THE ROLES OF COST AND RECOMMENDATIONS IN DRIVING VACCINE TAKE-UP

Evidence from the Herpes Zoster Vaccine for Shingles Prevention

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ABSTRACT

Vaccination has been called one of the greatest public health success stories, yet little is known about how to successfully increase adult vaccination rates. Analyzing shingles vaccination, we show that 60-year-olds—who were recommended by the Advisory Committee on Immunization Practices to receive the vaccine—were no more likely to be vaccinated than their 59-year-old counterparts prior to the Affordable Care Act. After the ACA's preventive services provision required private insurance plans to cover recommended vaccines without patient cost-sharing, adults aged 60 or older were more likely to receive the vaccine, and we document a similar increase for 50- to 59-year-olds after the recommendation age was lowered to 50. Because shingles is not a communicable disease, the benefits of vaccination are largely internalized. After accounting for the $6,000 medical and productivity savings associated with preventing a shingles episode, back-of-the-envelope calculations imply adults would have to price the leisure costs at $22,000 per episode for the coverage increase to have been welfare neutral.

KEYWORDS: immunization, shingles, ACA, aging
JEL CLASSIFICATION: I12, I18

I. Introduction

Vaccination has been called one of the greatest public health success stories, and throughout the 20th century rising vaccination rates contributed to dramatic reductions in the incidence and burden of vaccine-preventable diseases (CDC 2020a). Recognizing the disconnect between the private and social benefits of vaccination, policy makers have adopted a variety of strategies to increase and keep coverage rates at socially optimal levels. Within the United States, this has included requiring vaccination for school attendance and funding vaccines for children whose families would otherwise be unable to afford them. While there is a sizable

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literature analyzing the efficacy of these youth-targeted initiatives (Abrevaya and Mulligan 2011; Lawler 2017, 2020; Carpenter and Lawler 2019), less is known about how to increase adult vaccination rates—a fact that has been highlighted by the COVID-19 pandemic.

In this paper, we provide novel evidence on how patient costs and age-targeted vaccine recommendations by the Centers for Disease Control and Prevention's Advisory Committee on Immunization Practices (ACIP), a federal panel of immunization experts, affected adult take-up of the herpes zoster vaccine live (ZVL).[1] This vaccine provides protection against shingles—a viral infection causing a painful rash with fluid-filled blisters that affects over 1 million individuals in the United States each year (Mayo Clinic 2020; CDC 2021a). Approximately one in three people in the US develops shingles during their lifetime (Harbecke, Cohen, and Oxman 2021), and 10–20 percent of people with shingles (depending on age) will experience postherpetic neuralgia—a nerve pain persisting for weeks or even years after the blisters have subsided without any known effective disease-modifying therapy (Thomas and Hall 2004; Johnson and Rice 2014; Forbes et al. 2016). Postherpetic neuralgia can interfere with sleep, activities of daily living, and productivity, and can result in loss of independent living (Cohen 2013). While there has been an effective shingles vaccine approved for adults since 2006, as of 2019 only 38 percent adults aged 60 or older in the National Health Interview Survey (NHIS) had received the vaccine.

Between 2006 and 2017, ACIP recommended routine use of ZVL for adults aged 60 or older, though with a list price between $160 to $195 per dose the vaccine was over 10 times more expensive than a seasonal flu vaccine (Chen 2010). After the preventive services provision of the Affordable Care Act (ACA) was implemented in September 2010, ACIP's recommendation meant that adults aged 60 or older with private health insurance plans became eligible to receive the vaccine without patient cost-sharing, and Figure 1 shows a larger increase in coverage for 60-year-olds than for 59-year-olds coincident with the ACA. After ACIP lowered the recommended age to 50—newly requiring that the vaccine be available at no cost to adults aged 50 to 59 with private health insurance—coverage jumped among 59-year-olds.[2] Similarly, the gray circles in Figure 2, panel A, show that the likelihood of receiving the shingles vaccine varied smoothly through the recommendation threshold prior to the ACA. After the preventive services provision was implemented, the black triangles show a jump in vaccination at age 60.

Using data from 2008–19 NHIS, we test the relationship between vaccine recommendations and take-up using a regression discontinuity identification strategy where the counterfactual for those aged 60 or older is those just below the recommendation age after accounting for a smooth trend. To explore the role of cost in driving vaccine take-up, our primary

1 From 2006 to 2017, ZVL—sold under the trade name Zostavax—was the only shingles vaccine. In October 2017, the Food and Drug Administration approved the first recombinant zoster vaccine (RZV), which is sold under the trade name Shingrix. For narrative purposes, we broadly refer to these vaccines as "shingles vaccines," except where the distinction in type is important.

2 ACIP lowered the recommended age for routine vaccination to 50 on October 25, 2017. New recommendations are required to be covered in the plan year that begins on or exactly one year after the recommendation's issue date (KFF 2021).

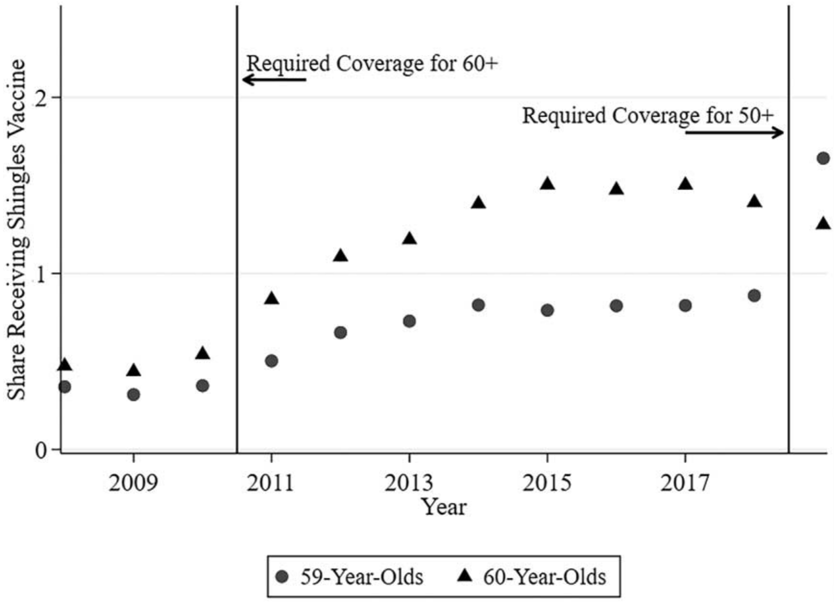

FIGURE 1. Shingles vaccination increased when insurance was required to cover the vaccine without patient cost-sharing. The gray circles plot the share of 59-year-olds who report receiving the shingles vaccine over time. The black triangles plot the share of 60-year-olds who report receiving the vaccine. The vaccine was required to be covered without patient cost-sharing for those 60 or older beginning in 2011, while the vaccine was required to be covered for all those 50 or older beginning in 2019. Source: National Health Interview Survey 2008–19.

specification is a difference-in-differences identification strategy comparing changes for those aged 60–61 with those aged 50–59 following the ACA's preventive services provision entitling privately insured adults aged 60 or older to receive the vaccine without patient cost-sharing. Using this same difference-in-differences design, we also exploit ACIP's decision to lower the recommended age for shingles vaccination to age 50 by comparing vaccination among adults aged 50 to 59 with those adults aged 60 to 61 who were already entitled to receive the vaccine without cost-sharing.

