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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, and policymakers have adopted a variety of strategies to increase and keep coverage rates at socially optimal levels. While researchers have documented successful strategies for increasing coverage rates in children and adolescents, little is known about how to successfully increase adult vaccination rates – a fact that has been highlighted by the COVID-19 pandemic. Using data from the 2008-2019 National Health Interview Survey, we show that 60-year-olds – who were recommended by the Advisory Committee on Immunization Practices to receive the shingles 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 insurance plans to cover recommended vaccines without patient cost-sharing, adults 60 or older were more likely to receive the vaccine, and we document a similar increase for 50-59-year-olds after the recommendation age was lowered to 50. Using both difference-in-differences and regression discontinuity identification strategies, we estimate that the ACA increased vaccine take-up of the shingles vaccine by 3.0-5.2 percentage points.

JEL Codes: I18; I12
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1. 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, policymakers 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 literature analyzing the efficacy of these youth-targeted initiatives (Abrevaya and Mulligan 2011; Lawler 2017; Carpenter and Lawler 2019; Lawler 2020), 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 (CDC) Advisory Committee on Immunization Practices (ACIP), a federal panel of immunization experts, affected adult take-up of the herpes zoster vaccine (ZVL).[2] 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 US each year (Mayo Clinic 2020; CDC 2021a). Approximately one in three people in the US develops shingles during their lifetime (Harbecke et al. 2021), and 10-50 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; Cohen 2013; Forbes et al. 2016). Post-herpetic neuralgia can

[2] From 2006-2017, zoster vaccine live (ZVL) – sold under the tradename Zostavax – was the only shingles vaccine. In October of 2017, the FDA approved the first recombinant zoster vaccine (RZV) which is sold under the tradename Shingrix. For narrative purposes, we broadly refer to these vaccines as 'shingles vaccines,' except where the distinction in type is important.

interfere with sleep, activities of daily living, productivity, and 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 had received the vaccine. Yet in 2019 shingles vaccination comprised over 90 percent ($857 million) of Medicare Part D vaccine spending (MedPAC 2021, Table 7-5 Page 254).

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 ten times more expensive than a seasonal flu vaccine (NYT 2010). After the Affordable Care Act preventive services provision was implemented in September of 2010, ACIP's recommendation meant that adults aged 60 or older became eligible to receive the vaccine without patient cost-sharing, and Figure 1 shows a larger increase in coverage for 60-year-olds than 59-year-olds coincident with the ACA. However, after ACIP lowered the recommended age to 50 – newly requiring that the vaccine be available at no cost to adults aged 50 to 59 – coverage jumped among 59-year-olds.[3] Similarly, the grey 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.[4]

Using data from 2008-2019 National Health Interview Surveys (NHIS), 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. Instead, using both difference-in-differences and regression

[3] ACIP lowered the recommended age for routine vaccination to 50 on October 25th of 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).

[4] Appendix Figure 1 shows that the jump in vaccination at 60 was no longer present after adults 50 or older became eligible to receive the vaccine without cost-sharing.

discontinuity identification strategies, we find that the preventive services provision increased shingles vaccination by 2.7-5.9 percentage points, suggesting that age-targeted recommendations on their own were not enough to drive adult vaccine take-up. Using these same models exploiting the timing of required coverage of the shingles vaccine at no patient cost for different ages, we do not detect any changes for other vaccines which were made available to all adults regardless of age (tetanus and influenza) or only to those with risk factors (hepatitis A and hepatitis B), indicating that our estimates identify a relationship unique to the shingles vaccine. We then show that the increase was driven by those (i) with health insurance, (ii) reporting a recent doctor visit, and (iii) with the most to gain from vaccination due to a history of chickenpox.[5] 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 adults would have to price the leisure costs of shingles at $48,000 per episode for the coverage increase to have been welfare neutral.

This paper contributes to several literatures. By providing the first quasi-experimental estimates on how prices affect adult vaccine take-up, we add to a larger literature on prices and health care utilization (Keeler and Rolph 1988; Newhouse et al. 1993; Chandra et al. 2010; Finkelstein 2012; Lipton and Decker 2015; Nilsson and Paul 2018; Han et al. 2020). We also build on prior work studying how ACIP's age-targeted vaccine recommendations affected child and adolescent coverage rates (Lawler 2017; Lawler 2020), as well as a broader literature on the determinants of vaccination (Abrevaya and Mulligan 2011; Bradford and Mandich 2013; Ward 2014; Walsh et al. 2016; Oster 2018; Carpenter and Lawler 2019; Richwine et al. 2019; Wen 2020; White 2021). Notably, we improve on prior work by disentangling the importance of

[5] Shingles is caused by a reactivation of the varicella-zoster virus which causes chickenpox (Mayo Clinic 2020).

recommendations and patient costs in driving coverage rates, and our estimates are likely of special interest to policymakers looking to increase adult vaccine take-up.

The rest of the paper proceeds as follows: Section 2 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, as well as the literature on how cost affects utilization of preventive services. Section 3 explains the National Health Interview Survey data that we use throughout the analysis, as well as our complementary empirical strategies. Section 4 reports the results, and Section 5 summarizes their policy implications and suggests areas for future work.

2. Background and Literature

2.1 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 tradename Zostavax, was approved by the 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 50-59 in 2011 (FDA 2011), though ACIP twice decided against lowering the recommended age – once in 2011 (MMWR 2011) and again in 2013 (MMWR 2014).

In October of 2017, the FDA approved the first recombinant zoster vaccine (RZV), produced by GlaxoSmithKline's under the trade name Shingrix, for adults aged 50 or older (MMWR 2018). RZV provides greater protection than ZVL (CDC 2020b, 2021b).[6] Further, the licensing of RZV expanded the population who could be vaccinated against shingles to people with

[6] ZVL reduced the risk of shingles by 51 percent. RZV – which is a 2-dose series – reduces the risk by 90 percent (CDC 2020b, 2021b).

immunocompromising conditions and people for whom the live vaccine (ZVL) requirement to be stored at freezing temperatures challenged access (Harbecke et al. 2021).[7] Five days after it was approved by the FDA, ACIP began recommending routine RZV vaccination for adults 50 or older, including for adults who had previously received ZVL (MMWR 2018). Merck discontinued Zostavax in 2020 (Merk 2020). Currently, adults 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 Affordable Care Act (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, health insurance plans became required to cover the shingles vaccine for adults 60 or older. [8] 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), 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.[9]

2.2 Existing Literature

Given the social benefits associated with widespread vaccination, policymakers have experimented with a myriad of policies intended to increase vaccine take-up, especially among children and

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[7] 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 et al. 2021).

