Efficiency and Equity Impacts of Energy Subsidies

Robert W. Hahn and Robert D. Metcalfe

American Economic Review 2021, 111(5): 1–32.

Online Appendix

A External Validity

Appendix A consists of three parts:

- A.1 presents the representativeness of our experimental sample in comparison to the whole CARE population;
- A.2 presents the examination of selection into CARE within our experimental sample; and
- A.3 presents a reweighting analysis to match the demographic composition of the general population of CARE customers to our experimental sample.

A.1 Representativeness of our sample

Despite our treatments being business as usual (and the control group not receiving BAU), it could be argued that the experimental sample is different from the rest of the CARE population because the sample is based on those customers that failed to recertify for CARE after receiving a notification from SoCalGas. Given our sample did not respond to one letter sent to their home address, it could be argued that they might be less price responsive than the average CARE customer. Table A11 shows the observable characteristics of those in our experimental sample compared to the rest of the CARE population in SoCalGas and the non-CARE population in SoCalGas. We do not find any meaningful economic differences between our sample and the rest of the CARE population with respect to pre-experiment gas use in both the summer and winter months, geographical location, use of other voluntary utility programs such as paperless billing, and in the Opower conservation program. We do find that the experimental sample has slightly higher incomes (as defined by the PRIZM codes) than the rest of the CARE population in SoCalGas. We will examine this difference when reweighting elasticities based on the observable characteristic of the full population (see section A.2 below).[26]

A.2 Heterogeneous Selection in the LATE

We examine selection into CARE within our experimental sample. In particular, we analyze whether encouragement letters selected a different type of gas user into enrolling into CARE as compared to those who did not select into CARE. We use the untreated outcome test (see, e.g., Kowalski 2018). In accord with Angrist et al. (1996), we define three categories: always takers – who are measured by the fraction of people in the control group who reenroll into CARE without an encouragement; never takers, who are measured by the fraction of people in the treatment and control groups who do not reenroll onto CARE; and compliers,

[26] The CARE customers are different than the non-CARE customers, in that the non-CARE customers consume more gas in the summer and winter months, are less likely to have very low incomes (as defined by the PRIZM codes), more likely to be a paperless billing customer, and more likely to reside in the greater LA area.

who represent the difference between these two categories. As has been shown in previous research by Einav et al. (2010), Kowalski (2016), Mogstad et al. (2018), Bertanha and Imbens (2019), if the difference in average untreated outcomes between compliers and never takers is statistically different from zero, then we reject the hypothesis there is homogeneous selection into CARE.

We begin by defining the percentage of customers in each category – always takers, never takers, and compliers – which is is 3%, 87%, and 10% respectively. Then, we test for selection heterogeneity (positive selection) by comparing the untreated outcome of never takers and the untreated outcome of compliers. Our analysis shows that the difference in the pre-treated gas use of compliers versus never takers is not statistically different from zero (and economically it is very small; the coefficient is -0.04 therms and the p-value is 0.9). This result suggests that our encouragement design and the LATE within our selected sample are externally valid. It may also have implications for overall selection into the experiment, in that if there are no differences in selection after a second letter, it might be very conceivable that there is no selection bias associated with the first letter (which we do not observe).

A.3 Reweighting the LATE

Despite very little heterogenous selection into CARE through our encouragement (section A.2), we do have some small differences in our CARE sample versus the entire CARE population in SoCalGas (section A.1). As a result, we will examine whether our estimated LATE from the field experiment is driven by the demographic composition of the study sample. We test the sensitivity of the results by reweighting the study sample to match the demographic composition of the general population of CARE customers. We have two types of households,–experimental households and other households on CARE (see table A11). We reweight the experimental sample so that they it looks like the population households, and that implies a reweighted LATE.

To implement the reweighting, we conduct the following five steps (similar to Stuart et al., 2001). First, we determine the household demographics we use to reweight. We choose all of the observable variables that were provided to us by the utility: socioeconomic status (whether household is underprivileged or not); previous consumption above or below the median (whether household consumption in the previous year exceeded that of the median user in the study sample in the year prior to the experiment period);[27] paperless status (whether they receive paperless billing or not); and Los Angeles residency (whether they live in Los Angeles or not). Second, we calculate the probability that each 'type' of household (i.e., each permutation in the vector of household demographics) is in the

[27] As a robustness check we also use different distributions of previous consumption than above or below the median (e.g., quartiles and quintiles) and it does not significantly change our estimates.

general population, we call this P. Third, we then calculate the probability of each 'type' of household being in the study sample, we call this p. Fourth, we generate a weight, w, so that $p \times w = P$, for each 'type' of household, and lastly, estimate the LATE of CARE using the weight w we generated as a population weight.

We do this reweighting for our two major specifications (tables 3 and 4 in the main analysis). In Table A12, we show that there is a slight increase in the LATE in both the specification that uses only observations from the first year of the study as well as the specification that also includes observations from the second year (experiment 1 only). In the first specification (only the first year), the LATE goes from 1.86 to 2.19. In the second specification (year one and two), the LATE goes from 1.64 to 1.72. The range for unweighted elasticities is -0.29 to -0.35 and the range for weighted elasticities is -0.31 to -0.43. In the welfare section we use a baseline elasticity of -0.35 (which represents the mid-point of the weighted and unweighted range). We also conduct sensitivity analyses for the elasticity for CARE households ranging from -0.2 to -0.5.

B Welfare Extensions

Appendix B consists of four parts:

- B.1 presents the key parameter values in the base case;
- B.2 presents some theory related to the model and its implementation;
- B.3 presents a further discussion of empirical results; and
- B.4 summarizes the programs used in the analysis that are available online.

B.1 Base case assumptions

The table below presents the values used in the base case of the welfare model discussed in body of the paper. This table's numbers have been rounded to two significant digits.[28]

Term	Description	Value in Base Case
E_c	Price elasticity of C	-0.35
E_n	Price elasticity of N	-0.14
SCC	Social cost of carbon/ton of CO_2 (\$)	40
MEC	Marginal external cost/therm (\$)	0.21
MPC	Marginal private cost/therm (\$)	0.47
MSC	Marginal social cost/therm (\$)	0.68
N_c	Sample of C	1,600,000
N_n	Sample of N	3,850,000
P_0	Price of Therm before CARE (\$)	0.90
P_{1c}	Price of Therm after CARE for C (\$)	0.75
P_{1n}	Price of Therm after CARE for N (\$)	0.95
Q_{0c}	Therms before CARE for C	290
Q_{0n}	Therms before CARE for N	500
Q_{1c}	Therms after CARE for C	310
Q_{1n}	Therms after CARE for N	490
A	Administrative cost (\$)	7,000,000

Notes: Parameters P_0, Q_{0c}, and Q_{0n} are estimated using our model.

B.2 Results on Theory and Model Implementation

B.2.1 Derivation of the demand curve for CARE and non-CARE households

We use the point-slope formula for a line to derive the demand curves for n and c. Consider the case of $Q^n = Q^n(P)$. We know P_{1n}, Q_{1n}, and the elasticity of demand for n, E_n. We wish to solve for $\frac{dQ}{dP}$, the slope of the demand curve, and this is sufficient with the point we observe on the demand curve to construct the entire linear demand curve through

[28] More detail is provided in the programs online.

that point. Using the definition for E_n, we have, $E_n = \frac{\frac{dQ}{Q}}{\frac{dP}{P}} = \left(\frac{dQ}{dP}\right)\left(\frac{P}{Q}\right)$, which implies $\frac{dQ}{dP} = E_n\left(\frac{Q}{P}\right)$.