We document several key findings: First, we do not find any evidence that 60-year-olds—who were recommended to receive the shingles vaccine—were more likely than their 59-year-old counterparts to be vaccinated prior to the ACA. After the ACA preventive services provision went into place, we find that shingles vaccination increased by 3.1–5.9 percentage points. While we cannot isolate whether this increase was attributable to the price reduction or potentially to behavioral changes on the part of physicians recommending the vaccine, these patterns indicate that age-targeted recommendations on their own were not enough to drive take-up of the shingles vaccine. We then show that the ACA-attributable increase

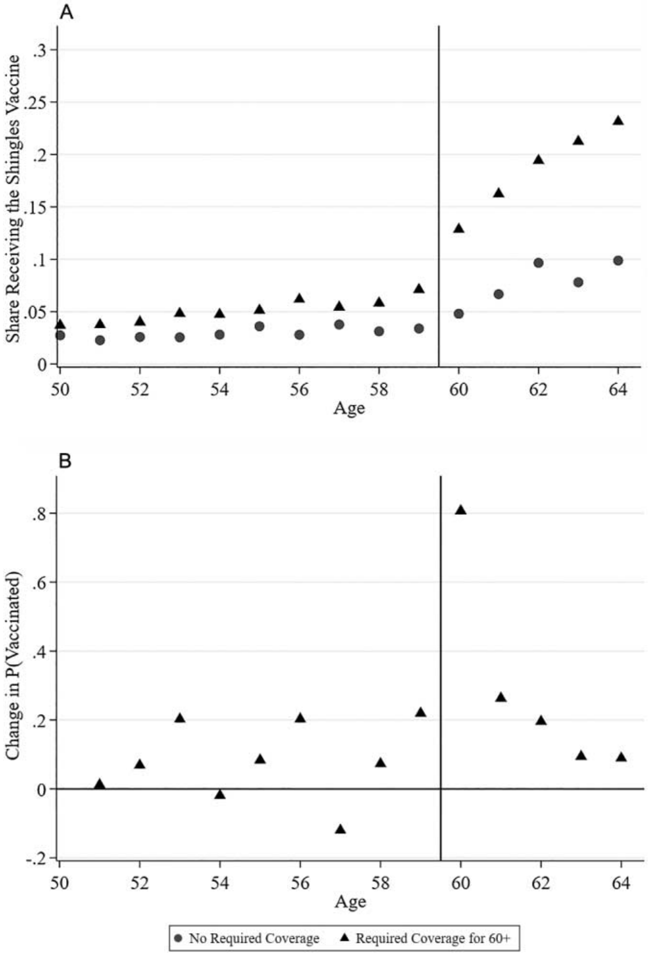

FIGURE 2. The discontinuity in vaccination appeared only after insurance became required to cover the vaccine for adults 60 or older without patient cost-sharing. The gray circles in panel A denote the share of each age reporting that they had received the shingles vaccine during the study period in which individuals 60+ were recommended to receive the vaccine but it was not yet required to be covered by health insurance (Q1 2008 to Q3 2010). The black triangles denote the share when it was recommended for those 60+ and it was required to be covered by health insurance but prior to when the second, more effective vaccine (RSV) was approved (Q4 2010 to Q2 2017). Panel B indicates the difference in the probability of receiving the vaccine at age $A + 1$ compared with the probability of receiving the vaccine at age A during the period when the vaccine was recommended for those 60+ and it was required to be covered by private health insurance. Source: National Health Interview Survey 2008–17.

was driven by those with health insurance and a greater connection to the health-care system. After accounting for the $6,000 medical and productivity savings associated with preventing a shingles episode (McLaughlin et al. 2015; Ozawa et al. 2016), back-of-the-envelope calculations imply that adults would have to price the leisure costs of shingles at $22,000 per episode for the coverage increase to have been welfare neutral. The required leisure valuation is nearly four times larger than the medical and productivity costs in part because shingles is not a communicable disease. As such, the benefits of vaccination are largely internalized by the patient, thereby limiting the market failure. Government policies promoting vaccination against communicable diseases, such as influenza and COVID-19, may be those most likely to achieve welfare gains.

This paper contributes to several strands of literature. By providing the first quasi-experimental estimates on how prices affect adult vaccine take-up, we add to a broader literature that has shown that patients respond to changes in health-care prices (Keeler and Rolph 1988; Newhouse and the Insurance Experiment Group 1993; Chandra, Gruber, and McKnight 2010; Finkelstein et al. 2012; Nilsson and Paul 2018; Han, Lien, and Yang 2020). We also build on prior work studying how ACIP's age-targeted vaccine recommendations affected child and adolescent coverage rates (Lawler 2017, 2020), as well as a broader literature on the determinants of vaccination (Abrevaya and Mulligan 2011; Bradford and Mandich 2015; Ward 2014; Walsh, Doherty, and O'Neill 2016; Oster 2018; Carpenter and Lawler 2019; Wen 2020; White 2021). Notably, we improve on prior work by disentangling the importance of recommendations and patient costs in driving coverage rates, and our estimates are likely of special interest to policy makers looking to increase adult vaccine take-up.

The rest of the paper proceeds as follows: Section II describes the institutional background regarding which age groups were eligible and recommended to receive the shingles vaccine each year. It then summarizes the literature on methods to improve vaccine take-up, especially with regards to adult vaccination. Section III explains the NHIS data that we use throughout the analysis, as well as our complementary regression discontinuity and difference-in-differences empirical strategies. Section IV reports the results, and Section V summarizes their policy implications and suggests areas for future work.

II. Background and Literature

A. CLINICAL AND POLICY HISTORY

Figure 3 presents a timeline of the relevant policy changes regarding vaccine approval, vaccine recommendations, and patient cost-sharing. Zoster vaccine live (ZVL), produced by Merck under the trade name Zostavax, was approved by the Food and Drug Administration (FDA) for patients ages 60 or older in 2006 (Mitka 2006), and ACIP began recommending routine vaccination for these individuals that same year (CDC 2006). The FDA then approved ZVL for adults aged 50–59 in 2011 (FDA 2011), though ACIP twice decided against lowering the recommended age—once in 2011 (CDC 2011) and again in 2013 (CDC 2014). While ZVL was found to be effective at reducing the risk for developing shingles in adults aged 50–59, ACIP cited limited data on the long-term protection afforded by the vaccine

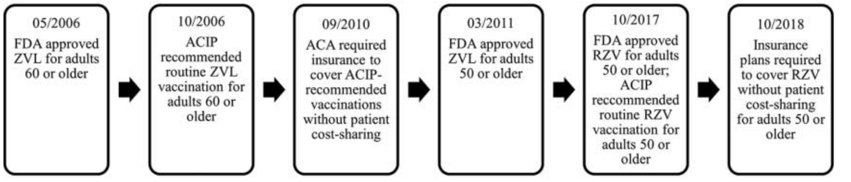

FIGURE 3. Timeline of relevant policy dates

and supply chain issues when deciding not to lower the recommended age for vaccination. Specifically, Merck was experiencing production shortfalls and prioritizing production of the chickenpox vaccines for children (CDC 2011).

In October 2017, the FDA approved the first recombinant zoster vaccine (RZV), produced by GlaxoSmithKline under the trade name Shingrix, for adults aged 50 or older (CDC 2018). RZV provides greater protection than ZVL (CDC 2020b, 2021b).[3] Further, the licensing of RZV expanded the population of who could be vaccinated against shingles to people with immunocompromising conditions and people for whom the live vaccine (ZVL) requirement to be stored at freezing temperatures challenged access (Harbecke, Cohen, and Oxman 2021).[4] Five days after RZV was approved by the FDA, ACIP began recommending routine RZV vaccination for adults 50 or older, including for adults who had previously received ZVL (CDC 2018). There was a nationwide shortage of RZV from approval in fall 2017 to 2019, however, and clinicians were advised to prioritize older patients who were immunocompromised for vaccination (Dawson 2019; Hetherly 2019). Merck discontinued Zostavax in 2020 (Merck 2020). Currently, adults aged 50 or older are recommended to receive two doses of RZV, and each dose costs approximately $200.

While the price of the shingles vaccine is considerably higher than that of other vaccines, the ACA requires private health insurance plans to cover recommended preventive services without cost-sharing. For vaccines, these recommendations are made by ACIP. So, when the preventive services provision became effective on September 23, 2010, private health insurance plans became required to cover the shingles vaccine for adults 60 or older.[5] The provision requires that plans begin covering newly recommended vaccines by one year after the

3 ZVL reduced the risk of shingles by 51 percent. RZV—which is a two-dose series—reduces the risk by 90 percent (CDC 2020b, 2021b).