[8] 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).

[9] 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 1st because of the fall open enrollment period (Marketplace 2017). Private insurance plans purchased during the traditional HealthCare.gov open enrollment period start on January 1st (KFF 2021).

adolescents. Perhaps most well-known are policies requiring children to receive certain vaccinations as a condition for school attendance. Indeed, the United States has a long history of school vaccine requirements stretching back to the late 19th and early 20th centuries, and Holtkamp (2020) found that these early smallpox vaccination mandates were successful in reducing infections, especially during epidemics. In a more recent setting, Abrevaya and Mulligan (2011) used the 1996-2007 National Immunization Survey (NIS) – Child data and found that school entry varicella (chickenpox) mandates increased vaccine take-up by 3-6 percentage points. Using the 2008-2013 NIS – Teen data and a difference-in-differences identification strategy, Carpenter and Lawler (2019) showed that middle school Tdap booster requirements increased the share of teens receiving a Tdap booster by approximately 14 percentage points, and Churchill (2021) showed that Washington, DC's 2014 HPV vaccine school requirement increased the probability that teen girls (boys) received the HPV vaccine by 11 (20) percentage points.

Researchers have recently begun examining policies allowing parents to opt their children out of school vaccine requirements due to personal or religious objections. In a working paper, Richwine et al. (2019) found that California SB 277 – which repealed all non-medical vaccine exemptions – reduced non-medical exemptions by 3.4 percentage points. However, the authors also found a 2.1 percentage point increase in medical exemptions, suggesting that vaccine-hesitant parents may have successfully found physicians willing to grant their children exemptions. Examining disease incidence, Bradford and Mandich (2013) found that states making it more difficult for parents to opt their children out of vaccination had lower incidence of pertussis.

Several recent papers have explored adult-targeted vaccine mandates, though these have largely been limited to health care settings (Carrera et al. 2021). Wen (2020) used a difference-in-differences identification strategy to show that state laws requiring nursing home residents to receive the influenza vaccine increased vaccine take-up by 6 percent and reduced the probability of an influenza-like illness by 20 percent. She also found suggestive evidence that laws requiring health care workers to receive the influenza vaccine reduced the incidence of influenza among nursing home residents. Exploiting county-level variation in influenza mandates for health care workers in California, White (2021) documented a 14 percent increase in vaccination and a 20 percent reduction in the number of influenza diagnoses during seasons with an effective vaccine. Anderson et al. (2020) exploited a policy in the United Kingdom prioritizing influenza vaccination for those aged 65 or older. Using a regression discontinuity identification strategy, the authors documented a 19.3-22.8 percentage point increase in the likelihood of receiving the flu vaccine at the cutoff. However, they did not detect any change in hospitalizations or mortality.

Along with the reviewed literature on vaccine mandates, there have been several studies within the economics literature examining how vaccine *recommendations* affected vaccine take-up, while this literature is limited to recommendations for children and adolescents. For example, Lawler (2017) exploited spatial and temporal variation in the timing when children were recommended by ACIP to receive the hepatitis A vaccine. She found that strong recommendations increased vaccine take-up by 20 percentage points. Similarly, Lawler (2020) found that age-targeted meningococcal vaccine recommendations increased vaccine take-up in the targeted group by 133 percent relative to their baseline mean. We are unaware of any comparable paper assessing adult vaccine recommendations, though these effects are likely of interest to policymakers given that adults traditionally have lower coverage rates than children and are generally not bound by vaccine mandates.

Our paper also relates to a large economics literature on how patients respond to changes in the price of health care. Analyzing data from the RAND Health Insurance Experiment, which randomly assigned families to 14 different insurance plans (Newhouse et al. 1993), Keeler and Rolph (1988) found that coinsurance reduced health care utilization. Similarly, leveraging variation induced by a lottery whereby some uninsured low-income adults were given the chance to apply for Medicaid as part of the Oregon Health Insurance Experiment, Finkelstein et al. (2012) showed that lottery winners were more likely to become insured and had higher health care utilization rates. Examining a policy change increasing copayments for retired public employees in California, Chandra et al. (2010) found copayment increases reduced elderly individuals' use of office visits and prescription drugs. More recently, Nilsson and Paul (2018) exploited a county-level change in Sweden which first lowered the age at which copayments became required from 20 to 7 before returning it back to 20. The authors found that free health care increased adolescent doctor visits by 5-10 percent, especially among low-income individuals. Using a similar regression discontinuity framework, Han et al. (2020) found that increased cost-sharing reduced children's use of outpatient care in Taiwan.

There is mixed evidence on whether lowering the cost of vaccines increases vaccine take-up. Using the 1995-2013 NIS-Child data, Walsh et al. (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. 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. Studying the Ontario Universal Influenza Immunization Campaign which recommended and subsidized the influenza vaccine for all ages, Ward (2014) concluded that the program reduced influenza-pneumonia hospital admissions by 48 percent in years with an effective vaccine. In a working paper, Hoffman et al. (2019) conducted a field experiment in partnership with a major Ecuadorian bank. They found that offering a discount for the influenza vaccine to the lowest earners did not affect vaccine take-up. However, they found that assigning employees to get vaccinated during the work week – when they were permitted to take time off to receive the vaccine – increased take-up by 112 percent compared to those assigned to receive the vaccine on Saturday. Considering COVID-19 vaccination amidst highly politicized discourse on the importance of the vaccine, Chang et al. (2021) used a randomized controlled experiment to examine effects of $10 or $50 financial incentives and report in their working paper that these financial incentives had no effects on vaccine up-take among a sample of Medicaid managed care beneficiaries.

