The Welfare Implications of Risk Adjustment in Imperfectly Competitive Markets

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Abstract

Risk adjustment is a common policy for mitigating the effects of adverse selection when government regulation limits insurer ability to rate consumers according to their expected risks. I study the social welfare implications of risk adjustment. I first show theoretically that risk adjustment may reduce social welfare because it can increase the expected risk of consumers who select into the insurance pool. I then assess how risk adjustment affects social welfare in the Affordable Care Act (ACA) insurance exchanges. Using consumer-level data from the California exchange, I estimate demand for insurance and obtain estimates of marginal cost that I relate to premiums to account for adverse selection. I compute equilibrium premiums under alternative scenarios and find risk adjustment raises premiums for less costly exchange plans. However, there is minimal net effect on social welfare because the ACA's price-linked subsidies shield consumers from premium increases. I conduct policy simulations using the estimated model and find the impact of risk adjustment is sensitive to the subsidy design. If ACA price-linked subsidies were converted to fixed subsidies as proposed in some legislative alternatives to the ACA, risk adjustment would decrease annual per-capita consumer surplus by $200 and social welfare by $400.

Keywords: Adverse selection, risk adjustment, imperfect competition, health insurance, ACA.

Introduction

Governments have increasingly intervened in health insurance markets to address inefficiencies resulting from asymmetric information and limited competition. A common model for government intervention is managed competition, in which insurers compete for consumers in regulated markets called exchanges and must comply with rules that govern pricing and design of insurance contracts (Enthoven, 1978). The insurance exchanges established under the Affordable Care Act (ACA) are a prominent example of managed competition.

One of the principal regulatory decisions in the managed competition model is the degree to which insurers are permitted to rate consumers according to their expected risks. This decision involves an economic tradeoff between reclassification risk and adverse selection (Handel et al., 2015). Reclassification risk may arise when insurers can price a change in expected risk by increasing future premiums. Adverse selection could occur if insurers cannot use information on individual risk to rate policies. Limiting insurer ability to rate consumers according to their expected risks reduces reclassification risk, but exacerbates adverse selection. Adverse selection may cause low-risk consumers to underinsure, reducing social welfare (Rothschild and Stiglitz, 1976).

Risk adjustment is a key policy instrument used to mitigate the effects of adverse selection when insurers cannot rate consumers according to their expected risks. Under the ACA, risk adjustment requires that insurers with lower-than-average risk consumers make transfer payments to insurers with higher-than-average risk consumers. The transfer payments equalize the expected risk borne by each firm, thereby eliminating the effect of selection between firms on expected risk. The motivating principle behind risk adjustment is to mitigate adverse selection without exposing consumers to reclassification risk, enhancing social welfare.

In this paper, I study whether risk adjustment enhances or reduces social welfare in a market where (1) insurer ability to rate consumers according to their expected risks is limited; (2) risk adjustment perfectly equalizes risk across firms; and (3) firms have market power such that they can set prices above marginal cost. I focus on the primary rationale for risk adjustment as a policy tool targeting adverse selection. A secondary objective is to protect insurers from disproportionately high-risk draws of consumers; I exclude this objective from my analysis by assuming risk pools are large and other policies such as reinsurance are in place.

To study whether risk adjustment enhances or reduces social welfare, I specify a differentiated products model where firms first set premiums and then consumers select plans. I show theoretically that risk adjustment can be welfare-reducing even if it perfectly equalizes risk across firms. The reason is that risk adjustment incentivizes firms to set premiums that may increase the expected risk of those who select into the insurance pool. Expected consumer risk may increase if (1) firm premiums and expected risk are positively correlated and (2) firm cost and adverse selection are negatively correlated. If firm premiums and expected risk are positively correlated, risk adjustment is likely to compress equilibrium premiums such that more expensive plans become cheaper and cheaper plans become more expensive. Negative correlation between firm cost and adverse selection leads to the departure of low-risk consumers from the market. For example, a cheap "bronze" plan with high cost sharing may attract disproportionately low-risk and low willingness-to-pay consumers compared to an expensive "platinum" plan with low cost sharing. Risk adjustment imposes an additional cost on the bronze plan, likely leading to a higher premium. This increase may cause some of its customers to exit the market rather than pay the higher premium or shift to the platinum plan, raising the average risk in the market and reducing social welfare.

I then study the impact of risk adjustment in the ACA exchanges using consumer-level data from the California state exchange. The data contain about 2.5 million records across the 2014 and 2015 plan years, accounting for approximately 15 percent of nationwide marketplace enrollment (Department of Health and Human Services, 2015). Detailed demographic information enables me to precisely calculate (1) the premium that consumers face for each plan in their choice sets; (2) the consumer-specific subsidy received for each plan and (3) the consumer-specific penalty imposed for forgoing coverage. I combine the consumer-level demand data with firm-level financial data from several sources, including the ACA medical loss ratio (MLR) reports.

Using these data, I estimate consumer-level demand and firm-level cost. First, I estimate demand for health insurance using a nested logit discrete choice model. To address the potential endogeneity of the premium, I use variation in premiums created by ACA regulations, including subsidy eligibility rules and exemptions from the individual mandate. Second, I obtain non-parametric estimates of plan marginal costs by inverting the firm's first-order conditions for profit maximization. I relate these estimates to premiums to measure how marginal costs vary with premiums. Adverse selection is present if higher premiums have a positive and statistically significant effect on marginal costs.

My estimates of demand and cost are consistent with theory. I find that low-income individuals, young adults, single individuals, and males have more premium-elastic demand. I estimate that a $100 annual premium increase would reduce a plan's demand by 20 percent, on average. If the premiums of all exchange plans were to increase by $100 per year, demand for exchange coverage would fall by about 2 percent. My estimates of cost provide statistically significant evidence of adverse selection. Controlling for plan generosity, I find that an increase in premiums results in higher marginal cost.

After estimating demand and cost, I simulate the impact of risk adjustment in the ACA exchanges. I find that risk adjustment compresses equilibrium premiums such that more expensive gold and platinum plans become cheaper and cheaper bronze and silver plans become more expensive. Consumer welfare increases by approximately $200 because premiums for more expensive plans decline and the ACA's price-linked subsidies offset the higher premiums for cheaper plans. Total social welfare is about the same under risk adjustment because the increase in consumer welfare is offset by an increase in subsidy spending.

These results suggest that the subsidy design plays a critical role in determining the welfare impact of risk adjustment. I simulate the impact of risk adjustment if fixed subsidies or vouchers that are set independently of premiums were to replace ACA subsidies, as proposed in ACA alternatives such as the American Health Care Act of 2017. In contrast to the ACA's price-linked subsidies, I find that risk adjustment reduces per-capita consumer surplus by about $200 and per-capita total social welfare by about $400 under vouchers. Because vouchers do not adjust to premium increases, consumers are exposed to any premium increases resulting from risk adjustment and some low-risk consumers choose to forgo insurance as a result, reducing social welfare.

The literature on risk adjustment is extensive (see Ellis (2008) and Breyer et al. (2012) for thorough reviews). While considerable research examines how well risk adjustment programs equalize firm risk (Brown et al., 2014; Newhouse et al., 2015; Geruso et al., 2016), comparatively less work has studied whether equalizing risk is welfare-enhancing (Handel et al., 2015; Layton, 2017). Layton (2017) finds that in perfectly competitive insurance markets, risk adjustment yields welfare gains by reducing inefficient consumer sorting between plans. Few studies have assessed the welfare impact of risk adjustment in the imperfectly competitive insurance markets that are observed in practice. Mahoney and Weyl (2017) develop a theoretical framework of risk adjustment in a setting such as Medicare Advantage (MA) where risk adjustment is coupled with external funding or subsidies that equate the risk borne by firms to the risk of those choosing the outside option. They show that firms with market power can capture part of the subsidy, resulting in higher premiums, reduced coverage, and lower social welfare. I build on their theoretical analysis by demonstrating that risk adjustment could also be welfare-reducing when it is not coupled with external funding.

Recent work has studied the economic tradeoffs between price-linked subsidies that adjust to premium changes and fixed subsidies or vouchers that are set independently of premiums. Jaffe and Shepard (2017) find that price-linked subsidies can result in higher premiums and lower social welfare relative to vouchers. Tebaldi (2017) finds that replacing the ACA price-linked subsidy with a voucher of the same amount would reduce average markups by 11 percent. In previous work, I simulate how the subsidy design interacts with the ACA's individual mandate and find that the mandate has little welfare effect in a market with price-linked subsidies, but is welfare-improving in a market with vouchers (Saltzman, 2017). In addition to the literature on subsidy design, my analysis links to recent work considering interactions between adverse selection and market power (Lustig, 2010; Starc, 2014; Ericson and Starc, 2015; Mahoney and Weyl, 2017). I contribute to the empirical literature that examines the welfare impact of adverse selection in health insurance markets (Cutler and Reber, 1998; Pauly and Herring, 2000; Cardon and Hendel, 2001; Einav et al., 2013; Handel, 2013; Hackmann et al., 2015). This study also adds to the economic literature studying the early experience of the ACA exchanges (Tebaldi, 2017; Frean et al., 2017; Abraham et al., 2017; Sacks, 2017).

This paper is organized as follows. Section 1 provides background on the ACA exchanges. Section 2 builds a model of risk adjustment that I take to the data. Section 3 describes the data I use to estimate the model. Section 4 details how I estimate the model. Section 5 presents estimates of demand and claims. Section 6 simulates the welfare impact of risk adjustment. Section 7 simulates how a change in the subsidy design affects the welfare impact of risk adjustment. Section 8 concludes.

1 Policy Background

Risk adjustment plays an important role in the ACA state insurance exchanges, where eligible consumers can receive financial assistance for purchasing individual market health insurance.[1] Exchange consumers select a plan from one of the four actuarial value (AV) tiers: bronze (60 percent AV), silver (70 percent AV), gold (80 percent AV), and platinum (90 percent AV). Select individuals, mostly those under age 30, can buy a more basic catastrophic plan. In California, plan benefit structures are standardized such that the cost sharing parameters for all plans offered in a metal tier are the same. Consumers with incomes below 250 percent of the federal poverty level (FPL) are eligible for cost sharing reductions (CSRs) that help them afford their deductibles, copays, and other cost sharing obligations. Consumers must purchase a silver tier plan to receive CSRs.

The ACA places a number of restrictions on the ability of insurers to rate consumers according to their expected risks. Insurers cannot deny consumers coverage based on a preexisting condition and must comply with modified community rating regulations that limit premium discrimination to three criteria: age, tobacco usage, and geographic residence. Insurers can charge a 64-year old up to 3 times as much as a 21-year old according to the default age rating curve (Centers for Medicare and Medicaid

[1] To be eligible for premium subsidies, consumers must satisfy the following criteria: 1) have income between 100 percent and 400 percent of the federal poverty level (FPL), 2) have citizenship or legal resident status, 3) be ineligible for public insurance such as Medicare, Medicaid, or the Children's Health Insurance Program (CHIP) and 4) lack access to an "affordable plan offer" through employer-sponsored insurance either as an employee or as a dependent. An employer offer for the 2014 plan year is defined as "affordable" if the employee's contribution to the single coverage plan is less than 9.5 percent of the employee's household income.

Services, 2013). Smokers face up to a 50 percent premium surcharge, although California and several other states prohibit tobacco rating. States also define geographic rating areas, usually composed of one or more counties, in which insurers must charge all consumers the same premium, conditional on age and tobacco usage. Insurers can opt to serve only part of a rating area.

One of the key ACA policy tools for mitigating adverse selection resulting from community rating regulations is risk adjustment. Firms with lower-than-average risk make transfer payments to firms with a higher-than-average risk such that net transfer payments sum to zero. The ACA's zero-sum transfer design contrasts with the design used in Medicare Advantage, where risk adjustment payments are benchmarked to the risk of those choosing the outside option (i.e., traditional Medicare) and do not necessarily sum to zero. Risk adjustment occurs at the state level for all firms participating in the individual market, including both exchange and off-exchange individual plans. States have the option of merging the individual and small group markets for purposes of risk adjustment, but only Vermont has done so. Risk adjustment therefore reduces the incentives of firms to market in favorable geographic regions of the state or off the exchanges.

Risk adjustment is only one of several ACA policy tools that seek to mitigate adverse selection that may result from community rating. Prominent among these policies is the individual mandate, which requires most consumers to purchase coverage or pay a penalty.[2] Exemptions from the mandate are made for several reasons, most notably for consumers who have income below the tax filing threshold or who do not have access to an affordable insurance plan (defined as a plan with a premium less than 8 percent of income in 2014). ACA premium subsidies also mitigate adverse selection by shielding consumers from premium increases. The amount of the subsidy equals the difference between the premium of the benchmark plan and the consumer's income contribution cap. The benchmark plan is the second-lowest cost silver plan available to the consumer and may vary between consumers because of heterogeneous entry into markets within a state marketplace. The consumer's income contribution cap ranged from 2 percent of annual income for a consumer earning 100 percent of FPL and 9.5 percent of annual income for a consumer earning 400 percent of FPL in the 2014 plan year. Consumers can apply the premium subsidy towards the premium of any metal plan offered in their marketplace. Reinsurance and risk corridors were temporary programs in effect between 2014 and 2016 that sought to stabilize the exchanges during their initial years of operation. Reinsurance funds help to offset the realized claims of high-utilization consumers and risk corridors reduce the variability of insurers' final earnings or losses.

[2]The amount of the penalty was phased in between the 2014 and 2016 plan years. For a single person, the penalty was the greater of $95 or 1 percent of income in 2014. By the 2016 plan year, the penalty was the greater of $695 or 2.5 percent of income.

2 Model

In this section, I develop a model of risk adjustment in the ACA exchanges that I take to the data. I consider a two-stage model where insurers first set premiums and then households select a plan. The design of the model reflects two key empirical considerations: (1) identification of the impact of risk adjustment in the complex ACA policy environment and (2) the availability of data. To address the first concern, I model the ACA community rating reforms and control for the subsidy design, individual mandate, and reinsurance program, which are likely to have important interaction effects with risk adjustment. Second, I structure the model to exploit the rich consumer-level enrollment data on plan choices and the more limited firm-level data on financial costs. After constructing the model, I conclude this section with several examples to illustrate how risk adjustment can affect social welfare in the model.

2.1 Demand

This subsection considers the second-stage problem where households choose the plan that maximizes utility. Households can either select an exchange plan or choose the outside option of forgoing insurance. Household i's utility for plan j equals

$$U_{ij} = \alpha(p_{ij}(\mathbf{p}) - \rho_i) + x_j'\beta + d_i'\varphi + p_{ij}(\mathbf{p})d_i'\gamma + \xi_{ij} + \epsilon_{ij} \tag{1}$$

where $\mathbf{p}$ is the vector of base premiums across all plans, $p_{ij}(\mathbf{p})$ is the premium household i pays for plan j including premium subsidies, ρ_i is the penalty for not purchasing coverage, x_j is a vector of observed product characteristics, d_i is a vector of demographic characteristics, ξ_{ij} is a vector of unobserved product characteristics which could vary across consumers, and ϵ_{ij} is an error term. Household i's utility for the outside option U_{i0} is normalized to zero. The specification of utility equation (1) captures potential heterogeneity in preferences across demographic groups. The parameter φ represents each demographic group's taste for any exchange plan relative to the outside option. The parameter γ measures premium sensitivity across important demographic attributes such as age and income that may be correlated with expected risk.

The ACA's community rating rules and subsidy formula govern how the plan base premiums determine what consumers pay. Firms set a base premium for each plan that they offer. The base premium is charged to the reference consumer, which I define as a 21-year-old nonsmoker living in Los Angeles County, CA. The subsidized premium $p_{ij}(\mathbf{p})$ is determined from $\mathbf{p}$ by: (1) multiplying plan j's base premium p_j by the household's rating factor r_{ij}, which accounts for the age, smoking status, and geographic residence of the household's members and (2) deducting the household's subsidy, which is computed as a function of the household's income and the premium of the benchmark plan. Because the price of choosing the outside option equals the mandate penalty, I deduct the penalty from the household's premium in utility equation (1).

2.2 Supply and Equilibrium

This subsection uses a differentiated products Bertrand model to analyze the first-stage problem where insurers set premiums to maximize profit. Without risk adjustment, a risk-neutral profit-maximizing firm f maximizes

$$\pi_f(\mathbf{p}) \quad = \quad R_f(\mathbf{p}) - (1-\tau_f)C_f(\mathbf{p}) - V_f - FC_f \tag{2}$$

where $R_f(\mathbf{p})$ is total premium revenue collected, $C_f(\mathbf{p})$ is total claims incurred, V_f is variable administrative cost, FC_f is fixed administrative cost, and τ_f is the actuarial value of the reinsurance contract. The actuarial value of the reinsurance contract is the expected percentage of firm f's claims that the program is expected to pay, summarizing the nonlinear reinsurance contract defined by the attachment point, coinsurance, and reinsurance cap. The first-order condition corresponding to (2) is given by

$$MR_j(\mathbf{p}) \quad = \quad (1-\tau_f)MC_j(\mathbf{p}) + v_f \frac{\partial q_f(\mathbf{p})/\partial p_j}{\partial q_j(\mathbf{p})/\partial p_j} \tag{3}$$

for each plan j offered by firm f, where $MR_j(\mathbf{p})$ is marginal revenue, $MC_j(\mathbf{p})$ is marginal claims, v_f is per-member variable administrative cost, $q_j(\mathbf{p})$ is plan j's demand, and $q_f(\mathbf{p})$ is firm f's total demand. The right-hand side of (3) is marginal cost and consists of both marginal claims and variable administrative cost. The fraction $(\partial q_f(\mathbf{p})/\partial p_j)/(\partial q_j(\mathbf{p})/\partial p_j)$ lies in the interval $[0,1]$ and measures the degree to which consumers substitute to a plans offered by other firms if it increases the premium for plan j (it equals 0 if there is no substitution and 1 if there is complete substitution to plans offered by other firms).

To model risk adjustment, I define (1) the firm's risk-adjusted share of total claims $s_f(\mathbf{p})$ and (2) the firm's efficiency score ϕ_f. The firm's risk-adjusted share takes into account the generosity of selected plans and any associated moral hazard associated with choosing a more generous plan. If all plans have the same actuarial value, the risk-adjusted share equals the firm's market share. The firm's efficiency score accounts for all unobserved factors that may cause a firm's net cost after risk adjustment to deviate from its risk-adjusted share of total claims. It may represent a firm's bargaining power or ability to exploit the risk adjustment formula. Firms with a higher-than-average efficiency score have $\phi_f > 1$ and firms with a lower-than-average efficiency score have $\phi_f < 1$. The risk adjustment transfer can be written as

$$RA_f(\mathbf{p}) \quad = \quad \phi_f C_f(\mathbf{p}) - s_f(\mathbf{p})C(\mathbf{p}) \tag{4}$$

where $C(\mathbf{p})$ is total claims incurred by all firms. Formula (4) indicates that the transfer equals the plan's expected claims (scaled by the plan's efficiency score) minus its risk-adjusted share of total claims. If its incurred claims are greater than its risk-adjusted share of total claims, the plan receives a risk adjustment transfer payment. Conversely, the plan makes a transfer payment if its incurred claims are less than its risk-adjusted share of total claims. Importantly, the risk adjustment transfers net to zero such that $\sum_f RA_f(\mathbf{p}) = 0$.