4 While ZVL is contraindicated in immunocompromised patients, it has been administered to many immunocompromised adults with few serious adverse events. Clinical trials for RZV, however, did include immunocompromised individuals and was deemed safe in this population (Harbecke, Cohen, and Oxman 2021).

5 While some plans were grandfathered and thus exempt from the preventive services provision, we do not expect that having a grandfathered plan would differ by our narrow age groups of treatment and comparison cohorts, described in the empirical strategy below. In 2011, the year following enactment of the ACA, 56 percent of workers at firms offering health benefits were enrolled in grandfathered plans (KFF 2011). In 2018, this rate was 16 percent (KFF 2018).

ACIP recommendation date (Department of the Treasury, Department of Labor, and Department of Health and Human Services 2015), so new insurance plans became required to cover the vaccine for adults 50 or older without cost-sharing starting October 25, 2018, with the overwhelming majority of new plans beginning on January 1, 2019.[6] Relatedly, states that opted to expand Medicaid to nonelderly adults with incomes at or below 138 percent of the federal poverty level must offer preventive services without cost-sharing to these enrollees. States that opted not to expand Medicaid but do cover all US Preventive Services Task Force Grade A or B services and ACIP-recommended vaccines without cost-sharing receive a 1 percentage point increase in the federal medical assistance percentage for those services.[7] Medicare Part B does not cover the shingles vaccine, though Medicare Part D plans may cover these vaccines with patient cost-sharing (Gates, Ranji, and Snyder 2014; ASPE 2022).

B. EXISTING LITERATURE

Given the social benefits associated with widespread vaccination, policy makers have experimented with a myriad of policies intended to increase vaccine take-up, especially among children and adolescents. Perhaps most well-known are policies requiring children to receive certain vaccinations as a condition for school attendance; these policies have been linked to increased take-up of the varicella (Abrevaya and Mulligan 2011), Tdap (Carpenter and Lawler 2019), and human papillomavirus (Churchill 2021) vaccines. Policy makers have also successfully used nonbinding age-targeted vaccine recommendations to increase hepatitis A vaccination in children (Lawler 2017) and meningococcal vaccination in adolescents (Lawler 2020). In contrast, less is known about how to increase adult vaccination rates. While several recent papers have shown the effectiveness of adult-targeted vaccine mandates, these have largely been limited to health-care settings (Wen 2020; Carrera, Lawler, and White 2021; White 2021). Exploiting a policy in the United Kingdom prioritizing influenza vaccination for those aged 65 or older, Anderson, Dobkin, and Gorry (2020) documented an approximate 20 percentage point increase in the likelihood of receiving the flu vaccine for adults above the age cutoff.

There is mixed evidence on whether lowering the cost of vaccines increases vaccine take-up. Walsh, Doherty, and O'Neill (2016) found that racial and ethnic coverage disparities shrank coincident with the introduction of the Vaccines for Children Program, which provides free vaccinations to uninsured children, and Ward (2014) showed that the Ontario Universal Influenza Immunization Campaign—which recommended and subsidized the influenza vaccine for all ages—reduced influenza-pneumonia hospital admissions. Leveraging spatial and temporal variation in state requirements that private health insurers cover childhood vaccinations, Chang (2015) documented an increase in the share of

6 According to Paul Fronstin, the director of health research at the Employee Benefit Research Institute, it is most common for employer-sponsored plans to start on January 1 because of the fall open enrollment period (Marketplace 2017). Private insurance plans purchased during the traditional HealthCare.gov open enrollment period start on January 1 (KFF 2021).

7 Granade et al. (2020) found that 33 of 49 fee-for-service plans covered the herpes zoster vaccine without cost-sharing.

children up to date with their 4:3:1 vaccine series.[8] Analyzing young adult women, Lipton and Decker (2015) found that the combination of the ACA preventive services and dependent coverage provisions increased human papillomavirus vaccination. Yet Mulligan et al. (2018) did not find evidence that state policies purchasing and distributing vaccines free of charge to vaccine providers increased vaccine take-up, and a field experiment in Ecuador by Hoffman, Mosquera, and Chadi (2019)found that offering a discount for the influenza vaccine did not affect vaccine take-up.[9] Similarly, Chang et al. (2021)used a randomized controlled experiment to examine effects of $10 or $50 financial incentives on COVID-19 vaccination. They found no effects on vaccine up-take among a sample of Medicaid managed care beneficiaries, though notably these results may be less generalizable to other vaccines given the fact that the political dialogue surrounding COVID vaccination has been different than that of other vaccines.

III. Data and Methodology

A. VACCINATION DATA: NATIONAL HEALTH INTERVIEW SURVEYS

We obtain data on shingles vaccination from the 2008–19 NHIS.[10] The NHIS are continually operating cross-sectional household surveys monitoring health behaviors and outcomes of the noninstitutionalized civilian US population. Interviews are conducted face to face and contain detailed information on demographic and socioeconomic characteristics. These data have been widely used within the economics literature to analyze various determinants of health, including health insurance eligibility (Currie and Gruber 1996; Miller 2012; Lipton and Decker 2015), income (Snyder and Evans 2006; Cawley, Moran, and Simon 2010), tobacco use (Pesko, Courtemanche, and Maclean 2020), and alcohol consumption (Carpenter and Dobkin 2009).

We construct an indicator variable for whether the respondent reported ever receiving the shingles vaccine from the following question:

8 The 4:3:1 series indicates that a child has received four doses of DTaP (to protect against diphtheria, tetanus, and pertussis), three doses of the polio vaccine, and one dose of the MMR vaccine (to protect against measles, mumps, and rubella).

9 Hoffman, Mosquera, and Chadi (2019) found that assigning employees to get vaccinated during the workweek—when they were permitted to take time off to receive the vaccine—increased take-up by 112 percent compared with those assigned to receive the vaccine on Saturday.

10 While the 2008–18 NHIS data used the same questionnaire design, in 2019 the questionnaire was redesigned to improve measurement and reduce the burden on respondents. In 2018, the NHIS question of interest stated, "Shingles is an illness that results in a rash or blisters on the skin and is usually painful. There are two vaccines now available for shingles: Zostavax®, which requires 1 shot, and Shingrix®, a new vaccine which requires 2 shots. Have you had a vaccine for shingles?" In 2019, the question was "Have you had a vaccine for shingles?" and the interviewer was prompted to only read the explanation about the shingles vaccine if necessary. While it seems unlikely that this change would differentially affect individuals based on whether they were 60 or older, we test the robustness of our estimates to excluding the 2019 data.

> "Shingles is an outbreak of a rash or blisters on the skin that may be associated with severe pain. The pain is generally on one side of the body or face. Shingles is caused by the chickenpox virus. A vaccine for shingles has been available since May 2006. Have you ever had the Zoster (ZOSS-ter) or Shingles vaccine, also called Zostavax®?"

Figure 1 plots shingles vaccination rates for two comparable groups: 60-year-olds and 59-year-olds.[11] These groups had similar vaccination rates prior to the ACA, even though the vaccine was approved and recommended only for those 60 or older. However, in 2011 the shingles vaccine was newly approved for adults aged 50–59, and the ACA began requiring private insurance plans to offer the vaccine free of charge to those 60 or older. While vaccination increased slightly for 59-year-old adults coinciding with expanded FDA approval, there was a disproportionate increase for 60-year-old adults who were now entitled to receive the vaccine without patient cost-sharing. Though ACIP lowered the recommended age to 50 in October 2017, there was no visual change in vaccination for 59-year-old adults until they became entitled to receive the vaccine without cost-sharing the following year.