Leveraging spatial and temporal variation in state requirements that private health insurers cover childhood vaccinations and using the 1995-1996 NIS-Child data, Chang (2015) documented a 1.8 percentage point increase in the share of children up-to-date with their 4:3:1 vaccine series.[10] Perhaps most related to our current study, Lipton and Decker (2015) used data from the 2008-2012 National Health Interview Surveys to test how the combination of the ACA preventive services and dependent coverage provisions affected human papillomavirus (HPV) vaccination among young women. The HPV vaccine costs around $250 per shot (CVS 2020), and at the time of their study the vaccine was a three-dose series. Comparing coverage rates among 19-25-year-old women with those of 18- and 26-year-olds before and after the ACA was implemented, the authors found that these two provisions increased HPV vaccine take-up by 7.7 percentage points.

[10] 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).

3. Data and Methodology

3.1 Vaccination Data: National Health Interview Surveys

We obtain data on shingles vaccination from the 2008-2019 National Health Interview Surveys (NHIS).[11] The NHIS are continuously operating cross-sectional household surveys monitoring health behaviors and outcomes of the non-institutionalized 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 et al. 2010), tobacco use (Pesko et al. 2020), and alcohol consumption (Carpenter and Dobkin 2009).

First, we examine impacts of the ACA preventive services provision mandating zero patient cost-sharing for ACIP-recommended vaccines. Figure 1 plots shingles vaccination rates for two comparable groups: 60-year-olds and 59-year-olds. These groups had similar vaccination rates prior to the ACA, even though the vaccine was only approved and recommended 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

[11] While the 2008-2018 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 affected individuals based on whether or not they were 60 or older, we test the robustness of our estimates to excluding the 2019 data.

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.

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 60 or older increased by 9 percentage points after the ACA was implemented, it only grew by 2.2 percentage points for those under 60 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 50 or older to receive the vaccine without patient cost-sharing. While vaccine take-up increased by 5.6 percentage points for 50-59-year-old adults after this change, it was essentially unchanged for older adults, yielding a difference-in-differences estimate of 4.3 percentage points.

3.2 Empirical Strategy: Difference-in-Differences & Regression Discontinuity

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

$$\text{VACC}_{iart} = \alpha + \beta \cdot \text{REQUIRED COVERAGE FOR SHINGLES VACCINE}_{iat} + X_{iat}'\gamma + \theta_r + \tau_t + \varepsilon_{iart} \qquad (1)$$

where VACC is an indicator for whether adult *i* age *a* in region *r* during period *t* had received 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 50 or older beginning in 2019.[12] Because the policy change requiring

[12] We observe data at the year-quarter level, and 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 23rd of 2010 (Q3 of 2010), we classify adults 60 or older as treated starting in Q4 of 2010. Similarly, because ACIP

insurance to cover the shingles vaccine without patient cost-sharing did not occur concurrently with FDA approval or 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 et al. 2015; Bloeman et al. 2017; Fitzpatrick and Moore 2018), we limit our sample to adults 50-61-years-old.

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

The coefficient of interest, β, measures the unique change in vaccination among adults newly eligible to receive the vaccine without cost-sharing compared to 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:

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recommended adults 50 or older receive the vaccine on October 25th of 2017 (Q4 of 2017) – and new recommendations are required to be covered for plans beginning one year after the recommendation date – we classify 50-59-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.

[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 50-59-years-old 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 with beginning in January 2019.

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

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.[14] This specification allows us to test the descriptive patterns in Figure 1 showing that 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.

Second, 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.[15] We formally test this pattern with the following regression discontinuity specification:

$$\text{VACC}_{iart} = \alpha + \beta \cdot \text{SIXTY OR OLDER}_{ia} + \pi \cdot \text{Age} + X_{iat}'\gamma + \theta_r + \tau_t + \varepsilon_{iart} \quad (3)$$

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

[14] 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.

[15] Appendix Figure 1 shows that this discontinuity was eliminated when adults 50 or older became eligible to receive the shingles vaccine without cost-sharing.

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 et al. 2014, 2015). We report heteroskedastic robust standard errors.[16]

4. Results

4.1 Vaccination

We begin by exploring how ACA's preventive services provision affected vaccine take-up. The dependent variable in Table 2 is an indicator for reporting shingles vaccination and the columns report the coefficient of interest estimated using equation (1). Standard errors, shown in parentheses, are clustered at the 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. The point estimate and statistical significance are essentially unchanged after including the additional

[16] We note that the public use NHIS data only include 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).

covariates in column 2. After employing the sample weights in column 3, we continue to find a statistically significant 5.2 percentage point increase in vaccination.[17,18]

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.

Next, Table 3 tests the sensitivity of the relationship to defining the sample using alternative age ranges. Column 1 reprints the preferred specification examining 50-61-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 58-61-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

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[17] In studying the effects of minimum legal drinking ages on alcohol consumption and mortality, Carpenter and Dobkin (2009) note that the NHIS sample weights "reduce the precision of the regressions significantly as the weights vary substantially across observations." Accordingly, we follow Solon et al.'s (2015) advice and "[report] both the weighted and unweighted estimates."

[18] In Appendix Table 2 we perform a similar analysis on data from the 2009-2019 Behavioral Risk Factor Surveillance System. Unlike in the NHIS data where we know exact age, over our sample period the BFSS data report age in 5-year groups (50-54, 55-59, 60-64, etc.). Analyzing a sample of 50-64-year-olds, we continue to find that the ACA preventive services provision increased shingles vaccination by 6.9-10.7 percentage points.

Because the NHIS data underwent a survey redesign in 2019, Appendix Table 3 Panel A reports results from estimating equation (1) using data from 2008-2018 – thereby exploiting only the first policy change in September of 2010. Meanwhile, Panel B limits the sample to 2011-2019 to exploit only the second policy change whereby 50-59-year-olds became eligible to receive the shingles vaccine without cost-sharing. In both cases, we continue to find that the ACA increased shingles coverage.

drops these individuals from the preferred specification. Regardless of the ages included in our sample, we find a statistically significant 5.2-6.6 percentage point increase in shingles vaccination.[19]

As an additional robustness test, Table 4 presents the regression discontinuity estimates obtained from equation (3).[20] 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. Columns 3 and 4 then examine the period in which adults 60 or older were eligible to receive the vaccine without cost-sharing. Regardless of whether we use OLS 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 3.0-4.1 percentage points, providing further evidence that it was the ability to receive the vaccine without cost-sharing that increased coverage.[21]

Table 5 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.[22] 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 of 2010, so we would not expect to observe

[19] Appendix Table 4 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.

