred before and after the recommendation. Importantly, although most drugs are covered under Medicare Part D, Medicare Part B covers the following vaccines for adults: the influenza vaccine, the pneumococcal vaccines, the hepatitis B vaccine (for those at high risk), and the rabies and tetanus vaccines (as needed for treatment or direct exposure).

Figure 1 demonstrates the unique change in pneumococcal vaccination that occurred for adults aged 65 or older in the NHIS data (Panel A). The grey circles plot the share of each age reporting that they had received the pneumococcal vaccine before ACIP's Prevnar 13 recommendation, and the black triangles plot the share for each age in the post-recommendation period. There is no evidence that

[28] In 2019, these data included claims for approximately 33.2 million beneficiaries, representing 51.5 percent of total Medicare beneficiaries (CMS, 2021). The HCPCS codes used to identify the PCV13 and PPSV23 vaccines are 90670 and 90732, respectively.

adults 50-64 years old experienced any increase in pneumococcal vaccination following ACIP's recommendation. However, there is a visually apparent increase in vaccine take-up among the recommended group in the post-recommendation period.[29] Figure 1 also presents descriptive trends in the number of Medicare Part B FFS claims per beneficiary for each of the two pneumococcal vaccines (Panel B). These trends show that there was a sharp and persistent increase in Prevnar 13 claims during the year following ACIP's recommendation. These trends also show a slight *reduction* in the number of Pneumovax doses administered to this population in 2015 and 2016. These dynamics are consistent with the fact that the new guidelines recommended that unvaccinated adults aged 65 or older should immediately receive Prevnar and return for Pneumovax in 6-12 months.

We examine whether ACIP's Prevnar 13 recommendation and Pfizer's subsequent advertising response increased self-reported pneumococcal vaccination in the NHIS data using the following difference-in-differences identification strategy relying on within-age-group changes among those recommended to

[29] Appendix Table A2 provides additional descriptive statistics for the full sample and by whether the individual was older/younger than 65-years-old. Appendix Figure A4 plots the share of adults aged 65-69 (black triangles) reporting that they had received a pneumococcal vaccine during the sample period. During the years when PCV13 was approved but not yet recommended for routine use in elderly adults, nearly 50 percent of those aged 65-69 reported receiving the pneumococcal vaccine. However, after ACIP recommended adults aged 65 or older receive PCV13 in series with PPSV23, the share of 65- to 69-year-old adults reporting pneumococcal vaccination increased by approximately 10 percentage points. Meanwhile, the share of adults aged 60-64 (grey circles) reporting that they had received the pneumococcal vaccine remained largely unchanged throughout the sample period.

receive the vaccine (Age ≥ 65) relative to those for whom the vaccine was approved but not ACIP recommended (50- to 64-year-olds):

$$VACC_{iart} = \alpha + \beta \cdot \mathbf{1}\{Age \geq 65\}_{ia} \times \mathbf{1}\{Recommended\ for\ Age \geq 65\}_{t} + X_{iart}'\gamma + \theta_a + \tau_{rt} + \varepsilon_{iart} \quad (2)$$

where the dependent variable, VACC, is an indicator for whether the respondent *i* aged *a* in census region *r* reported having received the pneumococcal vaccine in year-quarter *t*. The recommendation indicator takes on the value of one for adults aged 65 or older starting in Q4 2014 – the first fully treated quarter – and is zero otherwise.[30] In the Appendix, we show that our results are robust to iteratively narrowing the comparison group window to include only adults immediately around the age 65 threshold.

The vector X controls for individual demographic characteristics related to vaccination, including indicators for sex (male with female omitted), race/ethnicity (white, Black, Asian, Hispanic with 'other' omitted), educational attainment (less than high school, high school degree, some college with college graduate omitted), and health insurance status (insured with uninsured omitted). This last control may be particularly important given that most individuals become eligible for Medicare at age 65, and insured individuals are generally more connected to the health care

[30] We define treatment at the age-year-quarter level because the public use NHIS data do not include interview month. The results are robust to instead defining the recommendation period as Q3 2014.

system (Busch & Duchovny, 2005; Simon et al., 2017). Although we are unaware of any change in Medicare occurring concurrent with ACIP's Prevnar 13 recommendation, the Affordable Care Act Medicaid expansions may have increased health insurance coverage among our 50- to 64-year-old comparison group (McInerney et al., 2020; Miller et al., 2021). As the publicly available NHIS data do not include state identifiers, we are unable to control for these expansions directly – though we note that this likely makes it more difficult for us to detect a statistically significant increase in pneumococcal vaccination for adults aged 65 or older.[31]

We control for time-invariant age-specific propensities toward pneumococcal vaccination with age fixed effects, θ. We also account for secular changes in local attitudes toward vaccination and potential seasonality in vaccine take-up by including Census region-year-quarter fixed effects, τ. We report both heteroskedastic robust standard errors and wild bootstrapped p-values (Cameron et al., 2008; Cameron & Miller, 2015) obtained from clustering standard errors at the treatment group-time level (Abadie et al., 2017).

The coefficient of interest, β, estimates the increase in pneumococcal vaccination occurring for those aged 65 or older relative to the comparison group

[31] In the appendix we show that our results are robust to instead using data from the 2011-2019 Behavioral Risk Factor Surveillance System. While BRFSS data include state identifiers, allowing us to explicitly control for the ACA Medicaid expansions, they only report age in five-year groups, preventing us from granularly comparing 64- to 65-year-old adults.

coincident with ACIP's Prevnar 13 recommendation. Our identifying assumption is that, after accounting for the covariates and fixed effects, the treatment group's vaccination rate would have evolved similarly to the rate for the comparison group in the absence of the recommendation. While untestable, we assess the validity of this assumption with the following event study specification:

$$VACC_{iart} = \alpha + \sum_{j=-15,\, j\neq -1}^{20} \beta^{j} \cdot \mathbf{1}\{Age \geq 65\}_{ia} \times \mathbf{1}\{Quarter = j\}_{t} + X_{iart}'\gamma + \theta_{a} + \tau_{rt} + \varepsilon_{iart} \qquad (3)$$

where the coefficients, β^{j}, measure how pneumococcal vaccination differentially evolved for adults aged 65 or older compared to those 50-64 years old, relative to the quarter prior to the recommendation.

For analyses using the publicly available Medicare Part B summary files, we implement a slightly different identification strategy than for the NHIS, as our Medicare Part B data do not include information about patient age at the time of vaccination. Therefore, we identify the impact of the ACIP recommendation on pneumococcal vaccination by comparing uptake of a given pneumococcal vaccine to uptake of other adult vaccines that are similarly covered by Medicare Part B, but which plausibly should not be affected by the recommendation change. Specifically, our comparison group includes the hepatitis B, tetanus, and rabies vaccines, as these are only recommended to be administered as treatment in cases

of direct exposure (tetanus and rabies) or to specific high-risk populations (hepatitis B).[32] For these analyses we estimate the following equation:

$$VACC_{it} = \alpha + \beta \cdot \mathbf{1}\{\text{Brand=Prevnar 13}\}_i \times \mathbf{1}\{\text{Recommended for Age} \geq 65\}_t + \theta_i + \tau_t + \varepsilon_{it} \quad (4)$$

where the dependent variable, VACC, is an annual measure of the number of Medicare Part B FFS claims per beneficiary for vaccine brand *i* in year *t*. Since these data are at the annual level, the indicator variable **1**{Recommended for Age ≥ 65} takes on a value of one starting in the first full year following the recommendation change (2015) and is equal to zero otherwise. We include a full set of time-invariant drug-specific fixed effects, θ, and drug-invariant time fixed effects, τ. Regressions are weighted by the number of Medicare Part B Fee-For-Service beneficiaries in a given state-year.

The Medicare Part B claims data also allow us to examine the impact of the recommendation on Medicare Part B expenditure for pneumococcal vaccination, as it includes measures of average Medicare payments for each service. For these analyses, we estimate equation (4) described above, where the dependent variable is an annual measure of the total Medicare Part B FFS payments per beneficiary for vaccine brand *i* in year *t*.

[32] We plot the descriptive trends for these variables in Appendix Figure A5.

Sales Revenue: Annual Reports and SEC Form 10-K Filings

We explore the degree to which the ACIP recommendation of Pfizer's vaccine affected firm outcomes by examining changes in Prevnar 13 sales revenue. We obtain annual sales revenue data from the required financial statement (Form 10K) included in Pfizer's 2011-2019 annual reports. Figure 2 shows that, prior to ACIP's recommendation, Prevnar 13 sales remained stable at approximately $4 billion annually (Panel A). However, after ACIP recommended that adults aged 65 or older receive Prevnar 13, sales increased by over 60 percent to approximately $6 billion annually.[33]

To test whether the increased sales revenue was unique to Prevnar 13 or part of a broader trend in pharmaceutical sales, we collected product-specific sales data from annual reports and 10-K filings of other pharmaceutical firms. These reports contain information on the top-earning products each year. Because non-US sales figures may also be driven by variation in exchange rates or reporting requirements, we limit our comparison group to firms reporting annual sales in US dollars. We also require that sales information be reported in both the pre- and post-recommendation period. After starting with the 100 comparison products used to analyze advertising changes, these restrictions leave us with the 47 comparison products listed in Appendix Table A1. We empirically assess the relationship

[33] Consistent with the Medicare trends and the fact that Prevnar 13 and Pneumovax 23 are substitutes within a narrow time window, Appendix Figure A6 shows a temporary visual reduction pattern for Pneumovax 23 sales using data obtained from required financial statements.

between ACIP's recommendation and sales using the difference-in-differences specification and randomization inference procedure from equation (1).

RESULTS

Effects on Advertising and Awareness

We begin by testing whether Pfizer responded to ACIP's 2014 Prevnar 13 recommendation by increasing Prevnar 13-related advertising. On one hand, we might expect Pfizer to have reduced advertising for Prevnar 13 knowing that physicians were now more likely to recommend the vaccine. Yet Figure 5 suggests that Pfizer viewed ACIP's recommendation as complementary to their advertising (Panel A). The solid black line plots the event study coefficients obtained from estimating a version of equation (1) in which the dependent variable is Prevnar 13 direct-to-consumer advertising dollars, and the dashed grey lines are the corresponding 95 percent placebo intervals. In the months prior to the recommendation, the coefficients are small in magnitude and within the range one would expect to obtain by chance. However, several months after ACIP began recommending that elderly adults routinely receive Prevnar 13, monthly Prevnar direct-to-consumer advertising initially increased by approximately $15 million, and the coefficients are larger than their corresponding placebo intervals. Given existing evidence that direct-to-consumer advertising increases pharmaceutical take-up (Alpert et al., 2023; Lakdawalla et al., 2013; Shapiro, 2022; Sinkinson &

Starc, 2019), this result suggests that private firm decisions were likely an important pathway through which ACIP achieved its public policy goal.

Our results suggest that Pfizer's increased Prevnar-related direct-to-consumer advertising was a result of ACIP's recommendation,[34] which is consistent with financial statements (Pfizer, 2013) and earnings calls (Pfizer, 2012a, 2012b) where Pfizer executives indicated that their business would be slow to develop until ACIP's recommendation. As a result, any increase in vaccine take-up attributable to Pfizer's strategic marketing response may be interpreted as an indirect effect of ACIP's recommendation.

In Appendix Table A3, we further examine how the changes in advertising varied across media types (television, print, internet, and radio) and for national versus local-level ads.[35] These results suggest the observed increase in overall advertising expenditure was primarily driven by increases in television and print ads at the national level. Similarly, in Appendix Table A4 we show that the results are robust to refining the comparison group to only include drugs more similar to Prevnar 13's product lifecycle and those with positive advertising expenditure in the year prior to our reference year (Lawler & Skira, 2022).

[34] Although we cannot rule out that Pfizer's marketing response was driven by the CAPiTA findings as opposed to the ACIP recommendation, the overall timeline is not consistent with that interpretation. Specifically, the CAPiTA trial concluded in October 2013, and initial results were publicly released as early as February 2014, suggesting Pfizer had the results internally even earlier. However, we do not detect significant increases in direct-to-consumer advertising until November 2014, approximately 2 months after the ACIP recommendation was issued.

[35] We plot national and local advertising expenditure trends in Appendix Figure A7.

We next test whether ACIP's recommendation generated additional interest in Prevnar 13 using the 2011-2019 Google Trends data. Figure 5 shows that search intensity for 'Prevnar' was evolving similarly to that of other pharmaceuticals during the pre-recommendation period (Panel B). After ACIP began recommending that elderly adults routinely receive Prevnar 13, search intensity increased by more than would be expected from chance. Collectively, Figure 5 provides compelling evidence that ACIP's recommendation led to large increases in advertising and awareness about pneumococcal vaccination.[36]

Prior work has shown that television advertising can drive online search behavior (Du et al., 2019; Joo et al., 2013), and the visual patterns in Figure 5 suggest that increased Prevnar 13 direct-to-consumer advertising may partially explain the increased Google search activity.[37] Appendix Table A6 explores this possibility using an interrupted time series model that quantifies the relationship between advertising expenditure and Google searches for Prevnar after netting out the main effect of ACIP's recommendation and secular changes in information-

[36] Appendix Figure A8 shows that the advertising (Panel A) and Google Trends (Panel B) results are robust to instead using a weighted average of the comparison group to construct a 'Synthetic Prevnar' that best approximates true Prevnar advertising and search behavior during the pre-period and comparing the post-period outcome to this counterfactual. Appendix Table A5 shows suggestive evidence that ACIP's 2014 PCV13 recommendation increased search intensity for the terms 'pneumovax' and 'pneumonia,' though the estimates are statistically insignificant.

[37] There are numerous other potential channels through which the ACIP recommendation may have increased Google search activity, including increased conversations with doctors regarding the change or exposure to relevant news coverage. We are unable to disentangle these different channels.

seeking behavior.[38] We find that a one-standard-deviation increase in advertising expenditures was associated with a statistically significant 7.8 point (0.0013×$5,984.83) increase in Prevnar-related Google searches (column 1) and that the relationship was unique to contemporaneous advertising (column 2). These results further suggest that increased advertising is a mechanism through which ACIP's recommendation increased vaccine take-up.

Effects on Vaccination

We now use NHIS data to test whether ACIP's recommendation and the resulting marketing response translated into greater vaccine take-up among the targeted adults. The dependent variable in Table 2 is an indicator for reporting pneumococcal vaccination and the columns present the coefficient of interest from the difference-in-differences specification given in equation (2). As previously noted, in the NHIS data we cannot identify Prevnar take-up among individuals who had already received Pneumovax because the survey question does not distinguish between the vaccines. Therefore, the estimates are identified off increased take-up

[38] We control for a smooth linear trend in Google searches by including a continuous measure of time (measured in months). To allow the ACIP recommendation to change both the level and the slope of the trend we include an indicator for post-ACIP recommendation and the interaction between the post indicator and time in months. We then account for potential seasonality in Prevnar-related Google searches using calendar month fixed effects. Our independent variable of interest measures Prevnar 13 advertising expenditure in each year-month. To allow for a dynamic relationship between Prevnar 13 advertising and information-seeking behavior, we include three lags of the advertising variable; we include three leads as a falsification test. We conduct statistical inference by estimating the equation 100 times – iteratively acting as though each of the comparison pharmaceuticals had received Prevnar's advertising expenditure – and comparing our coefficients to their associated placebo distributions.

among individuals who would have otherwise remained completely unvaccinated. Heteroskedastic robust standard errors are shown in parentheses, and we report wild bootstrapped p-values from clustering standard errors at the treatment group-time level in brackets.

The results in Table 2 show that ACIP's Prevnar 13 recommendation and the subsequent change in Pfizer's advertising significantly increased pneumococcal vaccination among the elderly by 5.6-7.0 percentage points.[39] In 2013, there were approximately 44.6 million elderly adults in the US (SEER, 2022), so our estimates imply that ACIP's recommendation resulted in 2.5 million more adults receiving the pneumococcal vaccine. Event study coefficients obtained by estimating equation (3) are presented in Figure 6. There is no evidence that pneumococcal vaccination was differentially trending for the treated and comparison groups during the pre-period; the point estimates are all small in magnitude and statistically insignificant. However, after ACIP began recommending that adults aged 65 or older receive Prevnar 13, the likelihood that elderly adults reported pneumococcal vaccination increased by an average of 6.1 percentage points. In addition to our

[39] Appendix Figure A9 shows that our results persist when we limit the sample to include only adults with health insurance coverage. In Appendix Table A7 we do not detect any meaningful difference in vaccine take-up by sex, race/ethnicity, or educational attainment using the difference-in-differences model. Nor do we detect any significant differences across groups when we interact the right-hand side variables with demographic group-specific indicators in Appendix Table A8. Appendix Table A9 presents suggestive evidence that the effect of ACIP's recommendation on pneumococcal vaccine take-up was smaller for individuals with chronic conditions who were recommended to receive PCV13 prior to turning 65 years old. We plot these trends in Appendix Figure A10.

baseline estimate comparing changes in vaccination rates for adults aged 65-85+ to those aged 50-64 (Panel A), Appendix Table A10 shows that our results are robust to instead comparing changes in vaccination rates among adults aged 65-69 to those aged 60-64 (Panel B) and those aged 65-66 to those aged 63-64 (Panel C). In Appendix Table A11 we perform a similar analysis on data from the 2011-2019 Behavioral Risk Factor Surveillance System. Unlike in the NHIS data where we know exact age, the BRFSS data report age in 5-year groups (50-54, 55-59, 60-64, etc.), yet these data allow us to control for state-level time-varying policies (e.g., the Affordable Care Act Medicaid Expansion). Even after controlling for ACA Medicaid Expansion-by-age group effects, we continue to find increased pneumococcal vaccine take-up following ACIP's 2014 recommendation and Pfizer's direct-to-consumer advertising campaign.

Prior work has found that policies meant to increase take-up of particular adolescent vaccines can increase contact with health care providers and lead to increased childhood vaccination against other diseases (Carpenter & Lawler, 2019). To examine this possibility in our context, we use the NHIS data and the difference-in-differences model specified in equation (2). The results from these analyses are reported in Table 3. Each column reports the coefficient of interest from a separate regression, and all columns use the full set of controls. The results in columns 1 and 2 show that while the ACIP recommendation did not significantly affect the likelihood that elderly adults reported visiting any health care provider during the

prior 12 months, it did increase the probability of visiting a health care provider during the prior 2 weeks by 1.6 percentage points. This pattern of results suggests that the recommendation induced additional doctor visits among the subset of elderly individuals who were *already* in regular contact with their health care provider.[40] Column 3 shows a positive but not statistically significant increase in the likelihood elderly adults reported receiving the flu vaccine, while column 4 offers evidence that elderly adults were more likely to report receiving the herpes zoster vaccine for shingles prevention.[41] Notably, this latter vaccine was recommended for adults aged 60 or older during our sample period but had relatively low take-up in the pre-period (25.2 percent).[42]

We next examine the impact of the ACIP recommendation on vaccination uptake using publicly available Medicare Part B claims data, 2012-2019. The

[40] In addition to changing vaccine-seeking behavior among patients, the ACIP recommendation also likely changed the probability that doctors recommended the pneumococcal vaccine to their elderly patients during a healthcare visit (Churchill & Lawler, 2023). Unfortunately, we do not have data on doctor vaccine recommendations to test this directly.