B. EMPIRICAL STRATEGY: DIFFERENCE-IN-DIFFERENCES AND REGRESSION DISCONTINUITY

We first empirically test how mandated coverage without cost-sharing affected take-up of the shingles vaccine using the following difference-in-differences specification:

$$\begin{aligned} \mathrm{VACC}_{iart} = {} & \alpha + \beta \cdot \text{REQUIRED COVERAGE FOR SHINGLES VACCINE}_{at} \\ & + \mathrm{X}_{iart}'\gamma + \theta_a + \tau_t + \varepsilon_{iart} \end{aligned} \quad (1),$$

where VACC is an indicator for whether adult i age a in region r during year-quarter t reported ever receiving the shingles vaccine. The independent variable of interest, REQUIRED COVERAGE FOR SHINGLES VACCINE, is an indicator for whether the respondent was entitled to receive the shingles vaccine without cost-sharing. Thus, it takes on the value of 1 for those 60 or older starting in Q4 of 2010 and for those aged 50 or older beginning in 2019.[12] Because the policy change requiring insurance to cover the shingles vaccine without patient cost-sharing did not occur concurrently with FDA approval or

11 Online Appendix Figure 1 more granularly plots the vaccination rate at the year-quarter level. Again, we see a jump in vaccination concurrent with individuals becoming entitled to receive the shingles vaccine without patient cost-sharing.

12 We define treatment as the first full quarter during which individuals were eligible to receive the shingles vaccine without cost-sharing. Because the ACA was implemented on September 23, 2010 (Q3 of 2010), we classify adults 60 or older as treated starting in Q4 of 2010. Similarly, because ACIP recommended that adults 50 or older receive the vaccine on October 25, 2017 (Q4 of 2017)—and new recommendations are required to be covered for plans beginning one year after the recommendation date—we classify 50- to 59-year-olds as treated starting in Q1 of 2019. Our results are robust to instead defining treatment at Q3 of 2010 and Q4 of 2018.

ACIP's recommendation, this indicator identifies the relationship between shingles vaccination and the cost of the vaccine.[13] To reduce the possibility that our estimates are contaminated by retirement-related changes in health behaviors and outcomes (Coe and Zamarro 2011; Shoven and Slavov 2014; Hallberg, Johansson, and Josephson 2015; Bloeman, Hochguertel, and Zweerink 2017; Fitzpatrick and Moore 2018), we limit our sample to adults aged 50–61 years.[14]

The vector X includes indicators for race/ethnicity (white, black, Hispanic, and Asian, with "other" omitted), educational attainment (less than high school, high school degree, and some college, with college graduate omitted), health insurance status (covered, with no coverage omitted), and four census region fixed effects to account for time-invariant location-specific attitudes toward vaccination. The vector θ includes indicators for each age (50–60, with 61 omitted as the reference group). Similarly, the vector τ includes year-quarter fixed effects to account for location-invariant secular changes in vaccine take-up. Standard errors are clustered at the treatment age group-year-quarter level (Abadie et al. 2017), and for inference we report wild bootstrapped p-values (Cameron, Gelbach, and Miller 2008; Cameron and Miller 2015).[15]

The coefficient of interest, β, measures the unique change in vaccination among adults newly eligible to receive the vaccine without cost-sharing compared with those not experiencing a policy change. Our identifying assumption is that after including the covariates and fixed effects, vaccine take-up among the treated and comparison groups have evolved similarly in absence of the policy change. We assess the validity of this assumption using the following dynamic event study specification:

$$\mathrm{VACC}_{iart} = \alpha + \sum_{j=-44,\ j\neq-1}^{36} \beta^j \cdot Q^j{}_{iat} + \mathrm{X}_{iart}'\gamma + \theta_r + \tau_t + \varepsilon_{iart} \qquad (2),$$

where the independent variables of interest, Q, are indicators for respondent i being j quarters away from becoming eligible to receive the shingles vaccine free of charge due to the ACA.[16] This specification allows us to test the descriptive patterns in Figure 1 showing that

13 Adults aged 60 or older were always approved and recommended to receive the shingles vaccine. They became entitled to receive the vaccine without patient cost-sharing in September 2011. Adults aged 50–59 years were approved to receive the vaccine starting in March 2011 and were recommended to receive the vaccine starting in October 2017. This latter group became entitled to receive the vaccine without cost-sharing beginning in January 2019.

14 We otherwise include all other adults whose observation includes data on shingles vaccination, age, race/ethnicity, educational attainment, and health insurance coverage. In heterogeneity exercises, we explore whether the results varied along these dimensions.

15 In this context, treatment age group is an indicator for whether the individual is aged 60 or older. The conclusions are unchanged if we instead cluster at the treatment age group-year level or simply at the age level.

16 We estimate the full set of event study coefficients, but we only report the coefficients estimated within a balanced event window to ensure that our estimates are not driven by a change in which groups contribute to identification. Because we only observe individuals treated in 2010 starting in 2008, we have at most 11 pre-periods in a balanced window. Similarly, because our sample ends in 2019, we have at most 4 balanced post-periods.

treated individuals were not experiencing a differential pre-trend in vaccine take-up. Because the small number of clusters and relatively small cell sizes at the group-by-year-by-quarter level, we employ a wild bootstrap procedure that precludes us from easily calculating interpretable standard errors. However, we report the p-values from hypotheses tests of whether the pre- and post-ACA coefficients are statistically different from zero.

Next, we distinguish effects from ACIP's recommendation with and without mandated zero patient cost-sharing. The grey circles in Figure 2 Panel A show no evidence of a jump in shingles vaccination at age 60 during the years when ACIP recommended the vaccine for those 60 or older but they were not entitled to receive the vaccine free of charge. However, after the ACA was implemented, there was a clear increase in coverage at age 60, and Panel B shows that the increase from 59 to 60 was larger than for any other ages. We formally test this pattern with the following regression discontinuity specification:

$$\mathrm{VACC}_{iart} = \alpha + \beta \cdot \mathrm{SIXTY\ OR\ OLDER}_a + \pi \cdot \mathrm{Age} + \mathrm{X}_{iart}{}'\gamma + \theta_a + \tau_t + \varepsilon_{iart} \quad (3),$$

where the independent variable of interest, SIXTY OR OLDER, is an indicator for being at or above the recommended age. To disentangle the importance of cost and ACIP's recommendation, we divide the sample into the pre- and post-ACA periods. In the pre-ACA period, the regression discontinuity estimate will capture the effect of ACIP's recommendation on vaccine take-up, while the estimate in the later period will include both the effects of ACIP's recommendation and eligibility to receive the vaccine without cost-sharing.

While we include the same race/ethnicity, educational attainment, insurance status, and fixed effects as in equation 1, we now allow age to smoothly affect vaccine take-up. To compare changes immediately around the recommendation age, we restrict the sample to adults 58−61 years old, though we test the robustness of the results to employing a data-driven bandwidth selection procedure and report bias-corrected standard errors (Calonico, Cattaneo, and Titiunik 2014, 2015). We report heteroskedastic robust standard errors.[17]

IV. Results

A. VACCINATION

We begin by exploring descriptively how the ACA's preventive services provision affected vaccine take-up. Table 1 reports the average vaccination rates for the treated and comparison groups before and after the policy changes, noting differences in these unadjusted rates. Panel A shows that while vaccination among those aged 60 or older increased by 9 percentage points after the ACA was implemented, it only grew by 2.2 percentage points for those aged 50–59 during this same period. The unadjusted 2 × 2 difference-in-differences comparison indicates that the ACA was associated with a 6.8 percentage point increase in shingles vaccination. Panel B presents a similar story for the 2019 policy change entitling those

17 We note that the public-use NHIS data include only integer age and not exact birth date, which precludes us from more granularly assessing the discontinuity at the month level similar to Carpenter and Dobkin (2009).

TABLE 1. People entitled to receive the shingles vaccine without patient cost-sharing had higher vaccination rates

	(1)	(2)	(3)
A	No required coverage	Covered for age ≥60	Difference (2 − 1)
T. Age ≥60	0.057	0.147	0.090
C. Age <60	0.030	0.052	0.022
Difference T − C	0.027	0.092	**0.068**
B	Covered for age ≥60	Covered for age ≥50	Difference (2 − 1)
T. Age <60	0.052	0.098	0.056
C. Age ≥60	0.147	0.150	0.003
Difference T − C	−0.095	−0.052	**0.043**

Source: National Health Interview Survey 2008–19.
Note: In panel A, row T lists the share of adults 60 or older receiving the shingles vaccine and row C the share of adults under 60 receiving the shingles vaccine. In panel B, row T lists the share of adults under 60 receiving the shingles vaccine and row C the share of adults 60 or older receiving the shingles vaccine. In panel A, column 1 lists the shares prior to the preventive services provision of the Affordable Care Act, and column 2 the shares after ZVL was required to be covered for those 60 or older. In panel B, column 1 lists the shares when the shingles vaccine was required to be covered for those aged 60 or older, and column 2 when the shingles vaccine was required to be covered for all adults aged 50 or older. The bolded values indicate the difference-in-differences estimates.