[20] Appendix Table 6 shows that the observable righthand side characteristic varied smoothly through the discontinuity.

[21] We also explored a difference-in-discontinuities specification whereby we interacted the post-ACA variable with the righthand side variables from equation (3). Consistent with Table 3, we did not find any evidence that turning 60 was associated with any change in shingles vaccination during the pre-ACA period ($\hat{\beta} = 0.003$ with $p = 0.836$). However, in the post-period we estimated that turning 60 increased the probability of shingles vaccination by 2.7 percentage points, though the estimate was not statistically significant at conventional levels ($p = 0.116$).

[22] 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.

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

Table 6 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 righthand 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 4.8 percentage points for adults without a college degree. Meanwhile, those with a college degree saw an additional 3.3 percentage point increase for 8.1 percentage points total. In contrast, column 2 does not indicate any difference in vaccine take-up based on the respondent's sex. Column 3 shows that the ACA increased shingles vaccination by 3.7 percentage points for non-white respondents. While the point estimate suggests an additional 3.0 percentage point increase in vaccine take-up for white respondents, this latter relationship is not statistically significant after adjusting for the small number of clusters (p = 0.128).[23]

[23] Appendix Table 6 shows that these patterns remain after restricting the sample to those with health insurance.

4.2 Mechanisms

We next explore the possible channels through which the ACA may have increased shingles vaccination. Table 7 again fully interacts the righthand side variables from equation (1) with a group-specific indicator. Because the preventive services provision required health insurance plans to cover the vaccine without patient cost-sharing, we would expect the effect to be driven by insured individuals.[24] Consistent with this prediction, column 1 shows a statistically insignificant 1.9 percentage point increase in vaccine take-up among those without health insurance and an additional statistically significant 4.3 percentage point increase for those with insurance. Column 2 then shows that the increase was driven by those more connected to the health care system, as proxied by respondents reporting a recent doctor visit. Finally, column 3 explores whether the effect varied by the potential benefit of vaccination. While the ACA requires insurance plans to cover recommended preventive services free of charge, there are still non-monetary costs associated with taking the time to get vaccinated. Because shingles is caused by reactivation of the varicella zoster virus (chickenpox), those with a history of chickenpox have the most to gain from vaccination. Indeed, we find that adults with a history of chickenpox were 7.8 percentage points more likely to get the shingles vaccine after the ACA was implemented compared to a 3.0 percentage increase for those without a history of chickenpox.[25]

[24] 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 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.

[25] 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).

5. Conclusion

The COVID-19 pandemic has highlighted the difficulties policymakers 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 5.2 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 2020). 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),[26] the expected benefit of reduced risk of infection is worth $32 per vaccinated individual (0.0053 × $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

[26] 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.

(MedPAC 2021, Table 7-5 Page 254). 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 3 million more of these people to receive the shingles vaccine (57 million $\times$ 0.052). Thus, at a loss of $118 per vaccinated individual ($32 – 150), then accumulated over 3 million people, there was a social loss of $354 million at the vaccine's $150 price.[27] The vaccine would have to be priced at $32 for vaccination to be welfare neutral. If the vaccine was 100% 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 $46,864 for vaccination to be welfare neutral at a price of $150 per vaccinated individual (250 / (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 $40,864 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 National Health Interview Surveys, 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 when the ACA

[27] The current vaccine, RZV, is a 2-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 (NYT 2010). Because RZV offers almost twice as much protection at double the cost, the welfare implications are qualitatively similar.

required 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 which protect against diseases which are communicable or have higher mortality rates. 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 policymakers looking to improve adult vaccination rates should be mindful of the role of cost in driving vaccination decisions.

6. References

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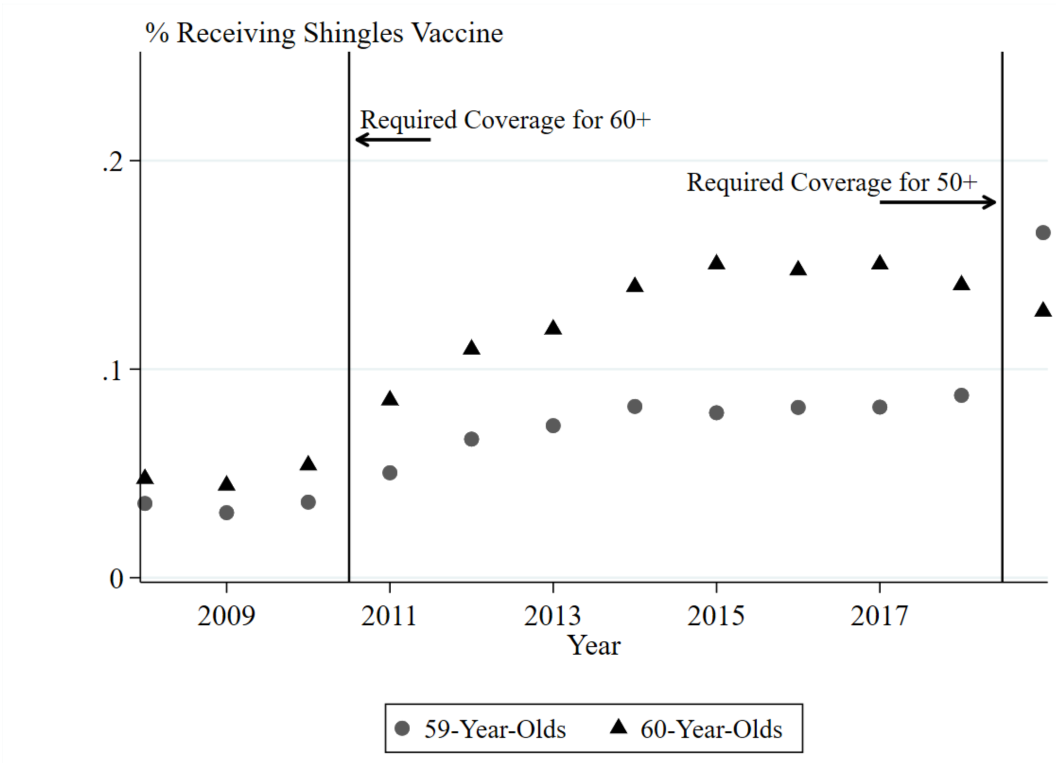
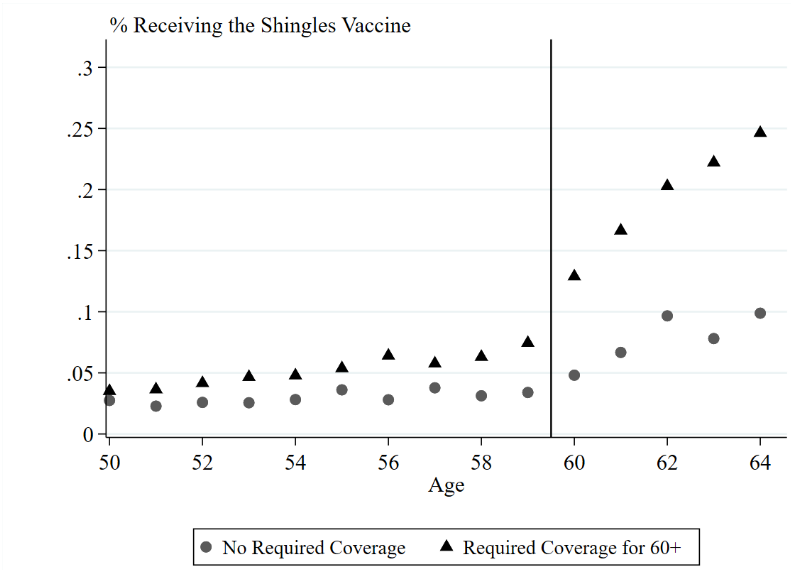
Figure 1: Shingles Vaccination Increased When Insurance Was Required to Cover the Vaccine Without Patient Cost-Sharing