The same analysis applies for deriving the demand curve for c, except now we substitute P_{1c}, Q_{1c}, and the elasticity of demand for c, E_c. Once we derive P_0 in equation (5), we can compute Q_{0n}, and Q_{0c}, because we have derived the demand curves for c and n. Since c and n are representative households, we can aggregate demand curves for the entire populations N and C by multiplying the representative demand curve for n and c by N_n and N_c, respectively.

B.2.2 Welfare for Non-CARE customers and CARE customers

First, consider the loss in welfare for non-CARE customers due to the increase in price.[29] We define the demand curve for n as $Q^n = Q^n(P)$, where Q^n is quantity demanded and P is price. Let N_n be the number of households not on CARE. The price increase for non-CARE households covers the subsidy to C and the administrative costs of the program. The change in consumer surplus for N is given by:

$$-N_n \int_{P_0}^{P_{1n}} Q^n(P)dP < 0 \tag{A1}$$

The integral consists of a rectangle that includes the transfer to C plus administrative costs, and a triangle that is the additional lost consumer surplus. It is a loss to N. Next, consider the welfare change for CARE households. This is very similar to the one for non-CARE households, except now we consider a price decrease for CARE households that results in an increase in welfare for C. Define the demand curve forcas $Q^c = Q^c(P)$, where Q^c is quantity demanded and P is price. Let N_c be the number of households on CARE. CARE households experience a gain from the subsidy because they consume more at a lower price. The gain is given by:

$$-N_c \int_{P_0}^{P_{1c}} Q^c(P)dP > 0 \tag{A2}$$

The integral is a trapezoid that represents the transfer rectangle associated with existing consumption and the consumer surplus triangle associated with increased consumption.

B.2.3 Conditions under which a subsidy can lead to an increase or decrease in total welfare.

Subsidies can increase or decrease total welfare, or leave it unchanged. Below, we derive a formula for total welfare under the assumption of linear demand. We then consider the welfare associated with the base case and link it to the slopes of the demand curves for

[29] For now, we treat welfare losses and gains for different groups with the same welfare weights. We relax this assumption in our discussion of equity below.

CARE and non-CARE customers. We then discuss how this analysis relates to the optimal taxation problem defined by Ramsey (1927). Finally, we identify some special cases where welfare increases or decreases with the introduction of a subsidy.

The net change in total welfare for introducing CARE is as follows:

$$\Delta W = N_n \int_{Q_{0n}}^{Q_{1n}} (P^n(Q) - \text{MSC})dQ + N_c \int_{Q_{0c}}^{Q_{1c}} (P^c(Q) - \text{MSC})dQ - A \tag{A3}$$

where ΔW is the net change in welfare. For simplicity, we consider the case where administrative costs are zero (i.e. $A = 0$).[30] Because the demand curve is linear, we can simplify the integrands in (A3). Consider the first term with N_n, but drop N_n for simplicity. With linear demand, this yields:

$$\frac{1}{2}(Q_{1n} - Q_{0n})(P_0 + P_{1n}) - (Q_{1n} - Q_{0n})\text{MSC} = (Q_{0n} - Q_{1n})[\text{MSC} - \frac{1}{2}(P_0 + P_{1n})]$$

Applying this same logic to C, and assuming $A = 0$, yields a total welfare change of:

$$\Delta W = N_n(Q_{0n} - Q_{1n})[\text{MSC} - \frac{1}{2}(P_0 + P_{1n}) + N_c(Q_{0c} - Q_{1c})[\text{MSC} - \frac{1}{2}(P_0 + P_{1c}) \tag{A4}$$

We can express the change in quantities in terms of a change in prices because the demand curves are linear. We know, for example, that $(Q_{0n} - Q_{1n}) = (\frac{dQ^n}{dP})(P_0 - P_{1n})$, and that a similar result obtains for c.[31] We can simplify the integrand for n as follows:

$$(Q_{0n} - Q_{1n})[\text{MSC} - \frac{1}{2}(P_0 + P_{1n})] =$$
$$(\frac{dQ^n}{dP})(P_0 - P_{1n})[\text{MSC} - \frac{1}{2}(P_0 + P_{1n})]$$

Substituting into ΔW in equation (A4) above yields:

$$\Delta W = [N_n(\frac{dQ^n}{dP})][P_0 - P_{1n}][\text{MSC} - \frac{1}{2}(P_0 + P_{1n})] + [N_c(\frac{dQ^c}{dP})][P_0 - P_{1c}][\text{MSC} - (\frac{1}{2})(P_0 + P_{1c})] \tag{A5}$$

Equation (A5) consists of two terms, each of which has three "sub-terms" within square brackets. The sign pattern for the first and second terms are $(-)(-)(?)$ and $(-)(+)(?)$. Neither of these two terms can be signed without further assumptions, and thus, the effect of introducing the subsidy on total welfare can be positive, negative or zero.

Consider now the problem of understanding the impact on total welfare of introducing CARE in the base case . A feature of this problem is that $[\text{MSC} - \frac{1}{2}(P_0 + P_{1n})] < 0$ and $[\text{MSC} - (\frac{1}{2})(P_0 + P_{1c})] < 0$. This means the first term of (A5) is negative and the second term is positive. For this case, (A5) says that there is a social welfare loss associated with

[30] Results below can be easily modified with constant administrative costs.

[31] $(\frac{dQ^n}{dP})$ refers to the derivative of quantity for n, with respect to change in the price for n, and similarly for c. The subscript on price is not used in the interest of simplicity.

N's reduction in quantity consumed and a social welfare gain associated with C's increase in quantity consumed. Total welfare will increase on net if the second effect dominates the first. Ceteris paribus, total welfare will increase if $(\frac{dQ^n}{dP})$ increases toward zero. In the extreme, if n's demand curve is perfectly inelastic, i.e., $(\frac{dQ^n}{dP}) = 0$, then n does not change consumption with the subsidy and there a gain in total welfare for society. A similar analysis holds for c. If c's demand becomes more elastic, so $(\frac{dQ^n}{dP})$ decreases further below zero, then total welfare increases.

This model is related to, but not the same as, Ramsey's optimal taxation problem. It is related in the sense that elasticities matter for computing CARE's impact on total welfare, but so do other parameters. Our analysis differs from Ramsey's in that we are not trying to identify optimal tax levels or markups, though that would be possible to do. Instead, we are comparing two pricing regimes, both of which deviate from the MSC and the MPC. Whether or not the new pricing regime improves welfare over the old regime depends on demand characteristics and the relationship between the MSC and new and old prices (see equation (A5)). For the base case analyzed above, under the assumption that administrative costs are zero, taxing the inelastic good (n's consumption) and subsidizing the elastic good (c's consumption) improves welfare, but that will not always be the case.