50 or older to receive the vaccine without patient cost-sharing. While vaccine take-up increased by 5.6 percentage points for 50- to 59-year-old adults after this change, it was essentially unchanged for older adults, yielding a difference-in-differences estimate of 4.3 percentage points.

We now explore the relationship between the preventive services provision and shingles vaccination using the empirical specification shown in equation 1. The dependent variable in Table 2 is an indicator for reporting shingles vaccination, and the columns report the coefficient of interest. Standard errors, shown in parentheses, are clustered at the treatment group-year-quarter level, and we report wild bootstrapped p-values in brackets. In the sparsest specification including only indicators for age and time, column 1 shows that the preventive services provision increased shingles vaccination by 5.9 percentage points. Column 2 augments the specification with the covariates and shows a 3.9 percentage point increase in shingles vaccination. After utilizing the sample weights in column 3, we continue to find a statistically significant 3.2 percentage point increase in vaccination.[18]

18 In studying the effects of minimum legal drinking ages on alcohol consumption and mortality, Carpenter and Dobkin (2009, 171) note that the NHIS sample weights “reduce the precision of the regressions

TABLE 2. Insurance coverage for the shingles vaccine without patient cost-sharing increased shingles vaccination

	(1)	(2)	(3)
Required coverage for shingles vaccine	0.059[a]	0.039[a]	0.032[a]
	(0.008)	(0.008)	(0.011)
	[0.009]	[0.001]	[0.062]
R^2	0.027	0.034	0.032
Mean	0.065	0.065	0.065
Observations	72,781	72,781	72,781
Age and time FE?	Y	Y	Y
Additional covariates?		Y	Y
Survey weights?			Y

Source: National Health Interview Survey 2008–19.

Note: The dependent variable is an indicator for whether the respondent reported receiving the shingles 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 whether ZVL was required to be covered for the respondent without patient cost-sharing, age (50–60, with 61 omitted), and year-by-quarter fixed effects. Column 2 includes indicators for race/ethnicity (white, black, Hispanic, and Asian, with "other" omitted), educational attainment (less than high school, high school degree, and some college, with college degree omitted), health insurance coverage (insured, with uninsured omitted), and whether the FDA had approved the shingles vaccine for that person's age. Column 2 also includes time-invariant census region fixed effects. Column 3 utilizes the survey weights. Robust standard errors, shown in parentheses, are clustered at the group-year-quarter level. Wild bootstrapped *p*-values are reported in brackets. [a]$p < 0.01$.

While Figure 1 does not show any evidence of a differential pre-trend in vaccine coverage, Figure 4 empirically tests this by plotting the event study estimates obtained from equation 2. There was an increase in the likelihood of vaccination in the quarters following when the ACA required plans to cover the vaccine without cost-sharing. In contrast, the pre-coverage point estimates are smaller in magnitude and mostly negative, though we are unable to conclude that either the pre- or post-ACA coefficients are jointly different from zero at such a granular level ($p^{Pre} = 0.757$ and $p^{Post} = 0.735$). However, when viewed alongside the annual trends in Figure 1, the quarterly event study coefficients in Figure 4 support the increase in vaccine take-up being limited to the post-coverage period.[19]

significantly as the weights vary substantially across observations." Accordingly, we follow the advice of Solon, Haider, and Wooldridge (2015, 308) and "[report] both the weighted and unweighted estimates."

19 It is possible that Merck responded to the ACA preventive services provision by heavily advertising Zostavax. If so, then the estimated increase would not fully be attributable to the reduction in patient cost-sharing for privately insured patients, but instead driven by a combination of the price reduction and the advertising-induced increase in demand. We explore this possibility in Online Appendix Figure 2

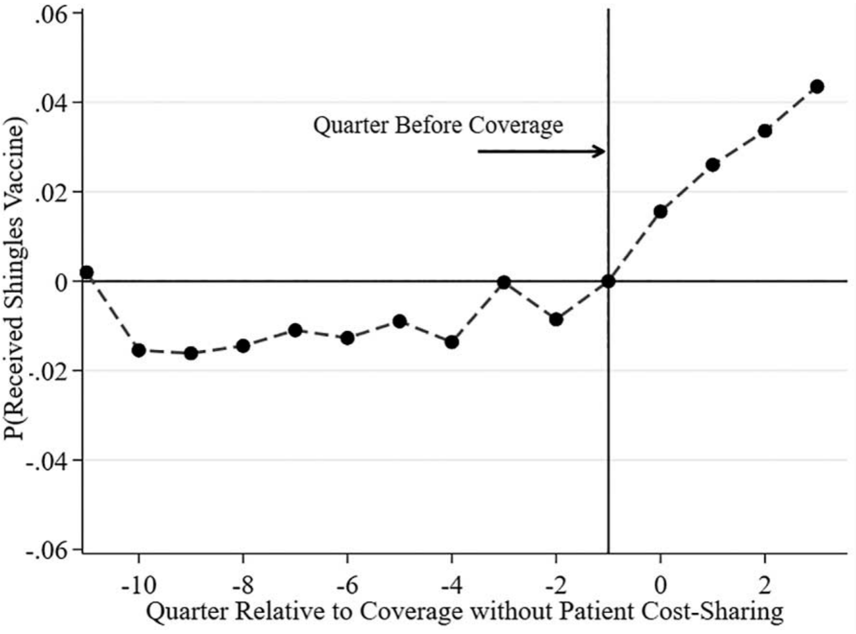

FIGURE 4. The increase in shingles vaccination was limited to the post-period. The black circles plot the event study coefficients measuring how the probability of shingles vaccination changed relative to when health insurance was required to cover the vaccine without patient cost-sharing. The regression includes the full set of controls from equation 2. Because there are a small number of clusters, inference is conducted using a wild bootstrap approach, though standard errors are not easily obtained from this procedure. However, we are unable to reject the null hypotheses that the pre-period coefficients or the post-period coefficients are statistically different from zero ($p^{Pre} = 0.757$ and $p^{Post} = 0.735$). Source: National Health Interview Survey 2008–19.

Our primary specification is identified off two distinct policy changes: the first entitled adults who had previously been recommended to receive the shingles vaccine (ZVL) to do

by plotting Merck's monthly advertising expenditure on Zostavax obtained from Kantar Media's 2007–16 Ad$pender database. In contrast to Online Appendix Figure 1, where we observe an immediate increase in the likelihood that 60-year-old adults reported shingles vaccination, there was zero Zostavax advertising expenditure during the 5 months preceding or 14 months following the ACA preventive services provision. Given prior work linking advertising to online search behavior (Joo et al. 2014; Du, Xu, and Wilbur 2019), Online Appendix Figure 3 examines changes in the relative search intensity for the terms *Zostavax* (panel A) or *shingles vaccine* (panel B) in the 2007–19 Google Trends data. There is no evidence of a change in information-seeking behavior immediately following the ACA preventive services provision. While these trends do not suggest that the documented increase in shingles vaccination was driven by Merck's Zostavax advertising, understanding how direct-to-consumer advertising affects vaccine take-up remains an important area for future research.