Adding the risk adjustment transfer to the firm's profit function yields

$$\pi_f(\mathbf{p}) \quad = \quad R_f(\mathbf{p}) - s_f(\mathbf{p})C(\mathbf{p}) - (1 - \phi_f - \tau_f)C_f(\mathbf{p}) - V_f - FC_f \tag{5}$$

The corresponding first-order condition is given by

$$MR_j(\mathbf{p}) \quad = \quad \overline{MC}_j(\mathbf{p}) + (1 - \phi_f - \tau_f)MC_j(\mathbf{p}) + v_f \frac{\partial q_f(\mathbf{p})/\partial p_j}{\partial q_j(\mathbf{p})/\partial p_j} \tag{6}$$

for each plan j offered by the firm. With some abuse of terminology, I refer to $\overline{MC}_j(\mathbf{p})$ as "average marginal claims," which are what plan j's marginal claims would have been if its enrollees had average risk. Average marginal claims differ by plan for two reasons: (1) there is a selection effect that depends on the slope of its average cost curve and (2) expected marginal claims decrease with greater cost sharing. A comparison of equation (3) with equation (6) reveals how risk adjustment changes firm incentives. Assuming the efficiency score $\phi_f = 1$, firms respond to what their plans' expected marginal claims would be if their enrollees were average risk, rather than the expected marginal claims of their risk pools. For firms that draw enrollees with lower-than-average risk, risk adjustment raises marginal cost. Conversely, firms with higher-than-average risk face lower marginal cost under risk adjustment. Equation (6) indicates that profit-maximizing firms adjust their premiums to reflect these changes in marginal cost.

Appendix B shows how every variable in the model can be written in terms of four variables that I can estimate, including: (1) the probability $q_{ij}(\mathbf{p})$ that household i selects plan j; (2) the partial derivative $\partial q_{ik}(\mathbf{p})/\partial p_{ij}(\mathbf{p})$ for all plans j and k; (3) the firm's average claims function $c_f(\mathbf{p})$; and (4) the vector of claim slopes with elements $\partial c_f(\mathbf{p})/\partial p_j$. The claim slope measures how firm average claims respond to a plan premium change and plays a key role in determining the combined effect of adverse selection and moral hazard. Assuming no moral hazard, large positive values of the claim slope indicate the presence of adverse selection, while negative values of the claim slope indicate the presence of advantageous selection. When moral hazard is present, the claim slope is likely to be negative for more generous platinum plans; increases in platinum plan premiums are likely to incentivize consumers to choose less generous plans or to select a plan offered by another firm. For a less generous bronze plan, the claim slope is likely to be positive when moral hazard is present.

The risk adjustment formula used in the ACA setting differs slightly from formula (4). Appendix C derives the ACA risk adjustment transfer formula and price equilibrium. Equations (3), (6), and (22) provide an empirical framework for the first-stage problem.

2.3 Examples

I now use the model to show how risk adjustment can either enhance or reduce social welfare. Risk adjustment may reduce social welfare if (1) premiums and expected risk are positively correlated and (2) firm cost and adverse selection are negatively correlated. Risk adjustment is likely to compress premiums, making cheaper plans more expensive and more expensive plans cheaper, if premiums without risk adjustment are positively correlated with expected risk. Low-risk consumers may exit the exchange in response to higher premiums for cheaper plans if those plans face stronger adverse selection.

To illustrate these predictions in the context of the model, I construct a simple example where premiums and expected risk are positively correlated and firm cost and adverse selection are negatively correlated. There are two insurers, L and H, that each sell a single plan with the same actuarial value. Risk adjustment is the only policy in place to mitigate the effects of adverse selection (i.e., premium subsidies, the individual mandate, and reinsurance are no longer in effect). Risk rating is completely prohibited such that firms L and H must charge all consumers the community-rated premiums p_L and p_H, respectively. The firms have the same bargaining power and ability to exploit risk adjustment such that $\phi_L = \phi_H = 1$ and there are no administrative or fixed costs.

To complete the setup of the example, I specify the firms' demand and average claims equations. The firms have the symmetric linear demand functions

$$\begin{aligned} q_L(\mathbf{p}) &= a - e_1 p_L + e_2 p_H \\ q_H(\mathbf{p}) &= a + e_2 p_L - e_1 p_H \end{aligned} \tag{7}$$

where $a > 0$ and $e_1 > e_2 > 0$ such that the own-premium effect exceeds the cross-premium effect. I assume that firms L and H have the asymmetric linear average claims functions

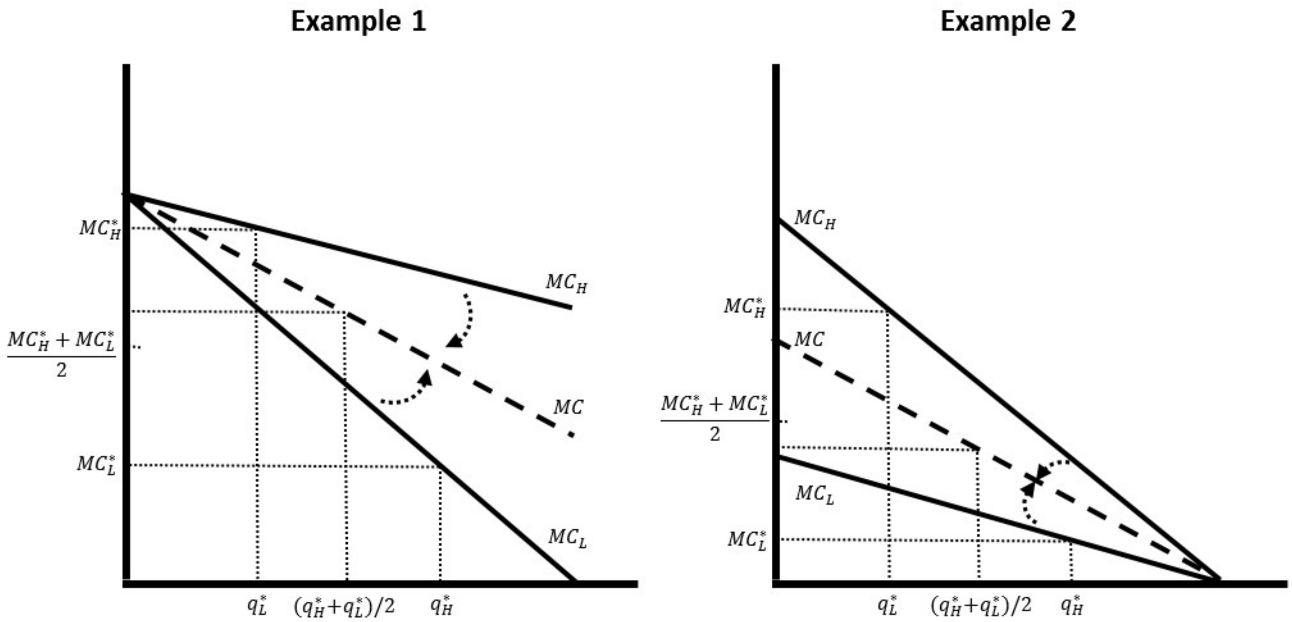
$$\begin{aligned} c_L(\mathbf{p}) &= \kappa - \lambda_1 q_L(\mathbf{p}) \\ c_H(\mathbf{p}) &= \kappa - \lambda_2 q_H(\mathbf{p}) \end{aligned} \tag{8}$$

where the intercept $\kappa > 0$ and the slope $\lambda_1 > \lambda_2 > 0$.

The demand equations (7) and the average claims equations (8) imply that the level of demand is symmetric, but the risk composition of demand may differ. The functional form of the average claims equations (8) has two important implications. First, firm L has weakly lower cost than firm H if the two firms charge the same premium. Firm L's lower cost may reflect its superior ability to attract low-risk consumers through means such as targeted advertising or strategic marketing. Second, it follows from the parameter constraint $\lambda_1 > \lambda_2 > 0$ that firm L faces stronger adverse selection, which means that the expected cost of its marginal consumer is more sensitive to premium changes. Firm L's aggressive targeting of low-risk consumers may result in greater sensitivity of the expected cost of its marginal consumer to premium changes. The strength of adverse selection can be represented mathematically as the magnitude of the slope of the marginal claims curves, $MC_L(p_L, BR_H(p_L))$ and $MC_H(BR_L(p_H), p_H)$, where $BR_L(\cdot)$ and $BR_H(\cdot)$ are the best response functions for firm L and H, respectively. Firm L faces stronger adverse selection because the magnitude of the slope of its marginal claims curve (with respect to quantity) equals $2\lambda_1$, while the magnitude of the slope of firm H's marginal claims curve equals $2\lambda_2$. The left panel of Figure 1 provides a visual representation of the firms' marginal claims functions. Firm L's marginal cost curve lies below firm H's marginal cost curve and has a steeper slope.

Before presenting the formal argument for why risk adjustment reduces welfare in this example, I first give an intuitive argument using Figure 2. Risk adjustment rotates firm L's marginal claims curve upwards and firm H's marginal claims curve downwards such that both have the same marginal claims function MC. Both demand and claims are symmetric under risk adjustment. Hence, the firms set the same premium in equilibrium; firm L's premium increases and firm H's premium decreases. Average claims risk in the market increases because the expected cost of firm L's marginal consumer is more responsive to premium changes than the expected cost of firm H's marginal consumer (i.e., firm L faces greater adverse selection). Total coverage in the market falls because of the adverse changes in the risk mix of consumers. Higher average premiums and less coverage reduce consumer welfare, as shown in Figure 2 by comparing the relative sizes of the shaded regions for firms L and H. Firm profit increases for firm H and decreases for firm L. Total industry profit declines because risk adjustment increases the proportion of insured consumers covered by the less cost efficient firm (i.e., firm H). The

Figure 1: Effect of Risk Adjustment on Firm Marginal Claims



Notes: Figure shows how risk adjustment affects the firms' marginal claims curves $MC_L \equiv MC_L(p_L, BR_H(p_L))$ and $MC_H \equiv MC_H(BR_L(p_H), p_H)$. The left panel corresponds to the first example where firms have the average claims functions given in (8). Firm L has lower marginal claims and faces stronger adverse selection, as indicated by its steeper marginal cost curve as a function of quantity. Risk adjustment rotates firm L's marginal claims curve upwards and firm H's marginal claims curve downwards such that both have the same marginal claims function MC. The right panel corresponds to the second example where firms have the average claims functions given in (9). Firm L still has lower marginal claims, but faces weaker adverse selection than firm H.

net impact of risk adjustment on social welfare is negative.

Now I formalize the argument. Define consumer surplus for the two firms as

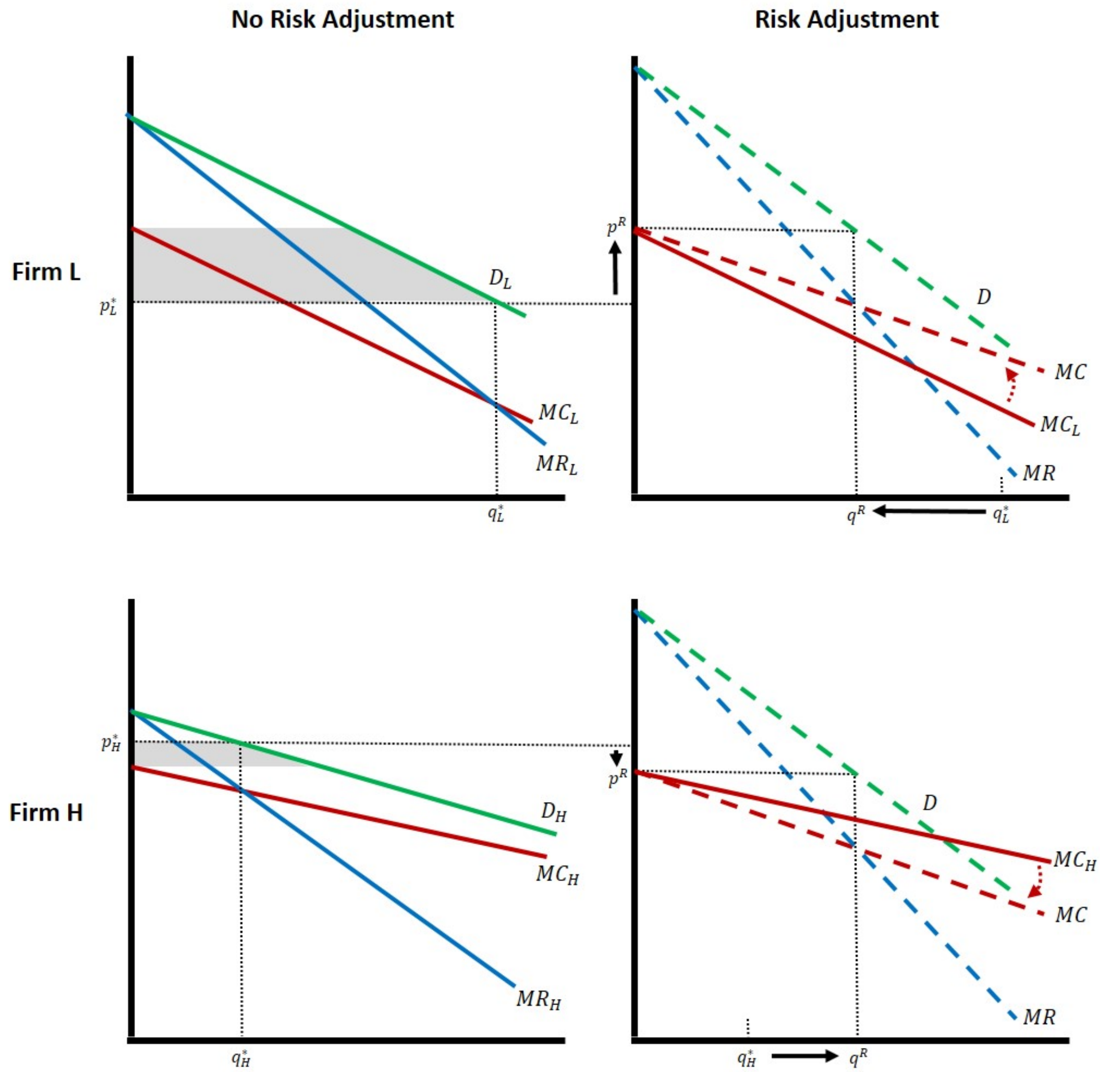
$$CS_L(\mathbf{p}) \equiv \int_{p_L}^{p_{0L}} q_L(x, p_H)dx = 0.5(p_{0L} - p_L)q_L(\mathbf{p})$$

$$CS_H(\mathbf{p}) \equiv \int_{p_H}^{p_{0H}} q_H(p_L, x)dx = 0.5(p_{0H} - p_H)q_H(\mathbf{p})$$

where $p_{0L} \equiv (a + e_2 p_H)/e_1$ and $p_{0H} \equiv (a + e_2 p_L)/e_1$ are the premiums that equate firm L's and firm H's quantity to 0, respectively. Denote $\pi_L(\mathbf{p})$ as the profit function for firm L and $\pi_H(\mathbf{p})$ as the profit function for firm H. The social welfare function $SW(\mathbf{p})$ sums consumer surplus and profit across the two firms. Proposition 2.1 characterizes the welfare impact of risk adjustment in this example.

Proposition 2.1. *Let the set of firms $F = \{L, H\}$ and suppose firm demand is given by (7) and firm*

Figure 2: Impact of Risk Adjustment When Adverse Selection and Firm Cost Are Negatively Correlated



Notes: Figure shows how risk adjustment affects the equilibrium between two imperfectly competitive firms L and H, where firm L has lower marginal cost and faces stronger adverse selection. Risk adjustment gives both firms the same marginal claims curve MC and marginal revenue curve MR. Firm L's enrollee population declines by a larger amount than the amount that firm H's enrollee population increases. Firm L's premium also increases by more than firm H's premium decreases. The loss in consumer surplus for firm L's plan exceeds the gain in consumer surplus for firm H's plan, as indicated by the relative sizes of the shaded regions.

claims are given by (8) where $a > 0, e_1 > e_2 > 0, \kappa > 0$ and $\lambda_1 > \lambda_2 > 0$. Suppose that the parameter constraints (13) and (14) in Appendix A are satisfied such that the problem is well-defined. Define (p_L^*, p_H^*) as the equilibrium premium vector in a market without risk adjustment and (p_L^R, p_H^R) as the equilibrium premium vector in a market with risk adjustment. Then risk adjustment

1. *Increases the average premium such that* $p_L^R + p_H^R > p_L^* + p_H^*$

2. *Decreases insurance coverage such that* $q_L(p_L^R, p_H^R) + q_H(p_L^R, p_H^R) < q_L(p_L^*, p_H^*) + q_H(p_L^*, p_H^*)$

3. *Increases average claims such that* $c_L(p_L^R, p_H^R) + c_H(p_L^R, p_H^R) > c_L(p_L^*, p_H^*) + c_H(p_L^*, p_H^*)$

4. *Decreases consumer surplus such that* $CS_L(p_L^R, p_H^R) + CS_H(p_L^R, p_H^R) < CS_L(p_L^*, p_H^*) + CS_H(p_L^*, p_H^*)$

5. *Decreases total profit such that* $\pi_L(p_L^R, p_H^R) + \pi_H(p_L^R, p_H^R) < \pi_L(p_L^*, p_H^*) + \pi_H(p_L^*, p_H^*)$

6. *Decreases social welfare such that* $SW(p_L^R, p_H^R) < SW(p_L^*, p_H^*)$.