[41] Appendix Figure A11 plots the trends for these outcomes.

[42] We also explored whether ACIP's recommendation resulted in changes in pneumococcal-related disease incidence. Appendix Table A12 analyzes changes in the incidence of invasive pneumococcal disease using 1998-2019 Active Bacterial Core Surveillance data collected by the CDC. Column 1 compares changes in pneumococcal disease among eight age groups, column 2 compares changes in pneumococcal disease for adults aged 65 or older to changes in three other diseases for which similar surveillance data are collected (Group A Streptococcus, Group B Streptococcus, and Haemophilus Influenzae), and column 3 uses a triple-difference specification with age group-by-disease, year-by-disease, and age group-by-year fixed effects. The results are inconclusive. Similarly, Appendix Figure A12 shows no evidence of a clear change in the crude death rate for pneumonia among adults aged 65 or older using the 2011-2019 CDC WONDER database, and the difference-in-differences estimate presented in Appendix Table A12 is not statistically different from zero (column 4). Consistent with ACIP's later assessment, these exhibits offer little consistent evidence that the 2014 PCV13 recommendation reduced the incidence of pneumococcal disease among elderly adults.

results in Table 4 show that the recommendation significantly increased the number of annual Medicare Part B FFS claims for Prevnar 13 by 0.079 claims per beneficiary (column 1). In 2015 there were 33.6 million FFS beneficiaries included in our data, implying approximately 2.6 million more FFS adults receiving Prevnar per year. Assuming a similar increase across the broader Medicare population (including Medicare Advantage) – and given the fact that the FFS beneficiaries in our data comprised 57.6 percent of all Medicare enrollees – our estimates imply approximately 4.6 million more vaccinated adults. This increase is larger than the detected increase in survey data, consistent with our inability to detect changes for those who had previously received Pneumovax 23 in the NHIS. Meanwhile, our estimate in column 2 suggests that the ACIP recommendation had a small negative effect on the number of claims per beneficiary for Pneumovax, although the significance is not robust to the wild bootstrap procedure. Consistent with the NHIS result, column 3 shows no evidence that the increased take-up of the pneumococcal vaccine had positive spillovers onto take-up of the influenza vaccine.[43]

Effects on Sales Revenue

Thus far, we have shown that: (i) Pfizer increased Prevnar-related advertising in response to ACIP's Prevnar 13 recommendation, (ii) Prevnar-related information-seeking behavior increased after ACIP's recommendation, and (iii) elderly adults

[43] We are unable to examine uptake of the zoster vaccine using these data, as it is not covered by Medicare Part B. It is covered by Medicare Part D.

were more likely to report pneumococcal vaccination in the post-recommendation period. We now explore how ACIP's Prevnar 13 recommendation affected Medicare expenditure for the pneumococcal vaccine. Appendix Figure A13 shows similar levels of spending per beneficiary for Prevnar 13 and other non-routinely recommended vaccines in the pre-recommendation period and a notable increase for Prevnar 13 in the post-period. The corresponding difference-in-differences estimate reported in Table 4 column 4 indicates that the 2014 recommendation and Pfizer's subsequent marketing response resulted in a statistically significant $14.41 increase in Medicare Part B FFS spending per beneficiary for the Prevnar 13 vaccine, or $483 million annually ($14.41 × 33.6 million Part B FFS beneficiaries).[44,45] The Medicare Part B FFS beneficiaries included in our analysis comprised 57.6 percent of all Medicare beneficiaries in 2015 (CMS, 2021). If we assume a similar increase in Prevnar 13 spending for those enrolled in Medicare

[44] In the Appendix, we explore how the recommendation affected Prevnar 13's price. Appendix Figure A14 presents suggestive evidence of an increase in Prevnar 13's price following the ACIP recommendation relative to the change experienced by Pneumovax 23. Indeed, Appendix Table A13 – which compares changes in prices of Prevnar to the associated changes in the prices of other plausibly unaffected vaccines covered by Medicare Part B – suggests that Pfizer raised the average price of Prevnar by approximately $38 following ACIP's recommendation (column 1). Yet we interpret these results cautiously given the pre-recommendation trends in prices of the comparison pharmaceuticals shown in Appendix Figure A15.

[45] We also conducted supplemental analyses using the Medicare Geographic Variation Public Use Files, 2011-2019, which contain information on total Part B drug expenditure per beneficiary, separately for enrollees younger than 65 and those aged 65 or older. Descriptive trends are presented in Appendix Figure A16. Results from estimating a version of equation (2), which compares outcomes for individuals below age 65 to outcomes for those aged 65 or older, before and after the recommendation change, indicate that the recommendation significantly increased Medicare Part B drug spending per beneficiary by $44.63 (robust SE=15.59, wild bootstrapped p-value=0.001). While larger in magnitude than our Prevnar 13-specific result in Table 4, we note that this estimate captures any potential spillover effects, and the confidence interval is large.

Advantage plans, our estimate implies over $839 million in additional annual spending on Prevnar 13.

To complement this analysis, Figure 7 compares changes in Prevnar 13 sales revenue to the associated changes in the 47 comparison products. There is no evidence that Prevnar 13 sales revenue was differentially trending relative to sales revenue from the comparison products during the pre-recommendation period; the point estimates are negative, smaller in magnitude, and within the placebo interval. However, in line with the implied increase in Medicare expenditure from Table 4, the average of the post-period event study coefficients indicates a statistically significant $1.03 billion annual increase in Prevnar 13 sales revenue.[46]

To explore the degree to which these estimated effects were due to ACIP's 2014 recommendation, as opposed to the results from the clinical trial that informed ACIP's decision, we leverage the fact that while ACIP's recommendation was unique to the US, these clinical data were known and discussed in other countries.[47] This setup allows us to net out the effect of the clinical trial by comparing changes in US sales to the associated changes in international sales. While country-specific pharmaceutical sales data is not readily available for all products in the comparison group, Pfizer's annual reports do distinguish between US and international Prevnar

[46] Appendix Figure A17 instead uses a data-driven approach to construct a 'synthetic' Prevnar that best mirrored Prevnar's true sales revenue in the pre-recommendation period. The conclusion remains unchanged.

[47] Notably, the ability of drug manufacturers to advertise directly to consumers is unique to the US and New Zealand (Ventola, 2011).

13 sales. Appendix Figure A18 shows that the statistically significant increase in Prevnar 13 sales revenue was unique to US sales, suggesting that the effect was driven by ACIP's recommendation and not the clinical trial performance. Notably, these patterns are consistent with Pfizer's own interpretation of the sales data. Speaking to investors on the Q1 2015 earnings call, Pfizer's then-CEO Ian C. Read stated that Prevnar 13's revenue growth was "primarily due to strong uptake amongst adults 65 years of age and older, following the positive recommendation from the US Centers for Disease Control and Prevention's Advisory Committee on Immunization Practice."

CONCLUSION

In this paper, we comprehensively study a policy intended to promote adult vaccination take-up. Using the 2011-2019 Ad$pender data on direct-to-consumer advertising, we show that Pfizer significantly increased Prevnar marketing following ACIP's Prevnar 13 recommendation, and we document concurrent increases in online Prevnar-related information-seeking behavior using 2011-2019 Google Trends data. We then use the 2011-2019 NHIS data and the 2012-2019 Medicare Part B Summary Files to show that ACIP's August 2014 recommendation and Pfizer's subsequent marketing increased the likelihood that elderly adults received Prevnar 13 by 5.6-7.9 percentage points in the post-recommendation period.

Our results provide the first quasi-experimental evidence of the impact of adult vaccine recommendations on firm marketing decisions and consumer behaviors. These findings have important policy implications. The American Medical Association has called for a ban on direct-to-consumer advertising of prescription drugs (AMA, 2015). Yet our results – viewed in conjunction with existing work linking direct-to-consumer advertising to increased pharmaceutical take-up (Alpert et al., 2023; Shapiro, 2018, 2022) – suggest that pharmaceutical advertising can help government agencies achieve public health goals. In contrast, Aizawa and Kim (2021) found that advertising by firms in the Affordable Care Act health insurance marketplace had modest market-expansion effects, in part because these private campaigns also sought to steal existing customers from other insurers. An important difference for our context is that Pfizer was the sole manufacturer of Prevnar 13, so ACIP's goal of increasing the share of elderly adults receiving Prevnar 13 was perfectly aligned with Pfizer's business interest. Additionally, by providing novel evidence that ACIP's PCV13 recommendation resulted in a cross-vaccine spillover onto another vaccine targeted toward older adults (the shingles vaccine), our results suggest that public health officials and clinicians may be able to increase take-up of recommended vaccines by bundling multiple immunizations into a single health care visit.

While our results show that the ACIP recommendation and Pfizer's advertising response led to increased vaccination rates among the elderly, ACIP

concluded in 2019 that their 2014 recommendation for routine vaccination of the elderly had done little to reduce PCV13-type disease at the population level for this age group. ACIP acknowledged historically low incidence of PCV13-type disease among the elderly, instead attributing these declines to pediatric take-up of Prevnar. Yet we identify at least one major beneficiary of the recommendation – Pfizer. We estimate that ACIP's Prevnar 13 recommendation increased annual Medicare Part B Fee-For-Service spending on Prevnar 13 by $14.41 per beneficiary, or $478 million per year. Given that the Medicare Part B FFS population we study represented approximately 57.6 percent of the total Medicare population in 2015 (CMS, 2021), this estimate extrapolates to a total increase in Medicare expenditure for the pneumococcal vaccine of $839 million per year. Similarly, we also find that the recommendation increased annual Prevnar 13 sales by approximately $1.03 billion compared to the associated changes experienced by comparison pharmaceuticals. Overall, these estimates highlight the value pharmaceutical firms can gain from health care recommendations.

This paper is subject to some limitations. For one, our measure of vaccine take-up is limited to self-reported information in the NHIS data. While it is likely that ACIP's recommendation increased awareness about vaccination among the targeted age group, it is not apparent that this would induce individuals to misreport their own status. Importantly, we identify similar patterns using the Medicare Part B Summary Files, and our findings are also consistent with Pfizer's own data on

pneumococcal vaccination. An additional limitation is our inability to disentangle the importance of an ACIP recommendation from Pfizer's subsequent marketing campaign. Because we find that ACIP's recommendation led Pfizer to increase their direct-to-consumer advertising, any increase in vaccine take-up attributable to this advertising campaign will be indirectly driven by ACIP's recommendation. Working to separate these pathways remains an important area for future research. Moreover, while we found that Pfizer responded to ACIP's recommendation by increasing direct-to-consumer advertising, data limitations prevented us from determining whether they also increased physician-targeted advertising. While we are unable to analyze changes in direct-to-physician advertising, prior evidence indicates that physician recommendations play an important role in vaccination decisions (Gargano et al., 2013; Moghtaderi & Adams, 2016). Additionally, while we detected large, robust increases in vaccine take-up and pharmaceutical sales following ACIP's PCV13 recommendation and Pfizer's subsequent advertising campaign, it is worth acknowledging that the targeted population (i.e., adults aged 65 or older) is highly insured and has regular contact with health care providers. As such, it is possible that ACIP recommendations targeted toward younger individuals may not generate as strong of a response. Finally, we also note that given the increased politicization of vaccination and falling trust in public health authorities resulting from the COVID-19 pandemic (Bargain & Aminjonov, 2020; Henkel et al., 2023; Sigrist and Bearth, 2021), we may expect future ACIP

recommendations to have very different effects. Despite these limitations, this paper offers the most comprehensive understanding to date of the market-wide effects of ACIP vaccination recommendations.

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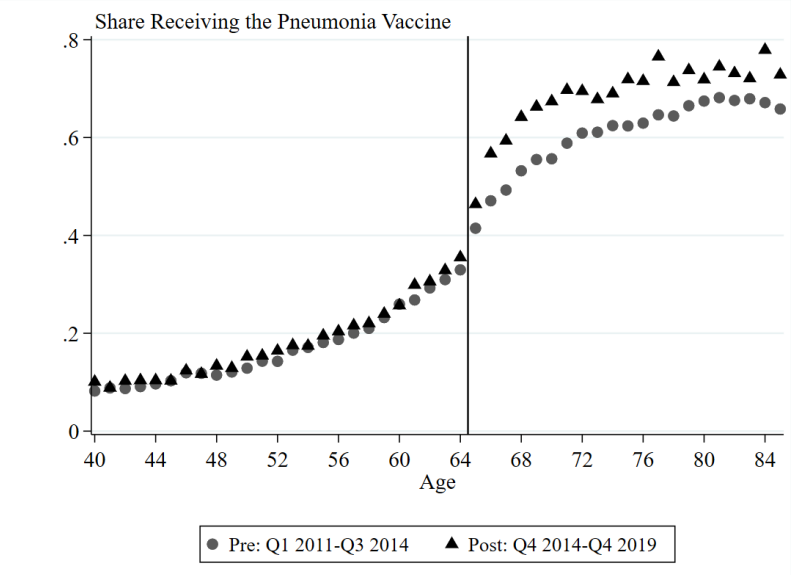
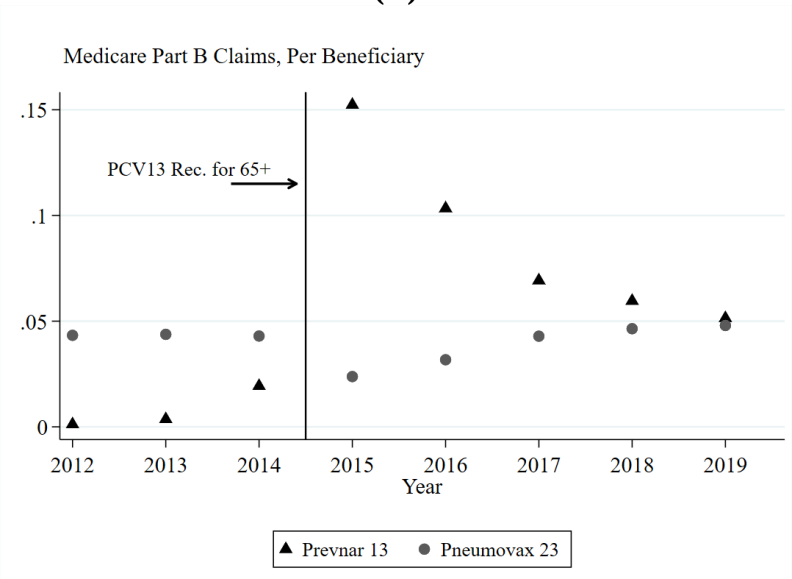


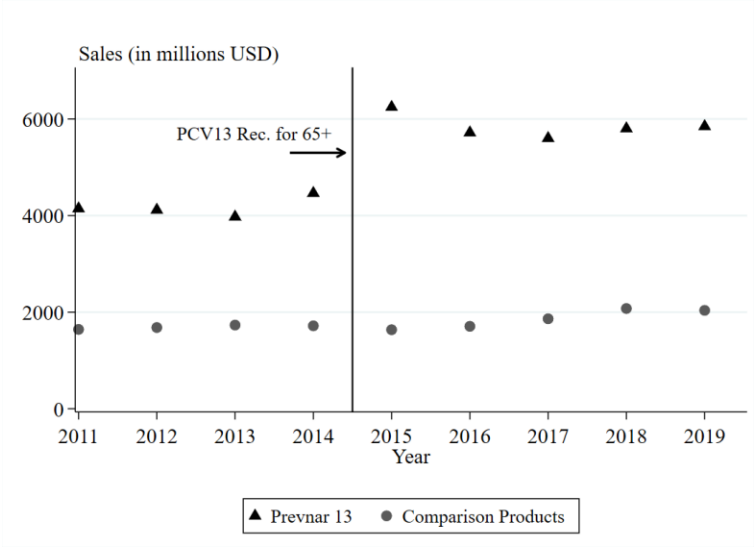
(A)



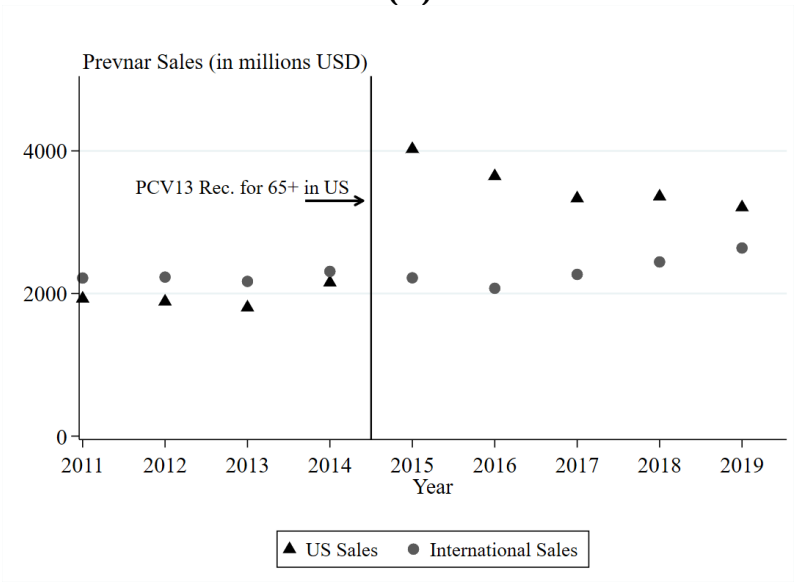
(B)

Source: National Health Interview Survey, 2011-2019; Medicare Part B Summary Files, 2012-2019
Note: The grey circles in Panel A denote the share of each age reporting that they had received the pneumonia vaccine prior to when PCV13 (Prevnar 13) was recommended for those 65+. The black triangles in Panel A indicate the share of each age reporting that they had received the pneumonia vaccine after PCV13 was recommended for those 65+. Panel B examines the annual number of claims per beneficiary for pneumococcal vaccination among Medicare Part B Fee-For-Service beneficiaries. The grey circles denote the annual number of claims per beneficiary for Pneumovax 23 and the black triangles indicate the annual number of claims per beneficiary for Prevnar 13.

Figure 1. Trends in Pneumococcal Vaccine Uptake and Claims.