Below, we examine some special cases in which total welfare improves. The two subterms, $[\text{MSC} - (\frac{1}{2})(P_0 + P_{1n})]$ and $[\text{MSC} - (\frac{1}{2})(P_0 + P_{1c})]$, can be useful for signing equation (A5). We consider three cases below for each of these expressions.

Case A1: $[\text{MSC} - (\frac{1}{2})(P_0 + P_{1n})] > 0$
The first term in (A5) has the following sign pattern: $(+)(+)(+) = (+)$. The second term has the following sign pattern: (+)(-)(?) = (?). Thus, we cannot sign (A5) without further assumptions. But if the first term is bigger in absolute value than the second term, we could ensure that the subsidy has a positive welfare effect. Inspection of (A5) yields the following observation:

Lemma 1: As $\frac{dQ^c}{dP}$ approaches 0, the second term gets sufficiently small and this will ensure that the subsidy has a positive impact on welfare.

Case A2: $[\text{MSC} - (\frac{1}{2})(P_0 + P_{1c})] > 0$
The first term has the following sign pattern: $(-)(-)(?) = (?)$. The second term has the following sign pattern: $(-)(+)(+) = (+)$. Thus, we cannot sign (A5) without further assumptions, similar to the ones in Case A1.

Case A3: $[\text{MSC} - (\frac{1}{2})(P_0 + P_{1n})] = 0$
Assume further that $P_{1c} < P_{1n}$, which is true for CARE. The first term has the following sign pattern: $(-)(-)(0) = (0)$. The second term has the following sign pattern: $(-)(+)(+) = (-)$.

Case A4: $[\text{MSC} - (\frac{1}{2})(P_0 + P_{1c})] = 0$
The first term has the following sign pattern: $(-)(-)(-) = (-)$. The second term has the following sign pattern: $(-)(+)(0) = (0)$. Together, case A3 and case A4 yield the following

result:

Lemma 2: If $[\text{MSC} - (\frac{1}{2})(P_0 + P_{1n})] = 0$ or $[\text{MSC} - (\frac{1}{2})(P_0 + P_{1c})] = 0$, then the welfare change is negative with the introduction of the subsidy.

Case A5: $[\text{MSC} - (\frac{1}{2})(P_0 + P_{1n})] < 0$

The first term has the following sign pattern: $(-)(-)(-) = (-)$. The second term has the following sign pattern: $(-)(+)(?) = (?)$. If we further assume that $\text{MSC} > (\frac{1}{2})(P_0 + P_{1c})$, then the second term can be signed as $(-)(+)(+) = (-)$. In this case, the welfare change is negative with the introduction of the subsidy. We could also follow the method used in Case A1 to sign this expression.

Case A6: $[\text{MSC} - (\frac{1}{2})(P_0 + P_{1c})] < 0$

The first term has the following sign pattern: $(-)(-)(-) = (-)$. The second term has the following sign pattern: $(-)(+)(-) = (+)$. In this case the sign is indeterminate. We could also follow the method used in Case A1 to sign this as positive or negative. For example, as $\frac{dQ^n}{dP}$ approaches 0, the first term gets sufficiently small and this will ensure that the subsidy has a positive impact on welfare.

In summary, we have identified cases where the subsidy could have a positive or negative effect on welfare. For our parameter choices, the CARE subsidy often has a negative impact on welfare.

B.2.4 Comparative statics associated with introducing CARE when there is a change in the demand elasticity.

We examine what happens if the demand curve for n or c changes. We consider the changes in welfare with a change in elasticity. Given the demand curves are straight lines, a change in elasticity is modeled as a rotation of the demand curve around a specific point, which means that the slope is changing.

We wish to show:

$$\frac{d\Delta W}{dE_c} >=< 0 \text{ if and only if } [\text{MSC} - \frac{1}{2}(P_0 + P_{1c})] >=< 0 \tag{A6}$$

And

$$\frac{d\Delta W}{dE_n} >=< 0 \text{ if and only if } [\text{MSC} - \frac{1}{2}(P_0 + P_{1n})] <=> 0 \tag{A7}$$

Consider the effect of a change in E_c on ΔW. Inspection of equation (A4) reveals that the only parameter that E_c affects is Q_{0c}, giving:

$$\frac{d\Delta W}{dE_c} = (\frac{dQ^{0c}}{dE_c})N_c[\text{MSC} - \frac{1}{2}(P_0 + P_{1c})] \tag{A8}$$

We can write:

$$\frac{dQ^{0c}}{dE_c} = \frac{dQ^{0c}}{dE} = (\frac{dQ^{0c}}{dm})(\frac{dm}{dE}) \tag{A9}$$

where E is substituted for E_c in the first equality and the second equality introduces the slope of c's demand curve, so $m = \frac{dQ}{dP}$. Writing the demand curve in point slope form, we have: $(Q_{0c} - Q_{1c}) = m(P_0 - P_{1c})$. Rearranging yields: $Q_{0c} = m(P_0 - P_{1c}) + Q_{1c}$. Thus, $\frac{dQ_{0c}}{dm} = P_0 - P_{1c}$.

We can compute the elasticity as follows: $E_c = E = (\frac{P_{1c}}{Q_{1c}})(\frac{dQ}{dP}) = km$, where $k = (\frac{P_{1c}}{Q_{1c}})$. Note that $(\frac{dm}{dE}) = \frac{1}{k}$. Substituting into equation (A9) gives:

$$\frac{dQ_{0c}}{dE_c} = \frac{dQ_{0c}}{dE} = (\frac{dQ_{0c}}{dm})(\frac{dm}{dE}) = \frac{P_0 - P_{1c}}{k} = \frac{(P_0 - P_{1c})Q_{1c}}{P_{1c}} > 0 \tag{A10}$$

Equation (A10) is positive so long as $P_0 > P_{1c}$, which is assumed (i.e., the CARE subsidy is lower than the original price). The first and second terms in equation (A10) are positive. This yields the desired result in equation (A6) .

Reasoning by analogy for n, we have (assuming $P_{1n} > P_0$):

$$\frac{dQ_{0n}}{dE_n} = \frac{(P_0 - P_{1n})Q_{1n}}{P_{1n}} < 0$$

Similar reasoning for n yields the general expression:

$$\frac{d\Delta W}{dE_n} = (\frac{dQ_{0n}}{dE_n})N_c[\text{MSC} - (\frac{1}{2})(P_0 + P_{1n})] \tag{A11}$$

The first term is negative and the second, N_c, is positive. This yields the desired result in equation (A7).

We can develop some intuition for this result on elasticity through a graphical analysis. The first thing to note is that the change in elasticity is similar to a change in slope around the point (Q_{1c}, P_{1c}). We consider the precise situation for c in a graph, but suppress the c subscript for simplicity. A similar analysis will apply to n.

We are comparing two situations: (1) the change in welfare associated with introducing the CARE subsidy in the new situation (ΔW_B), which is depicted in Panel 1 in Figure A4 when demand is less elastic; and (2) the change in welfare associated with introducing the CARE subsidy in the old situation (ΔW_A), which is depicted in Panel 2 of Figure A4 when demand is more elastic. Note that the demand curve rotates around the point in the diagram (Q_1, P_1), from D_A to D_B. We define $\frac{\Delta\Delta W}{\Delta E}$ as the change in the change in welfare from introducing CARE as demand becomes more inelastic, in this case for c. We wish to compute: $\frac{\Delta\Delta W}{\Delta E} = \Delta W_B - \Delta W_A$. Note in the limit $\frac{\Delta\Delta W}{\Delta E}$ approaches $\frac{d\Delta W}{dE}$ for c. We are asking what happens to the change in welfare associated with introducing CARE as demand becomes more inelastic for c.