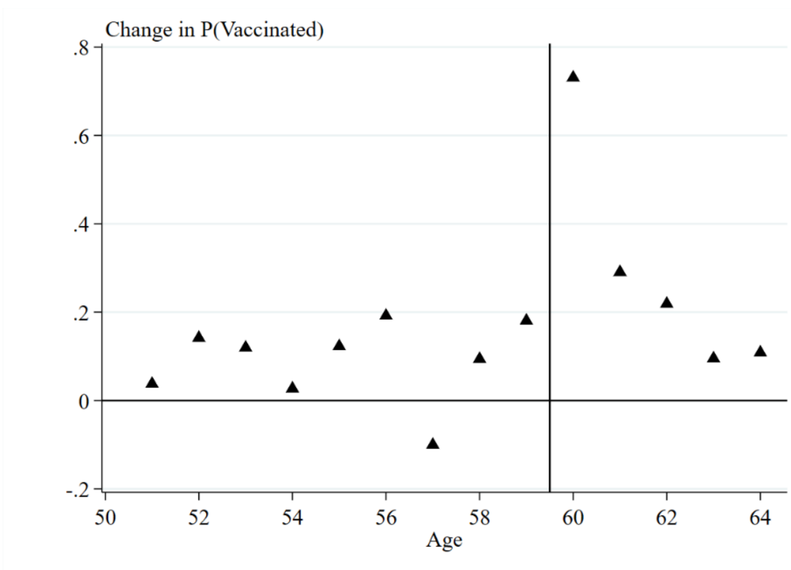


Source: National Health Interview Survey 2008-2019
Note: The grey circles plot the share of 59-year-olds who report receiving the shingles vaccine over time. The black triangles plot the share of 60-year-olds who report receiving the vaccine. The vaccine was required to be covered without patient cost-sharing 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.

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



(A)



(B)

Source: National Health Interview Survey 2008-2019

Note: The grey circles in Panel A denote the share of each age reporting that they had received the shingles vaccine during the period in which individuals 60+ were recommended to receive the vaccine but it was not yet required to be covered by health insurance. The black triangles denote the share when it was recommended for those 60+ and it was required to be covered by health insurance. Panel B indicates the difference in the probability of receiving the vaccine at age *A+1* compared to 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 health insurance.