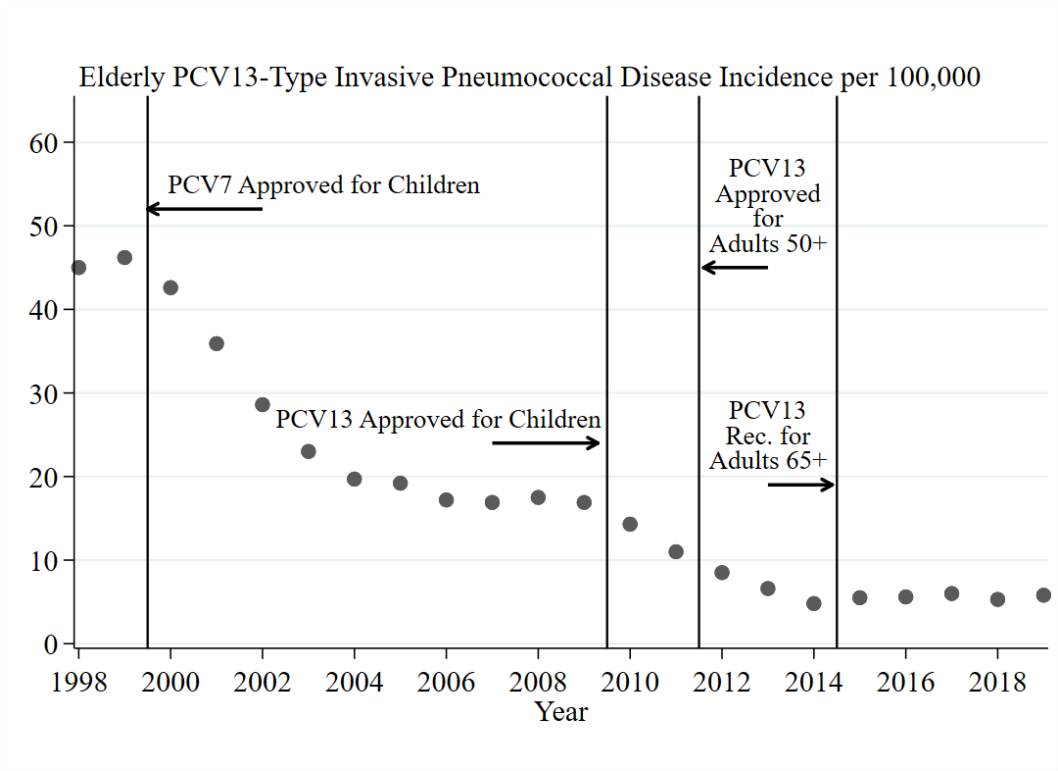
(A)



(B)

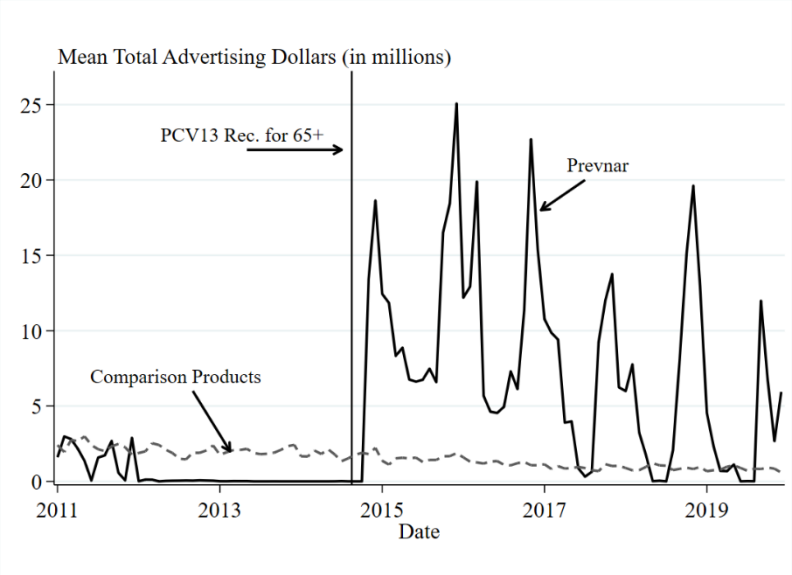
Source: Annual Reports, 2011-2019
Note: Panel A plots annual sales for Prevnar (black triangles) and the average of 47 non-Pfizer pharmaceutical products (grey circles). The comparison products are listed in Appendix Table 1. The figure in Panel B plots the annual US sales (black triangles) and the international sales (grey circles) of Prevnar 13.

Figure 2. Trends in Prevnar 13 Sales.

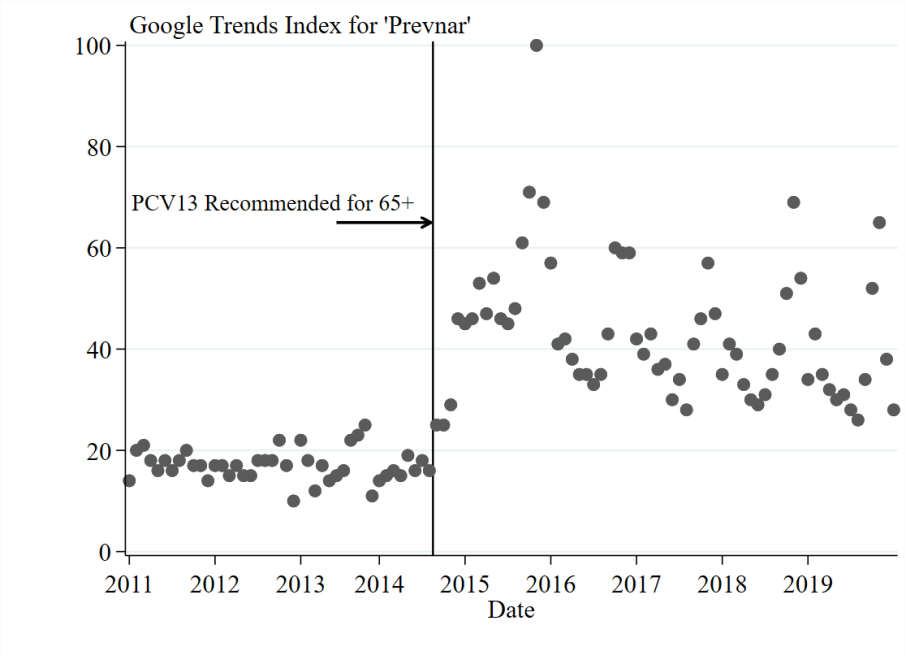


Source: Active Bacterial Core Surveillance Trends by Serotype Group, 1998-2019
Note: The grey dots plot the incidence of PCV13-type invasive pneumococcal disease (i.e., serotypes of pneumococcal disease that Prevnar 13 (PCV13) provides protection against) among adults aged 65 or older from 1998 through 2019 in the United States.

Figure 3. Invasive Pneumococcal Disease Incidence Over Time.



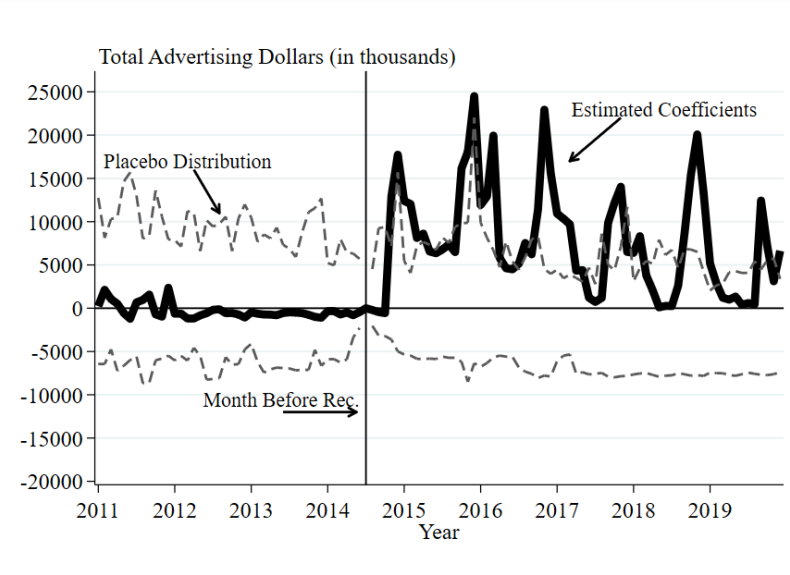
(A)



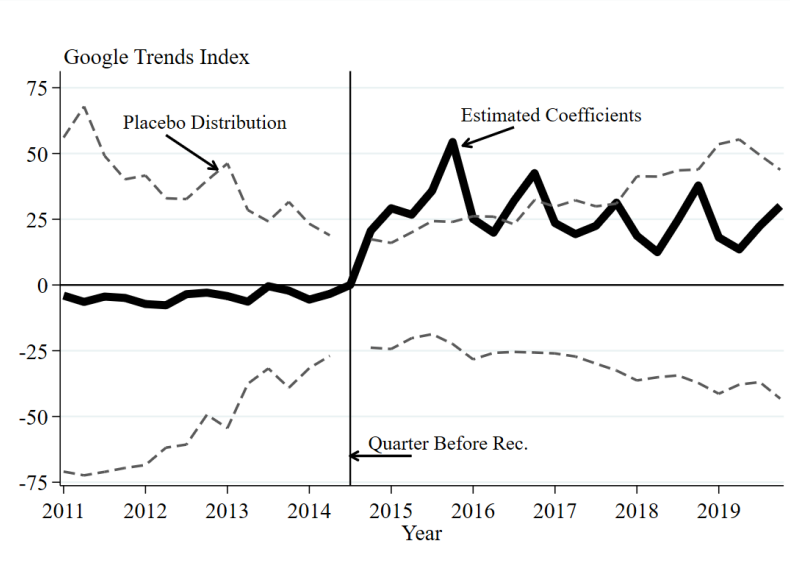
(B)

Source: Ad$pender, 2011-2019; Google Trends Index, 2011-2019
Note: Panel A plots monthly Prevnar-related advertising expenditure (in millions) and the advertising expenditure of the 100 non-Pfizer comparison pharmaceuticals listed in Appendix Table 1. The solid black line plots the total amount of money spent on advertising for Prevnar across all mediums over the sample period. The dashed grey line plots the average amount of money spent on advertising for the comparison products. Panel B examines information-seeking behavior using Google Trends data. The circles denote the relative search intensity for the term 'Prevnar' – the tradename of Pfizer's PCV13 pneumococcal vaccine – over time.

Figure 4. Trends in Prevnar Advertising and Google Searches.



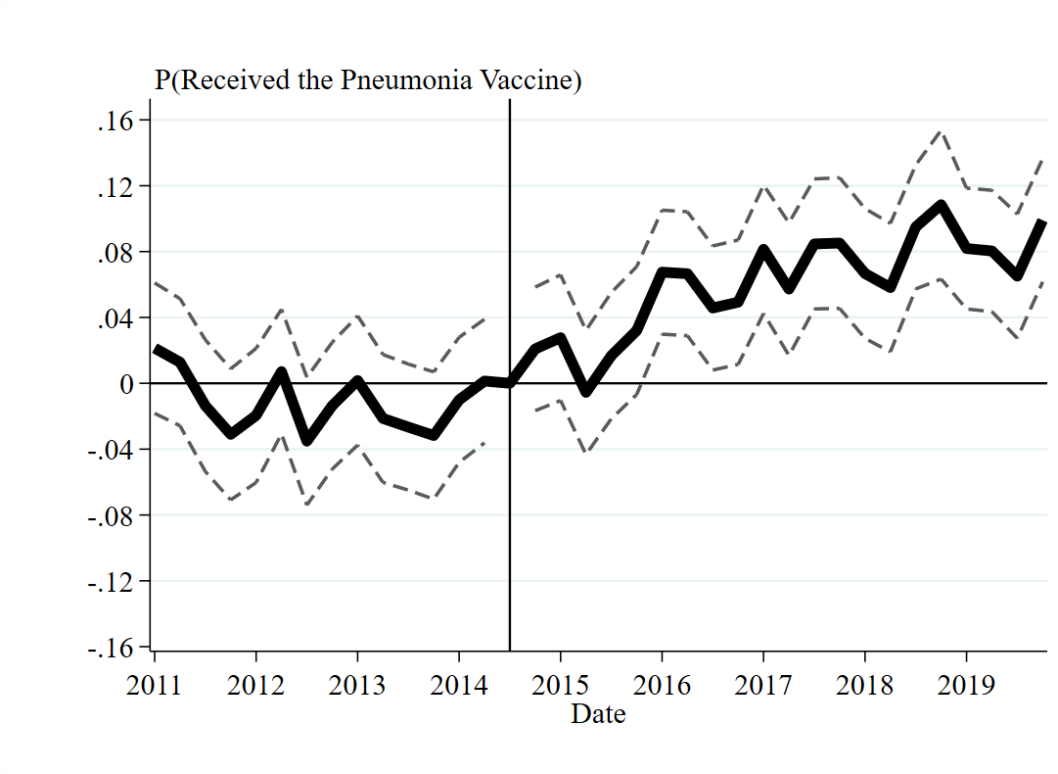
(A)



(B)

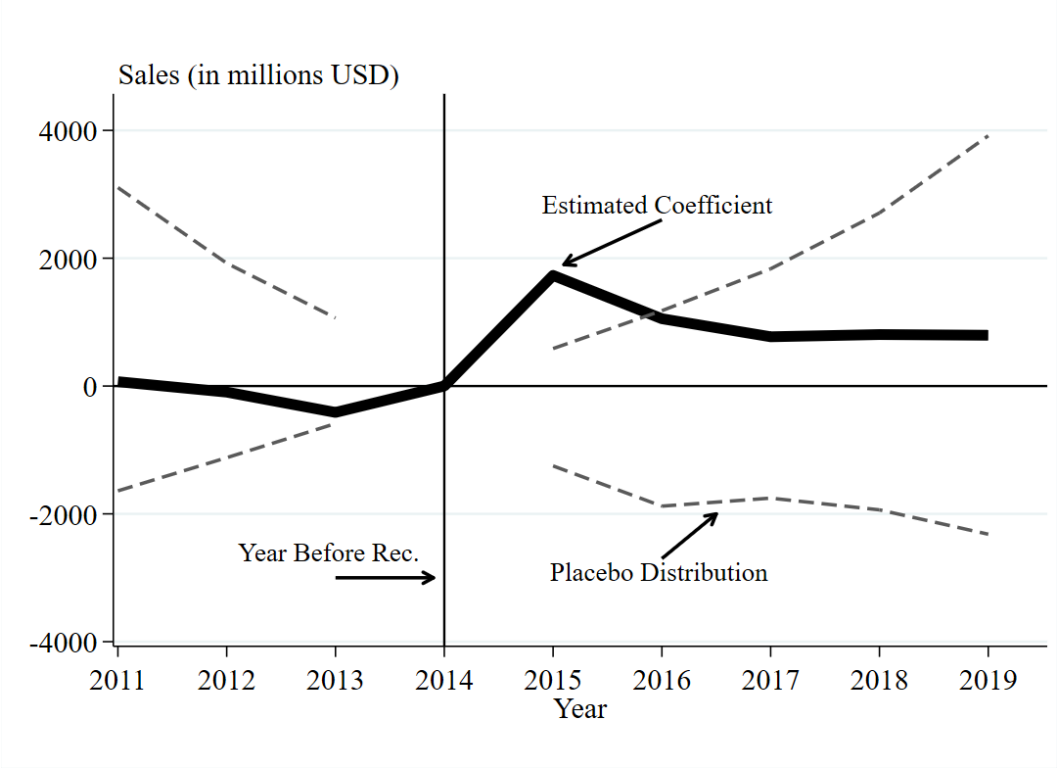
Source: Ad$pender, 2011-2019; Google Trends, 2011-2019
Note: The dependent variable in Panel A is the total monthly advertising dollars spent on a product (in thousands), while the dependent variable in Panel B is the Google Trends Index for the term 'Prevnar.' The solid black line plots the event study coefficients obtained from estimating equation (1) via ordinary least squares. The dashed grey lines plot the 95 percent placebo intervals obtained from iteratively assuming that each comparison product was treated, estimating equation (1), and saving the resulting placebo coefficients. When the solid black estimates obtained from the true treatment data are located within the placebo intervals, it indicates that the relationship was likely to have been obtained by chance. When the estimates are outside of the placebo interval, it indicates that the relationship was unlikely to have been obtained by chance.

Figure 5. Dynamic Effects of ACIP's Prevnar 13 Recommendation on Prevnar-Related Advertising and Information-Seeking Behavior.



Source: National Health Interview Survey, 2011-2019
Note: The solid dark line indicates the coefficients obtained from estimating equation (3). The lighter dashed lines plot the 95 percent confidence intervals. The dependent variable is an indicator for whether the respondent reported receiving the pneumonia vaccine. The sample includes individuals 50-85 years old.

Figure 6. Dynamic Effects of ACIP's Prevnar 13 Recommendation on Uptake of the Pneumonia Vaccine.



Source: Annual Reports, 2011-2019

Note: The figure plots the event study estimates from equation (1). The dependent variable is annual pharmaceutical sales (in millions USD). The independent variables are indicators for being *j* years away from ACIP recommending PCV13 (Prevnar 13) for adults 65 or older. The solid black line plots the point estimates, and the dashed gray lines plot the 95 percent placebo intervals generated from iteratively assuming each of the 47 comparison pharmaceuticals received ACIP's recommendation in August of 2014, estimating equation (4), and saving the placebo coefficients. The regression includes time-invariant fixed effects for each product, product-invariant year fixed effects, and a quadratic in the number of months since FDA approval.

Figure 7. Effects of ACIP's Prevnar 13 Recommendation on Prevnar Sales.

Table 1. Relevant policy dates for adult vaccination.

Vaccine type	Trade name	FDA approval		ACIP routine recommendation	
		Year	Age	Year	Age
PPSV23	Pneumovax 23	1989	50+	1989	65+
PCV13	Prevnar 13	2011	50+	2014-2019	65+

Note: Adults receiving PCV13 were still recommended to receive PPSV23. ACIP stopped recommending routine use of PCV13 for those aged 65 or older in 2019.

Table 2. Effect of ACIP's age-targeted Prevnar 13 recommendation on pneumococcal vaccination.