When MSC $= \frac{1}{2}(P_0 + P_1)$, it is clear from the geometry that $\Delta W_B = 0$ and ΔW_A=0, In both of these cases for demand, half of the increase in demand has willingness to pay (WTP) above MSC, and half of the increase in demand has WTP below MSC. In Figure

A4 the two welfare triangles are congruent in each panel (triangles Y and Z, and W and X), and cancel each other out. This shows the net welfare change is zero in both cases from introducing CARE. The preceding analysis provides the intuition for

$$\frac{d\Delta W}{dE_c} = 0 \text{ if and only if } [\text{MSC} - \frac{1}{2}(P_0 + P_{1c})] = 0$$

To provide the intuition for the *greater than* result in equation (A6), we must consider what happens to benefits and costs. Because the demand curves do not change, benefits to c are the same as the situation just analyzed. Consider what happens to cost if MSC increases, so that MSC $= \frac{1}{2}(P_0 + P_1) + k$, where $k > 0$. MSC increases by k for each additional unit that is consumed from introducing the subsidy. For the new situation, MSC increases by $(Q_1 - Q_B)k$, and for the old situation, costs increase by $(Q_1 - Q_A)k$. In this case: $\Delta W_B = -(Q_1 - Q_B)k$ and $\Delta W_A = -(Q_1 - Q_A)k$, and thus $\frac{\Delta W}{\Delta E} = \Delta W_B - \Delta W_A$ $= (Q_B - Q_A)k > 0$. The greater than inequality follows because $Q_B > Q_A$ (see Figure A4).

The preceding graphical analysis provides the intuition for *greater than* result in equation (A6). A similar analysis provides the intuition for the *less than* result in equation (A6). In that case, cost decreases by more in the old situation than the new situation, so on net, welfare decreases. An analogous graphical result can be constructed for n with the signs reversed in equation (A6) (see equation (A7)). In that case, the new price exceeds the old price.

We can use this analysis to explain the slope for the welfare change from making demand more inelastic in our base case for both n and c. The base case has MSC $< P_{1c} < P_0 < P_{1n}$. Equation (A6) implies $\frac{d\Delta W}{dE_c} < 0$ (because MSC $-\frac{1}{2}(P_0 + P_{1c}) < 0$) which is shown in figure 3; equation (A7) implies $\frac{d\Delta W}{dE_n} > 0$ (i.e., MSC $-\frac{1}{2}(P_0 + P_{1n}) < 0$) which is shown in figure A6.

For further intuition, consider the case of n. Start with a situation where n's demand is perfectly inelastic. There is no change in n's quantity demanded with the introduction of CARE, and thus the first term in (3) becomes zero in the limit.[32] Now, suppose n's demand curve has some elasticity less than 0. In this case, there is a change in n's quantity demanded with the introduction of CARE and the first term becomes negative (the other two terms in (3) remain the same). This shows welfare increases as the demand curve for N rotates from being downward sloping to becoming perfectly inelastic.

A similar argument applies for c, except the first and third terms in equation (3) do not change, and the second term becomes positive if c's demand is downward sloping (it approaches zero when c's demand becomes perfectly inelastic). This shows welfare decreases as the demand curve for C rotates from being downward sloping to becoming perfectly inelastic.

[32] We say in the limit because the willingness to pay is technically not defined for perfectly inelastic demand; but as the demand curve becomes perfectly inelastic, the value of the first term approaches zero.

B.2.5 Lump sum taxes and economic efficiency

A lump sum tax is generally an efficient form of taxation when prices reflect marginal cost. This will not always be the case when prices do not equal marginal cost, or marginal social cost when there is an externality. The intuition is that an ad valorem tax can actually move prices closer to the MSC, and thus may be preferred in some "second-best" situations. Below we will refine this intuition in our model and show the following: a lump sum tax increases (reduces) economic welfare if the resulting price for energy is closer to (or further away) from the MSC than the price that prevailed with an ad valorem tax.

We do this for non-CARE customers, N. We wish to compare economic welfare under a lump sum tax and an ad valorem tax for non-CARE customers. This is equivalent to identifying conditions under which a price move from P_{1n} to P_0 for n increases economic welfare. That is because with an ad valorem tax, N faces a price of P_{1n}; and with a lump sum tax, N faces a price of P_0. The expression for the change in welfare in moving from an ad valorem tax to a lump sum tax is:

$$\Delta W = N_n \int_{Q_{1n}}^{Q_{0n}} (P^n(Q) - \text{MSC})dQ$$

which follows from (A3).[33] We consider a representative consumer n without loss of generality for our welfare calculation. The welfare expression for n is

$$\Delta W = \int_{Q_{1n}}^{Q_{0n}} (P^n(Q) - \text{MSC})dQ$$

Following the logic in equation (A5), the welfare change for n becomes:

$$\Delta W = \frac{dQ^n}{dP}(P_{1n} - P_0)[\text{MSC} - \frac{1}{2}P_0 + P_{1n})]$$

The first term, $(\frac{dQ^n}{dP})$, is negative because demand is downward sloping; the second term, $(P_{1n} - P_0)$, is positive because this represents the ad valorem tax that n pays for subsidizing C. This yields the following lemma on welfare:

Lemma 3: $\Delta W >=< 0$ if and only if $[\text{MSC} - \frac{1}{2}(P_0 + P_{1n})] <=> 0$

The reasoning can be seen graphically. Consider panel 2 in Figure A4, and reverse the subscripts for P and Q, so that $P_1 > P_0$, and $P_1 = P_{1n}$ in this case. If $\text{MSC} = \frac{1}{2}(P_0 + P_{1n})$, welfare does not change in moving from an ad valorem tax to a lump sum tax to an ad (i.e., the area of triangle X equals the area of triangle W). If MSC increases so that $\text{MSC} - \frac{1}{2}(P_0 + P_{1n}) > 0$, the benefits to n stay the same, but the social costs go up, which implies the benefits of introducing a lump sum tax are negative (the lump sum tax results in a price that is further away from the MSC). Conversely, if MSC decreases so that

[33] This is true if administrative costs are the same with a lump sum tax and an ad valorem tax.

MSC $-\frac{1}{2}(P_0 + P_{1n}) < 0$, the benefits to n stay the same, but the social costs go down, which implies the benefits of introducing a lump sum tax are positive (the lump sum tax results in a price that is closer to the MSC.

This framework can also be applied to a case when there is not a lump sum tax, but a tax whose deadweight loss can be measured. Define T as the transfer from N that pays for CARE, which includes administrative costs (A) and the transfer to CARE customers (see equation (4)) Let kT be the welfare costs associated with T (typically $k \geq 0$).