Proof. See Appendix A. □

The key to the negative welfare result in Proposition 2.1 is negative correlation between firm cost and adverse selection that leads to the departure of low-risk consumers from the exchange. If instead firm cost and adverse selection are positively correlated, the impact of risk adjustment on welfare could be positive. Instead of (8), suppose firms L and H have the linear average claims functions

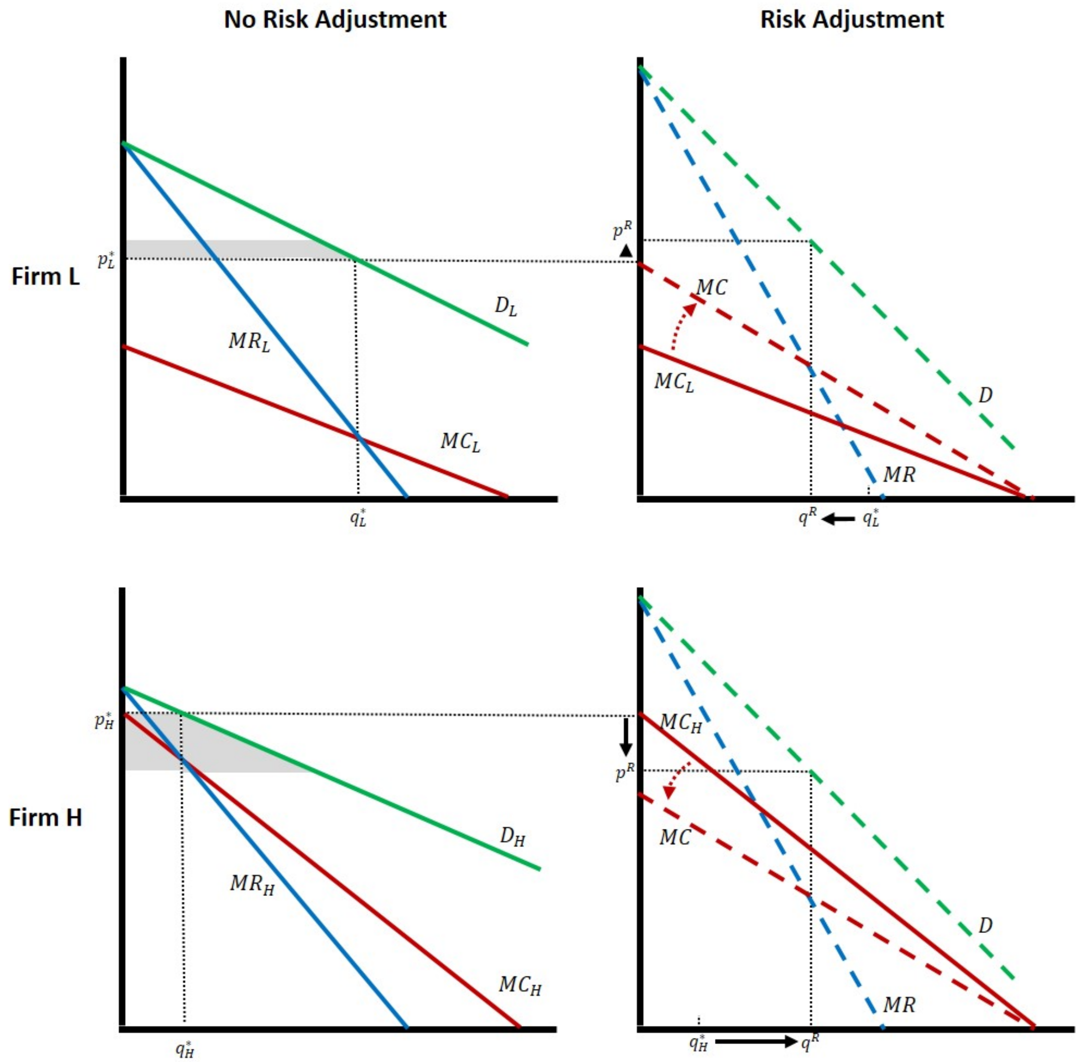
$$\begin{aligned} c_L(\mathbf{p}) &= \lambda_2\kappa - \lambda_2 q_L(\mathbf{p}) \\ c_H(\mathbf{p}) &= \lambda_1\kappa - \lambda_1 q_H(\mathbf{p}) \end{aligned} \tag{9}$$

where $\kappa > 0$ and $\lambda_1 > \lambda_2 > 0$. Firm L still has lower marginal claims, but now faces weaker adverse selection because $\lambda_1 > \lambda_2$. This situation could arise if the benefits of firm L's strategic marketing to low-risk consumers spill over to firm H by increasing general awareness and interest in exchange coverage. The spillover effect increases as more low-risk consumers opt into the market and the difference between the firms' marginal cost curves narrows at higher quantities, as shown in the right panel of Figure 1. Figure 3 shows that total coverage in the market increases. Lower average premiums and expanded coverage enhance consumer welfare, as shown in Figure 3 by comparing the relative sizes of the shaded regions for firms L and H. As in the previous example, firm L's profit declines, firm H's profit increases, and total industry profit declines. The net impact of risk adjustment on social welfare is ambiguous. Proposition 2.2 formalizes these results. Table 1 summarizes the equilibrium and welfare results for the two examples.

Proposition 2.2. *Let the set of firms* $F = \{L, H\}$ *and suppose firm demand is given by (7) and firm claims are given by (9) where* $a > 0, e_1 > e_2 > 0, \kappa > 0$ *and* $\lambda_1 > \lambda_2 > 0$. *Suppose that the parameter constraints (15) and (16) in Appendix A are satisfied such that the problem is well-defined. Define* (p_L^*, p_H^*) *as the equilibrium premium vector in a market without risk adjustment and* (p_L^R, p_H^R) *as the equilibrium premium vector in a market with risk adjustment. Then risk adjustment*

1. *Decreases the average premium such that* $p_L^R + p_H^R < p_L^* + p_H^*$

Figure 3: Impact of Risk Adjustment When Adverse Selection and Firm Cost Are Positively Correlated



Notes: Figure shows how risk adjustment affects the equilibrium between two imperfectly competitive firms L and H, where firm L has lower marginal cost and faces weaker adverse selection. Risk adjustment gives both firms the same marginal claims curve MC and marginal revenue curve MR. Firm L's enrollee population declines by a smaller amount than the amount that firm H's enrollee population increases. Firm L's premium also increases by less than firm H's premium decreases. The loss in consumer surplus for firm L's plan is less than the gain in consumer surplus for firm H's plan, as indicated by the relative sizes of the shaded regions.

2. *Increases insurance coverage such that* $q_L(p_L^R, p_H^R) + q_H(p_L^R, p_H^R) > q_L(p_L^*, p_H^*) + q_H(p_L^*, p_H^*)$

3. *Decreases the average claims risk such that* $c_L(p_L^R, p_H^R) + c_H(p_L^R, p_H^R) < c_L(p_L^*, p_H^*) + c_H(p_L^*, p_H^*)$

4. *Increases consumer surplus such that* $CS_L(p_L^R, p_H^R) + CS_H(p_L^R, p_H^R) > CS_L(p_L^*, p_H^*) + CS_H(p_L^*, p_H^*)$

5. *Decreases total profit such that* $\pi_L(p_L^R, p_H^R) + \pi_H(p_L^R, p_H^R) < \pi_L(p_L^*, p_H^*) + \pi_H(p_L^*, p_H^*)$.

Proof. See Appendix A. □

Table 1: Summary of Results on the Effect of Risk Adjustment

	Negative Correlation Between Adverse Selection and Firm Cost	Positive Correlation Between Adverse Selection and Firm Cost
Average Premium	Increases	Decreases
Average Claims	Increases	Decreases
Total Coverage	Decreases	Increases
Welfare		
Consumer Surplus	Decreases	Increases
Profit	Decreases	Decreases
Total	Decreases	Ambiguous

Notes: Table summarizes the impact of risk adjustment in the two examples considered above. The first column corresponds to the example where the firms have average claims given by (8), while the second column corresponds to the example where the firms have average claims given by (9).

These examples suggest that the welfare impact of risk adjustment depends on whether risk adjustment changes premiums such that cheaper plans become more expensive and low-risk consumers exit the market as a result. Other policies that I have omitted in these examples could prevent the loss of low-risk consumers that may result from risk adjustment. Price-linked subsidies provide an implicit source of external funding to mitigate the potential loss of low-risk consumers. Even though risk adjustment may increase premiums for bronze and silver plans, price-linked ACA subsidies shield consumers from premium increases. In my empirical analysis, I explore how the ACA's subsidy design interacts with risk adjustment.

3 Data

To estimate the model, I obtain demand and cost data from several sources. One of the distinguishing features of my empirical analysis is the use of detailed consumer-level enrollment data from Covered California, the ACA exchange in California. There are approximately 2.5 million records in my data, which cover the 2014 and 2015 plan years. Table 2 summarizes the demand data by firm market share. Relative to other ACA state exchanges, the California exchange has robust firm participation. There are four dominant firms – Anthem, Blue Shield, Centene, and Kaiser – that together have 95% of the market share. The other California firms largely serve local markets.

Table 2: Insurer Market Share in the California Exchange

	2014	2015
Anthem Blue Cross	29.0%	27.8%
Blue Shield of California	28.3%	26.4%
Centene/Health Net	19.7%	16.4%
Chinese Community Health Plan	1.1%	0.8%
Contra Costa Health Plan	0.1%	
Kaiser Permanente	17.4%	24.2%
L.A. Care Health Plan	2.3%	1.1%
Molina Healthcare	0.7%	1.5%
Sharp Health Care	1.0%	1.2%
Valley Health Plan	0.1%	0.1%
Western Health Advantage	0.3%	0.4%

Notes: Table reports the market shares for each firm participating in the California exchange during the 2014 and 2015 plan years.

The California exchange enrollment data indicate every exchange enrollee's selected plan and key demographic information, such as age, county of residence, income, gender, and subsidy eligibility. These demographic characteristics and rating factors from the insurer rate filings (Department of Managed Health Care, 2016) enable me to (1) define the household's complete menu of plan choices and (2) precisely calculate the household-specific premium $p_{ij}(\mathbf{p})$ from the base premium p_j for all plans. Defining the consumer's choice set and obtaining accurate consumer-specific premium information are the primary empirical challenges in analyzing individual health insurance markets (Auerbach and Ohri, 2006). I combine the marketplace enrollment data with data from the U.S. Census Bureau's American Community Survey (Ruggles et al., 2016) to obtain a representative sample of uninsured individuals who chose not to purchase insurance in the California exchange. I do not include uninsured individuals who are undocumented immigrants or have access to another source of coverage, such as Medicaid, the Children's Health Insurance Program (CHIP), or employer-sponsored insurance. Table 3 presents summary statistics on exchange enrollees and consumers who forgo exchange coverage.

Data on firm costs come from the 2014 and 2015 medical loss ratio (MLR) reports published by CMS (Centers for Medicare and Medicaid Services, 2017). To comply with the ACA's medical loss ratio requirements, every insurer must provide CMS with detailed financial information that is used to calculate MLR rebates and risk corridor payments. The MLR reports provide state-level information on firm claims, variable administrative cost, and fixed administrative cost for each firm.

I obtain data on firm reinsurance recoveries and risk adjustment transfers from CMS reports (Centers for Medicare and Medicaid Services, 2015, 2016). Table 4 summarizes per-member per-month risk ad-

Table 3: Choice and Demographic Distribution

	Exchange	Uninsured
Metals		
Catastrophic	0.7%	
Bronze	24.0%	
Silver	64.9%	
Gold	5.5%	
Platinum	4.8%	
Network Type		
HMO	45.7%	
PPO	45.1%	
EPO	9.2%	
Income		
0% to 138% of FPL	2.9%	2.8%
138% to 150% of FPL	15.0%	5.4%
150% to 200% of FPL	33.8%	20.5%
200% to 250% of FPL	17.4%	16.2%
250% to 400% of FPL	22.7%	29.6%
400%+ of FPL	8.2%	25.4%
Subsidy Eligibility		
Premium tax credits	90.7%	74.6%
Cost sharing reduction subsidies	68.5%	44.9%
Penalty Status		
Exempt	3.8%	6.3%
Subject	96.2%	93.7%
Age		
0-17	4.8%	3.2%
18-25	10.4%	20.9%
26-34	15.7%	25.5%
35-44	15.6%	17.0%
45-54	24.4%	17.8%
55-64	29.0%	15.4%
Gender		
Female	52.3%	43.1%
Male	47.7%	56.9%
Year		
2014	48.9%	58.9%
2015	51.1%	41.1%
Average Annual Population	1,239,268	1,407,430

NOTES: Table provides summary statistics on consumers in the California exchange market for the 2014 and 2015 plan years. Data on marketplace consumers come from Covered California. Data on the uninsured come from the ACS.

justment transfers and reinsurance recoveries for each firm in the 2014 and 2015 plan years. The data indicate that Contra Costa had the highest-risk enrollees and LA Care had the lowest-risk enrollees in 2014. Although I do not directly observe the efficiency scores, I can solve for them in the ACA risk adjustment transfer formula (20) using data on realized firm risk adjustment transfers, claims, premiums, and risk-adjusted shares. The utilization factors used in calculating the risk-adjusted share come directly from the formula used by CMS (Pope et al., 2014).

Table 4: Summary Financial Data by Year

	Average Claims		Risk Adj. Received		Reinsurance Received	
	2014	2015	2014	2015	2014	2015
Anthem	\$294	\$349	-\$26	-\$4	\$58	\$44
Blue Shield	\$338	\$378	\$24	\$26	\$63	\$40
Chinese Community	\$212	\$160	-\$119	-\$185	\$13	\$17
Contra Costa	\$912		\$179		\$234	
Health Net	\$306	\$365	-\$17	-\$23	\$54	\$43
Kaiser	\$344	\$336	\$17	-\$11	\$40	\$26
LA Care	\$196	\$177	-\$132	-\$126	\$1	\$1
Molina	\$114	\$141	-\$126	-\$130	\$13	\$6
Sharp	\$515	\$458	\$85	\$42	\$90	\$42
Valley	\$430	\$391	-\$21	-\$5	\$29	\$22
Western Health	\$569	\$425	\$63	-\$21	\$143	\$74

NOTES: Table provides insurer financial data for the 2014 and 2015 plan years on per-member per-month claims, risk adjustment received, and reinsurance received. Claims data are from the MLR reports. Risk adjustment and reinsurance data are from CMS reports (Centers for Medicare and Medicaid Services, 2015, 2016).

4 Estimation

In this section, I explain how I use the data to estimate the model. Recall that every variable in the model is defined in terms of four variables: (1) the probability $q_{ij}(\mathbf{p})$ that household i selects plan j; (2) the partial derivative $\partial q_{ik}(\mathbf{p})/\partial p_{ij}(\mathbf{p})$ for all plans j and k; (3) the firm's average claims function $c_f(\mathbf{p})$; and (4) the vector of claim slopes with elements $\partial c_f(\mathbf{p})/\partial p_j$. In the first subsection, I discuss how I estimate the demand function and its partial derivative with respect to the consumer's premium. The second subsection explains how I use the demand estimates to estimate the average claims function and the vector of claim slopes.

4.1 Estimating Demand

To estimate demand, I model equation (1) as a nested logit, where the vector of error terms ϵ_i has the generalized extreme value distribution. I create two nests: 1) a nest containing all exchange plans and 2) a nest containing only the outside option. This two-nest structure addresses the potential concern that a logit model would overestimate substitution to the outside option because of its proportional substitution assumption. A natural alternative would be to model each metal tier as a nest along with the outside option nest, but this nest structure would be very computationally intensive and problematic to implement because of the ACA's linkage of cost sharing subsidies to the purchase of silver plans.

The main empirical issue with estimating equation (1) is that the premium may be correlated with unobserved product characteristics. Including insurer and market fixed effects in equation (1) can control for many of these unobservables, such as insurer entry decisions, customer service, provider networks, formularies, and advertising, that vary at the insurer-market level. Ho and Pakes (2014) and Tebaldi (2017) follow a similar approach. ACA regulations create exogenous variation in household premiums that I can exploit to identify the effect of the premium on the household's choice. Specifically, I can use the following sources of variation: (1) the upper income limit for subsidy eligibility that creates a discontinuity in household premiums at 400 percent of FPL; (2) the 57 percent increase in the age rating curve that creates a discontinuity in premiums between ages 20 and 21 (Centers for Medicare and Medicaid Services, 2013); (3) the individual mandate exemption for having income below the tax filing threshold; (4) the individual mandate exemption for not having access to an affordable offer; and (5) the increase in penalty assessments between 2014 and 2015. Figures 6-9 in Appendix D provide reduced-form evidence of how these exogenous shocks affect demand for exchange coverage. Exchange enrollment is particularly responsive to the upper income limit for subsidy eligibility and the tax filing threshold exemption from the individual mandate.

To further address potential endogeneity of the premium, I estimate a nested logit discrete choice model with the control function approach of Petrin and Train (2010). Although the approach of Berry et al. (1995) is more commonly used for addressing price endogeneity in discrete choice models, significant household-level variation in premiums for the same product and in penalty assessments precludes applying the key insight of Berry et al. (1995): absorbing the premium endogeneity into product-level constants. I estimate the first stage at the plan-market-year level by regressing the premium p_{jnt} for plan j in rating area n in year t on instruments z_{jnt}, where the instrument vector includes (1) the non-premium product characteristics; (2) the geographic cost factors reported in state rate filings; and (3) the average premium that the insurer charges for j in other ratings areas in the same year. I calculate each household's predicted premium from the first stage and then compute the residuals μ_{ij}. I make the assumption that (μ_{ij}, ξ_{ij}) are jointly normal, which implies that $\xi_{ij}|\mu_{ij}$ is also normal with mean $\upsilon\mu_{ij}$ and variance ψ^2 (υ and ψ are parameters to be estimated). Setting the unobservables $\xi_{ij} = E[\xi_{ij}|\mu_{ij}] + \widetilde{\xi}_{ij}$ to "control" for potential correlations between μ_{ij} and ξ_{ij}, I rewrite demand equation (1) as

$$\begin{aligned} U_{ij} &= \alpha(p_{ij}(\mathbf{p}) - \rho_i) + x_j'\beta + d_i'\varphi + p_{ij}(\mathbf{p})d_i'\gamma + E[\xi_{ij}|\mu_{ij}] + \widetilde{\xi}_{ij} + \epsilon_{ij} \\ &= \alpha(p_{ij}(\mathbf{p}) - \rho_i) + x_j'\beta + d_i'\varphi + p_{ij}(\mathbf{p})d_i'\gamma + \upsilon\mu_{ij} + \psi\eta_{ij} + \epsilon_{ij} \end{aligned} \quad (10)$$

where $\eta_{ij} \sim N(0,1)$. The household choice probabilities can be computed as

$$q_{ij}(\mathbf{p};\boldsymbol{\theta}) \quad = \quad \int \left[\frac{e^{V_{ij}/\lambda}\left(\sum_j e^{V_{ij}/\lambda}\right)^{\lambda-1}}{1+\left(\sum_j e^{V_{ij}/\lambda}\right)^{\lambda}} \right] dG(\cdot) \tag{11}$$

where $\boldsymbol{\theta}$ is the vector of parameters in (10), $V_{ij} = \alpha(p_{ij}(\mathbf{p}) - \rho_i) + x_j'\beta + d_i'\varphi + p_{ij}(\mathbf{p})d_i'\gamma + \upsilon\mu_{ij} + \psi\eta_{ij}$, λ is the nesting parameter, and $G(\cdot)$ is the normal cumulative distribution function for $\xi_{ij}|\mu_{ij}$. I estimate the integral in equation (11) using simulation. I use maximum simulated likelihood to estimate the value of $\boldsymbol{\theta}$ that maximizes the log-likelihood function

$$LL(\boldsymbol{\theta}) = \sum_{i,j} w_i c_{ij} \ln q_{ij}(\mathbf{p};\boldsymbol{\theta})$$

where w_i is the household's weight and c_{ij} takes 1 if household i chose plan j and 0 otherwise. With the estimated parameter vector $\boldsymbol{\theta}$, I can estimate household i's demand $q_{ij}(\mathbf{p})$ for plan j and its partial derivatives $\partial q_{ik}(\mathbf{p})/\partial p_{ij}(\mathbf{p})$ for all plans k.