Figure 3: Timeline of Relevant Policy Dates

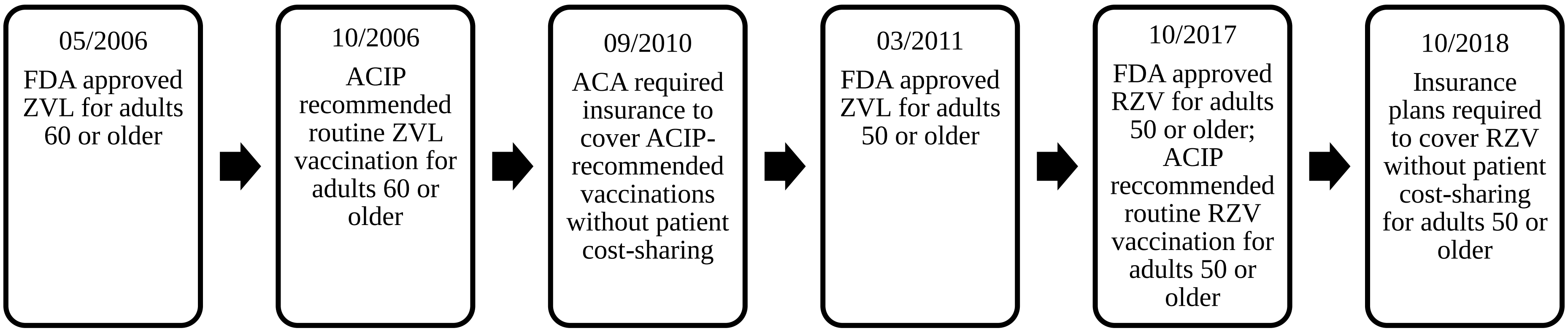
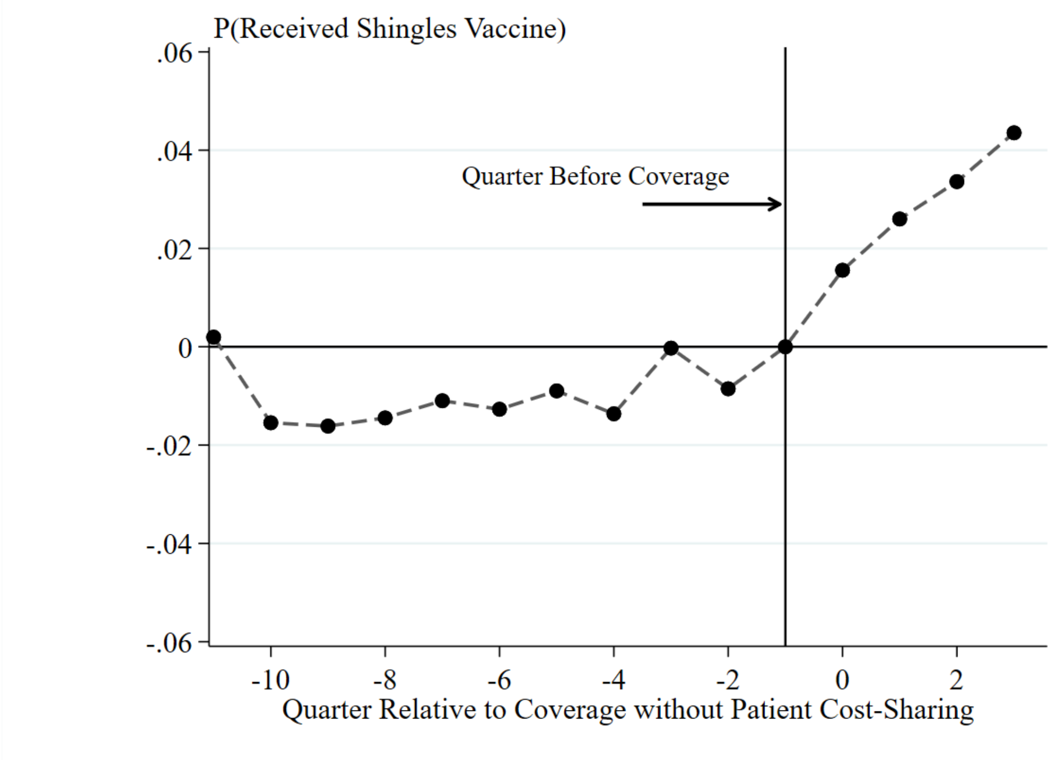


Figure 4: The Increase in Shingles Vaccination Was Limited to the Post-Period



Source: National Health Interview Survey 2008-2019

Note: 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 $p^{Post} = 0.735$).

Table 1: People Entitled to Receive the Shingles Vaccine without Patient Cost-Sharing Had Higher Vaccination Rates

	(1)	(2)	(3)
Panel 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**
Panel 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 2008-2019

Note: In Panel A, row T lists the share of adults 60 or older receiving ZVL and row C the share of adults under 60 receiving the ZVL. In Panel B, row T lists the share of adults under 60 receiving ZVL and row C the share of adults 60 or older receiving ZVL. 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 ZVL was required to be covered for those 60 or older and column 2 when ZVL was required to be covered for all adults 50 or older. The bolded values indicate the difference-in-differences estimates.

Table 2: Insurance Coverage for the Shingles Vaccine without Patient Cost-Sharing Increased Shingles Vaccination

	(1)	(2)	(3)
Required Coverage	0.059***	0.059***	0.052***
for Shingles Vaccine	(0.011)	(0.012)	(0.011)
	[0.009]	[0.008]	[0.006]
R^2	0.027	0.034	0.031
Mean	0.065	0.065	0.065
Observations	72,781	72,781	72,781
Age & Time FE?	Y	Y	Y
Additional Covariates?		Y	Y
Survey Weights?			Y

Source: National Health Interview Survey 2008-2019

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, 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 time-invariant census region fixed effects. Column 3 utilizes the survey weights. Robust standard errors, shown in parentheses, are clustered at the group-year level. Wild bootstrapped p-values are reported in brackets.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Table 3: The Relationship between Insurance Coverage for the Shingles Vaccine without Patient Cost-Sharing and Shingles Vaccination is Robust to Alternative Sample Choices

	(1)	(2)	(3)	(4)
Sample Ages →	50-61	50-64	58-61	50-57, 60-61
Required Coverage for Shingles Vaccine	0.052***	0.066***	0.061***	0.057***
	(0.011)	(0.010)	(0.006)	(0.008)
	[0.006]	[0.000]	[0.000]	[0.000]
R^2	0.031	0.073	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 2008-2019

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 50-64-year-old adults. Column 3 limits the sample to include 58-61-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 level. Wild bootstrapped p-values are reported in brackets.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Table 4: The Discontinuity in Shingles Vaccination at Age 60 Was Only Present When the Those Individuals Were Entitled to the Vaccine without Patient Cost-Sharing

	(1)	(2)	(3)	(4)
Sample Period →	No Coverage Requirement		Required Coverage for Age ≥ 60	
Specification →	OLS	CCT	OLS	CCT
1{Age ≥ 60}	0.003	0.014	0.030***	0.041***
	(0.014)	(0.013)	(0.010)	(0.011)
R^2	0.025	-	0.043	-
Observations	4,216	9,301	17,698	30,611

Source: National Health Interview Survey 2008-2019

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, Asian, with 'other' omitted), educational attainment (less than high school, high school degree, 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. Columns 1 and 3 limit the sample to 58-61-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. 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).

*** p < 0.01, ** p < 0.05, * p < 0.10

Table 5: The Vaccination Rate Increase Was Unique to the Shingles Vaccine

	(1)	(2)	(3)	(4)
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	High Risk Groups	High Risk Groups	All Adults
Required Coverage for Shingles Vaccine	0.015	-0.007	-0.010	0.000
	(0.010)	(0.005)	(0.008)	(0.013)
	[0.411]	[0.356]	[0.525]	[0.996]
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 2008-2019

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 50-61-year-old adults. Robust standard errors, shown in parentheses, are clustered at the group-year level. Wild bootstrapped p-values are reported in brackets.