Then the expression for ΔW for n becomes:

$$\Delta W = \frac{dQ^n}{dP}(P_{1n} - P_0)[\text{MSC} - \frac{1}{2}(P_0 + P_{1n})] - \frac{kT}{N_n}$$

Note that the last term in this equation, $-\frac{kT}{N_n}$ is added to reflect the fact that we are considering the tax cost for a representative non-CARE household, n. We would need to multiply the preceding equation by N_n to get the social welfare loss. If there were these deadweight costs associated with the tax, Lemma 3 would need to be revised to take them into account. For example, when MSC $= \frac{1}{2}(P_0 + P_{1n})$, the welfare would be lower under the alternative tax by kT than with the ad valorem tax. Thus, the existing tax on non-CARE customers would be preferred in this case.

In short, we have developed closed form expressions that allow us to compare the welfare effects of different tax regimes when prices depart from marginal social costs. We could also explore how the results here are affected by a change in demand elasticity.[34]

B.2.6 Some additional information on the welfare impacts of vouchers

We will assume there are three instruments: a standard subsidy, a standard voucher, and a behavioral voucher. The amount of the voucher is set equal to the subsidy. We wish to know whether vouchers will be better or worse for C and for social welfare compared with the subsidy.

For C, a standard voucher is generally preferred to a subsidy. The reason is that a representative CARE household could consume the same bundle she consumed with the subsidy. Under our assumptions of downward sloping demand, she chooses a different bundle, and is therefore better off using a revealed preference argument.

Figure A5 shows why standard vouchers are preferred to a subsidy. At the subsidized price P_1, c chooses Q_1 on demand curve D. At the unsubsidized price P_0 with the voucher, c chooses Q_0. c has a net welfare gain of triangle ABC for the standard voucher over the subsidy. She receives the voucher equal to rectangle P_0P_1CB, but loses the trapezoid in consumer surplus given by P_0P_1CA, so the remaining gain is triangle ABC.

For the behavioral voucher, we assume that c's "true" demand is given by D, but that

[34]The formal analysis is similar to the previous analysis of demand elasticity.

she does not demand A at P_0. In general, her demand with a voucher will exceed Q_0. If she chooses a point on the interior of this segment AC, then she is better off than she would have been with the subsidy (again using a revealed preference argument). In this case, she is not as well off as if she would be with the standard voucher because she consumes some units beyond Q_0 that reduce her surplus.[35] However, it is possible that the behavioral voucher could lead c to consume more than Q_1, say Q_2, in which case she would be worse off than with the subsidy. If she chose Q_2, her welfare loss would be AEF relative to the standard voucher, and her loss would exceed that of the subsidy relative to the standard voucher (ABC).

Thus, a standard voucher, as defined here, will always be preferred by C to a behavioral voucher or a subsidy under the assumptions of this model. In contrast, C's preference for a behavioral voucher is ambiguous in general. If voucher expenditures do not result in a quantity that exceeds that selected under the subsidy, CARE households prefer the standard voucher to the behavioral voucher to the subsidy.

As noted in the text, a more interesting question from a social perspective is whether these vouchers increase or decrease economic welfare compared with the subsidy. For a given MSC, the welfare associated with N's choices do not change because N picks the same quantity.

However, c's quantity choices will be affected by standard and behavioral vouchers. For c, the change in total social welfare in moving from a subsidy to a voucher is given by:

$$\int_{Q_{1c}}^{Q_I} (P^c(Q) - \text{MSC})dQ \tag{A12}$$

where $Q_{1c} = Q^c(P_{1c})$, and Q_I is the quantity selected under intervention, I. For the subsidy $Q_I = Q_{1c}$, so there is no change in welfare. For standard vouchers, $Q_I = Q^c(P_0)$. In words, equation (A12) says that the welfare change for standard vouchers is defined by the difference between the benefit tocand the marginal social cost for the reduction in quantity demanded as prices increase from the subsidized price, P_{1c}, to the original price, P_0.[36]. This welfare change per household is then multiplied by the total number of households to obtain the total welfare change.

For behavioral vouchers, c selects Q_B (using B for behavioral) at P_0. Let $Q_B = Q^c(P_0)$ plus the additional quantity demanded as a result of the bias. That additional quantity is defined by marginal propensity to consume from the voucher (between 0 and 1) multiplied by the cash value of the vouchers thatcreceives, and then divided by P_0.

To estimate welfare benefits, we will define the "true" demand curve for c as $Q^c(P)$.[37]

[35] If the behavioral voucher resulted in spending more than the voucher on the commodity, c would be worse off with the voucher than the subsidy. We think this case is unlikely. Also, if the behavioral voucher resulted in consumption that was far below Q_0, c could be worse off with the voucher than the subsidy. Again, we think this case is unlikely.

[36] In the case of linear demand, the integral is given by $\frac{1}{2}[(\text{MSC} - P_{1c}) + (\text{MSC} - P_0)](Q_{1c} - Q_{0c})$

[37] Our demand curve may not be the "true" one for a variety of reasons, including the possibility that some consumers may not

With behavioral vouchers, c selects a point on her observed demand curve. We take that the quantity Q_B and associate it with a price on the true demand curve $Q^c(P)$.[38] That price will be lower than P_0 if the voucher results in additional consumption. We then carry out the welfare analysis using equation (A12), with the upper limit of integration set to Q_B.

There is another way to rank the welfare of the subsidy and voucher policies that allows for a simpler comparison of quantities. Equation (A12) ranks vouchers and subsidies relative to the welfare associated with the subsidy. We could also have chosen a different reference point. One such point is the optimal level of output for c or $Q^c(\text{MSC})$. In this case the best policy would be the one that has the lowest social cost compared with this optimal policy.[39] This is given by the following formula: $-\frac{1}{2}(Q(\text{MSC})) - Q_I)^2 \frac{dP}{dQ}$.[40]

The formula shows that the closer the quantity selected, Q_I, is to the optimal quantity, $Q(\text{MSC})$, the smaller the welfare gain in moving to the optimal quantity. Hence, quantities closer to the optimal quantity have a higher level of economic welfare associated with them. Thus, if the standard voucher or behavioral voucher results in a quantity that is closer in distance to the optimal quantity than the subsidy, then society enjoys a higher level of economic welfare than with the subsidy. In the special case where the initial price is equal to the MSC, and the agent spends some of the voucher on gas, then the economic welfare for the standard voucher is higher than economic welfare for the behavioral voucher.

Under certain assumptions, we can show that the welfare associated with behavioral vouchers may actually exceed standard vouchers or a price subsidy. This may be viewed as unusual, because, by definition, the observed response to behavioral vouchers may be viewed as not consistent with theory. The result is again driven by the fact that such a response could bring the quantity demanded closer to the optimal quantity, $Q(\text{MSC})$, and thus improve welfare. For an example of behavioral vouchers being preferred to vouchers, assume that the voucher price $P_0 > \text{MSC}$, so $Q(P_0) < Q(\text{MSC})$. Define the additional fraction of each dollar spent from the voucher as the "bias," or b.[41] If the bias is sufficiently small, then the welfare of behavioral vouchers exceeds that of standard vouchers because the quantity selected with behavioral vouchers is closer to $Q(\text{MSC})$. To show that the welfare of behavioral vouchers may exceed that of a subsidy, assume that $P_0 = \text{MSC}$, so that the voucher price is optimal. In this case, the welfare of standard vouchers exceeds that of the subsidy. Again, if the bias is sufficiency small, the welfare associated with behavioral vouchers exceeds that of the subsidy.

appreciate the nature of the subsidy.