4.2 Estimating Claims

To estimate each firm's average claims function and vector of claim slopes, I develop a strategy that combines my demand estimates with firm-level data from several sources, including the MLR reports. Previous work typically assumes that the claims function is linear (Einav et al., 2010), implying that the claim slope $\partial c_f(\mathbf{p})\partial p_j$ does not vary with premiums. Because the medical spending distribution is highly skewed, it is possible that the rate of change in average claims varies with the premium. To allow for this possibility, I specify a more flexible average claims function with the quadratic form

$$c_f(\mathbf{p}) \quad = \quad \sum_{k\in J_f} \left[\frac{1}{2} b_1 p_k^2 + b_2 x_k p_k \right] + d_f \tag{12}$$

where x_k is a vector of observed plan characteristics (including the plan actuarial value, whether the plan is a health maintenance organization (HMO), and whether the plan allows enrollees to establish a health savings account (HSA)), and d_f is an intercept. The total derivative of (12) equals

$$dc_f(\mathbf{p}) = \sum_{k\in J_f} \frac{\partial c_f(\mathbf{p})}{\partial p_k} dp_k = \sum_{k\in J_f} \left[b_1 p_k + b_2 x_k \right] dp_k$$

where the claim slope $\partial c_f(\mathbf{p})/\partial p_k = b_1 p_k + b_2 x_k$ is linear in the premium p_k and product characteristics x_k. Given data on each plan's claim slope, premium, and product characteristics, I can estimate the claims function parameters b_1 and b_2 by regressing the claim slope on the premium and product characteristics. I estimate these parameters using ordinary least squares, as well as two-stage least squares to address potential endogeneity of the premium. I use the instruments suggested by Berry et al. (1995). I recover the claims function intercept d_f for each firm using the observed averaged claims and the predicted claim slopes as the initial condition.

The main empirical challenge with this approach is that I do not observe the claim slope $\partial c_f(\mathbf{p})/\partial p_j$. To obtain estimates of the claim slope, I assume that the California exchange is in equilibrium, allowing me to invert first-order conditions (22) to solve for the claim slopes. This inversion is possible because I have written the model such that the system of first-order conditions is full rank. In particular, formula (19) for average marginal claims does not necessitate knowledge of the claims cross-partial derivatives (i.e., how a firm's average claims respond to the base premium of plans sold by one of a firm's competitors). In the industrial organization literature, inversion of the first-order conditions is often used to back out firm cost from estimates of demand. In this case, I have cost data and instead use the first-order conditions to recover the partial derivative of claims with respect to the premium, accounting for the likely presence of adverse selection and moral hazard.

How valid is the equilibrium assumption? While volatility was quite high in many states during the 2014 and 2015 plan years, empirical evidence suggests that the California exchange was relatively stable. Table 5 indicates that firm participation in county markets changed little between 2014 and 2015. Only one small insurer (Contra Costa) entirely exited the California marketplace in 2015. Through the 2017 plan year, all 2015 California marketplace participants remain. Table 6 indicates that premium changes were modest between 2014 and 2015, rising about 3 percent.

5 Demand and Claims Estimates

5.1 Demand Estimates

This subsection summarizes my estimates of consumer demand in the ACA marketplaces. Estimates of the parameters in utility equation (10) are in Appendix E. I interpret these estimates by computing premium elasticities and semi-elasticities of demand. Appendix F presents formulas for computing elasticities and semi-elasticities in the ACA setting.

Table 7 summarizes the mean own-premium elasticity and semi-elasticity of demand by demographic group. The mean own-premium elasticity of demand is the percentage change in a plan's enrollment associated with a one percent increase in its base premium. The mean own-premium semi-elasticity of demand is the percentage change in a plan's enrollment associated with a \$100 increase in its annual

Table 5: Insurer County Participation in the California Exchange

	2014	2015
Anthem Blue Cross	58	58
Blue Shield of California	54	58
Centene/Health Net	22	19
Chinese Community Health Plan	2	2
Contra Costa Health Plan	1	0
Kaiser Permanente	31	31
L.A. Care Health Plan	1	1
Molina Healthcare	4	4
Sharp Health Care	1	1
Valley Health Plan	1	1
Western Health Advantage	8	8

Notes: Table shows the number of counties that each California insurer participated in. There are 58 counties in California.

Table 6: Insurers, Plans, and Premiums by Year

	2014	2015
Insurers Available		
Minimum	1.0	2.0
Median	5.0	5.0
Average	4.8	4.7
Maximum	6.0	6.0
Plans Available		
Minimum	5.0	10.0
Median	25.0	25.0
Average	24.6	24.5
Maximum	35.0	35.0
Silver Plan Premiums		
County Average	$309.70	$320.25
Minimum	$221.56	$230.31
Maximum	$480.59	$554.26
Minimum second-lowest	$253.27	$257.19
Maximum second-lowest	$422.58	$423.67

NOTES: The first two panels provide summary statistics on the number of insurers and plans available to consumers. The third panel shows variation in silver plan premiums for a 40-year old nonsmoker.

premium. California consumers have a mean own-premium elasticity of -7.8 and mean own-premium semi-elasticity of -19.8. Variation in premium sensitivity across demographic groups is consistent with theory. In particular, low-income individuals, males, and young adults between the ages of 18 and 34 are more premium sensitive.

Table 7: Estimated Mean Own-Premium Elasticities and Semi-Elasticities

	Elasticity	Semi-Elasticity
Overall	-7.8	-19.8
Income (% of FPL)		
0-138	-9.7	-24.5
138-250	-8.4	-21.1
250-400	-6.8	-17.3
400+	-6.8	-17.2
Gender		
Female	-6.8	-17.2
Male	-8.1	-20.5
Age		
18-34	-9.5	-22.9
35-54	-8.8	-21.3
55+	-5.9	-14.1
Household Size		
Single	-11.4	-29.2
Family	-5.7	-15.0
Mandate Status		
Exempt	-6.1	-15.6
Subject	-7.9	-20.1
Year		
2014	-7.7	-19.6
2015	-7.9	-20.0

Notes: Table shows mean own-premium elasticities and semi-elasticities by demographic group. A plan's own-premium elasticity indicates the percentage change in enrollment for a 1 percent increase in its premium and is computed using equation (23). A plan's own-premium semi-elasticity indicates the percentage change in enrollment for a $100 increase in its annual premium and is computed using equation (24).

Table 8 presents estimated premium elasticities and semi-elasticities for exchange coverage. The premium elasticity for exchange coverage is the percentage change in exchange enrollment associated with a one percent increase in the base premium of all exchange plans. The premium semi-elasticity for exchange coverage is the percentage change in exchange enrollment associated with a $100 annual increase in all exchange premiums. California consumers have an elasticity for exchange coverage of -0.6 and a semi-elasticity for exchange coverage of -1.8. Variation in premium sensitivity across demographic groups is similar to the own-premium elasticity estimates.

Table 8: Estimated Elasticities and Semi-Elasticities for Exchange Coverage

	Elasticity	Semi-Elasticity
Overall	-0.6	-1.8
Income (% of FPL)		
0-138	-0.7	-2.2
138-250	-0.6	-1.9
250-400	-0.5	-1.6
400+	-0.5	-1.6
Gender		
Female	-0.5	-1.6
Male	-0.6	-1.8
Age		
18-34	-0.7	-2.0
35-54	-0.6	-1.9
55+	-0.4	-1.3
Household Size		
Single	-0.7	-2.4
Family	-0.4	-1.2
Mandate Status		
Exempt	-0.4	-1.2
Subject	-0.5	-1.6
Year		
2014	-0.6	-1.8
2015	-0.6	-1.8

Notes: Table shows mean elasticities and semi-elasticities for exchange coverage by demographic group. The mean elasticity for exchange coverage indicates the percentage change in exchange enrollment if all exchange premiums increase by 1 percent and is computed using equation (25). The mean semi-elasticity for exchange coverage indicates the percentage change in exchange enrollment if all annual exchange premiums increase by $100 and is computed using equation (26).

5.2 Claims Estimates

Table 9 shows estimates of the parameters b_1 and b_2 in average claims function (12). The estimates are similar for both ordinary least squares and two-stage least squares. Only the coefficients for the base premium and the actuarial value are statistically significant. The estimated coefficients for the base premium and the actuarial value have an intuitive interpretation that decomposes the effects of adverse selection and moral hazard on the claim slope. In particular, the coefficient b_1 measures how the claim slope responds to premiums, given the plan actuarial value and any associated moral hazard. The positive value of b_1 indicates that selection worsens as the premium increases. Conversely, the negative coefficient on the actuarial value coefficient indicates that more generous plans have a lower claim slope, controlling for selection by holding the base premium fixed. A small increase in the premium of a more generous plan is likely to incentivize consumers to substitute to a less generous plan under which they consume less, reducing average claims. Overall, the model predictor variables explain about half of the variation in the claim slope.

Table 9: Predicting the Claim Slope ($\partial c_f(\mathbf{p})/\partial p_f$)

	Ordinary Least Squares	Instrumental Variables
Base Premium	0.010***	0.008***
	(0.001)	(0.002)
Actuarial Value	−7.685***	−6.910***
	(0.754)	(1.175)
HMO	−0.002	0.022
	(0.087)	(0.087)
HSA	0.299	0.307
	(0.190)	(0.193)
Observations	149	149
R^2	0.494	0.488
Adjusted R^2	0.480	0.474

Notes: ***Significant at the 1 percent level. **Significant at the 5 percent level. *Significant at the 10 percent level. Robust standard errors are in parentheses. Table shows parameter estimates for the linear regression of the claim slope on the premium and plan characteristics. Each observation is a plan-year combination.

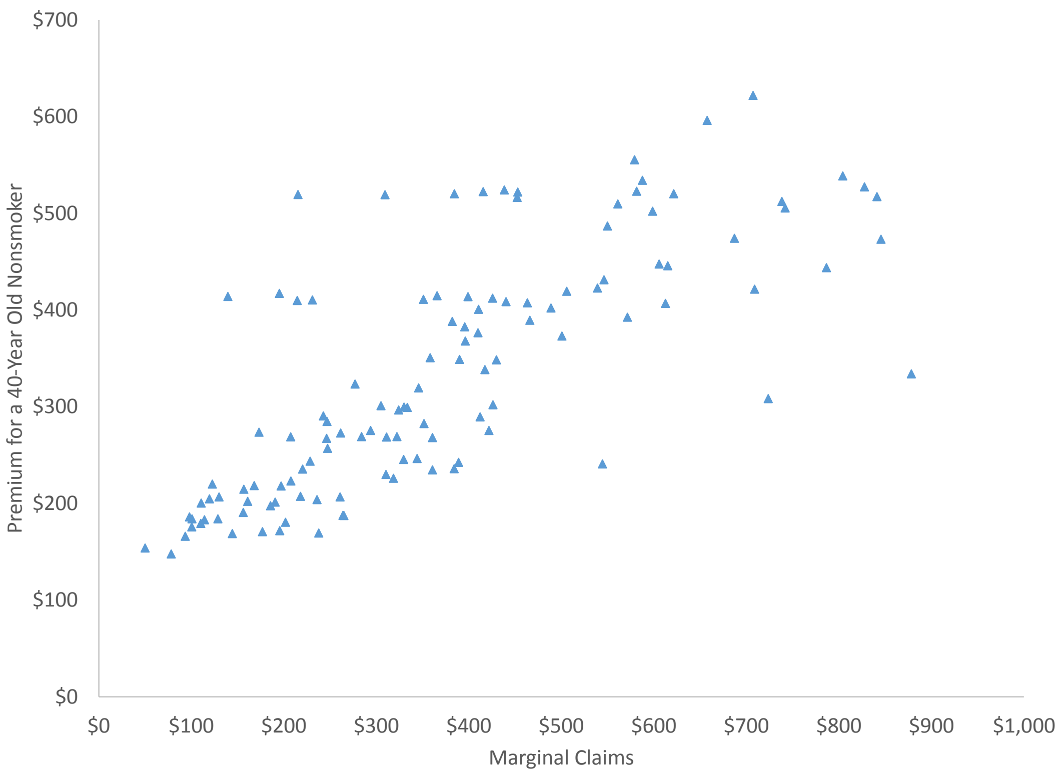
6 Impact of Risk Adjustment

This section presents my principal findings on the impact of risk adjustment in the ACA exchanges. I present (1) descriptive evidence of the important correlations identified in the theoretical analysis of the model and (2) simulation results of the impact of risk adjustment on premiums, coverage, and social welfare.

6.1 Evidence of Correlations Identified in Model Analysis

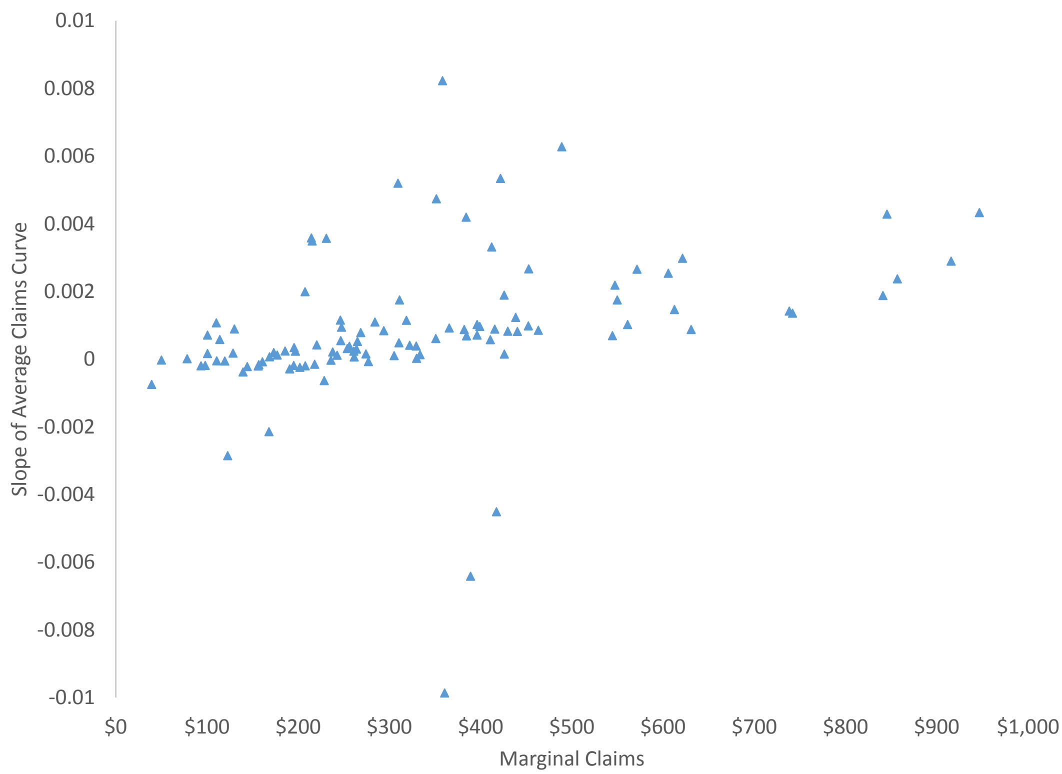
Examining the key correlations identified in the model analysis provides useful insight into the possible welfare impact of risk adjustment in the ACA exchanges. My analysis of the model suggests that risk adjustment may have a negative welfare impact if (1) premiums and consumer risk are positively correlated and (2) adverse selection and firm cost are negatively correlated. Figure 4 indicates that there is strong positive correlation between premiums and marginal claims in the California exchange. Implementation of risk adjustment is therefore likely to compress equilibrium premiums, making cheaper plans more expensive and more expensive plans cheaper. To assess whether there is negative correlation between adverse selection and firm cost, I plot the claim slope as a function of quantity against marginal claims in Figure 5. The claim slope is an imprecise measure of selection because it also captures moral hazard. More negative values of the claim slope as a function of quantity correspond to stronger adverse selection, controlling for moral hazard. The slight positive correlation between the claim slope as a function of quantity and marginal claims in Figure 5 suggests that adverse selection and firm cost are negatively correlated. Some low-risk consumers may, therefore, forgo exchange coverage as a result of cheaper plans becoming more expensive.

Figure 4: Scatter Plot of Premiums vs. Marginal Claims



Notes: Figure plots the premium for a 40-year old nonsmoker against marginal claims for every plan offered in the California exchange for the 2014 and 2015 plan years in the absence of risk adjustment.

Figure 5: Scatter Plot of the Average Claims Curve Slope vs. Marginal Claims



Notes: Figure plots the slope of the average claims curve as a function of quantity against marginal claims for every plan offered in the California exchange for the 2014 and 2015 plan years in the absence of risk adjustment.

6.2 Impact on Premiums

Table 10 reports the impact of risk adjustment on average premiums for a 40 year-old nonsmoker by metal tier and by insurer. The ACA risk adjustment program (column 2) compresses equilibrium premiums relative to the case without risk adjustment (column 1). Specifically, risk adjustment leads to reductions in platinum and gold premiums by 25 and 15 percent, respectively, and increases in bronze and silver premiums by 11 and 2 percent, respectively. Premium compression also occurs across insurers within metal tiers. The second panel of Table 10 indicates that risk adjustment reduces silver premiums for insurers such as Sharp Health Care and Western Health Advantage that have the highest premiums in the absence of risk adjustment. Conversely, premiums rise for insurers such as Chinese

Community Health Plan, Health Net, L.A. Care Health Plan, and Molina Healthcare that have the lowest premiums without risk adjustment. Replacing ACA risk adjustment formula (20) that adjusts for both medical risk and the administrative loading with formula (4) that adjusts only for medical risk (column 3) has a relatively small impact on premiums.

Table 10: Effect of Risk Adjustment on (Pre-Subsidy) Premiums for a 40 Year-Old Nonsmoker

	No Risk Adjustment	Risk Adjustment	Risk Adjustment (Claims Only)
Metal			
Bronze	\$198	\$221	\$203
Silver	\$267	\$273	\$267
Gold	\$367	\$315	\$327
Platinum	\$474	\$353	\$363
Insurer (Silver Premium)			
Anthem BC	\$271	\$291	\$289
Blue Shield	\$279	\$262	\$271
Chinese Community	\$268	\$342	\$335
Contra Costa	\$334	\$355	\$400
Health Net	\$222	\$233	\$239
Kaiser	\$286	\$292	\$250
LA Care	\$238	\$259	\$259
Molina	\$247	\$261	\$253
Sharp	\$380	\$324	\$325
Valley	\$286	\$353	\$367
Western	\$412	\$396	\$393

Notes: Table shows the impact of risk adjustment on weighted-average premiums by metal tier and by insurer for a 40-year old non-smoker. Plan premiums are weighted by the realized ACA plan market share for all simulated scenarios. The first column provides simulation results on the impact of eliminating risk adjustment and the third column provides simulation results on the impact of replacing ACA risk adjustment formula (20) with risk adjustment formula (4) that adjusts only for differences in medical claims. The second column summarizes observed premiums when ACA risk adjustment formula (20) is used.