so without patient cost-sharing, while the second change entitled a newly recommended group to receive a newer, more effective vaccine (RZV) without cost-sharing. Because these changes might have generated different treatment responses—and considering the growing literature on difference-in-differences with variation in treatment timing (Sun and Abraham 2021; Borusyak, Jaravel, and Spiess 2021; Callaway and Sant'Anna 2021; de Chaisemartin and D'Haultfoeuille 2020; Goodman-Bacon 2021)—Table 3 separately examines the policy changes. Panel A uses data from 2008 to 2018, assuring that the comparison is driven by comparing treated adults to never-treated adults. Across the three specifications, we find that adults aged 60 or older were 2.9–6.8 percentage points more likely to receive the shingles vaccine after they became entitled to do so without patient cost-sharing. Similarly, panel B uses data from 2011 to 2019, so that the estimate is identified by comparing changes in shingles vaccination among adults aged 50–59 who became entitled to receive the vaccine without cost-sharing and those aged 60 or older who were always entitled to receive the vaccine for free. We find a 3.2–4.2 percentage point increase in shingles vaccination. Overall, Table 3 provides compelling evidence that the relationship detected in our primary specification is not unique to the 2011 or 2019 policy changes, nor is it being driven by the negative weighting issues that can arise when there is variation in treatment timing.[20]

Table 4 tests the sensitivity of the relationship to defining the sample using alternative age ranges. Column 1 reprints the preferred specification examining 50- to 61-year-old adults from Table 2. Column 2 expands the sample to include those aged 50 to 64, thereby including some individuals over the Social Security early retirement age. In contrast, column 3 limits the sample to 58- to 61-year-old adults who are perhaps most similar. However, because those aged 58 and 59 might opt to forgo the vaccine until they are eligible to receive it without patient cost-sharing, column 4 drops these individuals from the preferred specification. Regardless of the ages included in our sample, we find a statistically significant 2.4–6.2 percentage point increase in shingles vaccination.[21]

In Table 5 we further strengthen confidence in our estimates by performing similar analyses on data from the 2009–19 Behavioral Risk Factor Surveillance System (BRFSS). Unlike in the NHIS data where we know exact age, over our sample period the BRFSS data report age in five-year groups (50–54, 55–59, 60–64, etc.). A strength of these data is that they include state-level identifiers, enabling us to include (1) state-by-age group fixed effects and (2) an indicator for whether the state had expanded Medicaid as part of the ACA interacted with each age indicator. Analyzing a sample of 50- to 64-year-olds, we continue to find that the ACA preventive services provision increased shingles vaccination by 4.2–10.7 percentage points. By documenting a similar effect of the ACA preventive services

20 The NHIS data also underwent a survey redesign in 2019. Table 3, panel A, shows that our estimates are not being driven by this policy change.

21 Online Appendix Table 2 tests whether our results may have been driven by compositional changes associated with policy change. Reassuringly, we do not detect any evidence that our sample was more likely to be insured in the post-period. Nor do we detect changes in sex, educational attainment, or race/ethnicity.

TABLE 3. Both the 2010 and the 2019 policy changes increased shingles vaccination

	(1)	(2)	(3)
A. Sample years 2008–18			
Required coverage for shingles vaccine	0.068[a]	0.034[a]	0.029
	(0.007)	(0.012)	(0.022)
	[0.000]	[0.108]	[0.571]
R^2	0.026	0.034	0.031
Mean	0.061	0.061	0.061
Observations	66,510	66,510	66,510
B. Sample years 2011–19			
Required coverage for shingles vaccine	0.042[a]	0.041[a]	0.032[b]
	(0.009)	(0.009)	(0.013)
	[0.021]	[0.024]	[0.127]
R^2	0.025	0.034	0.031
Mean	0.073	0.073	0.073
Observations	57,739	57,739	57,739
Age and time FE?	Y	Y	Y
Additional covariates?		Y	Y
Survey weights?			Y

Source: National Health Interview Survey 2008–19.
Note: The dependent variable is an indicator for whether the respondent reported receiving the shingles 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 whether ZVL was required to be covered for the respondent without patient cost-sharing, age (50–60, with 61 omitted), and year-by-quarter fixed effects. Column 2 includes indicators for race/ethnicity (white, black, Hispanic, and Asian, with "other" omitted), educational attainment (less than high school, high school degree, and some college, with college degree omitted), health insurance coverage (insured, with uninsured omitted), and whether the FDA had approved the shingles vaccine for that person's age. Column 2 also includes time-invariant census region fixed effects. Column 3 utilizes the survey weights. Panel A exploits only the first policy change by limiting the sample to 2008–18. Panel B exploits only the second policy change by limiting the sample to 2011–19. Robust standard errors, shown in parentheses, are clustered at the group-year-quarter level. Wild bootstrapped p-values are reported in brackets. [a]$p < 0.01$, [b]$p < 0.05$.

provision on shingles vaccination in a second independent data set, Table 5 offers reassuring evidence on the validity of our prior NHIS estimates.[22]

22 Similarly, in Online Appendix Table 3 we perform the NHIS analysis using data prior to the majority of the ACA state Medicaid expansions (2008–13). We continue to find that adults aged 60 or older were more

TABLE 4. The relationship between insurance coverage for the shingles vaccine without patient cost-sharing and shingles vaccination is robust to alternative sample choices

	Sample ages			
	50–61 (1)	50–64 (2)	58–61 (3)	50–57, 60–61 (4)
Required coverage for shingles vaccine	0.039[a]	0.024[a]	0.062[a]	0.033[a]
	(0.008)	(0.006)	(0.009)	(0.007)
	[0.001]	[0.007]	[0.000]	[0.003]
R^2	0.034	0.074	0.046	0.037
Mean	0.065	0.092	0.101	0.064
Observations	72,781	90,055	24,188	60,757

Source: National Health Interview Survey 2008–19.
Note: The dependent variable is an indicator for whether the respondent reported receiving the shingles vaccine. The columns use the controls and specification from Table 2, column 2. Column 1 reprints the estimate from Table 2, column 2. Column 2 expands the sample to include 50- to 64-year-old adults. Column 3 limits the sample to include 58- to 61-year-old adults. Column 4 uses the preferred sample but drops adults aged 58 or 59 who may opt to forgo the vaccine until they turn 60. Robust standard errors, shown in parentheses, are clustered at the group-year-quarter level. Wild bootstrapped p-values are reported in brackets. [a]$p < 0.01$.

To empirically disentangle the effects of ACIP's recommendation and the ACA preventive services provision, Table 6 presents the regression discontinuity estimates obtained from equation 3.[23] Columns 1 and 2 limit the sample to the period in which the vaccine was recommended for adults 60 or older but prior to when the ACA required insurance plans to cover the vaccine without cost-sharing. Therefore, these estimates indicate the effect of being above the recommended age prior to becoming entitled to receive the vaccine for free. Columns 3 and 4 then examine the period in which adults 60 or older were eligible to receive the vaccine without cost-sharing. So, these estimates indicate the effect of being above the recommended age when those recommended were entitled to receive the shingles vaccine without patient cost-sharing. Regardless of whether we use ordinary least squares or a data-driven approach to determine age bandwidths for comparison, we do not detect evidence of a discontinuity at age 60 prior to the ACA. However, in the post-ACA period we find estimates that turning 60 increased the likelihood of vaccination by 3.1–4.2 percentage points, providing further evidence that it was the ability to receive the vaccine without cost-sharing that increased coverage.

likely to report shingles vaccination after they became entitled to receive the vaccine without patient cost-sharing.

23 Online Appendix Table 4 shows that the observable right-hand-side characteristic varied smoothly through the discontinuity.

TABLE 5. The ACA preventive services provision increased shingles vaccination in the BRFSS data

	(1)	(2)	(3)
Required coverage for shingles vaccine	0.107[a]	0.070[a]	0.042[a]
	(0.005)	(0.000)	(0.010)
	[0.000]	[0.000]	[0.001]
R^2	0.085	0.102	0.083
Mean	0.136	0.136	0.136
Observations	280,081	280,081	280,081
Age and time FE?	Y	Y	Y
Additional covariates?		Y	Y
Survey weights?			Y

Source: Behavioral Risk Factor Surveillance System 2009–19.