[38] Our analysis is similar to Figure 4, p. 1172 in Chetty et al. (2009), except we are considering an overstatement in the observed demand. See also Chetty (2015), Figure 9.

[39] Strictly speaking, this is not the first-best policy, because n's quantity is not optimal.

[40] This formula can be derived as follows. In (A12) , substitute Q_1 as the lower limit of integration and $Q(\text{MSC})$ as the upper limit of integration. Then noting that $P_c(Q)$ is linear and MSC is a constant, integrating the function yields this result.

[41] By additional, we mean beyond what might be spent with an equivalent cash transfer. See Allcott and Taubinsky (2015) for an insightful treatment of the bias issue in the context of energy efficiency.

B.3 Further Discussion of Empirical Results

This section includes several subsections on topics of empirical interest. They include:

- B.3.1 - Extrapolating the welfare results to California;
- B.3.2 - Impact of introducing CARE;
- B.3.3 - Impact of using a different counterfactual for CARE price;
- B.3.4 - Welfare analysis with two-tiered pricing;
- B.3.5 - Welfare analysis when adding cap-and-trade;
- B.3.6 - Welfare analysis when prices are set equal to the marginal social cost;
- B.3.7 - Welfare analysis when prices are set equal to the marginal private cost;
- B.3.8 - Comparing the welfare impact of CARE vouchers with a CARE price subsidy; and
- B.3.9 - Computing an "optimal" subsidy.

B.3.1 Extrapolating the welfare results to California

We outline our approach for extrapolating our results to California. We do this by considering two other utilities that supply natural gas, Pacific Gas and Electric and San Diego Gas and Electric. Together, the three utilities represent about 80% of the gas supply in California. We use the same elasticities we used for SoCalGas as well as the same SCC values. However, prices, quantities, and administrative costs differ. The values we use are shown in Table A14 below along with the welfare and environmental results.

The key results are that net welfare decreases overall, and emissions increase for all the three utilities. The total welfare loss is about $3 million and the emissions increase is about 240,000 tons of CO_2. SoCalGas is responsible for the largest share of welfare losses and emissions.

B.3.2 Impact of introducing CARE

We consider two sensitivities in this subsection: varying the elasticity for non-CARE customers and varying the SCC.

In the base case, we assume that CARE customers have demand elasticities that are at least as elastic as non-CARE customers because they have lower incomes. Figure A6 shows how welfare changes with changes in the elasticity of N moving from -0.35 to 0. As non-CARE household demand becomes more inelastic, there is a small increase in total welfare for these households. The reasoning is similar to that for CARE customers. In this case, the reduction in consumption for N is smaller as demand becomes more inelastic, and thus the welfare loss for N is smaller. The utility increases its profits as the demand by

N is more inelastic, because the reduction in overall output is less. In contrast, pollution damages increase. Combining these factors leads to a small increase in total welfare as N's demand becomes more inelastic. We consider a range of elasticities for N from -0.35 to 0.[42] When the elasticity for N is -0.35, the welfare loss is about \$12 million; when the elasticity is 0, the welfare loss is about \$4 million.

Figure A7 shows the effect of varying the SCC on welfare associated with introducing CARE. The only impact of the change in the SCC is the effect of pollution damages on welfare. We vary the SCC from about \$4/ton to about \$76/ton. Total welfare goes from a loss of about \$2 million to a loss of about \$9.5 million. This exercise demonstrates that the CARE subsidy is likely to result in a loss in total welfare for plausible values of the SCC.

B.3.3 Impact of using a different counterfactual for CARE price

Our analysis assumes that CARE is paid for by non-CARE households, including the subsidy to CARE plus the administrative costs of the program. An alternative formulation is to assume that the change in utility profits is zero with the introduction of CARE. The following equation defines P_0, where the utility's profits do not change.

$$N_n(P_{1n} - \text{MPC})Q_{1n} - N_n(P_0 - \text{MPC})Q_{0n} + N_c(P_{1c} - \text{MPC})Q_{1c} - N_c(P_0 - \text{MPC})Q_{0c} = A \tag{A13}$$

The change in profits due to the change in quantity demand is the left hand side of this equation, and the right hand side is administrative costs. Assuming the utility pays for these costs, the net change in profit for the utility after introducing CARE is zero.

To solve for P_0, note that both Q_{0c} and Q_{0n} are determined by P_0 as points on their respective demand curves. We can write $Q_{0n} = a_n + b_n P_0$ and $Q_{0c} = a_c + b_c P_0$, where the a and b coefficients are taken from the respective demand curves for n and c. Substituting into equation (A13), and rearranging terms yields the following quadratic in equation in P_0.

$$\begin{aligned} -[N_n b_n + N_c b_c]P_0^2 - [N_n(a_n - \text{MPC}b_n) + N_c(a_c - b_c\text{MPC})]P_0 \\ +N_n(P_{1n} - \text{MPC})Q_{1n} + N_c(P_{1c} - \text{MPC})Q_{1c} + \text{MPC}[N_n a_n + N_c a_c] - A = 0 \end{aligned} \tag{A14}$$

When we solve the quadratic equations with known parameters, we get two roots. One yields a negative quantity demanded for CARE customers, and is not economically meaningful. The second root is about \$.91/therm, and we use that root. Our initial value for P_0 in the base case was also about \$.90/therm (rounded). Using the exact values, we find P_0 increases by less than 0.6% when using equation (A13), and overall welfare increases

[42] The range includes two extreme cases. The first extreme is that non-CARE households have the same elasticity as the CARE households. This is unlikely because we would expect households with higher incomes to have less elastic demand. The second extreme is that the elasticity of non-CARE households is perfectly inelastic.

by about 12%, yielding a total welfare loss of -\$4 million.

B.3.4 Welfare analysis with two-tiered pricing

Our calculations assumed that CARE and Non-CARE households face a single price. In actuality, there is two-tiered pricing for both CARE and non-CARE. This means households that demand more than a certain amount face a higher price at the margin.

This two-tiered system can be modelled by considering a representative consumer on each price tier for both CARE households and non-CARE households. We will denote the number of CARE households on tier one by N_{c1}, tier two by N_{c2}, and the same for Non-CARE households by N_{n1}, N_{n2}. As before, we can derive the counterfactual, prices P_{01} and P_{02} for the respective tiers, by adjusting equation (4) (shown below as (A15)) so that the transfer from non-CARE customers on both price tiers equals the sum of the transfer to CARE customers on both price tiers plus administrative costs.

$$N_n(P_{1n} - P_0)Q_{1n} = N_c(P_0 - P_{1c})Q_{1c} + A \tag{A15}$$

So that original equation (A15) becomes equation (A16) below.

$$\begin{aligned} &N_{n1}(P_{1n1} - P_{01})Q_{1n1} + N_{n2}[(P_{1n2} - P_{02})(Q_{1n2} - \bar{Q}) + (P_{1n1} - P_{01})\bar{Q}] \\ &= N_{c1}(P_{01} - P_{1c1})Q_{1c1} + N_{c2}[(P_{02} - P_{1c2})(Q_{1c2} - \bar{Q}) + (P_{01} - P_{1c1})\bar{Q}] + A \end{aligned} \tag{A16}$$

$P_{1n1}, P_{1n2}, P_{1c1}, P_{1c2}$ are observed prices after CARE is introduced. Q_{1c1}, Q_{1c2} are calculated from data for consumers on CARE above and below our the maximum quantity in the first tier, $\bar{Q}$. We do not observe the distribution of non-CARE customers or their consumption, but we know their total population and the mean annual consumption. To address this, we extrapolate from CARE consumption, using a normal distribution. We use this distribution around the mean of non-CARE consumption to produce estimates of N_{n1}, N_{n2} and Q_{1n1}, Q_{1n2}.