6.3 Impact on Insurance Coverage

Table 11 shows how risk adjustment affects insurance coverage. The total number of consumers who purchase insurance remains about the same, but the distribution of consumers across the metal tiers shifts. Higher pre-subsidy premiums for bronze and silver plans result in relatively modest enrollment declines in the bronze and silver tiers. Because most consumers receive subsidies that adjust to the benchmark second-lowest cost silver premium, the increased cost of bronze and silver plans is largely borne by taxpayers in the form of larger subsidy payments rather than by consumers. In contrast, enrollment in subsidy-ineligible catastrophic plans declines more precipitously. Larger subsidies and lower pre-subsidy premiums for platinum plans encourage robust enrollment in the platinum tier; the share of enrollees choosing platinum rises from 2 percent to nearly 5 percent. Replacing ACA risk adjustment formula (20) that adjusts for both medical risk and the administrative loading (column 2) with formula (4) that adjusts only for medical risk (column 3) has a relatively small impact on the coverage distribution.

Table 11: Effect of Risk Adjustment on Insurance Coverage

	No Risk Adjustment	Risk Adjustment	Risk Adjustment (Claims Only)
Catastrophic	2.0%	0.7%	0.9%
Bronze	24.5%	24.0%	24.5%
Silver	66.1%	64.9%	64.9%
Gold	5.3%	5.5%	5.1%
Platinum	2.0%	4.9%	4.6%
Total Coverage	1,316,258	1,310,535	1,327,284

Notes: Table shows the impact of risk adjustment on the insurance coverage distribution by metal tier. The first column provides simulation results on the impact of eliminating risk adjustment and the third column provides simulation results on the impact of replacing ACA risk adjustment formula (20) with risk adjustment formula (4) that adjusts only for differences in medical claims. The second column summarizes the observed coverage distribution when ACA risk adjustment formula (20) is used.

6.4 Impact on Per-Capita Social Welfare

In Table 12, I report the impact of risk adjustment on per-capita social welfare. To calculate per-capita amounts, I divide all total spending amounts by the total number of consumers in the market, including those choosing the outside option. Changes in total social welfare are relatively small, but risk adjustment alters the welfare distribution. In particular, risk adjustment increases consumer surplus by about $200 per consumer per year. The increase in consumer surplus is due to (1) the decline in premiums for the more generous gold and platinum plans and (2) the maintenance of after-subsidy premiums for the less generous bronze and silver plans despite increases in pre-subsidy bronze and silver premiums. Maintaining what consumers pay for the less generous bronze and silver plans requires considerable financing of premium subsidies. Specifically, premium subsidy spending increases by more than $200 per consumer per year, offsetting the gains in consumer surplus. Hence, risk adjustment coupled with price-linked subsidies has the effect of transferring welfare from taxpayers to consumers. Changes in other sources of government spending are negligible. Declines in firm profits are relatively small.

Table 12: Effect of Risk Adjustment on Annual Per-Capita Social Welfare

	No Risk Adjustment	Risk Adjustment	Risk Adjustment (Claims Only)
Consumer Surplus	$5,035	$5,231	$5,246
Profit	-$2	-$94	-$346
Government Spending			
Premium Subsidies	-$1,288	-$1,511	-$1,422
Cost Sharing Subsidies	-$122	-$131	-$126
Mandate Revenue	$188	$192	$188
Social Welfare	$3,812	$3,687	$3,540

Notes: Table shows the impact of risk adjustment on annual per-capita social welfare. The first column provides simulation results on the impact of eliminating risk adjustment and the third column provides simulation results on the impact of replacing ACA risk adjustment formula (20) with risk adjustment formula (4) that adjusts only for differences in medical claims. The second column summarizes observed social welfare levels when ACA risk adjustment formula (20) is used.

7 Policy Counterfactual: Change in Subsidy Design

In the previous section, I considered the impact of risk adjustment assuming that the ACA's price-linked subsidies remained in place. Because risk adjustment affects premiums (including the benchmark premium), the amount of the ACA's price-linked subsidies can change under risk adjustment. I now simulate the effect of replacing the ACA's price-linked subsidies with fixed subsidies or vouchers, which do not adjust to premium changes. I set the voucher amount equal to the ACA subsidy that a consumer would have received in the absence of risk adjustment.

Table 13 reports the impact on premiums for a 40 year-old non-smoker. For the most part, the results in Table 13 for vouchers are very similar to the results in Table 10 for ACA subsidies. Premiums for less generous bronze and silver plans rise, while premiums for more generous gold and platinum plans fall. The impact on premiums across insurers is similar as well.

In contrast, the replacement of ACA subsidies with vouchers does impact insurance coverage. Although risk adjustment increases bronze and silver (pre-subsidy) premiums by roughly the same amount under both subsidy schemes, consumers are only exposed to the increases in the voucher scenario. Consequently, insurance coverage falls by $35,000$ under risk adjustment, as reported in Table 14. As before, risk adjustment changes the distribution of enrollment across the metal tiers. Enrollment in the less generous bronze and silver plans declines, while enrollment in more generous gold and platinum plans increases.

Table 15 reports the impact of risk adjustment on annual per-capita social welfare when vouchers re-

Table 13: Effect of Risk Adjustment on (Pre-Subsidy) Premiums Under Vouchers

	No Risk Adjustment	Risk Adjustment
Metal		
Bronze	\$198	\$218
Silver	\$267	\$269
Gold	\$367	\$310
Platinum	\$474	\$346
Insurer (Silver Premium)		
Anthem BC	\$271	\$284
Blue Shield	\$279	\$261
Chinese Community	\$268	\$354
Contra Costa	\$334	\$367
Health Net	\$222	\$229
Kaiser	\$286	\$288
LA Care	\$238	\$247
Molina	\$247	\$262
Sharp	\$380	\$332
Valley	\$286	\$350
Western	\$412	\$391

Notes: Table shows the impact of risk adjustment on weighted-average premiums by metal tier and by insurer for a 40-year old non-smoker when the subsidy formula is changed to a voucher that does not adjust to premium changes. The voucher is set equal to the subsidy each household receives under the ACA in the absence of risk adjustment. Plan premiums are weighted by the realized ACA plan market share for all simulated scenarios. The first column is the same as the first column of Table 10. The second column provides simulation results for replacing ACA subsidies with vouchers with ACA risk adjustment formula (20) in place.

Table 14: Effect of Risk Adjustment on Insurance Coverage Under Vouchers

	No Risk Adjustment	Risk Adjustment
Catastrophic	2.0%	0.7%
Bronze	24.5%	23.8%
Silver	66.1%	64.0%
Gold	5.3%	5.9%
Platinum	2.0%	5.6%
Total Coverage	1,316,258	1,280,594

Notes: Table shows the impact of risk adjustment on the insurance coverage distribution by metal tier when the subsidy formula is changed to a voucher that does not adjust to premium changes. The voucher is set equal to the subsidy each household receives under the ACA in the absence of risk adjustment. The first column is the same as the first column of Table 10. The second column provides simulation results for replacing ACA subsidies with vouchers with ACA risk adjustment formula (20) in place.

place ACA subsidies. In this case, risk adjustment reduces per-capita social welfare by \$432 per year from \$3,812 to \$3,380. The most significant difference is the drop in consumer surplus of about \$200 per year, instead of an increase of about $200 per year when ACA subsidies were in place. Taxpayer outlays are largely unchanged. Hence, vouchers shift the burden of the premium increase due to risk adjustment from taxpayers back to consumers. Importantly, consumer surplus falls by more than the government saves in premium subsidy outlays, explaining most of the decrease in total social welfare (the remainder is due to a decline in firm profit).

Table 15: Effect of Risk Adjustment on Annual Per-Capita Social Welfare Under Vouchers

	No Risk Adjustment	Risk Adjustment
Consumer Surplus	$5,035	$4,826
Profit	-$2	-$234
Government Spending		
Premium Subsidies	-$1,288	-$1,277
CSRs	-$122	-$130
Mandate Revenue	$188	$195
Social Welfare	$3,812	$3,380

Notes: Table shows the impact of risk adjustment on annual per-capita social welfare when the subsidy formula is changed to a voucher that does not adjust to premium changes. The voucher is set equal to the subsidy each household receives under the ACA in the absence of risk adjustment. The first column is the same as the first column of Table 10. The second column provides simulation results for replacing ACA subsidies with vouchers with ACA risk adjustment formula (20) in place.

8 Conclusion

Risk adjustment is one of the principal policy remedies for mitigating adverse selection that results from limiting risk rating. In this paper, I have investigated whether risk adjustment may reduce social welfare when firms have market power. I showed theoretically that risk adjustment can be welfare-reducing if there is (1) positive correlation between firm premiums and expected risk and (2) negative correlation between firm cost and adverse selection. I then studied the impact of risk adjustment in the ACA exchanges. My results indicate that risk adjustment compresses equilibrium premiums in the ACA exchanges, but has minimal net welfare impact because ACA subsidies shield consumers from the higher bronze and silver premiums. If consumers are exposed to these premium increases under a fixed subsidy, risk adjustment has a negative impact on social welfare. Hence, risk adjustment needs to be coupled with a policy that limits the loss of low-risk consumers when premiums rise to avoid negative welfare consequences.

My analysis has several limitations. Omitting inertia in the model may upward bias my estimates of consumer premium elasticity, potentially overstating the impact of risk adjustment. Inertia also has important consequences for selection (Handel, 2013). I also make some assumptions that could be problematic in a new market, including (1) firms have perfect knowledge of their own and their competitors' claims functions and (2) the California exchange is in equilibrium. Several years or more may be required for firms to learn about consumer preferences, enrollee utilization, and strategic interactions with their competitors. Another issue concerns inversion of the firms' first-order conditions to estimate the claim slope. Inversion may fail or result in an imprecise estimate or over-estimate of the claim slope if the sum of the efficiency score and reinsurance factor is close to 1. Large estimates of the claim slope could magnify the impact of premium changes.

There are several dimensions along which the analysis in this paper could be extended. I assume that firms risk select by strategically setting premiums, holding non-premium characteristics fixed. While ACA exchange plans are standardized to some extent, insurers can still differentiate their products on certain attributes such as the provider network. A dynamic framework that models how insurers learn over time could improve estimates of the impact of risk adjustment. Another area for future research is to evaluate alternative measures for addressing the tradeoff between adverse selection and reclassification risk. Guaranteed renewable insurance policies with longer time horizons that are not subject to community rating regulation could be a promising alternative (Pauly et al., 1995; Herring and Pauly, 2006). Adequately-funded high risk pools that segregate the highest-risk consumers from the rest of the consumer population could address the selection problem while protecting the sick and chronically ill from reclassification risk with taxpayer assistance. Particularly in an imperfectly competitive market, these alternatives could help alleviate the negative welfare consequences of buttressing risk rating regulations with policies such as risk adjustment.

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Appendix A: Model Example Proofs

Proof of Proposition 2.1

1. First, I find the equilibrium premium vectors (p_L^*, p_H^*) and (p_L^R, p_H^R) for the example where firms have the linear demand functions (7) and the linear average claims functions (8). The Nash premium equilibrium is given by

$$\begin{aligned} p_L^* &= \frac{2(\kappa - 2\lambda_1 a + a/e_1)(1-\lambda_2 e_1) + (e_2/e_1 - 2\lambda_1 e_2)(\kappa - 2\lambda_2 a + a/e_1)}{4(1-\lambda_1 e_1)(1-\lambda_2 e_1) - e_2^2(1/e_1 - 2\lambda_1)(1/e_1 - 2\lambda_2)} \\ p_H^* &= \frac{2(\kappa - 2\lambda_2 a + a/e_1)(1-\lambda_1 e_1) + (e_2/e_1 - 2\lambda_2 e_2)(\kappa - 2\lambda_1 a + a/e_1)}{4(1-\lambda_1 e_1)(1-\lambda_2 e_1) - e_2^2(1/e_1 - 2\lambda_1)(1/e_1 - 2\lambda_2)} \end{aligned}$$

For this equilibrium to be well-defined, I need two constraints on the parameters:

(a) Positive Demand

$$q_H(p_L^*, p_H^*) > 0 \quad \Leftrightarrow \quad a > \kappa\,[e_1 - e_2] \tag{13}$$

(b) Positive Marginal Revenue

$$MR_L(p_L^*, p_H^*) > 0 \quad \Leftrightarrow \quad a < \kappa \left[\frac{4e_1 - 4\lambda_2 e_1^2 - 2\lambda_1 e_1 e_2 - e_2^2/e_1 + 2\lambda_2 e_2^2}{4\lambda_1 e_1 - 4\lambda_1\lambda_2 e_1^2 - 4\lambda_1\lambda_2 e_1 e_2 + 2\lambda_1 e_2}\right] \tag{14}$$

Putting constraints (13) and (14) together, it follows that the denominator D of the equilibrium premiums p_L^* and p_H^* is strictly positive. That is,

$$\begin{aligned} & e_1 - e_2 < \left[\frac{4e_1 - 4\lambda_2 e_1^2 - 2\lambda_1 e_1 e_2 - e_2^2/e_1 + 2\lambda_2 e_2^2}{4\lambda_1 e_1 - 4\lambda_1\lambda_2 e_1^2 - 4\lambda_1\lambda_2 e_1 e_2 + 2\lambda_1 e_2}\right] \\ \Leftrightarrow\quad & e_1(4\lambda_1 + 4\lambda_2) - 4\lambda_1\lambda_2 e_1^2 + 4\lambda_1\lambda_2 e_2^2 < e_2^2/e_1(2\lambda_1 + 2\lambda_2) + 4 - (e_2/e_1)^2 \\ \Leftrightarrow\quad & 4(1 - \lambda_1 e_1 + \lambda_2 e_1 + \lambda_1\lambda_2 e_1^2) - e_2^2\left(1/e_1^2 - 2\lambda_1/e_1 - 2\lambda_2/e_1 + 4\lambda_1\lambda_2\right) > 0 \\ \Leftrightarrow\quad & 4(1-\lambda_1 e_1)(1-\lambda_2 e_1) - e_2^2(1/e_1 - 2\lambda_1)(1/e_1 - 2\lambda_2) > 0 \\ \Leftrightarrow\quad & D > 0 \end{aligned}$$

Let N_L and N_H be the numerators of p_L^* and p_H^*, respectively. Using constraint (13) and the fact that $D > 0$, it follows that $p_L^* < p_H^*$ because

$$
\begin{aligned}
p_L^* < p_H^* &\Leftrightarrow N_L < N_H \\
&\Leftrightarrow 2(\kappa - 2\lambda_1 a + a/e_1)(1 - \lambda_2 e_1) + (e_2/e_1 - 2\lambda_1 e_2)(\kappa - 2\lambda_2 a + a/e_1) \\
&\quad < 2(\kappa - 2\lambda_2 a + a/e_1)(1 - \lambda_1 e_1) + (e_2/e_1 - 2\lambda_2 e_2)(\kappa - 2\lambda_1 a + a/e_1) \\
&\Leftrightarrow \lambda_1((e_1 - e_2)\kappa - a) < \lambda_2((e_1 - e_2)\kappa - a) \\
&\Leftrightarrow \lambda_1 > \lambda_2
\end{aligned}
$$

Moreover, $q_L(p_L^*, p_H^*) > q_H(p_L^*, p_H^*) > 0$ and $MR_H(p_L^*, p_H^*) > MR_L(p_L^*, p_H^*) > 0$. Because marginal revenue and marginal claims are equal at equilibrium, $MC_H(p_L^*, p_H^*) > MC_L(p_L^*, p_H^*) > 0$.

Implementation of risk adjustment eliminates firm L's cost advantage such that both firms have the same average claims function. Because both demand and claims are now symmetric, the firms set the same premium $p^R \equiv p_L^R = p_H^R$ and insure $q(p^R, p^R)$ consumers at equilibrium. Hence $c(p^R, p^R) = \kappa - 0.5(\lambda_1 + \lambda_2)q(p^R, p^R)$. Solving for the equilibrium vector yields

$$
p^R = \frac{e_1(\kappa - a(\lambda_1 + \lambda_2)) + a}{2e_1 + e_1(\lambda_1 + \lambda_2)(e_2 - e_1) - e_2}
$$

The risk adjustment premium p^R can be written (after some algebra) as

$$
\begin{aligned}
p^R &= \frac{e_1(\kappa - a(\lambda_1 + \lambda_2)) + a}{2e_1 + e_1(\lambda_1 + \lambda_2)(e_2 - e_1) - e_2} \times \frac{(2 - e_1\lambda_1 - e_1\lambda_2) + (e_2/e_1 - \lambda_1 e_2 - \lambda_2 e_2)}{(2 - e_1\lambda_1 - e_1\lambda_2) + (e_2/e_1 - \lambda_1 e_2 - \lambda_2 e_2)} \\
&= \frac{0.5(N_L + N_H) + a(\lambda_1 - \lambda_2)^2(e_1 + e_2)}{D + (\lambda_1 - \lambda_2)^2(e_1^2 - e_2^2)}
\end{aligned}
$$

Define $\overline{p}^* \equiv 0.5(p_L^* + p_H^*) = 0.5(N_L + N_H)/D$. Using the fact $D > 0$,

$$
\begin{aligned}
p^R > \overline{p}^* &\Leftrightarrow \frac{0.5(N_L + N_H) + a(\lambda_1 - \lambda_2)^2(e_1 + e_2)}{D + (\lambda_1 - \lambda_2)^2(e_1^2 - e_2^2)} > \frac{0.5(N_L + N_H)}{D} \\
&\Leftrightarrow a > \frac{0.5(N_L + N_H)(e_1 - e_2)}{D} \\
&\Leftrightarrow a > 0.5(p_L + p_H)(e_1 - e_2)
\end{aligned}
$$

Because of the constraint $q_H^* > 0 \Rightarrow a > e_1 p_H - e_2 p_L$,

$$\begin{aligned} a &> e_1 p_H - e_2 p_L \\ &> 0.5 e_1 (p_L + p_H) - e_2 p_L \\ &> 0.5 e_1 (p_L + p_H) - 0.5 e_2 (p_L + p_H) \\ &= 0.5 (p_L + p_H)(e_1 - e_2) \end{aligned}$$

which implies that $p^R > \overline{p}^*$.

2. Observe that

$$\begin{aligned} & 2q(p^R, p^R) < q_L(p_L^*, p_H^*) + q_H(p_L^*, p_H^*) \\ \Leftrightarrow\ & 2(a + (e_2 - e_1)p^R) < (a - e_1 p_L^* + e_2 p_H^*) + (a + e_2 p_L^* - e_1 p_H^*) \\ \Leftrightarrow\ & 2(e_2 - e_1)p^R < (e_2 - e_1)p_L^* + (e_2 - e_1)p_H^* \\ \Leftrightarrow\ & p^R > \overline{p}^* \end{aligned}$$

Because $p^R > \overline{p}^*$, it follows that $2q(p^R, p^R) < q_L(p_L^*, p_H^*) + q_H(p_L^*, p_H^*)$.