	(1)	(2)	(3)
1{Age ≥ 65}×	0.060***	0.070***	0.056***
1{Rec. for Age ≥ 65}	(0.005)	(0.005)	(0.006)
	[0.000]	[0.000]	[0.001]
R^2	0.183	0.216	0.227
Mean for Age ≥ 65 in 2013	0.593	0.593	0.593
Observations	139,742	139,742	139,742
Covariates?		Y	Y
Survey Weights?			Y

Source: National Health Interview Survey, 2011-2019

Note: The dependent variable is an indicator for whether the respondent reported receiving the pneumococcal vaccine. The estimates are obtained using the difference-in-differences specification shown in equation (2). Column 1 utilizes a sparse framework including only indicators for being over the recommended age, being in the post-recommendation period, and the interaction of these terms. Column 2 includes indicators for each age (50-85 with 85+ omitted), race/ethnicity (white, Black, Hispanic, Asian with 'other' omitted), educational attainment (less than high school, high school degree, some college with college degree omitted), and health insurance coverage (insured with uninsured omitted). Column 2 also includes Census region-by-year-quarter fixed effects. Column 3 utilizes the survey weights. Robust standard errors are shown in parentheses, and wild bootstrapped p-values obtained after clustering standard errors at the group-year level are reported in brackets.

*** p < 0.01; ** p < 0.05; * p < 0.10.

Table 3. Effect of ACIP's age-targeted Prevnar 13 recommendation on receipt of other health care.

	(1)	(2)	(3)	(4)
Outcome →	Visited any health care provider during prior 12 months	Visited any health care provider during prior 2 weeks	Influenza vaccination	Herpes Zoster vaccination for shingles prevention
1{Age ≥ 65}×	0.005	0.016**	0.010	0.058***
1{Rec. for Age ≥ 65}	(0.004)	(0.005)	(0.005)	(0.007)
	[0.190]	[0.017]	[0.159]	[0.005]
R^2	0.069	0.019	0.096	0.092
Mean for Age ≥ 65 in 2013	0.850	0.297	0.669	0.252
Observations	125,768	127,188	142,402	69,325

Source: National Health Interview Survey, 2011-2018

Note: The dependent variable in column 1 is an indicator for whether the respondent reported having a health care visit during the prior 12 months, in column 2 an indicator for whether the respondent reported having a health care visit during the prior 2 weeks, in column 3 an indicator for whether the respondent reported receiving the influenza vaccine, and in column 4 an indicator for whether the respondent reported receiving the herpes zoster vaccine for shingles prevention. The sample in column 4 is limited to the period prior to the introduction of a new, more effective shingles vaccine that was recommended for adults aged 50 or older. We also limit the sample in column 4 to adults who were always recommended to receive the shingles vaccine (adults aged 60 or older). The estimates are obtained using the difference-in-differences specification shown in equation (2). Robust standard errors are shown in parentheses, and wild bootstrapped p-values obtained after clustering standard errors at the group-year level are reported in brackets.

*** p < 0.01; ** p < 0.05; * p < 0.10.

Table 4. Effect of ACIP's Prevnar 13 recommendation on vaccination claims and spending in Medicare Part B.

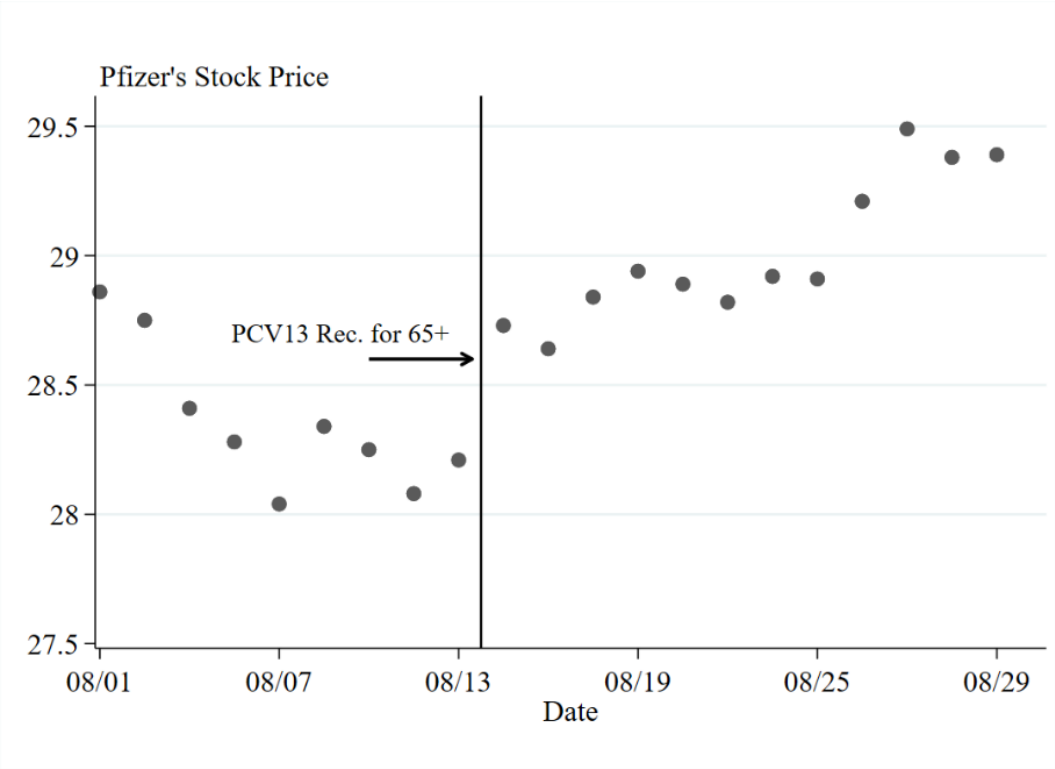
	(1)	(2)	(3)	(4)
Outcome →	Prevnar 13 claims per beneficiary	Pneumovax 23 claims per beneficiary	Influenza vaccination claims per beneficiary	Prevnar 13 spending per beneficiary
1{Treated Group}×	0.0788***	-0.00528	0.00381	14.41***
1{PCV13 Rec.}	(0.003)	(0.001)	(0.00932)	(0.369)
	[0.002]	[0.273]	[0.751]	[0.002]
R^2	0.811	0.884	0.888	0.847
Mean for Treated group in 2013	0.00329	0.0391	0.399	0.454
Observations	1,224	1,224	1,224	1,224

Source: Medicare Part B Claims Public Use Summary Files, 2012-2019

Note: The dependent variable in column 1 is the number of Prevnar 13 (PCV13) claims per beneficiary, in column 2 the number of Pneumovax 23 (PPSV23) claims per beneficiary, in column 3 the number of influenza vaccine administration claims per beneficiary, and in column 4 the amount of Medicare Part B spending on Prevnar 13 per beneficiary. The specification in all columns compare changes in outcomes to the concurrent changes in outcomes of other non-routinely recommended vaccines covered by Medicare Part B (hepatitis B, rabies, and tetanus) using equation (4). All columns include year fixed effects and product fixed effects. Robust standard errors are shown in parentheses and wild bootstrapped p-values obtained after clustering standard errors at the group-year level are reported in brackets. Regressions are weighted by the total number of Medicare Part B Fee-For-Service beneficiaries in a given state-year.

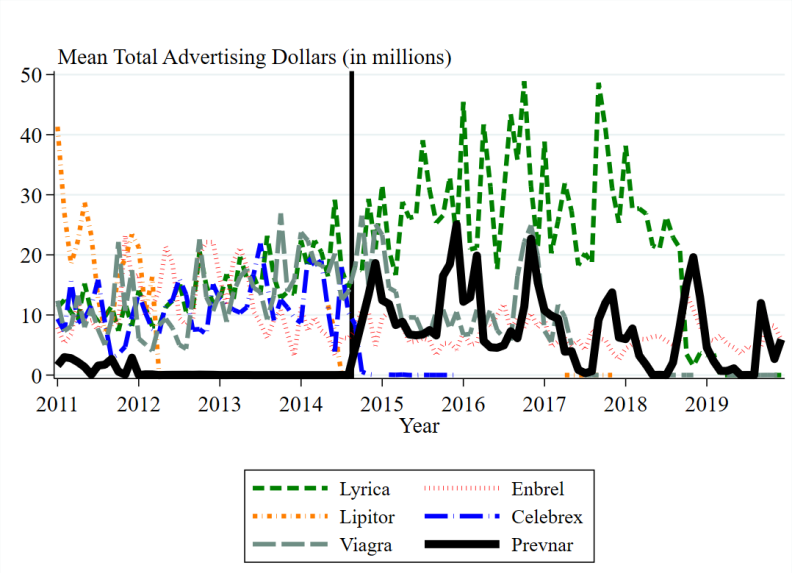
*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

APPENDIX – FOR ONLINE PUBLICATION

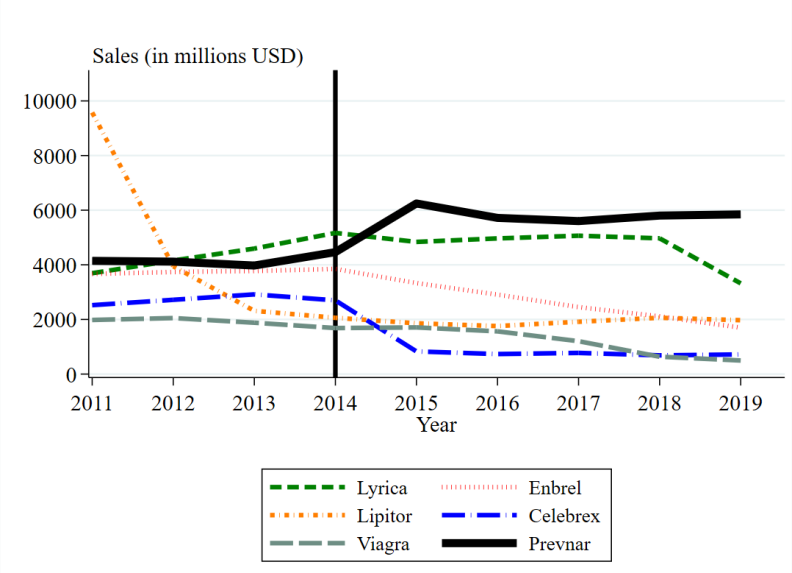


Source: CRSP, 2014
Note: The grey dots plot how Pfizer's stock price evolved during the month of ACIP's recommendation that adults aged 65 or older receive PCV13 (August 2014).

Appendix Figure A1. Trends in Pfizer's Stock Price.



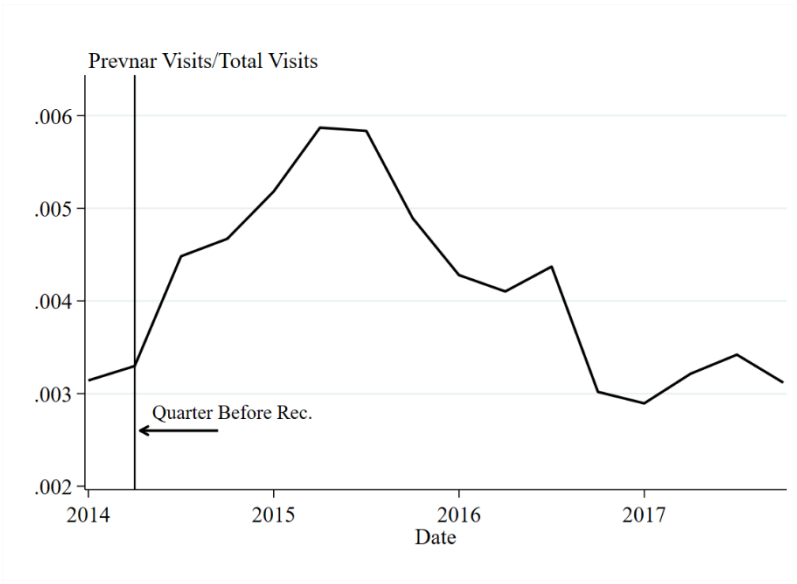
(A)



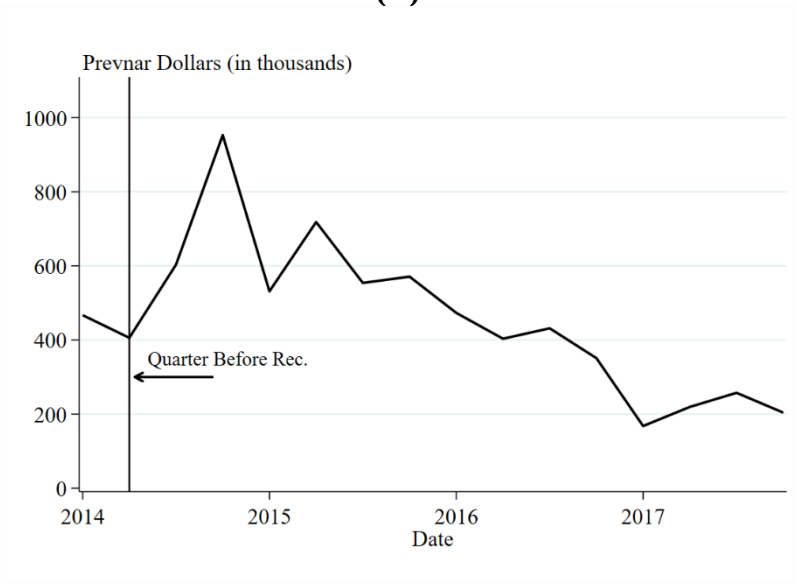
(B)

Source: Ad$pender, 2011-2019; Annual Reports, 2011-2019
Note: Panel A plots total advertising dollars for 5 other Pfizer products. Panel B plots the corresponding annual sales revenue for these products. We note that the Celebrex patent expired in May 2014.

Appendix Figure A2. Advertising Trends of Other Pfizer Products.



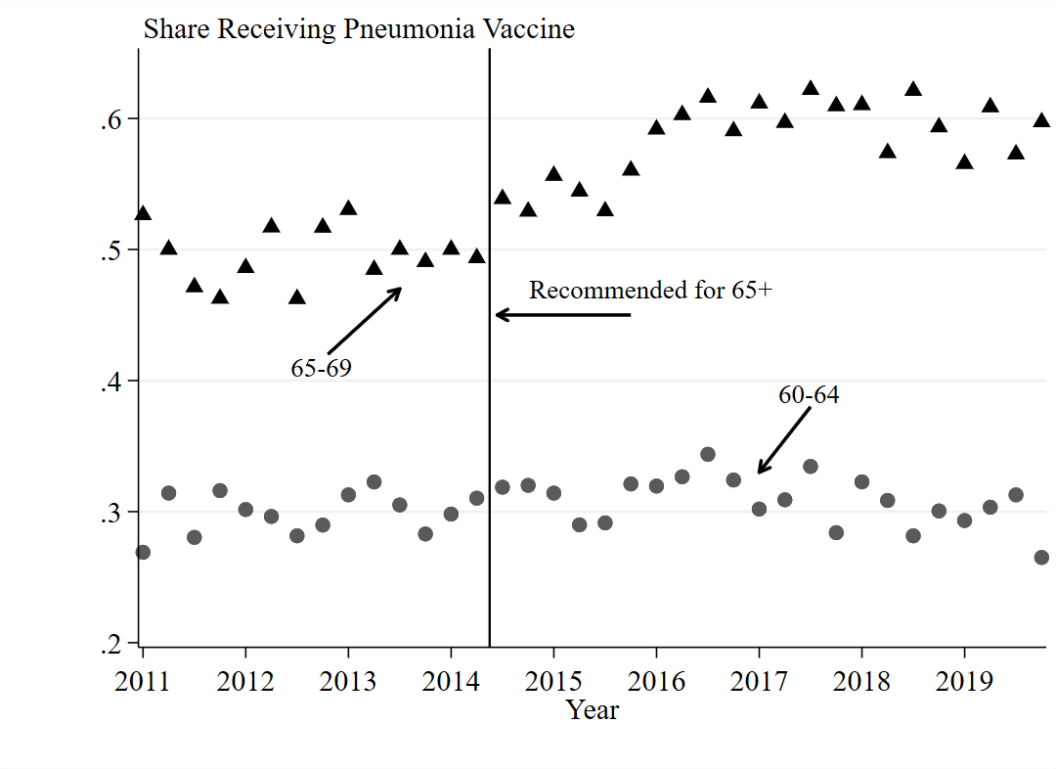
(A)



(B)

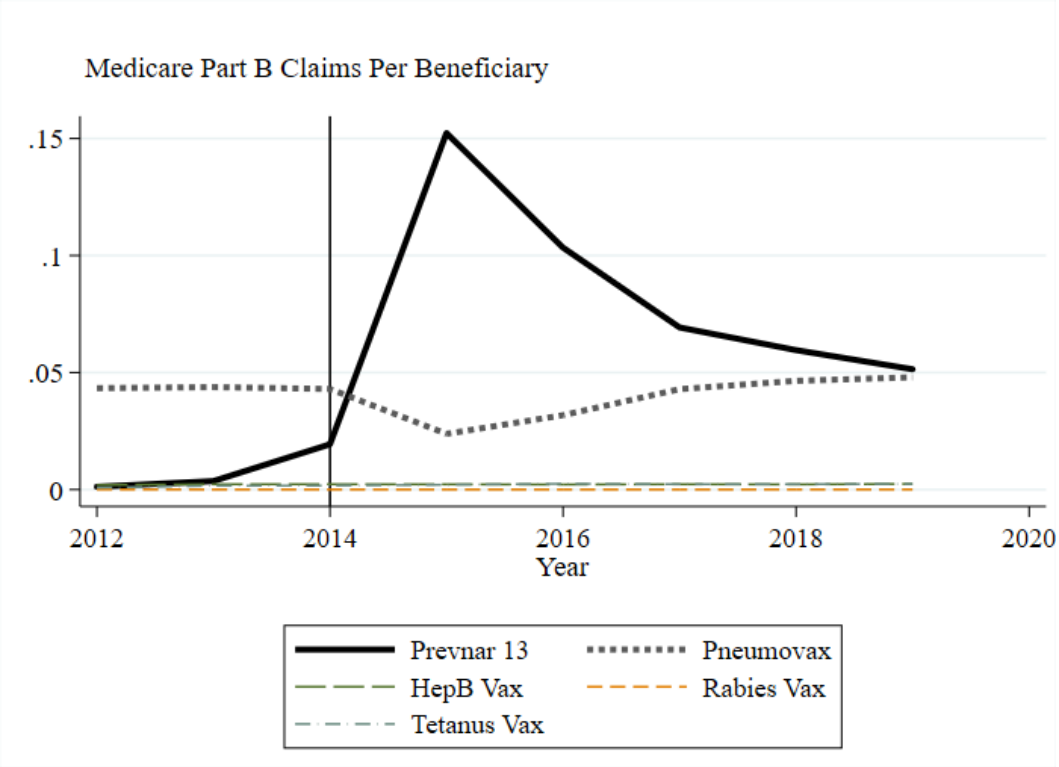
Source: CMS Open Payments, 2014-2017
Note: Panel A plots the fraction of all visits in the Open Payments database where physicians received 'food and beverage' related to Prevnar. Panel B plots the total dollars (in thousands) spent on the Prevnar-related 'food and beverage' transfers.