*** p < 0.01, ** p < 0.05, * p < 0.10

Table 6: The Increase in Shingles Vaccination Was Larger for College Educated Adults

	(1)	(2)	(3)
Group Indicator →	College Degree	Male	White
Required Coverage for Shingles Vaccine	0.048**	0.056**	0.037**
	(0.011)	(0.012)	(0.011)
	[0.014]	[0.012]	[0.032]
Required Coverage for Shingles Vaccine × Group	0.033**	0.006	0.030
	(0.012)	(0.009)	(0.013)
	[0.025]	[0.618]	[0.128]
R^2	0.037	0.035	0.037
Observations	72,781	72,781	72,781

Source: National Health Interview Survey 2008-2019

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 righthand 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 health insurance, in column 2 whether the respondent had a college degree, in column 3 whether the respondent was male, and in column 4 whether the respondent was white. The sample is respondents 50-61-years-old. Robust standard errors, shown in parentheses, are clustered at the group-year level. Wild bootstrapped p-values are reported in brackets.

*** p < 0.01, ** p < 0.05, * p < 0.10

Table 7: The Increase in Shingles Vaccination Was Larger for Those with Health Insurance, a Recent Doctor Visit, and a History of Chickenpox

	(1)	(2)	(3)
Group Indicator →	Health Insurance Coverage	Recent Doctor Visit	Ever Had Chickenpox
Required Coverage for Shingles Vaccine	0.019	0.018	0.030**
	(0.011)	(0.010)	(0.006)
	[0.164]	[0.181]	[0.025]
Required Coverage for Shingles Vaccine × Group	0.043**	0.046***	0.048**
	(0.012)	(0.010)	(0.009)
	[0.046]	[0.007]	[0.041]
R^2	0.037	0.038	0.039
Observations	72,781	72,623	63,357

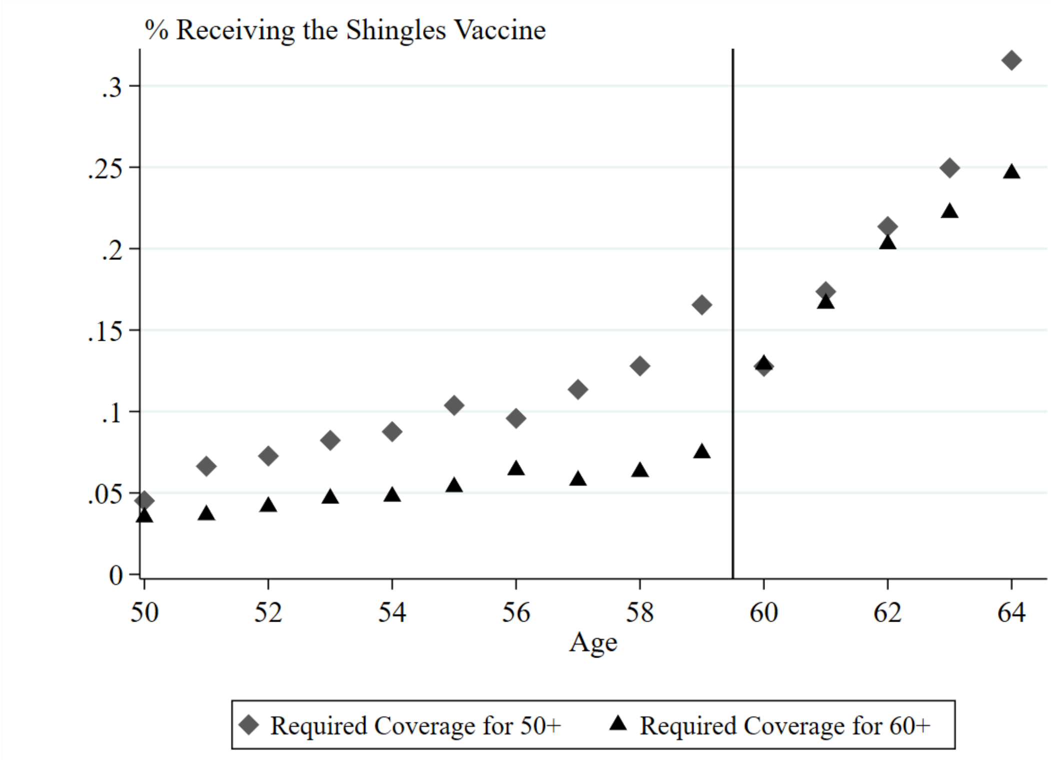
Source: National Health Interview Survey 2008-2019

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 righthand 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 health insurance, in column 2 whether the respondent reported a doctor visit within the prior 12 months, in column 3 whether the respondent reported a history of chickenpox. The sample is respondents 50-61-years-old. Robust standard errors, shown in parentheses, are clustered at the group-year level. Wild bootstrapped p-values are reported in brackets.

*** p < 0.01, ** p < 0.05, * p < 0.10

7. Appendix

Appendix Figure 1: There Was No Discontinuity in Shingles Vaccination at Age 60 After Health Insurance Was Required to Cover Vaccination with No Patient Cost-Sharing for Adults 50 or Older



Source: National Health Interview Survey 2010-2019

Note: The black triangles denote the share of each age receiving the shingles vaccine when the vaccine was required to be covered without patient cost-sharing for adults 60 or older. The grey diamonds indicate the share of each age reporting coverage during the period when the vaccine was required to be covered without patient cost-sharing for adults 50 or older.

Appendix Table 1: Summary Statistics

	(1)	(2)	(3)
	Full Sample	No Required Coverage	Required Coverage
Shingles Vaccination	0.065	0.048	0.131
Health Insurance	0.870	0.862	0.899
Male	0.460	0.460	0.462
Less than High School	0.123	0.127	0.109
High School Degree	0.270	0.272	0.263
Some College	0.306	0.306	0.307
College Degree	0.300	0.295	0.322
White	0.677	0.669	0.709
Black	0.147	0.152	0.126
Hispanic	0.119	0.122	0.106
Asian	0.044	0.045	0.042
Other	0.013	0.012	0.017
Northeast	0.172	0.171	0.177
Midwest	0.220	0.220	0.220
South	0.364	0.364	0.361
West	0.244	0.244	0.242

Source: National Health Interview Survey 2008-2019

Note: The summary statistics indicate the shares of the samples with each characteristic based on whether the adult was eligible to receive the shingles vaccine without patient cost-sharing.