3. Denote $c(p^R, p^R)$ as the average claims in the market with risk adjustment. Because $2q(p^R, p^R) < q_L(p_L^*, p_H^*) + q_H(p_L^*, p_H^*)$ and $q_L(p_L^*, p_H^*) > q_H(p_L^*, p_H^*)$, it follows that

$$\begin{aligned} c(p^R, p^R) &= \kappa - 0.5(\lambda_1 + \lambda_2) q(p^R, p^R) \\ &> \kappa - 0.25(\lambda_1 + \lambda_2)[q_L(p_L^*, p_H^*) + q_H(p_L^*, p_H^*)] \\ &= \kappa - 0.5[\lambda_1 q_L(p_L^*, p_H^*) + \lambda_2 q_H(p_L^*, p_H^*)] + 0.25(\lambda_1 - \lambda_2)[q_L(p_L^*, p_H^*) - q_H(p_L^*, p_H^*)] \\ &= 0.5(c_L(p_L^*, p_H^*) + c_H(p_L^*, p_H^*)) + 0.25(\lambda_1 - \lambda_2)[q_L(p_L^*, p_H^*) - q_H(p_L^*, p_H^*)] \\ &> 0.5(c_L(p_L^*, p_H^*) + c_H(p_L^*, p_H^*)) \end{aligned}$$

4. The change in consumer surplus ΔCS can be written as

$$
\begin{aligned}
\Delta CS &= [CS(p^R,p^R) - CS_L(p_L^*,p_H^*)] + [CS(p^R,p^R) - CS_H(p_L^*,p_H^*)] \\
&= -(p^R - p_L^*)q(p^R,p^R) - 0.5(p^R - p_L^*)[q_L(p_L^*,p_H^*) - q(p^R,p^R)] \\
&\quad - (p^R - p_H^*)q(p^R,p^R) - 0.5(p^R - p_H^*)[q_H(p_L^*,p_H^*) - q(p^R,p^R)] \\
&= -0.5(p^R - p_L^*)[q(p^R,p^R) + q_L(p_L^*,p_H^*)] - 0.5(p^R - p_H^*)[q(p^R,p^R) + q_H(p_L^*,p_H^*)] \\
&< -0.5(p^R - p_L^*)[q(p^R,p^R) + q_L(p_L^*,p_H^*)] + 0.5(p^R - p_L^*)[q(p^R,p^R) + q_H(p_L^*,p_H^*)] \\
&< 0
\end{aligned}
$$

where the first inequality follows because $p^R > \overline{p}^*$ and the second inequality follows because $2q(p^R,p^R) < q_L(p_L^*,p_H^*) + q_H(p_L^*,p_H^*)$.

5. The change in profit $\Delta\pi$ can be written as

$$
\begin{aligned}
\Delta\pi &= 2\pi(p^R,p^R) - \pi_L(p_L^*,p_H^*) - \pi_H(p_L^*,p_H^*) \\
&= 2[p^R - c(p^R,p^R)]q(p^R,p^R) - [(p_L^* - c_L(p_L^*,p_H^*)]q_L(p_L^*,p_H^*) - [(p_H^* - c_H(p_L^*,p_H^*)]q_H(p_L^*,p_H^*) \\
&= (p^R - p_L^*)q(p^R,p^R) + (p^R - p_H^*)q(p^R,p^R) \\
&\quad - p_L^*[q_L(p_L^*,p_H^*) - q(p^R,p^R)] - p_H^*[q_H(p_L^*,p_H^*) - q(p^R,p^R)] \\
&\quad - [c(p^R,p^R) - c_L(p_L^*,p_H^*)]q(p^R,p^R) - [c(p^R,p^R) - c_H(p_L^*,p_H^*)]q(p^R,p^R) \\
&\quad + c_L(p_L^*,p_H^*)[q_L(p_L^*,p_H^*) - q(p^R,p^R)] + c_H(p_L^*,p_H^*)[q_H(p_L^*,p_H^*) - q(p^R,p^R)]
\end{aligned}
$$

It can be shown (after very tedious and messy algebra) that the above expression for the change in profit is strictly negative when substituting the explicit equilibrium solutions for p^R, p_L^*, and p_H^* into the above expression. A more intuitive explanation for the decline in total profit notes that by Proposition 2.1, risk adjustment increases the proportion of insured consumers covered by the less cost efficient firm (i.e., firm H) without any change in consumer preferences for the firms' plans. Hence, total profit across the two firms declines.

6. The reduction in social welfare follows immediately from the decline in consumer surplus and firm profit. A direct proof proceeds by writing the change in social welfare ΔSW as

$$
\begin{aligned}
\Delta SW &= \Delta\pi + \Delta CS \\
&= [-0.5p_L^* - 0.5p^R + c_L(p_L^*, p_H^*)][q_L(p_L^*, p_H^*) - q(p^R, p^R)] \\
&\quad - [(3/2)p_H^* - 0.5p^R - c_H(p_L^*, p_H^*)][q_H(p_L^*, p_H^*) - q(p^R, p^R)] \\
&\quad - [2c(p^R, p^R) - c_L(p_L^*, p_H^*) - c_H(p_L^*, p_H^*)]q(p^R, p^R) \\
&< [-0.5p_L^* - 0.5p^R + c_L(p_L^*, p_H^*)][q_L(p_L^*, p_H^*) - q(p^R, p^R)] \\
&\quad - [(3/2)p_H^* - 0.5p^R - c_H(p_L^*, p_H^*)][q_H(p_L^*, p_H^*) - q(p^R, p^R)]
\end{aligned}
$$

where the inequality follows because $2c(p^R, p^R) < c_L(p_L^*, p_H^*) + c_H(p_L^*, p_H^*)$. Note that the inequality $q(p^R, p^R) - q_L(p_L^*, p_H^*) > q_H(p_L^*, p_H^*) - q(p^R, p^R)$ follows directly from $2q(p^R, p^R) < q_L(p_L^*, p_H^*) + q_H(p_L^*, p_H^*)$. Also observe that

$$
\begin{aligned}
& [-0.5p_L^* - 0.5p^R + c_L(p_L^*, p_H^*)] + [(3/2)p_H^* - 0.5p^R - c_H(p_L^*, p_H^*)] \\
<\ & [-(p_L^* - c_L(p_L^*, p_H^*)) + (p_H^* - c_H(p_L^*, p_H^*))] + 0.5(p_H^* - p_L^*) \\
<\ & -[p_L^* - c_L(p_L^*, p_H^*)] + [p_H^* - c_H(p_L^*, p_H^*)] \\
<\ & 0
\end{aligned}
$$

where the final inequality follows because the linear demand function is log-concave (and hence the margin is increasing in quantity or decreasing in the premium). Therefore,

$$
\begin{aligned}
\Delta SW &< [-0.5p_L^* - 0.5p^R + c_L(p_L^*, p_H^*)][q_L(p_L^*, p_H^*) - q(p^R, p^R)] \\
&\quad - [(3/2)p_H^* - 0.5p^R - c_H(p_L^*, p_H^*)][q_H(p_L^*, p_H^*) - q(p^R, p^R)] \ < \ 0
\end{aligned}
$$

Proof of Proposition 2.2

1. First, I find the equilibrium premium vectors (p_L^*, p_H^*) and (p_L^R, p_H^R) for the example where firms have the linear demand functions (7) and the linear average claims functions (9). The Nash premium equilibrium is given by

$$
\begin{aligned}
p_L^* &= \frac{2(\lambda_2\kappa - 2\lambda_2 a + a/e_1)(1-\lambda_1 e_1) + (e_2/e_1 - 2\lambda_2 e_2)(\lambda_1\kappa - 2\lambda_1 a + a/e_1)}{4(1-\lambda_1 e_1)(1-\lambda_2 e_1) - e_2^2(1/e_1 - 2\lambda_1)(1/e_1 - 2\lambda_2)} \\
p_H^* &= \frac{2(\lambda_1\kappa - 2\lambda_1 a + a/e_1)(1-\lambda_2 e_1) + (e_2/e_1 - 2\lambda_1 e_2)(\lambda_2\kappa - 2\lambda_2 a + a/e_1)}{4(1-\lambda_1 e_1)(1-\lambda_2 e_1) - e_2^2(1/e_1 - 2\lambda_1)(1/e_1 - 2\lambda_2)}
\end{aligned}
$$

For this equilibrium to be well-defined, I need two constraints on the parameters:

(a) Positive Demand

$$
q_H(p_L^*, p_H^*) > 0 \quad \Leftrightarrow \quad a > \kappa \left[\frac{2e_1\lambda_1 - e_2\lambda_2 - 2e_1^2\lambda_1\lambda_2 + 2e_2^2\lambda_1\lambda_2 + (e_2^2/e_1)\lambda_1}{2 - 2\lambda_2 e_1 - 2\lambda_2 e_2 + e_2/e_1} \right] \tag{15}
$$

(b) Positive Marginal Revenue

$$
MR_L(p_L^*, p_H^*) > 0 \quad \Leftrightarrow \quad a < \kappa \left[1 - \frac{e_2}{2e_1} \right] \tag{16}
$$

Putting constraints (15) and (16) together, it follows that the denominator D of the equilibrium premiums p_L^* and p_H^* is strictly positive. That is,

$$
\begin{aligned}
& \frac{2e_1\lambda_1 - e_2\lambda_2 - 2e_1^2\lambda_1\lambda_2 + 2e_2^2\lambda_1\lambda_2 + (e_2^2/e_1)\lambda_1}{2 - 2\lambda_2 e_1 - 2\lambda_2 e_2 + e_2/e_1} < 1 - \frac{e_2}{2e_1} \\
\Leftrightarrow \quad & e_1(4\lambda_1 + 4\lambda_2) - 4\lambda_1\lambda_2 e_1^2 + 4\lambda_1\lambda_2 e_2^2 < e_2^2/e_1(2\lambda_1 + 2\lambda_2) + 4 - (e_2/e_1)^2 \\
\Leftrightarrow \quad & 4(1 - \lambda_1 e_1 + \lambda_2 e_1 + \lambda_1\lambda_2 e_1^2) - e_2^2\left(1/e_1^2 - 2\lambda_1/e_1 - 2\lambda_2/e_1 + 4\lambda_1\lambda_2\right) > 0 \\
\Leftrightarrow \quad & 4(1-\lambda_1 e_1)(1-\lambda_2 e_1) - e_2^2(1/e_1 - 2\lambda_1)(1/e_1 - 2\lambda_2) > 0 \\
\Leftrightarrow \quad & D > 0
\end{aligned}
$$

Let N_L and N_H be the numerators of p_L^* and p_H^*, respectively. Using constraint (16) and the fact that $D > 0$, it follows that $p_L^* < p_H^*$ because

$$
\begin{aligned}
p_L^* < p_H^* &\Leftrightarrow N_L < N_H \\
&\Leftrightarrow 2(\lambda_2\kappa - 2\lambda_2 a + a/e_1)(1-\lambda_1 e_1) + (e_2/e_1 - 2\lambda_2 e_2)(\lambda_1\kappa - 2\lambda_1 a + a/e_1) \\
&\quad < 2(\lambda_1\kappa - 2\lambda_1 a + a/e_1)(1-\lambda_2 e_1) + (e_2/e_1 - 2\lambda_1 e_2)(\lambda_2\kappa - 2\lambda_2 a + a/e_1) \\
&\Leftrightarrow \lambda_1(2\kappa - 2a - (e_2/e_1)\kappa) < \lambda_2(2\kappa - 2a - (e_2/e_1)\kappa) \\
&\Leftrightarrow \lambda_1 > \lambda_2
\end{aligned}
$$

Moreover, $q_L(p_L^*, p_H^*) > q_H(p_L^*, p_H^*) > 0$ and $MR_H(p_L^*, p_H^*) > MR_L(p_L^*, p_H^*) > 0$. Because marginal revenue and marginal claims are equal at equilibrium, $MC_H(p_L^*, p_H^*) > MC_L(p_L^*, p_H^*) > 0$.

Implementation of risk adjustment eliminates firm L's cost advantage such that both firms have the same average claims function. Because both demand and claims are now symmetric, the firms set the same premium $p^R \equiv p_L^R = p_H^R$ and insure $q(p^R, p^R)$ consumers at equilibrium. Hence $c(p^R, p^R) = -0.5(\lambda_1 + \lambda_2)[q(p^R, p^R) - \kappa]$. Solving for the equilibrium vector yields

$$
p^R = \frac{e_1(0.5(\lambda_1+\lambda_2)\kappa - a(\lambda_1+\lambda_2)) + a}{2e_1 + e_1(\lambda_1+\lambda_2)(e_2-e_1) - e_2}
$$

The premium p^R can be written (after some algebra) as

$$
\begin{aligned}
p^R &= \frac{e_1(0.5(\lambda_1+\lambda_2)\kappa - a(\lambda_1+\lambda_2)) + a}{2e_1 + e_1(\lambda_1+\lambda_2)(e_2-e_1) - e_2} \times \frac{(2 - e_1\lambda_1 - e_1\lambda_2) + (e_2/e_1 - \lambda_1 e_2 - \lambda_2 e_2)}{(2 - e_1\lambda_1 - e_1\lambda_2) + (e_2/e_1 - \lambda_1 e_2 - \lambda_2 e_2)} \\
&= \frac{0.5(N_L+N_H) + (a - \kappa/2)(\lambda_1-\lambda_2)^2(e_1+e_2)}{D + (\lambda_1-\lambda_2)^2(e_1^2 - e_2^2)}
\end{aligned}
$$

Using the fact $D > 0$,

$$
\begin{aligned}
p^R < \overline{p}^* &\Leftrightarrow \frac{0.5(N_L+N_H) + (a-\kappa/2)(\lambda_1-\lambda_2)^2(e_1+e_2)}{D + (\lambda_1-\lambda_2)^2(e_1^2-e_2^2)} < \frac{0.5(N_L+N_H)}{D} \\
&\Leftrightarrow a < \frac{\kappa}{2} + \frac{0.5(N_L+N_H)(e_1-e_2)}{D} \\
&\Leftrightarrow a < \frac{\kappa}{2} + 0.5(p_L+p_H)(e_1-e_2)
\end{aligned}
$$

Because the constraint $MC_L > 0$ implies that

$$MC_L(\mathbf{p}) > 0 \quad \Leftrightarrow \quad q_L(\mathbf{p}) < \frac{\kappa}{2}$$
$$\Leftrightarrow \quad a < \frac{\kappa}{2} + e_1 p_L - e_2 p_H$$

it follows that $a < \kappa/2 + e_1 p_L - e_2 p_H < \kappa/2 + 0.5(p_L + p_H)(e_1 - e_2)$. Hence, $p^R < \overline{p}^*$.

2. Observe that

$$\begin{aligned} & 2q(p^R, p^R) > q_L(p_L^*, p_H^*) + q_H(p_L^*, p_H^*) \\ \Leftrightarrow \quad & 2(a + (e_2 - e_1)p^R) > (a - e_1 p_L^* + e_2 p_H^*) + (a + e_2 p_L^* - e_1 p_H^*) \\ \Leftrightarrow \quad & 2(e_2 - e_1)p^R > (e_2 - e_1)p_L^* + (e_2 - e_1)p_H^* \\ \Leftrightarrow \quad & p^R < \overline{p}^* = 0.5(p_L^* + p_H^*) \end{aligned}$$

Because $p^R < \overline{p}^*$, it follows that $2q(p^R, p^R) > q_L(p_L^*, p_H^*) + q_H(p_L^*, p_H^*)$.

3. Denote $c(p^R, p^R)$ the average claims in the market with risk adjustment. Because $2q(p^R, p^R) > q_L(p_L^*, p_H^*) + q_H(p_L^*, p_H^*)$ and $q_L(p_L^*, p_H^*) > q_H(p_L^*, p_H^*)$, it follows that

$$\begin{aligned} & c(p^R, p^R) \\ & = -0.5(\lambda_1 + \lambda_2)[q(p^R, p^R) - \kappa] \\ & < -0.25(\lambda_1 + \lambda_2)[q_L(p_L^*, p_H^*) + q_H(p_L^*, p_H^*)] + 0.5(\lambda_1 + \lambda_2)\kappa \\ & = -0.5[\lambda_2 q_L(p_L^*, p_H^*) + \lambda_1 q_H(p_L^*, p_H^*)] + 0.25(\lambda_2 - \lambda_1)[q_L(p_L^*, p_H^*) - q_H(p_L^*, p_H^*)] + 0.5(\lambda_1 + \lambda_2)\kappa \\ & = 0.5(c_L(p_L^*, p_H^*) + c_H(p_L^*, p_H^*)) + 0.25(\lambda_2 - \lambda_1)[q_L(p_L^*, p_H^*) - q_H(p_L^*, p_H^*)] \\ & < 0.5(c_L(p_L^*, p_H^*) + c_H(p_L^*, p_H^*)) \end{aligned}$$

4. The change in consumer surplus ΔCS can be written as

$$
\begin{aligned}
\Delta CS &= [CS(p^R,p^R) - CS_L(p_L^*,p_H^*)] + [CS(p^R,p^R) - CS_H(p_L^*,p_H^*)] \\
&= -(p^R - p_L^*)q(p^R,p^R) - 0.5(p^R - p_L^*)[q_L(p_L^*,p_H^*) - q(p^R,p^R)] \\
&\quad - (p^R - p_H^*)q(p^R,p^R) - 0.5(p^R - p_H^*)[q_H(p_L^*,p_H^*) - q(p^R,p^R)] \\
&= -0.5(p^R - p_L^*)[q(p^R,p^R) + q_L(p_L^*,p_H^*)] - 0.5(p^R - p_H^*)[q(p^R,p^R) + q_H(p_L^*,p_H^*)] \\
&> -0.5(p^R - p_L^*)[q(p^R,p^R) + q_L(p_L^*,p_H^*)] + 0.5(p^R - p_L^*)[q(p^R,p^R) + q_H(p_L^*,p_H^*)] \\
&> 0
\end{aligned}
$$

where the first inequality follows because $p^R < \overline{p}^*$ and the second inequality follows because $2q(p^R,p^R) > q_L(p_L^*,p_H^*) + q_H(p_L^*,p_H^*)$.

5. The change in profit $\Delta\pi$ can be written as

$$
\begin{aligned}
\Delta\pi &= 2\pi(p^R,p^R) - \pi_L(p_L^*,p_H^*) - \pi_H(p_L^*,p_H^*) \\
&= 2[p^R - c(p^R,p^R)]q(p^R,p^R) - [(p_L^* - c_L(p_L^*,p_H^*)]q_L(p_L^*,p_H^*) - [(p_H^* - c_H(p_L^*,p_H^*)]q_H(p_L^*,p_H^*) \\
&= (p^R - p_L^*)q(p^R,p^R) + (p^R - p_H^*)q(p^R,p^R) \\
&\quad - p_L^*[q_L(p_L^*,p_H^*) - q(p^R,p^R)] - p_H^*[q_H(p_L^*,p_H^*) - q(p^R,p^R)] \\
&\quad - [c(p^R,p^R) - c_L(p_L^*,p_H^*)]q(p^R,p^R) - [c(p^R,p^R) - c_H(p_L^*,p_H^*)]q(p^R,p^R) \\
&\quad + c_L(p_L^*,p_H^*)[q_L(p_L^*,p_H^*) - q(p^R,p^R)] + c_H(p_L^*,p_H^*)[q_H(p_L^*,p_H^*) - q(p^R,p^R)]
\end{aligned}
$$

It can be shown (after very tedious and messy algebra) that the above expression for the change in profit is strictly negative when substituting the explicit equilibrium solutions for p^R, p_L^*, and p_H^* into the above expression. A more intuitive explanation for the decline in total profit notes that by Proposition 2.2, risk adjustment increases the proportion of insured consumers covered by the less cost efficient firm (i.e., firm H) without any change in consumer preferences for the firms' plans. Hence, total profit across the two firms declines.