Note: The dependent variable is an indicator for whether the respondent reported receiving the shingles 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 whether ZVL was required to be covered for the respondent without patient cost-sharing, age group (50–54 and 55–59, with 60–64 omitted), and year-month fixed effects. Column 2 includes indicators for race/ethnicity (white, black, Hispanic, and Asian, with "other" omitted), and educational attainment (less than high school, high school degree, and some college, with college degree omitted). Column 2 also includes time-invariant state fixed effects and an indicator for whether the state had expanded Medicaid as part of the Affordable Care Act. Column 3 utilizes the survey weights. Robust standard errors, shown in parentheses, are clustered at the group-year-quarter level. Wild bootstrapped p-values are reported in brackets. [a]$p < 0.01$.

Table 7 presents several falsification tests to build confidence that the detected increase in shingles vaccination was attributable to the ACA, instead of a general change in vaccine sentiment.[24] The dependent variable in column 1 is an indicator for whether the respondent reported having a tetanus shot during the prior 10 years. Notably, one tetanus booster has been covered for all adults since the ACA was implemented in September 2010, so we would not expect to observe differential increases based on whether adults were above or below 60 years old. Similarly, the dependent variables in columns 2 and 3 are indicators for ever having received the hepatitis A or B vaccines, both of which are covered only for adults with certain risk factors. Finally, the dependent variable in column 4 is an indicator for having received the flu vaccine during the past 12 months; influenza vaccination has been covered for all adults since the preventive services provision was implemented. Across all four columns, the point estimates are smaller in magnitude than our main finding and

24 Of course, it is possible that the ACA may have had spillovers onto other vaccines if it changed adults' engagement with the health-care system. In this instance, we would expect to detect increases for these other vaccines.

TABLE 6. The discontinuity in shingles vaccination at age 60 was only present when those individuals were entitled to the vaccine without patient cost-sharing

Sample period:	No coverage requirement		Required coverage for age ≥60	
Specification:	OLS (1)	CCT (2)	OLS (3)	CCT (4)
1{Age ≥60}	0.003	0.014	0.031[a]	0.042[a]
	(0.014)	(0.013)	(0.010)	(0.011)
R^2	0.025	-	0.043	-
Observations	4,216	9,301	17,698	30,661

Source: National Health Interview Survey 2008–17.

Note: The dependent variable is an indicator for whether the respondent reported receiving the shingles vaccine. The independent variable of interest is an indicator for whether the respondent was 60 or older. Each column also allows age to affect vaccine take-up linearly and includes indicators for race/ethnicity (white, black, Hispanic, and Asian, with "other" omitted), educational attainment (less than high school, high school degree, and some college, with college degree omitted), health insurance coverage (insured, with uninsured omitted), location-invariant year-by-quarter fixed effects, and time-invariant region fixed effects. Because we are only leveraging the discontinuity at age 60, we limit our sample to the period prior to when RZV was approved to ensure that any changes are not attributed to the introduction of the new shingles vaccine. Columns 1 and 3 limit the sample to 58- to 61-year-old adults. Columns 2 and 4 utilize a data-driven approach to select the bandwidth. Robust standard errors are shown in parentheses. Columns 1 and 3 estimate the model using ordinary least squares (OLS). Columns 2 and 4 use the local polynomial point estimators with robust bias-corrected confidence intervals and inference detailed in Calonico, Cattaneo, and Titiunik (2015). [a]$p < 0.01$.

statistically insignificant, supporting our interpretation that the increase in shingles vaccination was not part of a general trend in vaccine take-up.

Table 8 explores whether the ACA preventive services provision had differential effects on shingles vaccination based on observable demographic characteristics. Each column reports the coefficients of interest from a modified version of equation 1 whereby we fully interact all the right-hand-side variables with a group-specific indicator. In column 1, the group indicator denotes whether the respondent had a college degree, in column 2 whether the respondent was male, and in column 3 whether the respondent was white. Column 1 shows that the ACA increased shingles vaccination by 3.2 percentage points for adults without a college degree. Meanwhile, those with a college degree saw an additional 2.6 percentage point increase, for 5.8 percentage points total. In contrast, columns 2 and 3 do not indicate any difference in vaccine take-up based on the respondent's sex or race/ethnicity.[25]

25 Online Appendix Table 5 shows that these patterns remain after restricting the sample to those with health insurance.

TABLE 7. The vaccination rate increase was unique to the shingles vaccine

Outcome:	Tetanus shot within past 10 years	Ever had the hepatitis A vaccine	Ever had the hepatitis B vaccine	Flu vaccine within past 12 months
Covered under ACA:	All adults (1)	High-risk groups (2)	High-risk groups (3)	All adults (4)
Required coverage for shingles vaccine	0.002	−0.009	0.008	0.020
	(0.009)	(0.012)	(0.019)	(0.014)
	[0.815]	[0.713]	[0.797]	[0.315]
R^2	0.044	0.028	0.036	0.057
Mean	0.635	0.104	0.259	0.423
Observations	65,075	62,934	63,717	73,489

Source: National Health Interview Survey 2008–19.

Note: The dependent variable in column 1 is an indicator for whether the respondent reported having a tetanus shot within the past 10 years, in column 2 ever having received the hepatitis A vaccine, in column 3 ever having received the hepatitis B vaccine, and in column 4 having received a flu vaccine during the prior 12 months. The independent variable of interest is an indicator for whether the shingles vaccine is required to be covered without patient cost-sharing. The columns use the controls and specification from Table 2, column 2. The sample is limited to 50- to 61-year-old adults. Robust standard errors, shown in parentheses, are clustered at the group-year-quarter level. Wild bootstrapped p-values are reported in brackets.

B. MECHANISMS

We next explore the possible channels through which the ACA may have increased shingles vaccination. Table 9 again fully interacts the right-hand-side variables from equation 1 with a group-specific indicator. While the ACA requires private insurance plans to cover recommended preventive services free of charge, there are still nonmonetary costs associated with taking the time to get vaccinated. Because shingles is caused by reactivation of the varicella zoster virus (chickenpox), those with a self-reported history of chickenpox likely perceive themselves as having the most to gain from vaccination (Mayo Clinic 2020). Yet column 1 does not reveal any additional increase in shingles vaccination among those who reported a history of chickenpox.[26] Instead, column 2 shows a 4.4 percentage point increase in shingles vaccination among those who reported a recent health-care visit, compared with a statistically insignificant 1.7 percentage point increase among those

26 Those without a history of chickenpox can receive the vaccine. Indeed, the ACIP recommendation stated, “Before administration of zoster vaccine, patients do not need to be asked about their history of varicella (chickenpox)” (CDC 2008). However, some physician groups recommend vaccination only among those previously exposed to chickenpox (Johns Hopkins Medicine 2021).

TABLE 8. The increase in shingles vaccination was larger for college-educated adults

	Group indicator		
	College degree (1)	Male (2)	White (3)
Required coverage for shingles vaccine	0.032[a]	0.036[a]	0.034[a]
	(0.008)	(0.010)	(0.009)
	[0.021]	[0.025]	[0.011]
Required coverage for shingles vaccine × group	0.026[c]	0.007	0.008
	(0.015)	(0.012)	(0.010)
	[0.209]	[0.682]	[0.543]
R^2	0.038	0.035	0.037
Observations	72,781	72,781	72,781

Source: National Health Interview Survey 2008–19.
Note: The dependent variable is an indicator for whether the respondent reported receiving the shingles vaccine. The independent variable of interest is an indicator for whether health insurance was required to cover the shingles vaccine for the respondent without cost-sharing. The estimates use a modified version of preferred specification from Table 2, column 2, where the right-hand-side variables are fully interacted with an indicator for being a member of the group of interest. The indicator in column 1 indicates whether the respondent had a college degree, in column 2 whether the respondent was male, and in column 3 whether the respondent was white. The sample is respondents 50 to 61 years old. Robust standard errors, shown in parentheses, are clustered at the group-year-quarter level. Wild bootstrapped p-values are reported in brackets. [a]$p < 0.01$, [c]$p < 0.10$.

not reporting a recent visit.[27] This indicates that the effect was largest with those most connected to the health-care system.