Appendix Figure A3. Trends in Prevnar-Related Open Payments.



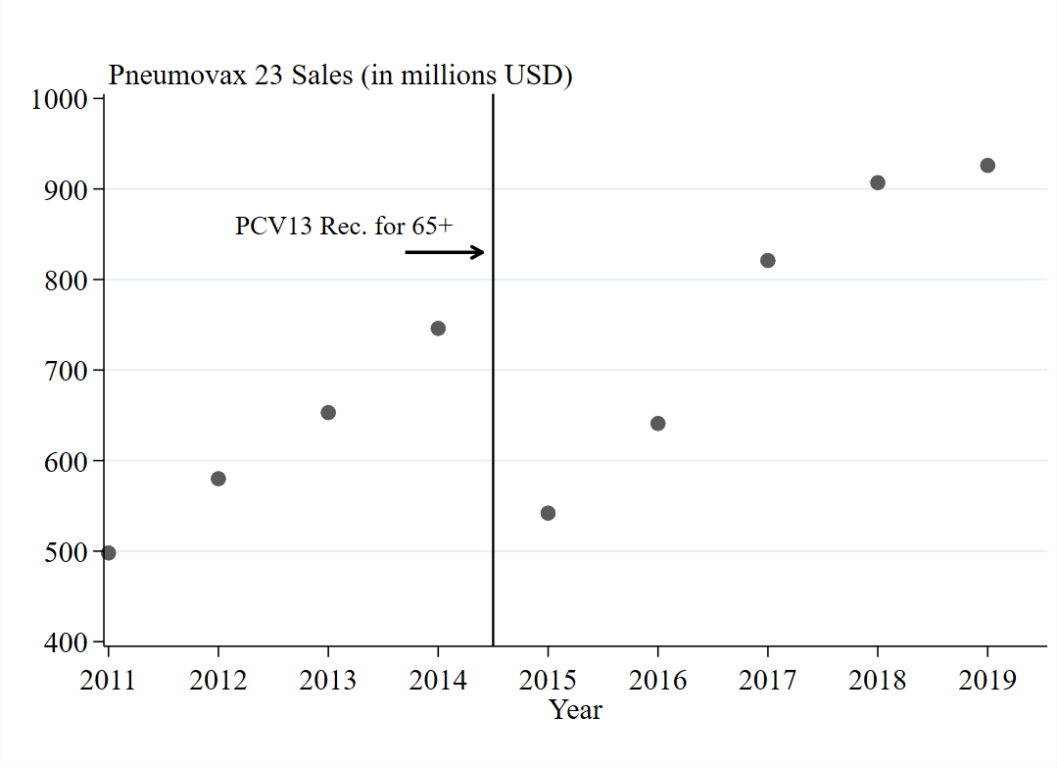
Source: National Health Interview Survey, 2011-2019
Note: The grey circles denote the share of 60- to 64-year-old individuals reporting that they had received the pneumonia vaccine. The black triangles indicate the share of 65- to 69-year-old individuals reporting that they had received the pneumonia vaccine. PCV13 was recommended for people over 65 in August 2014.

Appendix Figure A4. Share of Adults Receiving the Pneumonia Vaccine Over Time.



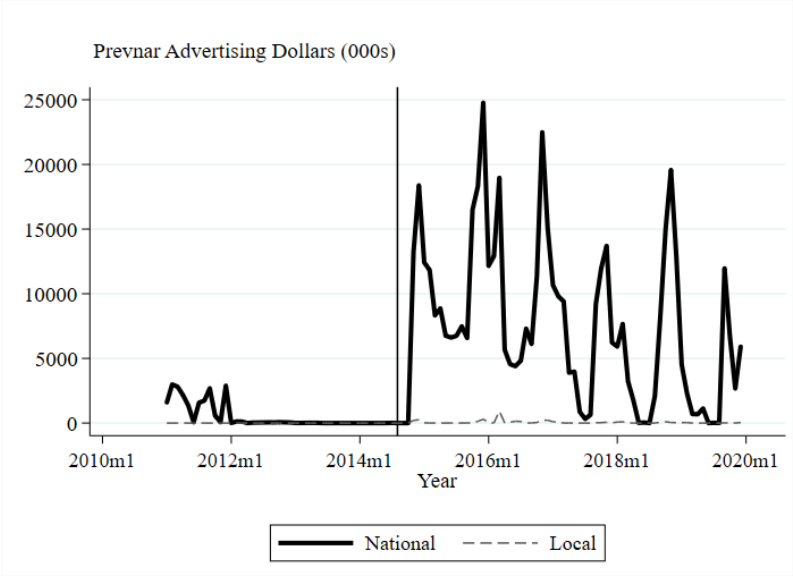
Source: Part B Summary Files, 2012-2019
Note: The figure plots the annual number of claims per beneficiary for covered vaccines among Medicare Part B Fee-For-Service beneficiaries.

Appendix Figure A5. Trends in Medicare Part B Claims.

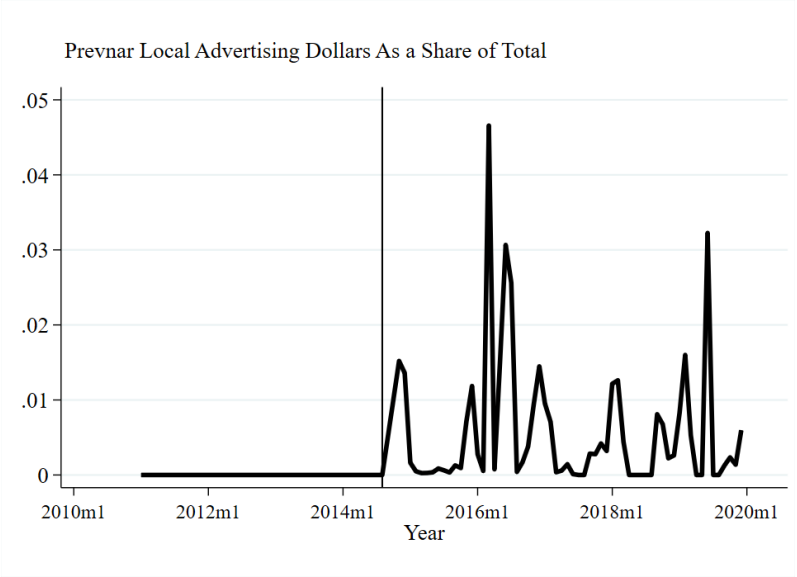


Source: Annual Reports, 2011-2019
Note: The grey circles plot the annual sales (in millions USD) of Pneumovax 23 in the years surrounding the 2014 ACIP recommendation that adults aged 65 or older receive PCV13.

Appendix Figure A6. Pneumovax 23 Sales Trends.



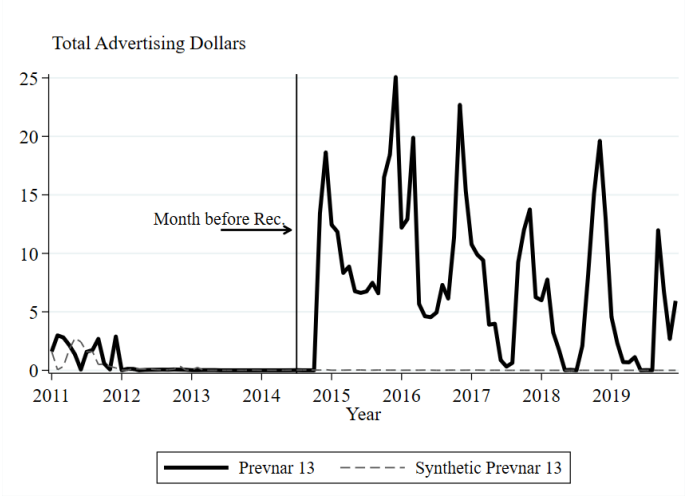
(A)



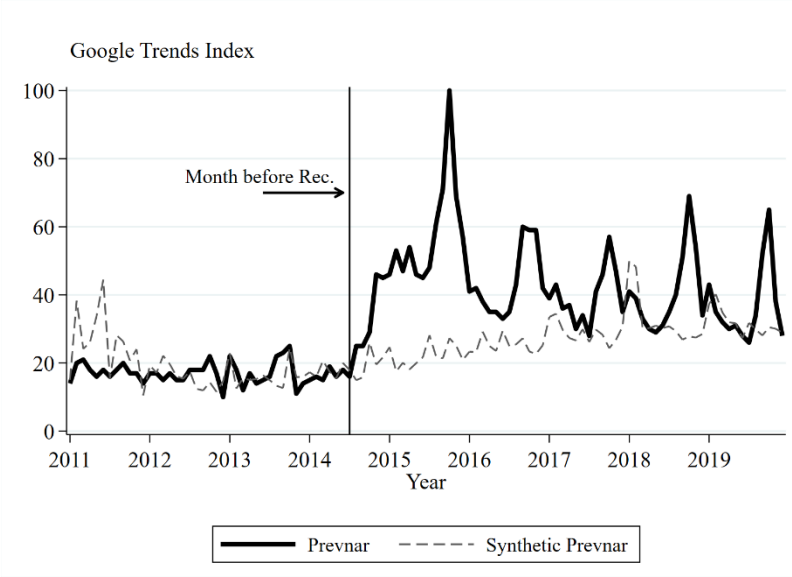
(B)

Source: Ad$pender, 2011-2019
Note: The solid black line in Panel A plots national advertising dollars for Prevnar 13 over time. The dashed grey line plots advertising dollars spent in local media markets. The solid black line in Panel B plots the share of total Prevnar 13 advertising dollars that were spent at the local level.

Appendix Figure A7. National and Local Trends in Prevnar Advertising Expenditures.



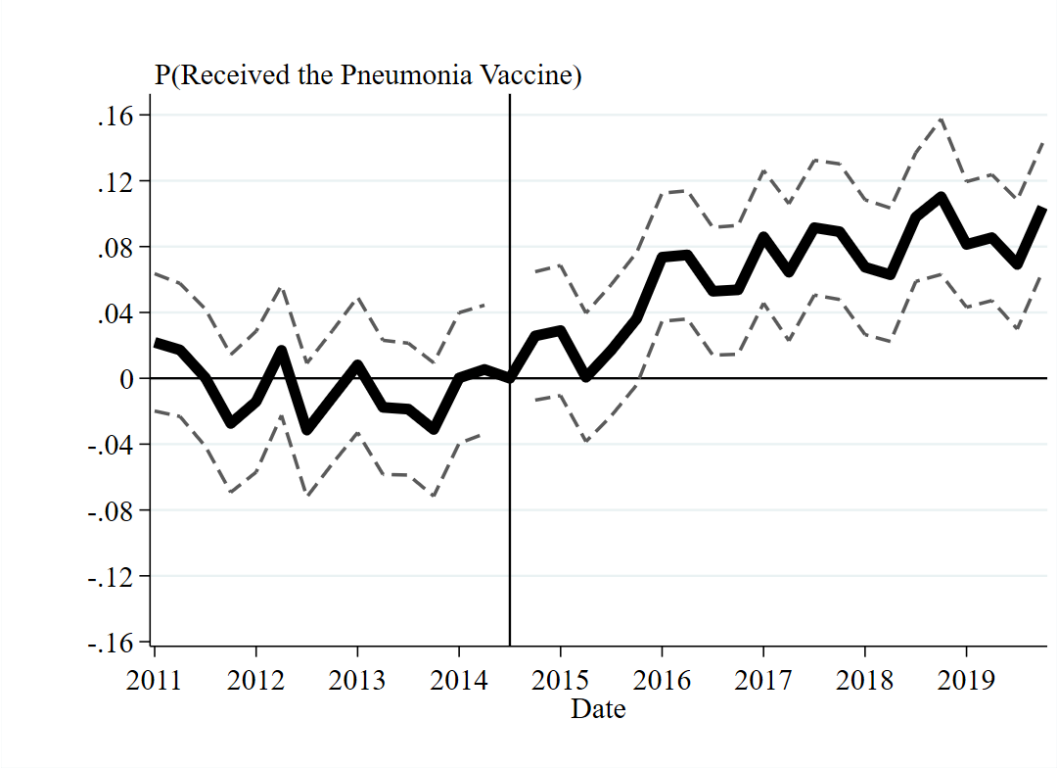
(A)



(B)

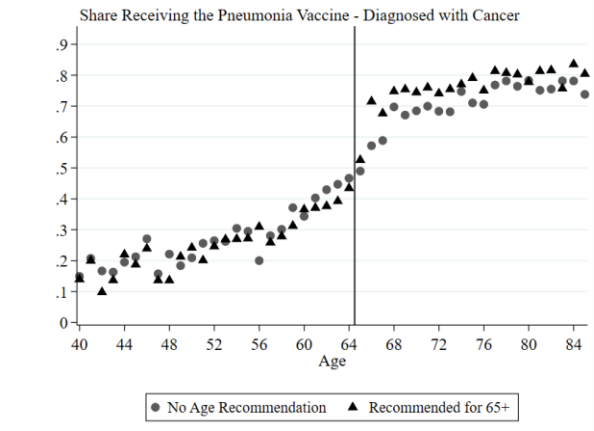
Source: Ad$pender 2011-2019; Google Trends 2011-2019
Note: In Panel A the solid black line plots monthly direct-to-consumer advertising expenditure (in millions) by Pfizer on Prevnar 13. The grey dashed line plots the advertising expenditures for a 'Synthetic Prevnar' which is constructed by determining the weighted average of placebo pharmaceuticals which best approximates advertising expenditures on Prevnar 13 during the pre-period. Synthetic Prevnar is determined by matching on advertising expenditures in January and July of each year prior to ACIP's recommendation. Similarly, in Panel B the solid black line plots the Google Trends Index for the search term 'Prevnar.' The grey dashed line plots the Google Trends Index for a 'Synthetic Prevnar' which is constructed by determining the weighted average of placebo terms which best approximates searches for 'Prevnar' during the pre-period. Synthetic Prevnar is determined by matching on Google searches in January and July of each year prior to ACIP's recommendation.

Appendix Figure A8. Dynamic Effects on Advertising and Google Searches, Synthetic Control Approach.

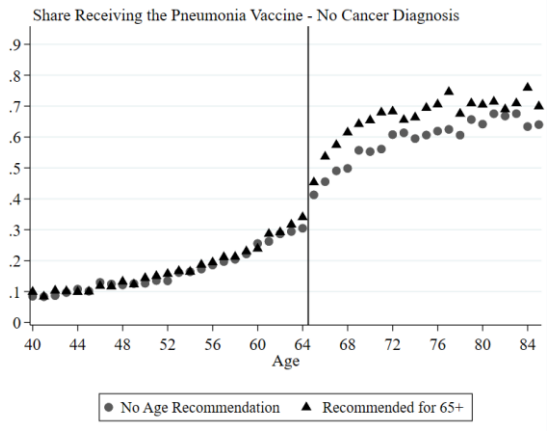


Source: National Health Interview Survey, 2011-2019
Note: The solid black line indicates the coefficients obtained from estimating equation (3). The grey dashed lines plot the 95 percent confidence intervals. The dependent variable is an indicator for whether the respondent reported receiving the pneumonia vaccine. The sample includes individuals 50-85 years old with health insurance.

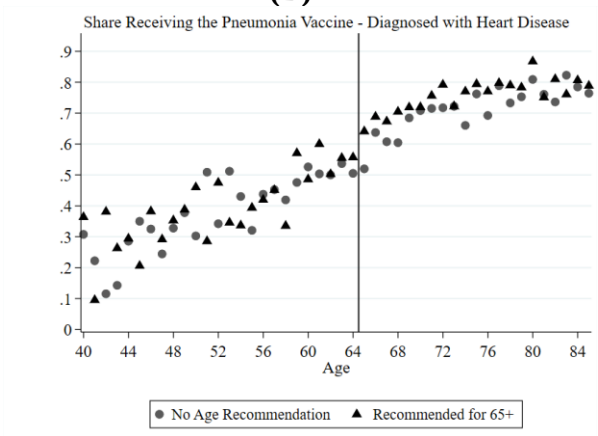
Appendix Figure A9. Dynamic Effects of ACIP's Recommendation on Vaccination for the Sample of Adults with Health Insurance.