The counterfactual prices P_{01}, P_{02} are no longer uniquely identified in equation (A16) because there is 1 equation and 2 unknowns, so we consider two solutions:

1. The utility equalizes the tax difference between tiers, $P_{1n1} - P_{01} = P_{1n2} - P_{02}$
2. The utility equalizes subsidy difference between tiers, $P_{01} - P_{1c1} = P_{02} - P_{1c2}$

Both conditions are plausible for the utility, yet imposing both concurrently leads to an over-determined system in (A16). We present the welfare analysis under these two solutions, as well as a third case that minimizes the squared sum of the tax difference and the subsidy difference across tiers.

Finally, the demand curves for each tier are calculated to be linear curves that sum point-wise to the aggregate demand of that group in the original demand system (see sections 4.1.1 and B.2.1). These yield values for Q_{0n1}, Q_{0c1} corresponding to P_{01}, and Q_{0n2}, Q_{0c2} corresponding to P_{02}.

The first case for counterfactual prices leads to P_{01}, P_{02} values of \$0.87, \$1.08/therm for the two tiers, and an overall welfare decrease of 1% compared with the original simulation. The second case leads to P_{01}, P_{02} values \$0.86, \$1.12/therm for the two tiers and an overall welfare increase of 32% in comparison to our base case. The third case yields values between the previous two scenarios. In all cases, the change in welfare is still negative with the introduction of the CARE subsidy, as was the case in our original analysis. More detailed parameter estimates are summarized in the table A13.

B.3.5 Welfare analysis when adding cap-and-trade regime

Cap-and-trade is modeled as an exogenous price on CO_2 emissions determined by the market. There are two key points of the analysis of cap-and-trade. First, a single policy instrument will not achieve the first best outcome because of the different prices faced by CARE and non-CARE consumers. Given the subsidy for CARE customers, at least one of the prices will be different from marginal social cost with cap-and-trade. The sub-optimal nature of this policy is a necessary consequence of the CARE subsidy. This means that we must consider a second-best result in the maximization. The second result is an empirical finding. Welfare is generally negative upon introducing a cap-and-trade scheme for SoCalGas customers. In this particular case, both the natural gas price for CARE and non-CARE customers start above the MSC. Adding cap-and-trade leads to welfare losses as prices depart further from the MSC.

The change in overall welfare for introducing cap-and-trade is given by:

$$N_n \int_{Q_{1n}}^{Q_{2n}} (P^n(Q) - \text{MSC})dQ + N_c \int_{Q_{1c}}^{Q_{2c}} (P^c(Q) - \text{MSC})dQ \tag{A17}$$

The initial quantities Q_{1n} and Q_{1c} are determined by the introduction of CARE. The new quantities are determined by adding an allowance price, t, to P_{1n} and P_{1c}, yielding the new quantities Q_{2n} and Q_{2c}.[43] [44] Note that equation (A17) has the same structure as equation (3), but without additional administrative costs.[45]

We can also apply equation (A17) to replacing the subsidy with vouchers. In this case, there is no welfare change for N because non-CARE customers do not change their

[43] With no uncertainty, perfect information and a competitive market, the tax and the allowance scheme can be shown to be equivalent in terms of their impact on pollution (Baumol and Oates, 1988).

[44] For the scenario in which the price for n moves from P_{1n} to the MSC, the upper limit of integration is defined by the quantity demanded by n at the MSC. For the scenario in which the price for n moves from P_{1n} to the MPC, the upper limit of integration is defined by the quantity demanded by n at the MPC. We consider these cases in the appendix, along with the same price movements for c.

[45] We assume that administrative costs of the program are a sunk cost, and thus they do *not* enter into (A17), as they did with the introduction of the CARE program. If the administrative costs change in these scenarios, this cost would need to be included in the welfare analysis.

quantity consumed with the introduction of a voucher for CARE customers. There is a welfare change for C based on the impact of the voucher on the quantity consumed. We provide the details of this calculation in the appendix sections B.2.6 and B.3.8.

We are interested in modeling the welfare impacts of introducing a CO_2 allowance price, t, which represents the price of an allowance in \$/therm. This price will be assumed to be reflected in the price of gas for C and N. Our analysis does not address how the broader cap-and-trade regime affects welfare (please see Borenstein et al., 2019); instead, it specifically focuses on gas customers.

Figure A12 shows what happens when the allowance price for utility customers varies holding the SCC constant, and when the SCC varies holding the allowance price constant. The figure plots the change in welfare in adding a cap-and-trade mechanism to the prices faced by CARE and non-CARE customers. The SCC takes on three values: \$6/ton, \$40/ton, and \$74/ton. The horizontal axis shows the allowance price, which varies from \$0 to \$20 per ton.

We wish to understand what happens to the change in welfare as the SCC increases at a given allowance price. Introducing a positive allowance price reduces energy consumption and CO_2 emissions by a fixed amount. The effect of an increase in the SCC at that price is to value those emission reductions more highly. Thus, the change in welfare increases with increases in the SCC at a given allowance price. For example, assume the allowance price is \$13/ton, a plausible mid-range price in recent years for the California market.[46] At this price there is a welfare loss of \$13 million associated with an SCC of \$6, a welfare loss of \$8 million associated with an SCC of \$40, and a welfare loss of \$1 million associated with an SCC of \$74 (see the vertical dashed line in Figure A12). The verticle dashed line represents the allowance price at \$13/ton.

Whether or not an increase in the allowance price increases welfare depends on whether the new price for gas (which includes the allowance price) is below or above the MSC for CARE and non-CARE customers. The effect of the allowance price on the welfare change depends on a weighted average for the two classes of customers.[47] Introducing a CO_2 allowance price of \$13/ton in addition to existing prices results in a net loss in social welfare of about \$7.4 million.

Note that within a standard cap-and-trade framework, the allowance price cannot be set so that the price equals MSC for both N and C. That is because C is subsidized by about 20% initially, so the prices for C and N differ. C's price is below N's by about \$0.20/therm. This means that we must consider a second best result in the maximization where the price for N is above the MSC and the price for C is below the MSC. This framework allows us to compare how revenues grom the cap-and-trade program and welfare compare for different

[46] http://calcarbondash.org/

[47] For all these cases the MSC is less than P_{1c}, which means that adding the allowance price to the price of natural gas unambiguously reduces welfare for both CARE and non-CARE customers.

values of the allowance price. Figure A8 reproduces the high SCC curve for the welfare associated when moving to a cap-and-trade when the SCC is $74/ton. The other curve in the figure is the value of allowances as a function of the allowance price. The figure shows that there is an increasing gap between the value of allowances and the welfare change as the allowance price increases. The gap is even more pronounced if the low or medium value for the SCC is used.