Appendix B: Mathematical Formulas in Model

In this appendix, I write the variables in the model in terms of four variables: (1) the household choice probability $q_{ij}(\mathbf{p})$; (2) the partial derivative $\partial q_{ik}/\partial p_{ij}(\mathbf{p})$ for all plans j and k; (3) the firm's average claims function $c_f(\mathbf{p})$; and (4) the vector of claim slopes with elements $\partial c_f(\mathbf{p})/\partial p_j$.

Demand Variables

Formulas for plan demand $q_j(\mathbf{p})$, firm demand $q_f(\mathbf{p})$, market demand $q(\mathbf{p})$, and the risk-adjusted share are given by

$$q_j(\mathbf{p}) = \sum_{i \in I} q_{ij}(\mathbf{p})$$

$$q_f(\mathbf{p}) = \sum_{k \in J_f} q_k(\mathbf{p}) = \sum_{i \in I, k \in J_f} q_{ik}(\mathbf{p})$$

$$q(\mathbf{p}) = \sum_{l \in J} q_l(\mathbf{p}) = \sum_{i \in I, l \in J} q_{il}(\mathbf{p})$$

$$s_f(\mathbf{p}) = \frac{\sum_{i \in I, k \in J_f} h_k q_{ik}(\mathbf{p})}{\sum_{i \in I, l \in J} h_l q_{il}(\mathbf{p})}$$

where h_j is an expected utilization measure that accounts for the actuarial value of plan j and associated moral hazard.

Revenue Variables

Formulas for total firm premium revenue $R_f(\mathbf{p})$ and total premium revenue across all firms $R(\mathbf{p})$ are given by

$$R_f(\mathbf{p}) = \sum_{i \in I, k \in J_f} r_{ik} p_k q_{ik}(\mathbf{p})$$

$$R(\mathbf{p}) = \sum_{f \in F} R_f(\mathbf{p}) = \sum_{i \in I, l \in J} r_{il} p_l q_{il}(\mathbf{p})$$

Claims Variables

Formulas for total firm claims $C_f(\mathbf{p})$ and total incurred claims across all firms $C(\mathbf{p})$ are given by

$$C_f(\mathbf{p}) = c_f(\mathbf{p}) q_f(\mathbf{p}) = c_f(\mathbf{p}) \sum_{i \in I, k \in J_f} q_{ik}(\mathbf{p})$$

$$C(\mathbf{p}) = \sum_{f \in F} C_f(\mathbf{p}) = \sum_{f \in F} c_f(\mathbf{p}) \left(\sum_{i \in I, k \in J_f} q_{ik}(\mathbf{p}) \right)$$

Market-wide average claims $c(\mathbf{p})$ can be written as

$$c(\mathbf{p}) = \frac{\sum_{f\in F} q_f(\mathbf{p}) c_f(\mathbf{p})}{\sum_{f\in F} q_f(\mathbf{p})} = \frac{\sum_{f\in F} c_f(\mathbf{p}) \left(\sum_{i\in I, k\in J_f} q_{ik}(\mathbf{p})\right)}{\sum_{f\in F} q_f(\mathbf{p})}$$

Administrative Cost Variables

Variable administrative cost can be written as

$$V_f = v_f q_f(\mathbf{p}) = v_f \sum_{i\in I, k\in J_f} q_{ik}(\mathbf{p})$$

where v_f is the per-member, per-month variable administrative cost.

Demand Partial Derivatives

The partial derivatives of individual demand, plan demand, firm demand, and the risk-adjusted share with respect to the plan base premium can be written as

$$\frac{\partial q_{ik}(\mathbf{p})}{\partial p_j} = \sum_{l\in J} \frac{\partial q_{ik}(\mathbf{p})}{\partial p_{il}(\mathbf{p})} \frac{\partial p_{il}(\mathbf{p})}{\partial p_j}$$

$$\frac{\partial q_j(\mathbf{p})}{\partial p_j} = \sum_{i\in I} \frac{\partial q_{ij}(\mathbf{p})}{\partial p_j} = \sum_{i\in I, l\in J} \frac{\partial q_{ij}(\mathbf{p})}{\partial p_{il}(\mathbf{p})} \frac{\partial p_{il}(\mathbf{p})}{\partial p_j}$$

$$\frac{\partial q_f(\mathbf{p})}{\partial p_j} = \sum_{i\in I, k\in J_f} \frac{\partial q_{ik}(\mathbf{p})}{\partial p_j} = \sum_{i\in I, k\in J_f, l\in J} \frac{\partial q_{ik}(\mathbf{p})}{\partial p_{il}(\mathbf{p})} \frac{\partial p_{il}(\mathbf{p})}{\partial p_j}$$

$$\frac{\partial s_f(\mathbf{p})}{\partial p_j} = \frac{\sum_{i\in I, l\in J} h_l q_{il}(\mathbf{p}) \sum_{i\in I, k\in J_f} h_k \partial q_{ik}(\mathbf{p})/\partial p_j - \sum_{i\in I, k\in J_f} h_k q_{ik}(\mathbf{p}) \sum_{i\in I, l\in J} h_l \partial q_{il}(\mathbf{p})/\partial p_j}{\left(\sum_{i\in I, l\in J} h_l q_{il}(\mathbf{p})\right)^2}$$

Because of the ACA's complex subsidy design, the change in the household's subsidized premium with respect to a change in the base premium $(\partial p_{il}(\mathbf{p})/\partial p_j)$ is somewhat involved. If j is not the benchmark plan, a dollar increase in the plan's base premium increases the household's premium for j by the rating factor r_{ij}.[3] If j is the benchmark plan, a dollar increase in plan j's premium does not affect what consumers pay for plan j because of offsetting subsidies, but rather decreases what consumers pay for all other plans by r_{ij} dollars. Alternative subsidy designs may change how consumer premiums respond to the firms' base premiums. Under a voucher design, an increase in plan j's premium affects only what consumers pay for plan j.

[3] The change must be sufficiently small for plan j not to become the benchmark plan.

Marginal Revenue, Marginal Claims, and Average Marginal Claims

Marginal revenue $MR_j(\mathbf{p})$, marginal claims $MC_j(\mathbf{p})$, and average marginal claims $\overline{MC}_j(\mathbf{p})$ can be expressed as

$$MR_j(\mathbf{p}) = \frac{\partial R_f(\mathbf{p})}{\partial q_j(\mathbf{p})} = \left(\frac{\partial q_j(\mathbf{p})}{\partial p_j}\right)^{-1} \sum_{i \in I} \left(r_{ij} q_{ij}(\mathbf{p}) + \sum_{k \in J_f} r_{ik} p_k \frac{\partial q_{ik}(\mathbf{p})}{\partial p_j} \right) \tag{17}$$

$$MC_j(\mathbf{p}) = \frac{\partial C_f(\mathbf{p})}{\partial q_j(\mathbf{p})} = \left(\frac{\partial q_j(\mathbf{p})}{\partial p_j}\right)^{-1} \left[c_f(\mathbf{p}) \frac{\partial q_f(\mathbf{p})}{\partial p_j} + q_f(\mathbf{p}) \frac{\partial c_f(\mathbf{p})}{\partial p_j} \right] \tag{18}$$

$$\overline{MC}_j(\mathbf{p}) = \frac{\partial (s_f(\mathbf{p}) C(\mathbf{p}))}{\partial q_j(\mathbf{p})} = \left(\frac{\partial q_j(\mathbf{p})}{\partial p_j}\right)^{-1} \left[C(\mathbf{p}) \frac{\partial s_f(\mathbf{p})}{\partial p_j} + s_f(\mathbf{p}) \frac{\partial C(\mathbf{p})}{\partial p_j} \right] \tag{19}$$

where the partial derivative of total claims incurred by all firms with respect to the base premium equals

$$\frac{\partial C(\mathbf{p})}{\partial p_j} = \sum_{f' \in F} \sum_{k' \in J_{f'}} \frac{\partial C_{f'}(\mathbf{p})}{\partial q_{k'}(\mathbf{p})} \frac{\partial q_{k'}(\mathbf{p})}{\partial p_j} = \sum_{f' \in F} \sum_{k' \in J_{f'}} MC_{k'}(\mathbf{p}) \frac{\partial q_{k'}(\mathbf{p})}{\partial p_j}$$

Note that the formula for $\partial C(\mathbf{p})/\partial p_j$ does not require data on the claims cross-partial derivatives. That is, it is not necessary to calculate $\partial C_f(\mathbf{p})/\partial p_j$ if plan j is not sold by firm f. Elimination of the cross-partial derivatives makes empirical estimation of the model feasible when only firm-level cost data is available.

Appendix C: Risk Adjustment Under the ACA

In this appendix, I derive the ACA risk adjustment formula and price equilibrium in the ACA setting. I start with Pope et al. (2014)'s transfer formula as derived in their first appendix, which allows plans to vary only by their actuarial values (and not by differences in firm efficiency, geographic costs, allowable rating factors, or moral hazard).[4] Pope et al. (2014) show that the per-member per-month risk adjustment transfer can be calculated according to formula ($A14$):

[4] I start with this formula because I want to capture all differences in expected risk, except for cost sharing and any associated moral hazard, in the plan's risk score (i.e., cost sharing and moral hazard are addressed through the risk-adjusted share $s_f(\mathbf{p})$). In contrast, the plan liability risk score $PLRS_j$ as defined in Pope et al. (2014)'s second appendix does not account for certain differences such as variation in geographic cost. Instead, Pope et al. (2014) account for these differences by applying factors in the transfer formula.

$$T_j = PLRS_j \times \overline{p} - \frac{AV_j}{\sum_l AV_l s_l} \overline{p}$$

where T_j is the PMPM transfer received by plan j, $PLRS_j$ is plan j's plan liability risk score, $\overline{p}$ is the share-weighted average statewide premium, AV_l is the actuarial value of plan l, and s_l is plan l's market share. Pope et al. (2014) define the plan liability risk score as the ratio of the plan's average liability to the weighted-average liability across firms, which in my notation is $c_j(\mathbf{p})/c(\mathbf{p})$. The per-member per-month risk adjustment transfer $ra_j(\mathbf{p})$ of plan j in my notation equals

$$\begin{aligned} ra_j(\mathbf{p}) &= \frac{C_j(\mathbf{p})/q_j(\mathbf{p})}{C(\mathbf{p})/q(\mathbf{p})} \frac{R(\mathbf{p})}{q(\mathbf{p})} - \frac{h_j q(\mathbf{p})}{\sum_{l \in J} h_l q_l(\mathbf{p})} \frac{R(\mathbf{p})}{q(\mathbf{p})} \\ &= \frac{C_j(\mathbf{p}) R(\mathbf{p})}{q_j(\mathbf{p}) C(\mathbf{p})} - \frac{h_j}{\sum_{l \in J} h_l q_l(\mathbf{p})} R(\mathbf{p}) \end{aligned}$$

where I have replaced the actuarial value factors with the total utilization factors h_j to account for moral hazard. The total risk adjustment transfer $RA_j(\mathbf{p})$ for plan j is given by

$$RA_j(\mathbf{p}) = ra_j(\mathbf{p}) q_j(\mathbf{p}) = \frac{C_j(\mathbf{p}) R(\mathbf{p})}{C(\mathbf{p})} - s_j(\mathbf{p}) R(\mathbf{p})$$

Summing across all plans k offered by firm f yields

$$RA_f(\mathbf{p}) = \frac{C_f(\mathbf{p}) R(\mathbf{p})}{C(\mathbf{p})} - s_f(\mathbf{p}) R(\mathbf{p})$$

To allow for variation in the firm bargaining power and ability to exploit risk adjustment, I multiply the first term by the efficiency score ϕ_f to yield the ACA risk adjustment transfer formula:

$$RA_f(\mathbf{p}) = \frac{\phi_f C_f(\mathbf{p}) R(\mathbf{p})}{C(\mathbf{p})} - s_f(\mathbf{p}) R(\mathbf{p}) \tag{20}$$

Adding the ACA transfer (20) to firm f's profit function yields

$$\pi_f(\mathbf{p}) = (1 - s_f(\mathbf{p})) R(\mathbf{p}) + \phi_f C_f(\mathbf{p}) R(\mathbf{p}) / C(\mathbf{p}) - (1 - \tau_f) C_f(\mathbf{p}) - V_f - FC_f \tag{21}$$

Firm f's corresponding first-order conditions are given by

$$MR_j(\mathbf{p}) = \overline{MR}_j(\mathbf{p}) - \phi_f MC'_j(\mathbf{p}) + (1 - \tau_f) MC_j(\mathbf{p}) + v_f \frac{\partial q_f(\mathbf{p}) / \partial p_j}{\partial q_j(\mathbf{p}) / \partial p_j} \tag{22}$$

for $j \in J_f$, where $\overline{MR}_j(\mathbf{p}) \equiv \partial[s_f(\mathbf{p})R(\mathbf{p})]/\partial q_j(\mathbf{p})$ and $MC'_j(\mathbf{p}) = \partial[C_f(\mathbf{p})R(\mathbf{p})/C(\mathbf{p})]/\partial q_j(\mathbf{p})$. Formulas for $\overline{MR}_j(\mathbf{p})$ and $MC'_j(\mathbf{p})$ are given by

$$\overline{MR}_j(\mathbf{p}) = \frac{\partial(s_f(\mathbf{p})R(\mathbf{p}))}{\partial q_j(\mathbf{p})} = \left(\frac{\partial q_j(\mathbf{p})}{\partial p_j}\right)^{-1}\left[R(\mathbf{p})\frac{\partial s_f(\mathbf{p})}{\partial p_j} + s_f(\mathbf{p})\frac{\partial R(\mathbf{p})}{\partial p_j}\right]$$

$$\begin{aligned} MC'_j(\mathbf{p}) &= \frac{\partial}{\partial q_j(\mathbf{p})}\left(\frac{C_f(\mathbf{p})R(\mathbf{p})}{C(\mathbf{p})}\right) \\ &= \frac{C(\mathbf{p})\left[\frac{\partial C_f(\mathbf{p})}{\partial p_j}R(\mathbf{p}) + C_f(\mathbf{p})\frac{\partial R(\mathbf{p})}{\partial p_j}\right] - C_f(\mathbf{p})R(\mathbf{p})\frac{\partial C(\mathbf{p})}{\partial p_j}}{\frac{\partial q_j(\mathbf{p})}{\partial p_j}[C(\mathbf{p})]^2} \\ &= MC_j(\mathbf{p})\frac{R(\mathbf{p})}{C(\mathbf{p})} + \frac{C_f(\mathbf{p})\sum_{f'\in F}\sum_{k'\in J_{f'}}\left(C(\mathbf{p})MR_{k'}(\mathbf{p}) - R(\mathbf{p})MC_{k'}(\mathbf{p})\right)\frac{\partial q_{k'}(\mathbf{p})}{\partial p_j}}{[C(\mathbf{p})]^2} \end{aligned}$$

where

$$\frac{\partial R(\mathbf{p})}{\partial p_j} = \sum_{f'\in F}\sum_{k'\in J_{f'}}\frac{\partial P_{f'}(\mathbf{p})}{\partial q_{k'}(\mathbf{p})}\frac{\partial q_{k'}(\mathbf{p})}{\partial p_j} = \sum_{f'\in F}\sum_{k'\in J_{f'}} MR_{k'}(\mathbf{p})\frac{\partial q_{k'}(\mathbf{p})}{\partial p_j}$$

$$\frac{\partial C(\mathbf{p})}{\partial p_j} = \sum_{f'\in F}\sum_{k'\in J_{f'}}\frac{\partial C_{f'}(\mathbf{p})}{\partial q_{k'}(\mathbf{p})}\frac{\partial q_{k'}(\mathbf{p})}{\partial p_j} = \sum_{f'\in F}\sum_{k'\in J_{f'}} MC_{k'}(\mathbf{p})\frac{\partial q_{k'}(\mathbf{p})}{\partial p_j}$$

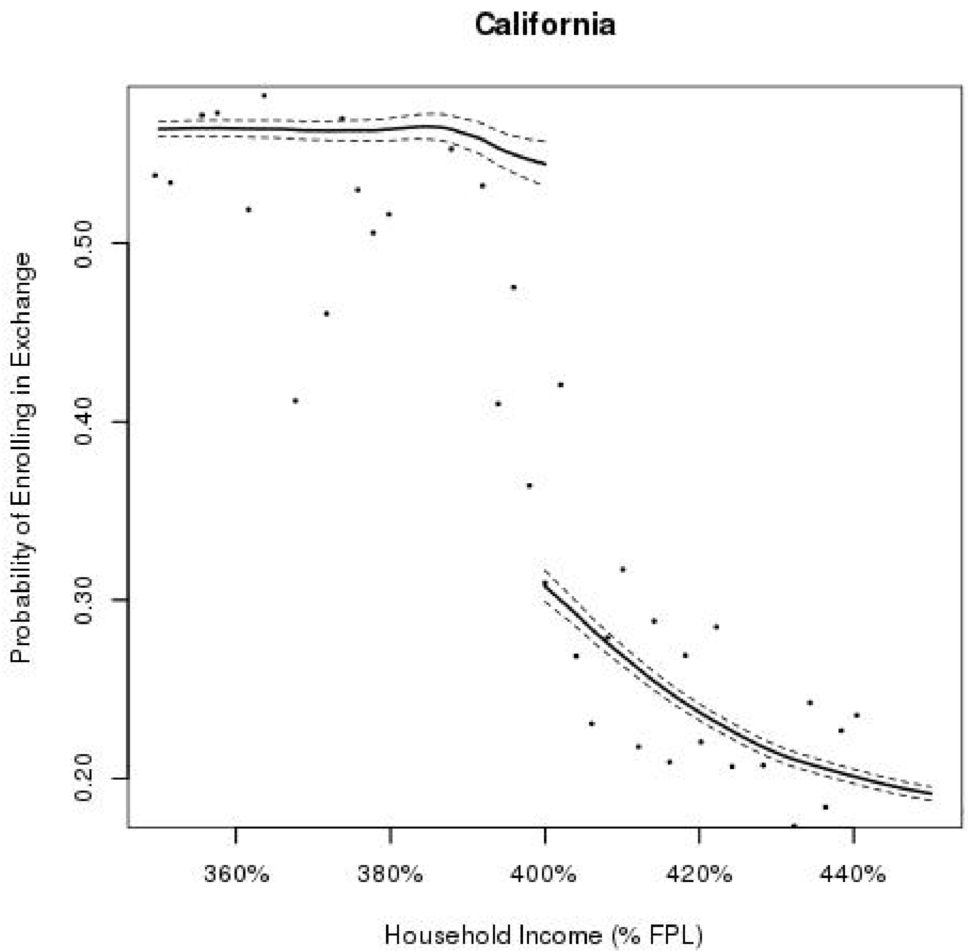
Appendix D: Reduced-Form Evidence of Premium Sensitivity