Appendix Table 2: The ACA Preventive Services Provision Increased Shingles Vaccination in the BRFSS Data

	(1)	(2)	(3)
Required Coverage	0.107***	0.105***	0.069***
for Shingles Vaccine	(0.005)	(0.005)	(0.007)
	[0.000]	[0.000]	[0.000]
R^2	0.085	0.097	0.079
Mean	0.136	0.136	0.136
Observations	280,081	280,081	280,081
Age & Time FE?	Y	Y	Y
Additional Covariates?		Y	Y
Survey Weights?			Y

Source: Behavioral Risk Factor Surveillance System 2009-2019

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, 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 time-invariant census region fixed effects. Column 3 utilizes the survey weights. Robust standard errors, shown in parentheses, are clustered at the group-year level. Wild bootstrapped p-values are reported in brackets.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Appendix Table 3: Both the 2010 and 2019 Policy Changes Increased Shingles Vaccination

	(1)	(2)	(3)
Panel A: Sample Years 2008-2018			
Required Coverage	0.068***	0.068***	0.061***
for Shingles Vaccine	(0.007)	(0.007)	(0.008)
	[0.000]	[0.000]	[0.000]
R^2	0.026	0.033	0.031
Mean	0.061	0.061	0.061
Observations	66,510	66,510	66,510
Panel B: Sample Years 2011-2019			
Required Coverage	0.042**	0.040**	0.030
for Shingles Vaccine	(0.009)	(0.009)	(0.013)
	[0.021]	[0.027]	[0.143]
R^2	0.025	0.033	0.031
Mean	0.073	0.073	0.073
Observations	57,739	57,739	57,739
Age & Time FE?	Y	Y	Y
Additional Covariates?		Y	Y
Survey Weights?			Y

Source: National Health Interview Survey 2008-2019

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, 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 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 2008-2018. Panel B exploits only the second policy change by limiting the sample to 2011-2019. Robust standard errors, shown in parentheses, are clustered at the group-year level. Wild bootstrapped p-values are reported in brackets.

*** p < 0.01, ** p < 0.05, * p < 0.10

Appendix Table 4: The Righthand Side Covariates Varied Smoothly through ACIP's ZVL Recommendation Age of 60

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Health Insur.	Male	Less than High School	High School Degree	Some College	College Degree	White	Black	Hispan.	Asian	Other
Required Coverage	0.002	-0.010	-0.003	-0.009	0.001	0.011	-0.013	0.004	0.009	0.002	-0.002
for Shingles Vaccine	(0.007)	(0.009)	(0.005)	(0.009)	(0.012)	(0.012)	(0.009)	(0.007)	(0.006)	(0.003)	(0.002)
	[0.799]	[0.371]	[0.642]	[0.402]	[0.942]	[0.470]	[0.232]	[0.607]	[0.221]	[0.611]	[0.258]
R^2	0.013	0.001	0.003	0.001	0.001	0.003	0.010	0.006	0.005	0.002	0.002
Observations	72,781	72,781	72,781	72,781	72,781	72,781	72,781	72,781	72,781	72,781	72,781

Source: National Health Interview Survey 2008-2018

Note: The dependent variable in column 1 is an indicator for health insurance coverage, in column 2 for being male, in column 3 for having less than a high school degree, in column 4 for having a high school degree, in column 5 for having some college education, and in column 6 for having a four-year degree or more. The dependent variable in column 7 is an indicator for being white, in column 8 for being black, in column 9 for being Hispanic, in column 10 for being Asian, and in column 11 for being classified as 'other.' The independent variables include an indicator for whether the respondent was entitled to receive the shingles vaccine without patient cost-sharing, indicators for age, and year-by-quarter fixed effects. Robust standard errors, shown in parentheses, are clustered at the group-year level. Wild bootstrapped p-values are reported in brackets.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Appendix Table 5: The Righthand Side Covariates Varied Smoothly through ACIP's ZVL Recommendation Age of 60

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Health Insur.	Male	Less than High School	High School Degree	Some College	College Degree	White	Black	Hispan.	Asian	Other
Age ≥ 60	-0.002	-0.017	-0.004	-0.011	-0.003	0.017	-0.007	-0.005	0.002	0.011*	-0.001
	(0.010)	(0.017)	(0.011)	(0.015)	(0.015)	(0.015)	(0.015)	(0.011)	(0.010)	(0.006)	(0.004)
R^2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mean for 59-Year-Olds	0.889	0.464	0.119	0.257	0.313	0.301	0.711	0.141	0.099	0.036	0.012
Observations	18,149	18,149	18,149	18,149	18,149	18,149	18,149	18,149	18,149	18,149	18,149

Source: National Health Interview Survey 2010-2018

Note: The dependent variable in column 1 is an indicator for health insurance coverage, in column 2 for being male, in column 3 for having less than a high school degree, in column 4 for having a high school degree, in column 5 for having some college education, and in column 6 for having a four-year degree or more. The dependent variable in column 7 is an indicator for being white, in column 8 for being black, in column 9 for being Hispanic, in column 10 for being Asian, and in column 11 for being classified as 'other.' The independent variables include a continuous measure of age and an indicator for being above 60 years old. The sample period is 2010-2018 and the sample is limited to 58-61-year-olds. Robust standard errors are shown in parentheses.

*** p < 0.01, ** p < 0.05, * p < 0.10

Appendix Table 6: The Increase in Shingles Vaccination Was Larger for College Educated Adults Even After Limiting the Sample to Those with Health Insurance

	(1)	(2)	(3)
Group Indicator →	College Degree	Male	White
Required Coverage for Shingles Vaccine	0.051**	0.058**	0.042**
	(0.011)	(0.012)	(0.011)
	[0.015]	[0.013]	[0.031]
Required Coverage for Shingles Vaccine × Group	0.033**	0.010	0.028
	(0.011)	(0.010)	(0.013)
	[0.026]	[0.441]	[0.134]
R^2	0.038	0.036	0.037
Observations	63,291	63,291	63,291

Source: National Health Interview Survey 2008-2019

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 righthand side variables are fully interacted with an indicator for being a member of the group of interest. The indicator in column 1 is an indicator for 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 50-61-years-old with health insurance. Robust standard errors, shown in parentheses, are clustered at the group-year level. Wild bootstrapped p-values are reported in brackets.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$