Share Receiving the Pneumonia Vaccine - Diagnosed with Cancer
Age
No Age Recommendation
Recommended for 65+

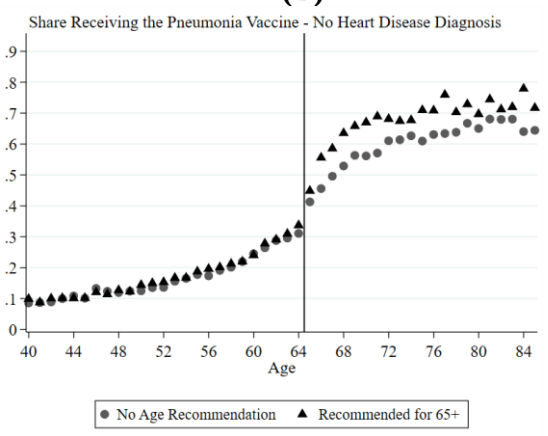
(B)


Share Receiving the Pneumonia Vaccine - No Cancer Diagnosis
Age
No Age Recommendation
Recommended for 65+

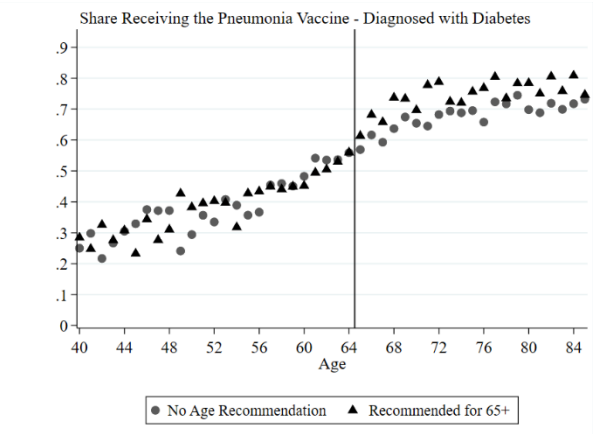
(B)


Share Receiving the Pneumonia Vaccine - Diagnosed with Heart Disease
Age
No Age Recommendation
Recommended for 65+

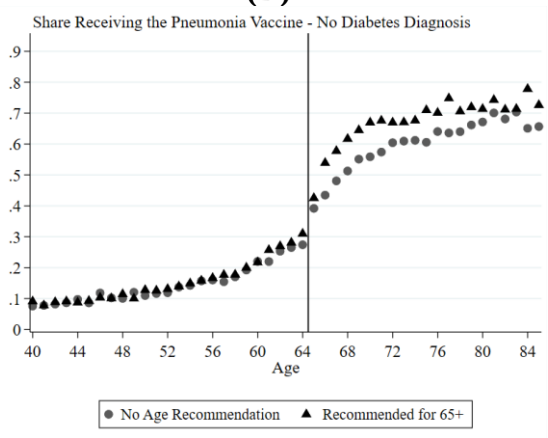
©


Share Receiving the Pneumonia Vaccine - No Heart Disease Diagnosis
Age
No Age Recommendation
Recommended for 65+

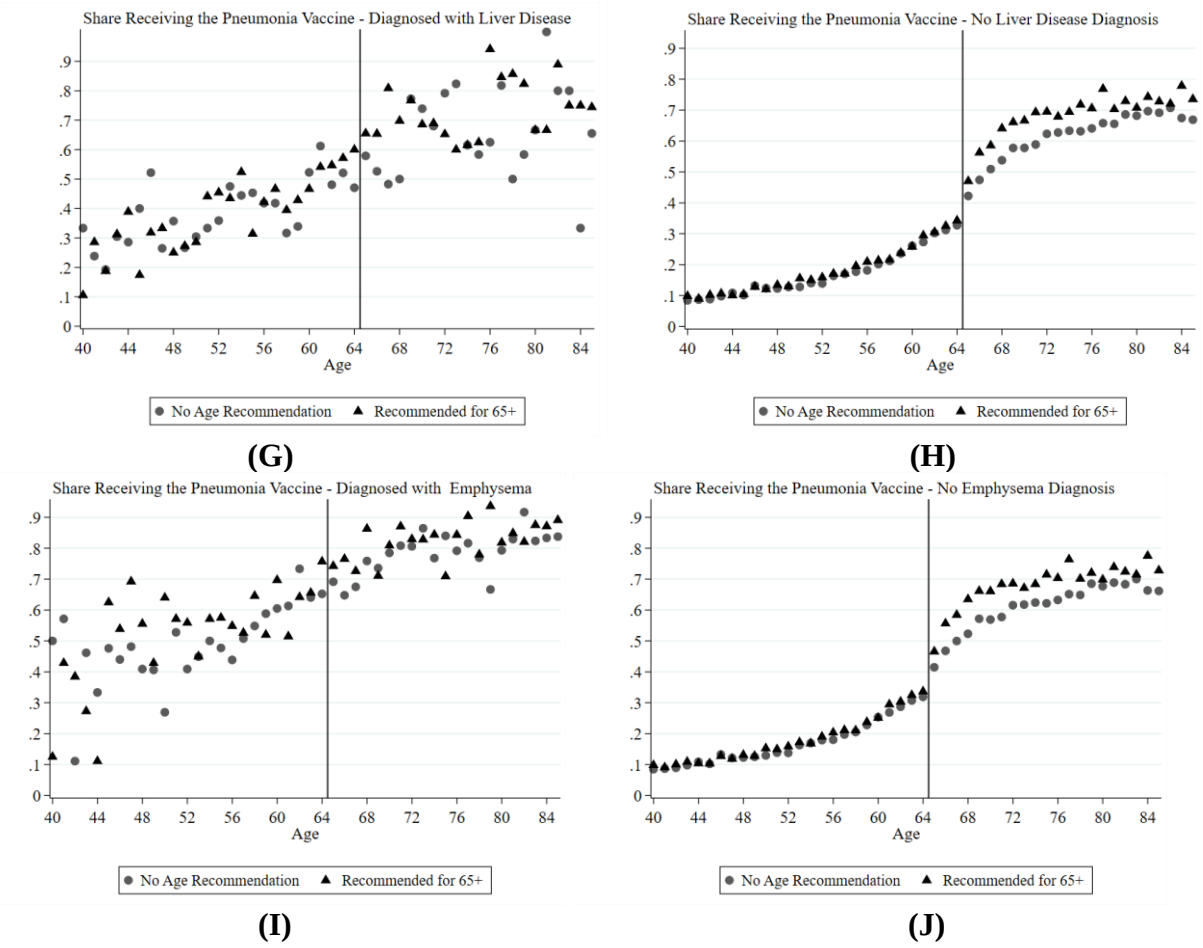
(D)


Share Receiving the Pneumonia Vaccine - Diagnosed with Diabetes
Age
No Age Recommendation
Recommended for 65+

(E)

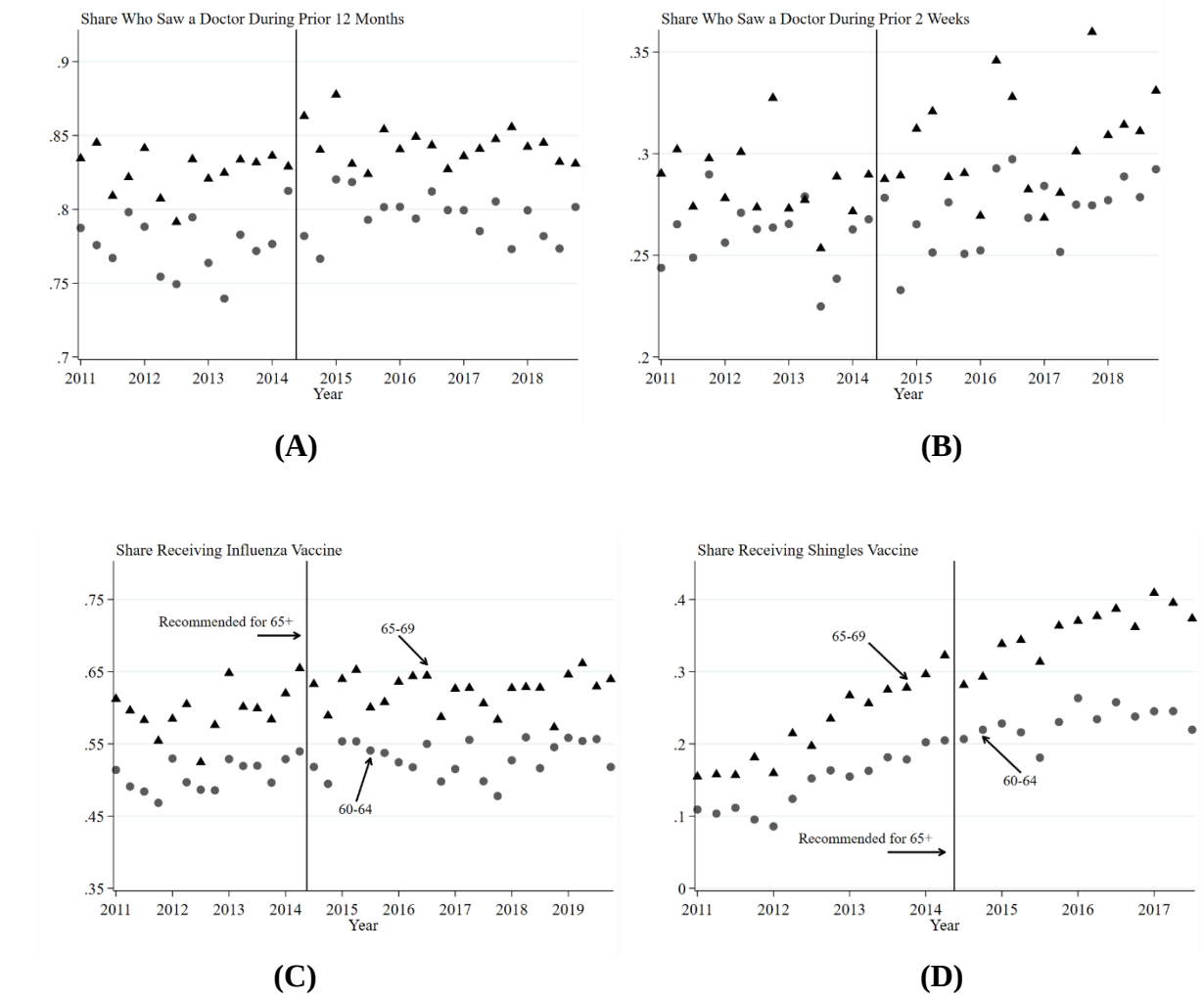

Share Receiving the Pneumonia Vaccine - No Diabetes Diagnosis
Age
No Age Recommendation
Recommended for 65+

(F)



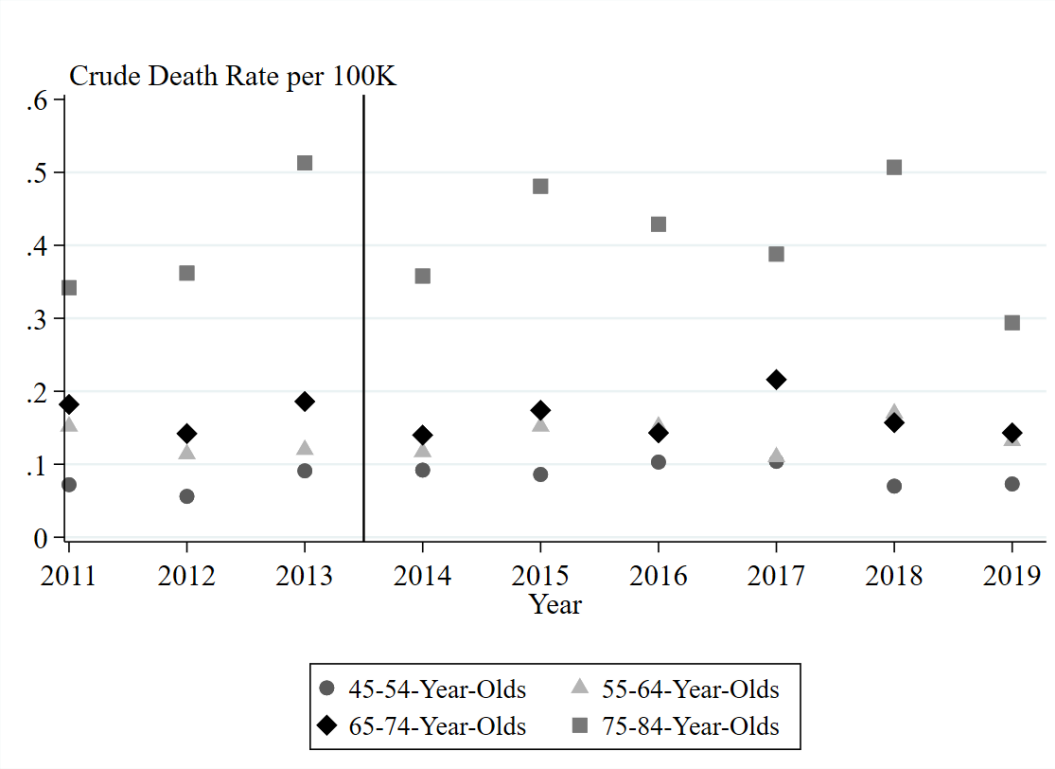
Source: National Health Interview Survey, 2011-2019
Note: The grey circles denote the share of each age reporting that they had received the pneumonia vaccine prior to when PCV13 (Prevnar 13) was recommended for those 65+. The black triangles in indicate the share of each age reporting that they had received the pneumonia vaccine after PCV13 was recommended for those 65+. The separate panels indicate whether the respondent had been diagnosed with a chronic condition. Panels A and B separate the sample based on whether the respondent had been diagnosed with cancer, Panels C and D by whether the respondent had been diagnosed with heart disease, Panels E and F by whether the respondent had been diagnosed with diabetes, Panels G and H by whether the respondent had been diagnosed with liver disease, and Panels I and J by whether the respondent had been diagnosed with emphysema.

Appendix Figure A10: Trends in Pneumococcal Vaccination, by Chronic Conditions.



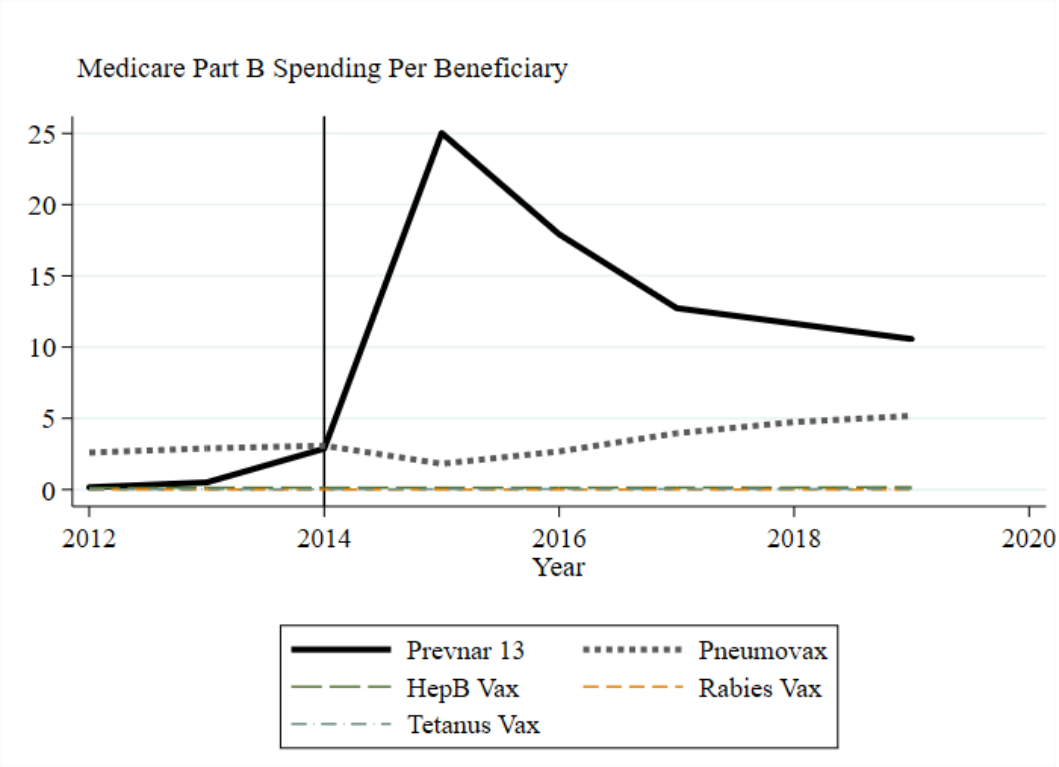
Source: National Health Interview Survey, 2011-2019
Note: In each panel, the grey circles denote the share of 60- to 64-year-old individuals and the black triangles indicate the share of 65- to 69-year-old individuals. Panel A measures the share reporting they saw a doctor during the prior 12 months, Panel B measures the share reporting they saw a doctor during the prior two weeks, Panel C measures the share reporting they received the influenza vaccine, and Panel D measures the share reporting they received the shingles vaccine. The sample in Panel D is limited to the period prior to the introduction of a new, more effective shingles vaccine that was recommended for adults aged 50 or older. In August 2014, PCV13 was recommended for people over 65.

Appendix Figure A11. Trends in Additional NHIS Outcomes Over Time.



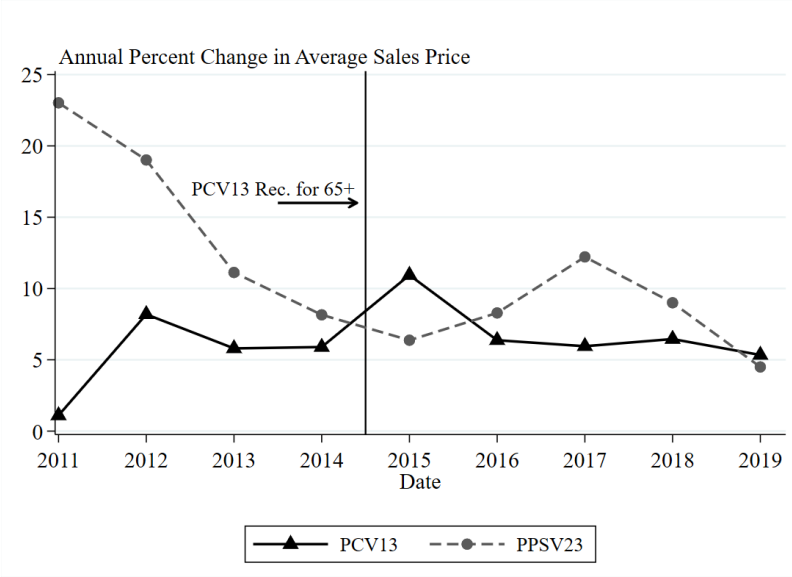
Source: CDC Wonder, 2011-2019
Notes: The figure plots the pneumonia-related crude death rate per 100,000 by age group.

Appendix Figure A12. Trends in Pneumonia-Related Mortality.

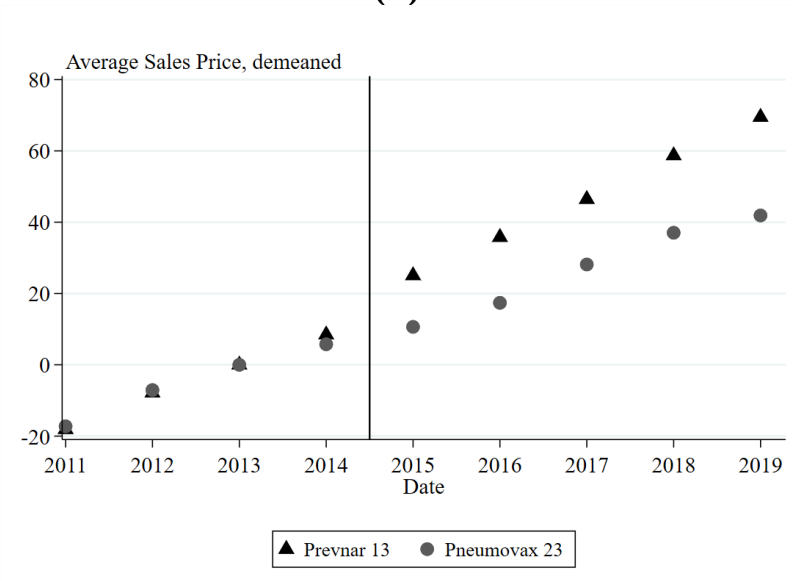


Source: Part B Summary Files, 2012-2019
Note: The figure examines the annual spending per beneficiary for covered vaccines among Medicare Part B Fee-For-Service beneficiaries.

Appendix Figure A13. Trends in Medicare Part B Payments.