Table 16: Regression Discontinuity Results on Marketplace Enrollment Probability

	Change in Enrollment Probability
Premium Changes	
400% Subsidy Eligibility Threshold	-0.237^{***}
	(0.010)
Age 21 Rating Curve Breakpoint	0.013
	(0.017)
Mandate Exemptions	
Tax Filing Threshold	0.188^{***}
	(0.017)
Affordability Threshold	-0.006
	(0.014)

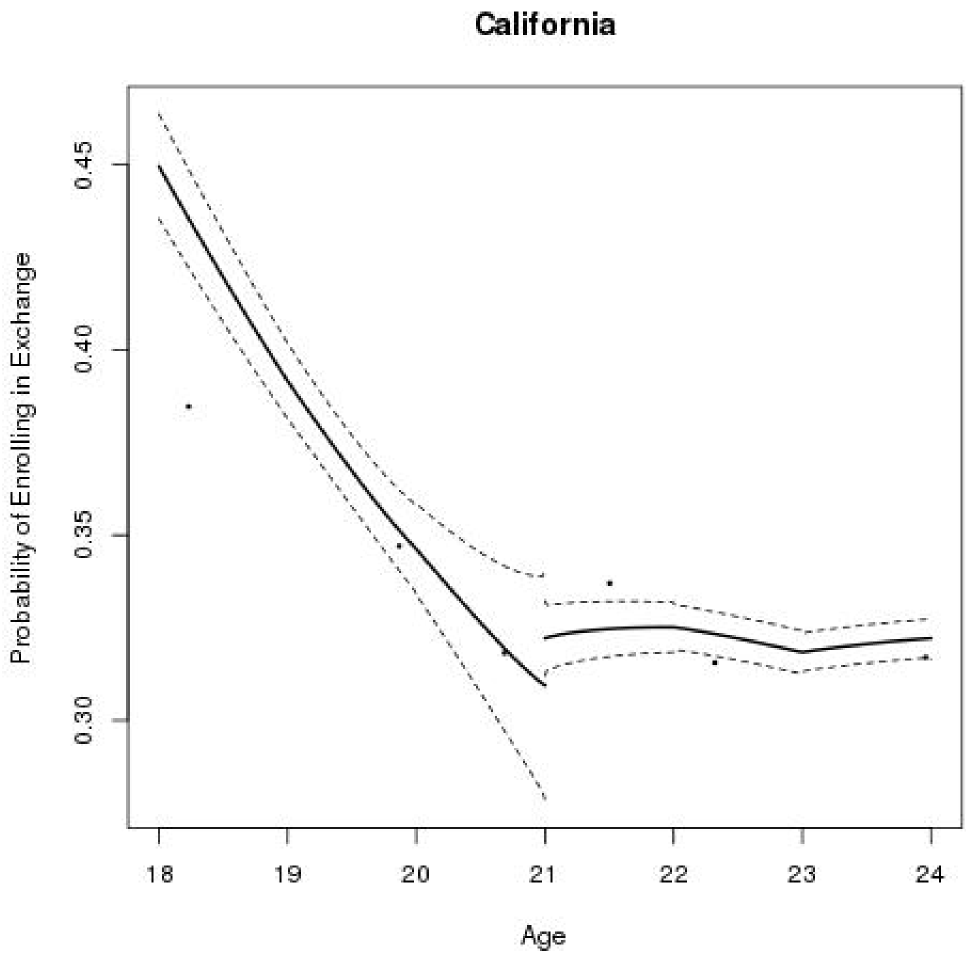
Notes: ***Significant at the 1 percent level. **Significant at the 5 percent level. *Significant at the 10 percent level. Robust standard errors are in parentheses. Table shows the results of four different regression discontinuity design regressions in which the choice of enrolling in an exchange plan is regressed on dummy variables for whether (1) the household has income above the upper limit for receiving subsidies of 400 percent of FPL; (2) the consumer is above the age of 21 (3) the household has income above the tax filing threshold; and (4) the household has an affordable offer. Local linear regressions are performed on either side of the thresholds using a triangular kernel and the Imbens-Kalyanamaran optimal bandwidth calculation.

Figure 6: Probability of Enrolling in an Exchange Plan by Income



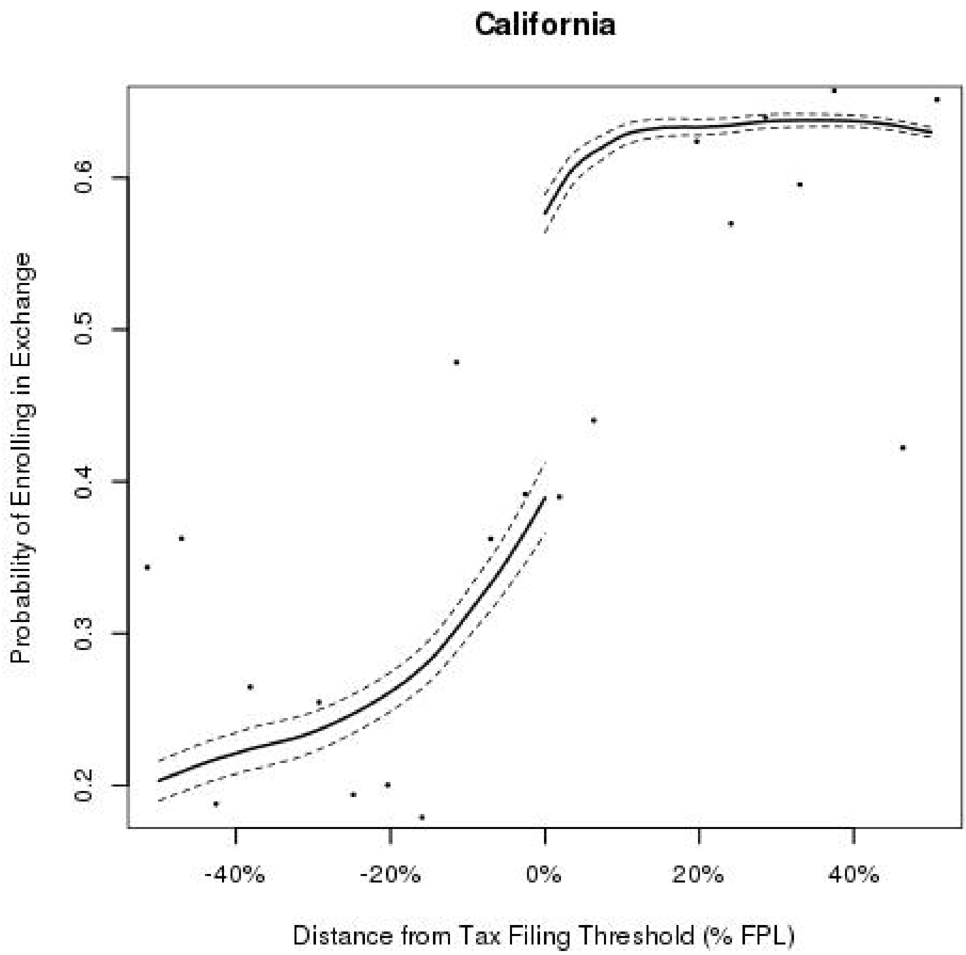
Notes: Figure shows how the probability of enrolling in an exchange plan changes at 400 percent of poverty, the upper income eligibility limit for receiving premium subsidies. Local linear regressions are performed on either side of the subsidy threshold using a triangular kernel and the Imbens-Kalyanamaran optimal bandwidth calculation.

Figure 7: Probability of Enrolling in an Exchange Plan by Age



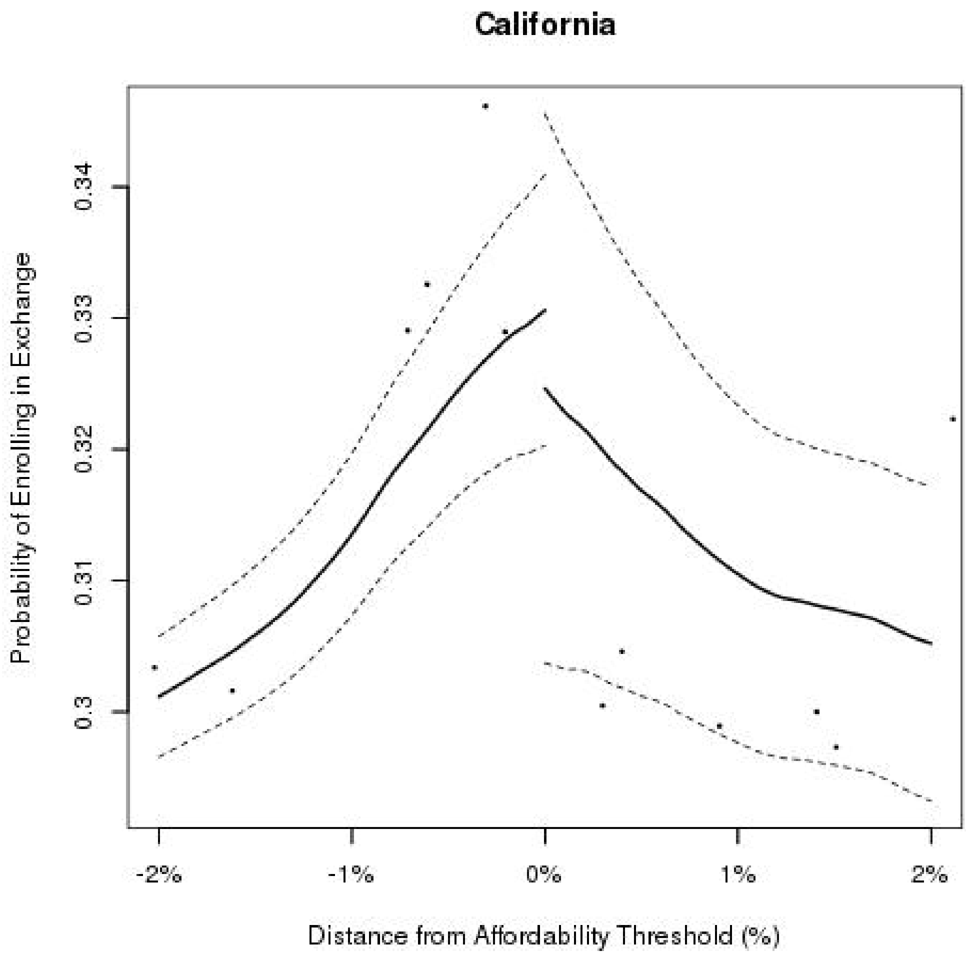
Notes: Figure shows how the probability of enrolling in an exchange plan changes at age 21. Local linear regressions are performed on either side of the age threshold using a triangular kernel and the Imbens-Kalyanamaran optimal bandwidth calculation.

Figure 8: Probability of Enrolling in an Exchange Plan by Tax Filing Status



Notes: Figure shows how tax filing status affects the probability of enrolling in an exchange plan. Distance from tax filing threshold is the difference between the household's income and its tax filing threshold, measured as a percent of the poverty level. Local linear regressions are performed on either side of the tax filing threshold using a triangular kernel and the Imbens-Kalyanamaran optimal bandwidth calculation.

Figure 9: Probability of Enrolling in an Exchange Plan by Affordability Exemption Status



Notes: Figure shows how affordability exemption status affects the probability of enrolling in an exchange plan. Distance from affordability threshold is the difference between the household's income and its affordability threshold, measured as a percent of household income. The affordability threshold was 8 percent of household income in 2014 and 8.05 percent of household income in 2015. Local linear regressions are performed on either side of the affordability threshold using a triangular kernel and the Imbens-Kalyanamaran optimal bandwidth calculation.

Appendix E: Estimated Parameters of Demand Model

Table 17: Control Function Regression Results

	Nested Logit	Control Function
Monthly Premium ($100)	-0.304^{***}	-0.283^{***}
	(0.087)	(0.103)
Actuarial Value (AV)	2.208^{***}	2.147^{**}
	(0.715)	(0.960)
HMO	-0.116^{***}	-0.114^{**}
	(0.037)	(0.047)
Anthem	0.225^{***}	0.225^{**}
	(0.078)	(0.109)
Blue Shield CA	0.264^{***}	0.264^{**}
	(0.092)	(0.126)
Centene/Health Net	0.233^{***}	0.233^{**}
	(0.083)	(0.110)
Chinese Community	0.235^{***}	0.239^{**}
	(0.083)	(0.112)
Kaiser	0.420^{***}	0.420^{**}
	(0.142)	(0.193)
LA Care	0.075^{***}	0.074^{**}
	(0.028)	(0.035)
Molina	-0.123^{***}	-0.147^{*}
	(0.042)	(0.079)
Sharp	0.245^{***}	0.246^{**}
	(0.083)	(0.111)
Valley	-0.003	-0.012
	(0.012)	(0.018)
Western Health	0.117^{***}	0.106^{**}
	(0.039)	(0.041)
Premium ($100) ×		
138-250	0.045^{***}	0.040^{***}
	(0.013)	(0.012)
250-400	0.095^{***}	0.093^{***}
	(0.027)	(0.031)
400+	0.096^{***}	0.096^{***}
	(0.026)	(0.031)
Male	-0.018^{***}	-0.024^{*}
	(0.006)	(0.013)
0-17	0.024	0.030
	(0.017)	(0.028)

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Table 17 – *Continued from previous page*

	Nested Logit	Control Function
18-34	-0.115^{***}	-0.118^{**}
	(0.036)	(0.052)
35-54	-0.094^{***}	-0.098^{**}
	(0.030)	(0.045)
Family	0.186^{***}	0.189^{**}
	(0.060)	(0.087)
Year 2015	-0.005^{***}	-0.006^{**}
	(0.002)	(0.002)
Mandate	-0.060^{**}	-0.060
	(0.027)	(0.038)
Intercept		
Base	-2.639^{***}	-2.671^{**}
	(0.724)	(1.116)
400+	-1.046^{***}	-1.059^{***}
	(0.193)	(0.231)
Male	0.049	0.049
	(0.041)	(0.052)
0-17	-2.765^{***}	-2.769^{***}
	(0.150)	(0.135)
18-34	-1.461^{***}	-1.456^{***}
	(0.054)	(0.049)
35-54	-1.135^{***}	-1.132^{***}
	(0.060)	(0.059)
Family	1.850^{***}	1.828^{***}
	(0.070)	(0.082)
Year 2015	0.417^{***}	0.414^{***}
	(0.043)	(0.041)
Mandate	0.663^{***}	0.654^{***}
	(0.137)	(0.212)
Rating Areas		
CA2	2.322^{***}	2.344^{***}
	(0.231)	(0.201)
CA3	0.810^{***}	0.812^{***}
	(0.121)	(0.106)
CA4/8	2.330^{***}	2.349^{***}
	(0.186)	(0.130)
CA5	2.228^{***}	2.256^{***}
	(0.292)	(0.256)
CA6	2.034^{***}	2.050^{***}

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Table 17 – *Continued from previous page*

	Nested Logit	Control Function
	(0.149)	(0.133)
CA7	2.024***	2.047***
	(0.177)	(0.154)
CA9	1.227***	1.254***
	(0.145)	(0.124)
CA10	−0.260	−0.242*
	(0.165)	(0.147)
CA11	−1.210***	−1.187***
	(0.124)	(0.118)
CA12	1.509***	1.536***
	(0.143)	(0.090)
CA14	−1.499***	−1.478***
	(0.117)	(0.104)
CA15	−0.036	−0.024
	(0.114)	(0.068)
CA16	0.573***	0.573***
	(0.100)	(0.063)
CA17	−0.893***	−0.884***
	(0.097)	(0.059)
CA18	0.573***	0.579***
	(0.134)	(0.076)
CA19	0.595***	0.598***
	(0.134)	(0.090)
Residual		−0.000
		(0.000)
eta		0.005
		(0.012)
Nesting Parameter	0.184***	0.200**
	(0.063)	(0.100)

Notes: ***Significant at the 1 percent level. **Significant at the 5 percent level. *Significant at the 10 percent level. Robust standard errors that correct for potential misspecification are shown in parentheses (see p.503 of Wooldridge (2010)). Table shows full regression results for the base nested logit and the control function approach of Petrin and Train (2010)

Appendix F: Elasticity and Semi-Elasticity Formulas

This appendix provides equations for the elasticity and semi-elasticity estimates. The own-premium elasticity of demand ε_{ij} of household i for plan j equals

$$\begin{aligned} \varepsilon_{ij} &= \frac{\partial \ln q_{ij}(\mathbf{p})}{\partial \ln p_j} = \left(r_{ij} p_j \frac{\partial \ln q_{ij}(\mathbf{p})}{\partial p_{ij}(\mathbf{p})} \right) \frac{\partial p_{ij}(\mathbf{p})}{\partial p_j} \\ &= \overline{\alpha}_i r_{ij} p_j \left(\frac{1}{\lambda} + \left(\frac{\lambda - 1}{\lambda} \right) \frac{q_{ij}(\mathbf{p})}{\sum_j q_{ij}(\mathbf{p})} - q_{ij}(\mathbf{p}) \right) \end{aligned} \tag{23}$$

The own-premium semi-elasticity of demand ς_{ij} of household i for plan j equals

$$\begin{aligned} \varsigma_{ij} &= \frac{\partial \ln q_{ij}(\mathbf{p})}{\partial p_j} \times (100/12) \\ &= \overline{\alpha}_i \left(\frac{1}{\lambda} + \left(\frac{\lambda - 1}{\lambda} \right) \frac{q_{ij}(\mathbf{p})}{\sum_j q_{ij}(\mathbf{p})} - q_{ij}(\mathbf{p}) \right) \times (100/12) \end{aligned} \tag{24}$$

The exchange coverage elasticity of demand ϱ_i of household i equals

$$\varrho_i = \sum_j q_{ij}(\mathbf{p}) \left[\frac{\partial \ln \left(\sum_j q_{ij}(\mathbf{p}) \right)}{\partial \ln p_j} \right] = \sum_j \left[\overline{\alpha}_i r_{ij} p_j q_{ij}(\mathbf{p}) \left(1 - \frac{q_{ij}(\mathbf{p})}{\sum_j q_{ij}(\mathbf{p})} \right) \right] \tag{25}$$

The exchange coverage semi-elasticity of demand ϑ_i of household i equals

$$\vartheta_i = \sum_j q_{ij}(\mathbf{p}) \left[\frac{\partial \ln \left(\sum_j q_{ij}(\mathbf{p}) \right)}{\partial p_j} \right] = \sum_j \left[\overline{\alpha}_i q_{ij}(\mathbf{p}) \left(1 - \frac{q_{ij}(\mathbf{p})}{\sum_j q_{ij}(\mathbf{p})} \right) \right] \times (100/12) \tag{26}$$