The preventive services provision required private health insurance plans to cover the vaccine without patient cost-sharing, so we would expect the effect to be driven by insured individuals.[28] Consistent with this prediction, column 3 shows no statistically significant change in vaccine take-up among those without health insurance. Instead, the entire 4.5 percentage point increase was driven by those with health insurance. Notably, the ACA required

27 It is also possible that the ACA preventive services provision increased engagement with the health-care system. While we do not detect any significant increase in the likelihood that adults aged 60–61 reported a recent health-care visit relative to those aged 50–59 ($\hat{\beta} = -0.005$, SE $= 0.006$, $p = 0.356$), physicians may have changed the frequency with which they recommended shingles vaccination for those aged 60 or older. Unfortunately, neither the NHIS nor the BRFSS data contain information on recommendations of the shingles vaccine.

28 The NHIS asks about whether individuals *ever* received the shingles vaccine and their *current* health insurance status. So, it is possible that some individuals reporting current coverage were recently uninsured or that those reporting no coverage recently had insurance. However, by limiting our sample to those at most 61 years old, we expect most individuals' current coverage to reflect their coverage when they were 60.

TABLE 9. The increase in shingles vaccination was larger for those with health insurance and a recent doctor visit

	Group indicator		
	Ever had chickenpox (1)	Recent doctor visit (2)	Health insurance coverage (3)
Required coverage for shingles vaccine	0.035	0.017	0.001
	(0.022)	(0.011)	(0.006)
	[0.603]	[0.200]	[0.876]
Required coverage for shingles vaccine × group	−0.008	0.027[b]	0.044[a]
	(0.033)	(0.011)	(0.010)
	[0.784]	[0.131]	[0.012]
R^2	0.039	0.038	0.037
Observations	63,357	72,623	72,781

Source: National Health Interview Survey 2008–19.

Note: The dependent variable is an indicator for whether the respondent reported receiving the shingles vaccine. The independent variable of interest is an indicator for whether health insurance was required to cover the shingles vaccine for the respondent without cost-sharing. The estimates use a modified version of preferred specification from Table 2, column 2, where the right-hand-side variables are fully interacted with an indicator for being a member of the group of interest. The indicator in column 1 indicates whether the respondent reported a history of chickenpox, in column 2 whether the respondent reported a doctor visit within the prior 12 months, and in column 3 whether the respondent had health insurance. The sample is respondents 50 to 61 years old. Robust standard errors, shown in parentheses, are clustered at the group-year-quarter level. Wild bootstrapped p-values are reported in brackets. [a]$p < 0.01$, [b]$p < 0.05$.

private insurance plans to cover the preventive services without patient cost-sharing. State Medicaid plans had the option to cover the vaccine, and Granade et al. (2020) found that only 33 of 49 Medicaid fee-for-service arrangements did so without patient cost-sharing. As such, we would expect to detect the largest increase among privately insured adults. Consistent with this prediction, Online Appendix Table 6 reveals no meaningful change among the uninsured or those with Medicaid (−0.8 to 0.1 percentage points). Instead, the increase was entirely driven by adults with private insurance coverage (5.2 percentage points).

V. Conclusion

The COVID-19 pandemic has highlighted the difficulties policy makers face when trying to increase vaccine take-up, especially among adults. Over the last year, public health officials have experimented with numerous strategies designed to increase vaccine coverage, including offering recommendations and entering vaccinated individuals into lotteries for cash prizes (Dave et al. 2021). In this paper, we provide the first quasi-experimental evidence that vaccine recommendations alone were not enough to increase adult take-up of the shingles vaccine. Instead, we show that once individuals who were recommended to receive the vaccine became eligible to do so free of charge, coverage increased by 3.2–5.9 percentage points, underscoring the importance of cost in adult vaccine decisions.

It is worth quantifying the welfare implications of increased shingles vaccination. Of first note, because shingles is not a communicable illness and managing symptoms typically does not require informal caregiving, the benefits of vaccination are largely internalized. Among the recommended age group, adults aged 60 or older, the annual incidence of shingles was 10.46 per 1,000 people in 2011 (Johnson et al. 2015). The available vaccine, ZVL, reduced the risk of acquiring shingles by 51 percent and offered protection for five years (Oxman et al. 2005; CDC 2020b). The expected benefit to a vaccinated individual in the age-recommended population is then a reduced risk of shingles infection by 5.3 per 1,000 people (0.01046×0.51). Assuming a per case cost of shingles of \$6,000, including medical and productivity costs (McLaughlin et al. 2015; Ozawa et al. 2016),[29] the expected benefit of reduced risk of infection is worth \$32 per vaccinated individual ($0.0053 \times \$6{,}000$). Meanwhile, the shingles vaccine is expensive, with Medicare Part D spending \$857 million on shingles vaccination in 2019 for an average price of \$150 per dose (MedPAC 2021, 254, Table 7–5). Thus, the vaccine cost exceeds the value of the expected benefit and accumulates across individuals induced to receive the vaccine through the preventive services provision mandating zero patient cost-sharing. According to data from the National Cancer Institute's Surveillance, Epidemiology, and End Results (SEER) Program, there were 57 million adults aged 60 or older in 2010, and our estimates imply that the ACA led approximately 2.2 million more of these people to receive the shingles vaccine (57 million $\times$ 0.039). Thus, at a loss of \$118 per vaccinated individual (\$32–\$150), then accumulated over 2.2 million people, there was a social loss of \$260 million at the vaccine's \$150 price.[30] The vaccine would have to be priced at \$32 for vaccination to be welfare neutral. If the vaccine were 100 percent effective, a price of about \$63 would lead to welfare neutrality ($0.01046 \times 1.00 \times \$6{,}000$). Put another way, the value of a prevented shingles case would have to be \$28,118 for vaccination to be welfare neutral at a price of \$150 per vaccinated individual ($150/(0.01046 \times 0.51)$). Considering that medical and productivity costs have been estimated at \$6,000 per shingles case (McLaughlin et al. 2015; Ozawa et al. 2016), adults aged 60 or older would have to place a disutility of \$22,118 on the experience of shingles infection in order for vaccination to be welfare neutral (at the \$150 price).

Overall, our study highlights the importance of cost in driving adult vaccine take-up, though it is subject to some limitations. First, self-reported vaccination status—which we use throughout the paper—may differ from actual vaccination. While this issue is common to papers utilizing the NHIS, we cannot rule out the possibility that the ACA changed the likelihood that individuals reported being vaccinated. However, this explanation would require differential responses for those above and below 60 coincident with the period

29 Note that the estimated cost of shingles includes approximately \$2,000 in medical costs and \$4,000 in productivity (McLaughlin et al. 2015). It does not include leisure time costs.

30 The current vaccine, RZV, is a two-dose series costing \$150–\$200 per dose. In 2010, the shingles vaccine, ZVL, was a single shot. However, ZVL was similarly priced at \$150 per shot (Chen 2010). Because RZV offers almost twice as much protection at double the cost, the welfare implications are qualitatively similar.

when the ACA required private insurance plans to cover the vaccine without cost-sharing for these groups. Additionally, while shingles can cause substantial pain and lead to subsequent complications, shingles-related mortality is relatively low, and the cost of the vaccine is relatively high. As such, our results may not generalize to other vaccines that protect against diseases that are communicable or have greater disease burden.

An additional limitation is our inability to identify whether the ACA preventive services provision affected the likelihood that physicians recommended the shingles vaccine, given that prior evidence has highlighted the importance of physician recommendations in adolescent vaccination decisions (Gargano et al. 2013; Moghtaderi and Adams 2016). Finally, it is possible that Merck more heavily advertised the shingles vaccine after privately insured adults aged 60 or older became eligible to receive the vaccine without patient cost-sharing. While we did not find any visual change in Merck's advertising expenditure concurrent with the implementation of the ACA preventive services provision, such a change would likely lead us to overstate the effect of the price reduction on vaccine take-up. Understanding the interplay between government policies to promote vaccination, firm advertising decisions, and vaccine take-up remains an important area for future work. Despite these limitations, our results provide the first quasi-experimental evidence that the ACA increased take-up of the shingles vaccine. These results suggest that policy makers looking to improve adult vaccination rates should be mindful of the role of cost in driving vaccination decisions.

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