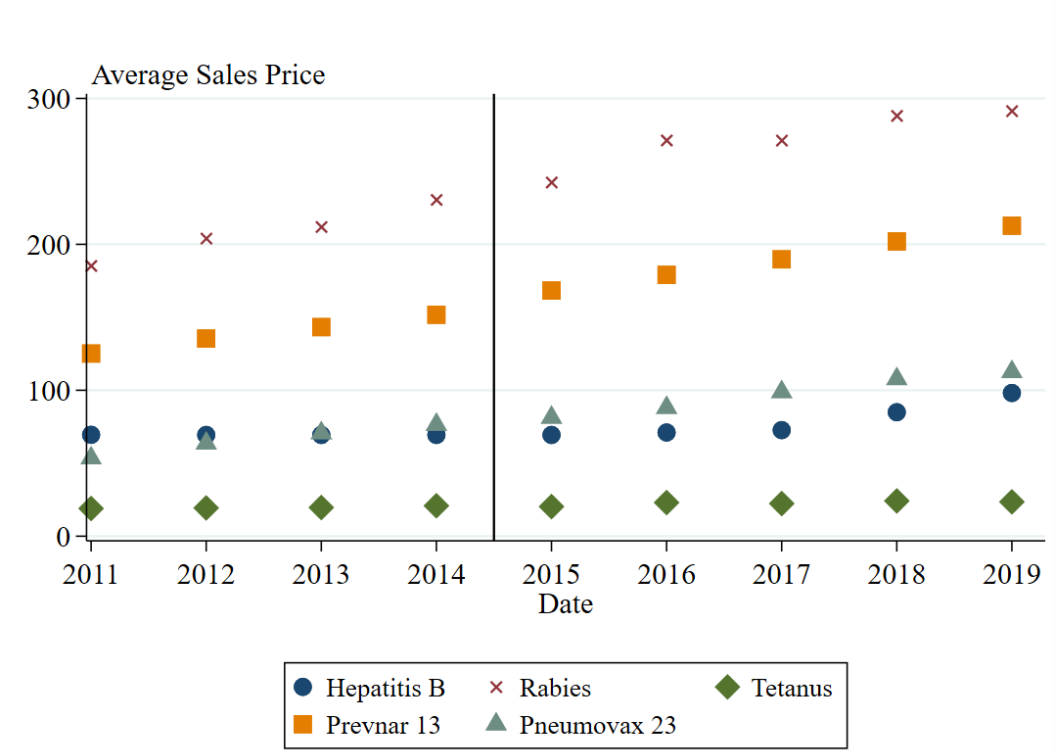
(A)



(B)

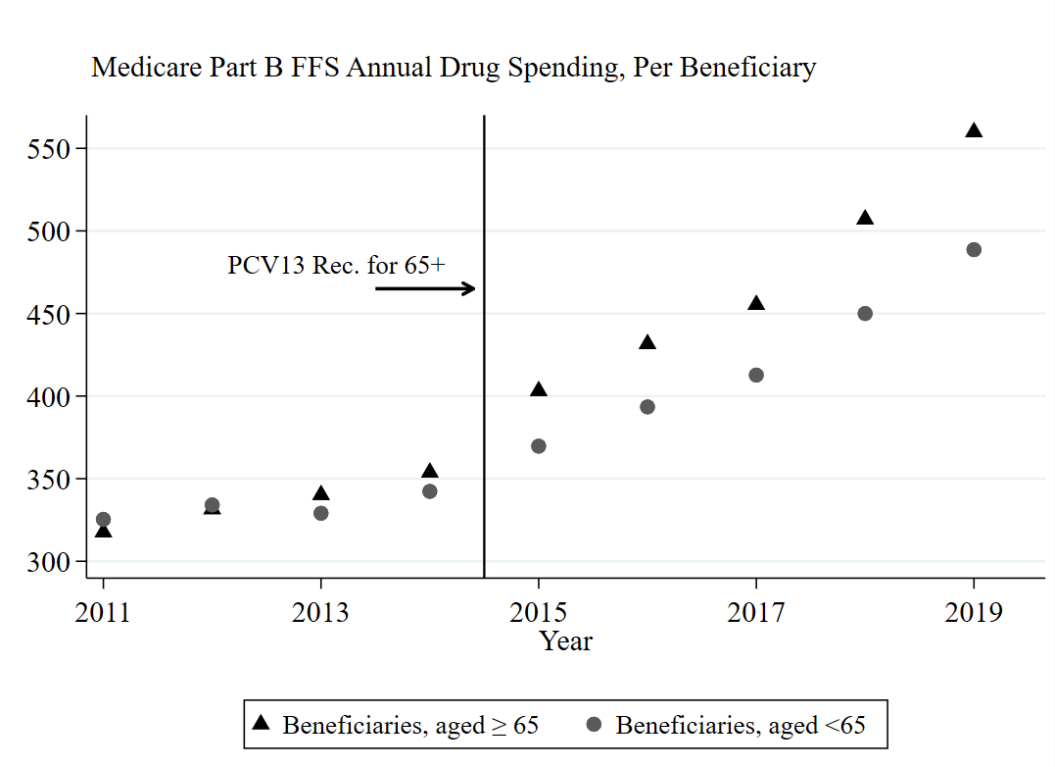
Source: Medicare Part B Average Sales Price Drug Pricing Files, 2011-2019
Note: Panel A plots the annual percent change in the average sale price of PCV13 (black triangles) and PPSV23 (grey circles) relative to the prior year. Panel B plots the demeaned sales price for PCV13 (black triangles) and PPSV23 (grey circles).

Appendix Figure A14. Trends in Medicare Part B Pneumococcal Vaccine Average Sale Price.



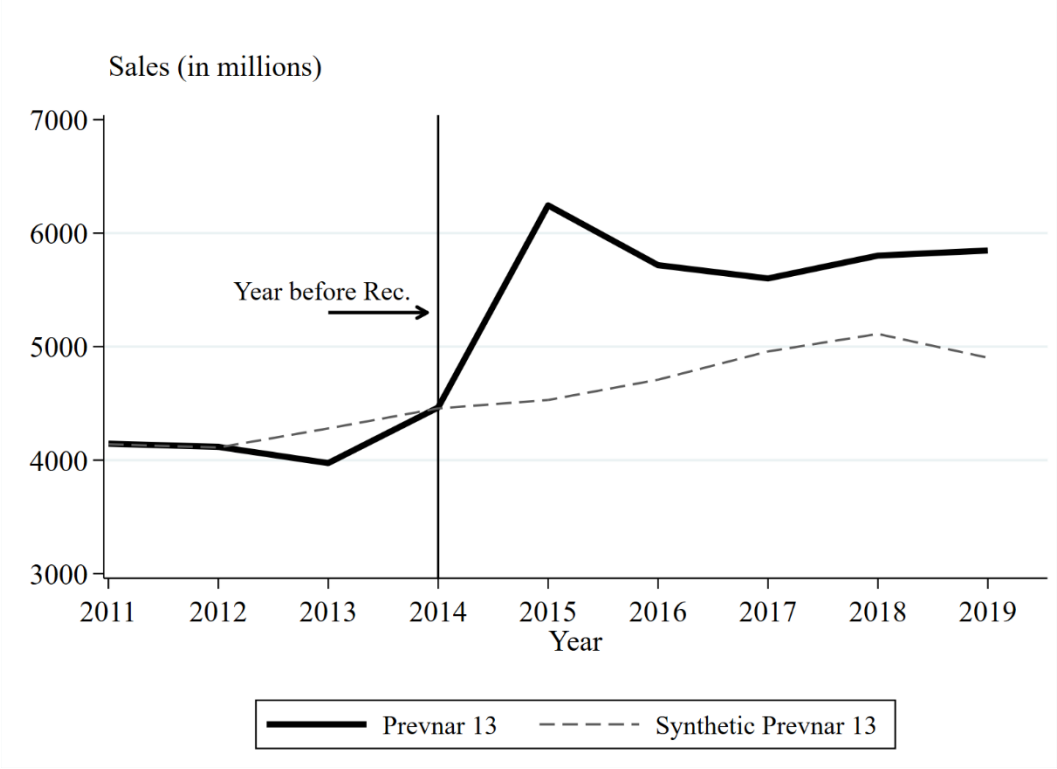
Source: Medicare Part B Average Sales Price Drug Pricing Files, 2011-2019
Note: The figure plots the average sales prices for the drugs used in our analyses.

Appendix Figure A15. Average Sales Price of Medicare Part B-Covered Vaccines Over Time.



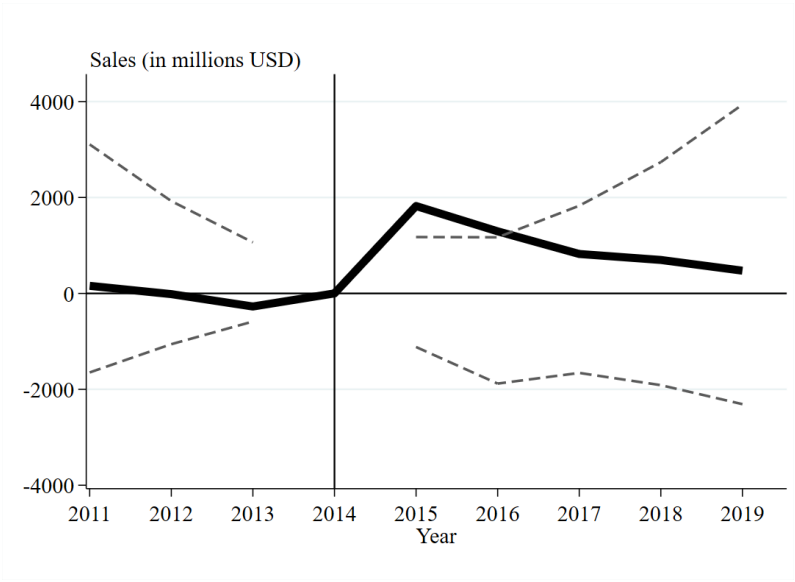
Source: Medicare Geographic Variation Public Use Files, 2011-2019
Note: The figure plots the annual per beneficiary Medicare Part B expenditure on drugs for Fee-For-Service beneficiaries aged 65 or older (black triangles) and under 65 (grey circles).

Appendix Figure A16. Trends in Medicare Part B Drug Spending.

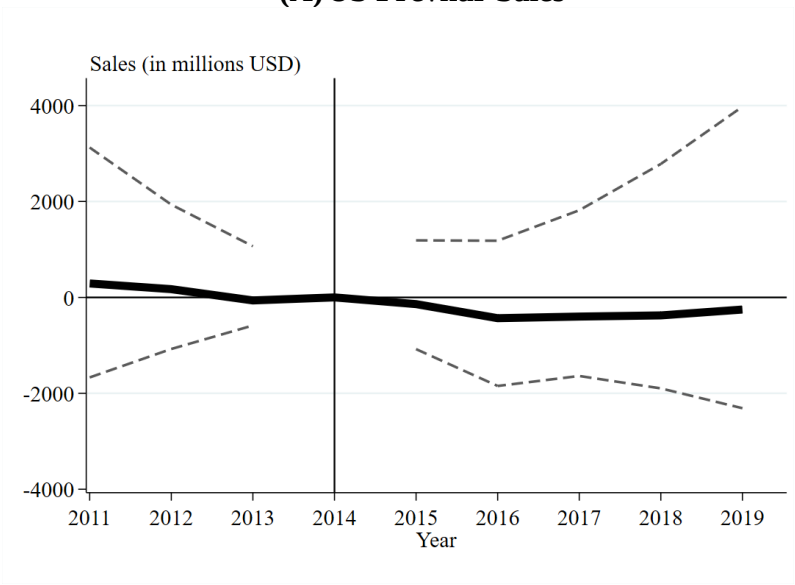


Source: Annual Reports, 2011-2019
Note: The solid black line plots annual sales for Prevnar 13. The grey dashed line plots annual sales for 'Synthetic Prevnar' which is constructed by determining the weighted average of placebo sales which best approximates sales for 'Prevnar' during the pre-period. Synthetic Prevnar is determined by matching on sales data in 2012 and 2014.

Appendix Figure A17: Dynamic Effects of ACIP's Recommendation on Prevnar Sales, Synthetic Control Approach.



(A) US Prevnar Sales



(B) International Prevnar Sales

Source: Annual Reports, 2011-2019
Note: Panels A and B plot the event study coefficients obtained from equation (4), and the dependent variable is annual pharmaceutical sales. Panel A uses US Prevnar sales and Panel B international Prevnar sales. The comparison pharmaceuticals are global sales. The independent variables are indicators for being *j* years away from ACIP recommending PCV13 for adults 65 or older. The solid black line plots the point estimates obtained from equation (4). The dashed gray lines plot the 95 percent placebo intervals generated from iteratively assuming each of the 47 comparison pharmaceuticals received ACIP's recommendation in August of 2014, estimating equation (4), and saving the placebo coefficients.

Appendix Figure A18: Dynamic Effects of Prevnar 13 Recommendation on US and International Prevnar Sales.

Appendix Table A1. Comparison group products and terms.

	(1)	(2)	(3)
Included in →	Ad$pender	Google Trends	Sales
Abilify	Y	Y	Y
Aciphex	Y	Y	
Actemra	Y	Y	
Aczone	Y	Y	
Advair	Y	Y	Y
Allegra	Y	Y	
Amitiza	Y	Y	
Ampyra	Y	Y	Y
Androgel	Y	Y	Y
Asclera	Y	Y	
Atelvia	Y	Y	
Auvi-Q	Y	Y	
Axiron	Y	Y	
Belviq	Y	Y	
Beyaz	Y	Y	
Boniva	Y	Y	
Botox	Y	Y	Y
Brovana	Y	Y	
Cialis	Y	Y	Y
Cimzia	Y	Y	Y
Crestor	Y	Y	Y
Cymbalta	Y	Y	Y
Daytrana	Y	Y	
Dexilant	Y	Y	
Diovan	Y	Y	Y
Dulera	Y	Y	Y
Eloric	Y	Y	
Epiduo	Y	Y	
Essure	Y	Y	
Evista	Y	Y	Y
Exelon Patch	Y	Y	Y
Flovent	Y	Y	Y
Flumist	Y	Y	Y
Fluzone	Y	Y	
Gardasil	Y	Y	Y
Gilenya	Y	Y	Y
Horizant	Y	Y	
Humalog	Y	Y	Y
Humira	Y	Y	Y
Incivek	Y	Y	Y
Intermezzo	Y	Y	
Intuniv	Y	Y	

Invega Sustenna	Y	Y	Y
Invokana	Y	Y	Y
Jalyn	Y	Y	Y
Januvia	Y	Y	Y
Juvederm	Y	Y	
Lantus	Y	Y	
Latisse	Y	Y	Y
3Levemir Flexpen	Y	Y	
Livalo	Y	Y	
Lo Loestrin	Y	Y	Y
Lovaza	Y	Y	Y
Lunesta	Y	Y	
Mirena	Y	Y	
Nasonex	Y	Y	Y
Nexium	Y	Y	Y
Nexplanon	Y	Y	Y
Niaspan	Y	Y	
Novolog	Y	Y	
Nuedexta	Y	Y	
Nuvaring	Y	Y	Y
Nuvigil	Y	Y	Y
Omnaris	Y	Y	
Onglyza	Y	Y	Y
Oracea	Y	Y	
Orencia	Y	Y	Y
Osphena	Y	Y	
Paragard	Y	Y	
Plavix	Y	Y	
Pradaxa	Y	Y	
Prolia	Y	Y	Y
Provenge	Y	Y	
Radiesse	Y	Y	
Rapaflo	Y	Y	
Reclast	Y	Y	
Restasis	Y	Y	Y
Sculptra Aesthetic	Y	Y	
Seasonique	Y	Y	
Seroquel	Y	Y	Y
Simponi	Y	Y	Y
Sklice	Y	Y	
Staxyn	Y	Y	
Stelara	Y	Y	Y
Strattera	Y	Y	Y
Suboxone	Y	Y	
Symbicort	Y	Y	Y

Synvisc One	Y	Y	
Tamiflu	Y	Y	
Tradjenta	Y	Y	
Ulesfia	Y	Y	
Vesicare	Y	Y	
Victoza	Y	Y	
Viibryd	Y	Y	
Vimovo	Y	Y	Y
Voltaren Gel	Y	Y	Y
Vyvanse	Y	Y	Y
Xarelto	Y	Y	Y
Xiaflex	Y	Y	Y
Zetia	Y	Y	Y

Appendix Table A2. NHIS summary statistics.

	(1)	(2)	(3)
	Full sample	Below recommended age	Above recommended age
Pneumococcal Vaccination	0.431	0.225	0.645
Health Insurance	0.935	0.880	0.994
Male	0.437	0.460	0.412
Educational Attainment			
Less than High School	0.148	0.120	0.178
High School Degree	0.278	0.265	0.291
Some College	0.288	0.310	0.266
College Degree	0.286	0.305	0.265
Race/Ethnicity			
White	0.727	0.693	0.762
Black	0.125	0.139	0.110
Hispanic	0.095	0.111	0.079
Asian	0.041	0.042	0.040
Other	0.012	0.014	0.010
Region			
Northeast	0.176	0.173	0.180
Midwest	0.221	0.219	0.224
South	0.362	0.364	0.359
West	0.241	0.245	0.237

Source: National Health Interview Survey, 2011-2019

Note: The summary statistics indicate the shares of the samples with each characteristic based on whether the adult was 65 or older.

Appendix Table A3. Estimated effects on monthly Prevnar advertising expenditures, by type.

	(1)	(2)	(3)	(4)	(5)
Outcome →	Total dollars (000s)	TV dollars (000s)	Print dollars (000s)	Internet dollars (000s)	Radio dollars (000s)
Panel A: Total Advertising					
1{Drug= Prevnar}×	8,146.8**	6,437.1**	1,632.9*	49.64	8.185
1{Rec. for Age ≥ 65}	(276.2)	(219.3)	(97.93)	(14.67)	(3.694)
	[0.03]	[0.02]	[0.09]	[0.67]	[0.18]
R^2	0.588	0.601	0.348	0.244	0.109
Mean for Prevnar in 2013	5.650	0	0	5.650	0
Observations	10,777	10,777	10,777	10,777	10,777
Panel B: National Advertising					
1{Drug= Prevnar}×	7,967.0**	6,379.1**	1,522.8*	47.58	1.905
1{Rec. for Age ≥ 65}	(264.4)	(212.1)	(91.41)	(14.26)	(1.901)
	[0.03]	[0.02]	[0.07]	[0.69]	[0.74]
R^2	0.590	0.601	0.354	0.240	0.0941
Mean for Prevnar in 2013	5.650	0	0	5.650	0
Observations	10,777	10,777	10,777	10,777	10,777
Panel C: Local Advertising					
1{Drug= Prevnar}×	179.8	58.00	110.0*	2.068	6.280*
1{Rec. for Age ≥ 65}	(41.62)	(13.78)	(35.95)	(0.683)	(3.198)
	[0.16]	[0.23]	[0.08]	[0.35]	[0.06]
R^2	0.226	0.217	0.192	0.204	0.114
Mean for Prevnar in 2013	0	0	0	0	0
Observations	10,777	10,777	10,777	10,777	10,777

Source: Ad$pender, 2011-2019

Note: The estimates are obtained using the difference-in-differences specification shown in equation (1), with the vector of indicator variables capturing calendar months relative to the recommendation adoption replaced with the single indicator, **1**{Rec. for Age ≥ 65}, which is equal to one in 9/2014 and all subsequent months and is zero otherwise. All specifications include a quadratic in product age (in months), and year-month and product fixed effects. Robust standard errors are shown in parentheses, and p-values obtained from β-randomization inference are in square brackets.

*** p < 0.01; ** p < 0.05; * p < 0.10.

Appendix Table A4. Estimated effects on total monthly Prevnar advertising expenditures, alternative control groups.

	(1)	(2)	(3)	(4)	(5)
Outcome →	Total Dollars (000s)	TV Dollars (000s)	Print Dollars (000s)	Internet Dollars (000s)	Radio Dollars (000s)
Panel A: Excluding drugs with generic entry					
1{Drug= Prevnar}×	6,600.4**	5,263.3**	1,242.1	20.88	52.73***
1{Rec. for Age ≥ 65}	(449.0)	(389.6)	(151.4)	(15.83)	(0.849)
	[0.021]	[0.021]	[0.104]	[0.792]	[0.000]
R^2	0.623	0.633	0.322	0.232	0.0671
Mean for Prevnar in 2013	5.658	0	0	5.658	0
Observations	6,183	6,183	6,183	6,183	6,183
Panel B: Excluding drugs with no advertising in 2012					
1{Drug= Prevnar}×	7,407.3*	5,904.0**	1,371.7	53.95	61.39**
1{Rec. for Age ≥ 65}	(368.0)	(296.9)	(122.3)	(17.85)	(4.796)
	[0.058]	[0.047]	[0.105]	[0.628]	[0.047]
R^2	0.531	0.547	0.297	0.206	0.0907
Mean for Prevnar in 2013	5.658	0	0	5.658	0
Observations	11,252	11,252	11,252	11,252	11,252
Panel C: Excluding drugs with generic entry or no advertising in 2012					
1{Drug= Prevnar}×	6,535.6**	5,174.0**	1,264.1	27.04	52.70***
1{Rec. for Age ≥ 65}	(503.9)	(436.2)	(167.7)	(17.80)	(0.995)
	[0.024]	[0.024]	[0.122]	[0.732]	[0.000]
R^2	0.630	0.643	0.325	0.231	0.0715
Mean for Prevnar in 2013	5.658	0	0	5.658	0
Observations	5,368	5,368	5,368	5,368	5,368

Source: Ad$pender, 2010-2020

Note: The estimates are obtained using the difference-in-differences specification shown in equation (1), with the vector of indicator variables capturing calendar months relative to the recommendation adoption replaced with the single indicator, **1**{Rec. for Age ≥ 65}, which is equal to one in 9/2014 and all subsequent months and is zero otherwise. The unit of observation is at the drug-month level, and outcome variable captures the total (national + local) advertising dollars in the media category listed in the column header. All specifications include a quadratic in product age (in months), and year-month and product fixed effects. Robust standard errors are shown in parentheses, and p-values obtained from β-randomization inference are in square brackets.

*** p < 0.01; ** p < 0.05; * p < 0.10.

Appendix Table A5. Effects of ACIP's Prevnar 13 recommendation on internet search behavior for 'Pneumovax' and 'Pneumonia'.

	(1)	(2)
Outcome →	Google Trends index for 'Pneumovax'	Google Trends index for 'Pneumonia'
1{Drug= Prevnar}×	25.338	18.006
1{Rec. for Age ≥ 65}	(9.427)	(2.086)
	[0.19]	[0.45]
R^2	0.577	0.575
Mean for Outcome in 2013	36.583	42.417
Observations	10,908	10,908

Source: Google Trends, 2011-2019

Note: The estimates are obtained using the difference-in-differences specification shown in equation (1), in which the vector of indicator variables capturing calendar quarters relative to the recommendation adoption is replaced with the single indicator, **1**{Rec. for Age ≥ 65}, which is equal to one in 9/2014 and all subsequent months and is zero otherwise. Column 1 includes a linear and quadratic in product age (in months). Both columns include year-month and search term fixed effects. Robust standard errors are shown in parentheses, and p-values obtained from β-randomization inference are in square brackets.

Appendix Table A6. Advertising expenditure and Prevnar-related information-seeking behavior.

	(1)	(2)
Advertising 3 Months Prior		0.0000
		(0.0002)
		[0.920]
Advertising 2 Months Prior		-0.0002
		(0.0003)
		[1.000]
Advertising 1 Month Prior		-0.0003
		(0.0003)
		[1.000]
Current Advertising	0.0013***	0.0011**
	(0.0002)	(0.0004)
	[0.000]	[0.020]
Advertising 1 Month Later		0.0004
		(0.0003)
		[0.210]
Advertising 2 Months Later		0.0005
		(0.0004)
		[0.100]
Advertising 3 Months Later		0.0000
		(0.0002)
		[0.850]
R^2	0.863	0.903
Mean in 2013	17.417	17.417
Observations	108	102

Source: Google Trends, 2011-2019; Ad$pender, 2011-2019

Note: The dependent variable is the Google Trends Index for the term 'Prevnar' in a given year-month. The independent variable of interest is the total spending on Prevnar 13 advertising in the same month (column 1) and with 3 leads/lags (column 2). The regression controls for time in year-months, an indicator for ACIP's August 2014 PCV13 recommendation, and the interaction of these terms. The regression also includes calendar month fixed effects. Robust standard errors are shown in parentheses. The brackets report p-values obtained from iteratively assuming the 100 comparison pharmaceuticals received the Prevnar 13 advertising, estimating the regression, and saving these placebo values. We then compare the Prevnar 13 coefficients to the distribution of these placebo coefficients.

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

Appendix Table A7. Effect of ACIP's Prevnar 13 recommendation on pneumococcal vaccination, by demographic group.

	(1)	(2)	(3)	(4)	(5)	(6)
Sample Restriction →	Health insurance	Male	Female	White	Black	Hispanic
1{Age ≥ 65}×	0.069***	0.077***	0.065***	0.057***	0.074***	0.065***
1{Rec. for Age ≥ 65}	(0.005)	(0.007)	(0.006)	(0.006)	(0.014)	(0.016)
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.002]
R^2	0.202	0.211	0.216	0.238	0.142	0.123
Observations	130,712	61,025	78,717	101,559	17,484	13,307
	(7)	(8)	(9)	(10)	(11)	(12)
Sample Restriction →	Asian	Other	Less than HS	HS graduate	Some college	College graduate
1{Age ≥ 65}×	0.057***	0.111	0.057***	0.060***	0.056***	0.072***
1{Rec. for Age ≥ 65}	(0.023)	(0.052)	(0.013)	(0.009)	(0.009)	(0.009)
	[0.001]	[0.144]	[0.000]	[0.000]	[0.000]	[0.000]
R^2	0.200	0.163	0.206	0.217	0.217	0.266
Observations	5,749	1,643	20,716	38,805	40,304	39,917

Source: National Health Interview Survey, 2011-2019

Note: The dependent variable is an indicator for reporting receipt of the pneumococcal vaccine. The independent variable of interest is an indicator for whether ACIP recommended the pneumococcal vaccine for adults aged 65 or older. The regression includes the full set of controls from equation (2). Each column restricts the sample to a specific group: column 1 limits the sample to those with health insurance, column 2 to men, column 3 to women, column 4 to white individuals, column 5 to Black individuals, column 6 to Hispanic individuals, column 7 to Asian individuals, and column 8 to those classified as 'other.' Similarly, column 9 limits the sample to those with less than a high school degree, column 10 to those with a high school degree, column 11 to those with some college education, and column 12 to those with a college degree. Robust standard errors are shown in parentheses, and wild bootstrapped p-values obtained after clustering standard errors at the age group-year level are reported in brackets.

*** p < 0.01; ** p < 0.05; * p < 0.10.

Appendix Table A8. Differential effects of ACIP's Prevnar 13 recommendation on pneumococcal vaccination, by demographic group.

	(1)	(2)	(3)
Group →	Male	White	College educated
1{Age ≥ 65}×	0.065***	0.073***	0.064***
1{Rec. for Age ≥ 65}	(0.006)	(0.009)	(0.006)
	[0.001]	[0.000]	[0.000]
1{Group = j} × **1**{Age ≥ 65}	0.012	-0.015	0.008
× **1**{Rec. for Age ≥ 65}	(0.010)	(0.011)	(0.011)
	[0.307]	[0.188]	[0.374]
R^2	0.216	0.222	0.219
Mean for Age ≥ 65 in 2013	0.593	0.593	0.593
Observations	139,742	139,742	139,742

Source: National Health Interview Survey, 2011-2019

Note: The dependent variable is an indicator for whether the respondent reported receiving the pneumococcal vaccine. The estimates are obtained using a modified version of the difference-in-differences specification shown in Table 2 column 2 whereby the right-hand side variables are fully interacted with an indicator for the group of interest shown in the column header. Column 1 interacts the right-hand side variables with an indicator for being male, column 2 for being white, and column 3 for being college educated. Robust standard errors are shown in parentheses, and wild bootstrapped p-values obtained after clustering standard errors at the group-year level are reported in brackets.

*** p < 0.01; ** p < 0.05; * p < 0.10.

Appendix Table A9. Effects of ACIP's PCV13 recommendation on pneumococcal take-up, by chronic condition.

	(1)	(2)	(3)	(4)	(5)
Condition →	Cancer	Heart Disease	Diabetes	Liver disease	Emphysema
1{Age ≥ 65}×	0.069***	0.074***	0.067***	0.064***	0.065***
1{Rec. for Age ≥ 65}	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
1{Age ≥ 65}×	0.011	-0.034*	0.004	0.004	-0.045
1{Rec. for Age ≥ 65} × **1**{Had Condition}	(0.014)	(0.019)	(0.014)	(0.041)	(0.029)
	[0.478]	[0.116]	[0.795]	[0.921]	[0.161]
R^2	0.222	0.227	0.241	0.215	0.220
Mean for Age ≥ 65 with Condition in 2013	0.699	0.707	0.665	0.667	0.793
Mean for Age ≥ 65 without Condition in 2013	0.561	0.573	0.572	0.592	0.584
Observations	139,616	139,354	135,969	122,481	122,655

Source: National Health Interview Survey, 2011-2019

Note: The dependent variable is an indicator for whether the respondent reported receiving the pneumococcal vaccine. The estimates are obtained using a modified version of the difference-in-differences specification shown in equation (1) whereby the righthand side variables are fully interacted with an indicator for the health condition shown in the column header. Column 1 examines differential effects by whether the respondent reported ever having cancer, column 2 heart disease, column 3 diabetes, column 4 liver disease, and column 5 emphysema. Robust standard errors are shown in parentheses, and wild bootstrapped p-values obtained after clustering standard errors at the age group-year level are reported in brackets.

*** p < 0.01; ** p < 0.05; * p < 0.10.

Appendix Table A10. Effect on pneumococcal vaccination, alternative age groups.

	(1)	(2)	(3)
Panel A: Aged 50-85+			
1{Age ≥ 65}×	0.060***	0.070***	0.056***
1{Rec. for Age ≥ 65}	(0.005)	(0.005)	(0.006)
	[0.000]	[0.000]	[0.001]
R^2	0.183	0.216	0.227
Mean for Age ≥ 65 in 2013	0.593	0.593	0.593
Observations	139,742	139,742	139,742
Panel B: Aged 60-69			
1{Age ≥ 65}×	0.077***	0.079***	0.068***
1{Rec. for Age ≥ 65}	(0.009)	(0.009)	(0.011)
	[0.000]	[0.000]	[0.000]
R^2	0.066	0.093	0.097
Mean for Age ≥ 65 in 2013	0.593	0.593	0.593
Observations	45,876	45,876	45,876
Panel C: Aged 63-66			
1{Age ≥ 65}×	0.050***	0.059***	0.053***
1{Rec. for Age ≥ 65}	(0.01)	(0.014)	(0.018)
	[0.001]	[0.000]	[0.000]
R^2	0.027	0.057	0.061
Mean for Age ≥ 65 in 2013	0.593	0.593	0.593
Observations	18,641	18,641	18,641
Covariates?		Y	Y
Survey Weights?			Y

Source: National Health Interview Survey, 2011-2019

Note: The dependent variable is an indicator for whether the respondent reported receiving the pneumococcal vaccine. The estimates are obtained using the difference-in-differences specification shown in equation (1). Column 1 utilizes a sparse framework including only indicators for being over the recommended age, being in the post-recommendation period, and the interaction of these terms. Column 2 includes indicators for each age (50-85 with 85+ omitted), race/ethnicity (white, Black, Hispanic, Asian with 'other' omitted), educational attainment (less than high school, high school degree, some college with college degree omitted), and health insurance coverage (insured with uninsured omitted). Column 2 also includes Census region-by-year-quarter fixed effects. Column 3 utilizes the survey weights. Panel A uses the full sample of adults aged 50-85+, Panel B a limited sample of adults aged 60-69, and Panel C the most limited sample of adults aged 63-66. Robust standard errors are shown in parentheses, and wild bootstrapped p-values obtained after clustering standard errors at the age group-year level are reported in brackets.

*** p < 0.01; ** p < 0.05; * p < 0.10.

Appendix Table A11. Effect of ACIP's Prevnar 13 recommendation on pneumococcal vaccination, BRFSS data.

	(1)	(2)	(3)
1{Age ≥ 65}×	0.027***	0.026***	0.026***
1{Recommended for Age ≥ 65}	(0.001)	(0.001)	(0.003)
	[0.000]	[0.000]	[0.000]
R^2	0.193	0.216	0.210
Mean	0.605	0.605	0.605
Observations	1,788,994	1,788,994	1,788,994
Covariates?		Y	Y
Survey Weights?			Y

Source: Behavioral Risk Factor Surveillance System, 2011-2019

Note: The dependent variable is an indicator for whether the respondent reported receiving the pneumococcal vaccine. The independent variable of interest indicates whether individuals were treated by ACIP's August 2014 PCV13 recommendation. Column 1 utilizes a sparse framework including only indicators for being over the recommended age, being in the post-recommendation period, and the interaction of these terms. Column 2 adds state fixed effects, year and month fixed effects, and indicators for each age group (50-54, 55-59, 60-64, 65-69, 70-74, 75-79 with 80+ omitted), race/ethnicity (white, Black, Hispanic, Asian with 'other' omitted), educational attainment (less than high school, high school degree, some college with college degree omitted), and sex (male with female omitted). Column 2 also fully interacts the age indicators with an indicator for whether the state had expanded Medicaid as part of the Affordable Care Act at the time of survey. Column 3 utilizes the survey weights. Robust standard errors are shown in parentheses, and wild bootstrapped p-values obtained after clustering standard errors at the age group-year level are reported in brackets.

*** p < 0.01; ** p < 0.05; * p < 0.10.

Appendix Table A12. Effect of ACIP's Prevnar 13 recommendation on incidence of pneumococcal disease and pneumonia-related mortality.

	(1)	(2)	(3)	(4)
Outcome →	IHS(incidence per 100K)	IHS(incidence per 100K)	IHS(incidence per 100K)	Pneumonia-related mortality per 100K
1{Age ≥ 65}×	0.013	-0.767***	0.018	-0.936
1{Rec. for Age ≥ 65}	(0.052)	(0.087)	(0.059)	(0.582)
	[0.772]	[0.002]	[0.741]	[0.226]
R^2	0.974	0.965	0.987	0.998
Mean for Age ≥ 65 in 2013	30.4	30.4	30.4	27.92
Observations	184	92	736	27
Age in Sample	All	65+	All	45-74
Disease in Sample	Pneumonia	All	All	Pneumonia
Age FE?	Y			
Year FE?	Y	Y		Y
Disease FE?		Y		Y
Age-by-Year FE?			Y	
Age-by-Disease FE?			Y	
Year-by-Disease FE?			Y	

Source: Active Bacterial Core Surveillance 1998-2019; CDC WONDER 2011-2019

Note: The dependent variable in columns 1-3 is the inverse hyperbolic sine of the disease incidence rate per 100,000. The estimates in column 1 are obtained using a difference-in-differences specification comparing changes in pneumococcal disease incidence for eight age groups (<1, 1 year old, 2-4 years old, 5-17 years old, 18-34 years old, 35-69 years old, 50-64 years old, and ≥ 65 years old) over time. Column 2 reports the difference-in-differences coefficient obtained by comparing changes in pneumococcal incidence for adults aged 65+ to the associated changes in three other diseases (Group A Streptococcus, Group B Streptococcus, and Haemophilus Influenzae) among this age group over time. Column 3 presents the triple-difference estimate obtained from including all four diseases and eight age groups in a single specification and including age-by-year, age-by-disease, and year-by-disease fixed effects. All columns control for the approval of PCV7 and PCV13 for children < 5 and adults aged 50 or older. Column 4 uses CDC WONDER mortality data and includes age group fixed effects (45-54, 55-64, with 65-74 omitted) and year fixed effects. Robust standard errors are shown in parentheses, and wild bootstrapped p-values obtained after clustering standard errors at the group-year level are reported in brackets.

*** p < 0.01; ** p < 0.05; * p < 0.10.

Appendix Table A13. Effect of ACIP's Prevnar 13 recommendation on average vaccine prices.

Outcome →	(1) Average Price of PCV13	(2) Average Price of PPSV23
1{Treated Group}×	38.189***	18.991***
1{PCV13 Rec.}	(2.363)	(2.997)
	[0.000]	[0.000]
R^2	0.974	0.972
Mean for Treated group in 2013	143.30	70.71
Observations	290	290
Time Fixed Effects?	Y	Y
Product Fixed Effects?	Y	Y

Source: Medicare Part B Average Sales Price, 2011-2019

Note: The dependent variable in column 1 is the average price of PCV13 and in column 2 the average price of PPSV23. The columns compare changes in outcomes for PCV13 and PPSV23 to the concurrent changes in outcomes of other vaccines covered by Medicare Part B (hepatitis B, rabies, and tetanus). These columns include year fixed effects and product fixed effects. Robust standard errors are shown in parentheses and wild bootstrapped p-values obtained after clustering standard errors at the group-year level are reported in brackets.

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.