We can also formally derive how welfare from introducing a cap-and-trade scheme changes with a change in the allowance price. This derivation will show conditions under which welfare increases or decreases, and it will depend on the relationship of MSC to prices.

The effect of a change in the allowance price on a change in welfare can be derived from equation (A17):

Consider the first integrand in this equation. The analytical expression for the welfare change is given by:

$$\frac{1}{2}(Q_{2n} - Q_{1n})(P_{1n} + P_{2n}) - \mathrm{MSC}(Q_{2n} - Q_{1n}) \tag{A18}$$

The first term represents the consumer surplus loss for n with the change in price, and the second term represents the change in social costs associated with the change in quantity. Note that the first term is negative and the second term is positive. The expression shows that as the MSC increases, the change in welfare from introducing cap and trade increases. This is true for the SCC as well because the SCC and MSC are linearly related.

Now consider the point slope form for the demand curve for n: $(Q_{2n} - Q_{1n}) = (P_{2n} - P_{1n})\frac{dQ^n}{dP}$. Substituting into (A3) and simplifying yields:

$$\begin{aligned}\frac{1}{2}(P_{2n} - P_{1n})(\frac{dQ^n}{dP})(P_{1n} + P_{2n}) - \mathrm{MSC}(P_{2n} - P_{1n})(\frac{dQ^n}{dP}) =\\ (\frac{dQ^n}{dP})[\frac{1}{2}(P_{2n} - P_{1n})(P_{1n} + P_{2n}) - \mathrm{MSC}(P_{2n} - P_{1n})]\end{aligned}$$

Substituting: $P_{2n} = P_{1n} + t$ gives:

$$(\frac{dQ^n}{dP})[\frac{1}{2}t(2P_{1n} + t) - t\ \mathrm{MSC}] = (\frac{dQ^n}{dP})(tP_{1n} + \frac{1}{2}t^2 - t\ \mathrm{MSC})$$

Note that this expression for welfare is quadratic in t. Differentiating the previous expression with respect to t yields:

$$(\frac{dQ^n}{dP})(P_{1n} + t - \mathrm{MSC}) \tag{A19}$$

Equation (A19) will be negative if $P_{1n} + t - \mathrm{MSC} > 0$, since the demand curve is downward sloping. Furthermore, the second derivative with respect to t is $(\frac{dQ^n}{dP}) < 0$. The formulas for c and n are analogous with c substituted for n in (A19), so the general formula for the first derivative is:

$$(\frac{d\Delta W}{dt}) = N_n(\frac{dQ^n}{dP})(P_{1n} + t - \text{MSC}) + N_c(\frac{dQ^c}{dP})(P_{1c} + t - \text{MSC}) \tag{A20}$$

In general the sign of (A19) will depend on $(P_{1n} + t - \text{MSC})$ and $(P_{1c} + t - \text{MSC})$. If, for example, $(P_{1c} + t - \text{MSC}) > 0$, welfare will decrease with an increase in the allowance price (recall $P_{1n} > P_{1c}$, which implies $(P_{1n} + t - \text{MSC}) > 0$. In this case, new prices for c and n both exceed the MSC, and raising the price moves prices away from the MSC, which reduces welfare. A similar argument shows that welfare will increase when $(P_{1n} + t - \text{MSC}) > 0$. The second derivative is always constant and negative. It is given by the formula:

$$(\frac{d^2\Delta W}{dt^2}) = N_n(\frac{dQ^n}{dP}) + N_c(\frac{dQ^c}{dP}) < 0$$

This explains the concavity of the curves for SCC values of \$6, \$40 and \$74 in Figure A12.

B.3.6 Welfare analysis when prices are set equal to the marginal social cost

We know that as price moves toward the marginal social cost, welfare increases. The intuition is that if price is below (above) MSC, then a household should consume less (more). That is because society puts a higher (lower) value on the marginal unit of consumption than the household does if the price is < (>) MSC. We estimate the quantitative impact of moving existing prices to the marginal social cost. This could be accomplished in a number of ways, including adjusting variable costs and fixed costs for different customer classes (e.g., Borenstein and Bushnell, 2019).

The amount of the welfare increase will depend on the deviation between the current price and the marginal social cost. This deviation will differ for N and C for a given MSC because CARE customers are subsidized, so the two groups face different prices.

To compute the welfare change for moving prices to the MSC, we start with equation (A17) and redefine the upper limits of integration. Specifically, define $Q_{2n} = Q_{2n}(\text{MSC})$ as the upper limit for n and $Q_{2c} = Q_{2c}(\text{MSC})$ as the upper limit for c.

Figure A9 shows the welfare change for various assumed values of the MSC ranging from \$0.50/therm to \$0.86/therm (corresponding to an SCC of \$6/ton and \$74/ton, respectively). The figure has three curves: the welfare gains associated with moving from the current price N faces to the MSC for N; analogous welfare gains for C; and the total welfare gains. Total welfare gains represent the vertical sum of the gains for N and C at a given MSC. We use the price for CARE households ($P_{1c} = 0.75$) and the price for non-CARE households ($P_{1n} = 0.95$) as the benchmark for making welfare comparisons (see equation (A17)). Welfare gains are 0 for C when the MSC $= P_{1c} = 0.75$ and welfare gains are 0 for N when MSC $= P_{1n} = 0.95$ (which is beyond the range of values used for the

SCC).

The gains associated with N, C, and total welfare are parabolas as a function of the MSC. The key message of this figure is that welfare gains will always be positive as prices are moved to the MSC, but exhibit substantial variation depending on which MSC is selected. The differences in the welfare gains can be explained by the extent to which existing prices deviate from the assumed MSC.The actual MSC (and SCC) is uncertain. To illustrate plausible potential gains, we consider three simulations associated with SCC's of \$6, \$40, and \$74 per ton (in 2014 dollars).[48] These numbers correspond to the SCC calculated with discount rates of 2.5%, 3%, and 5%, respectively (Greenstone et al., 2013). The welfare gains of setting a price equal to MSC for an SCC equal to \$6/ton are about \$35 million; for a price associated with an SCC of \$40/ton, they drop to about \$10 million; and for a price associated with an SCC of \$74/ton they decrease to about \$3 million. The analysis shows that the potential gains from setting price equal to the MSC will vary dramatically depending on the precise value of the SCC.

B.3.7 Welfare analysis when prices are set equal to the marginal private cost

The CARE and non-CARE prices appear to be above the marginal private cost, and may be substantially above the MPC. We consider two issues: the effect of varying the MPC on the change in welfare associated with introducing CARE; and the welfare impact of setting prices equal to the MPC for CARE and non-CARE customers.

Figure A11 shows the effect of varying the MPC on the welfare associated with introducing CARE. The figure varies MPC from 0 percent to over 100% of the price that non-CARE households face, or from \$0/therm to \$0.95/therm. The lower bound of 0 is obviously an extreme case. We include it to show the breakeven point for total welfare in the figure. At an MPC of \$0.27/therm, total welfare declines to \$0. Above that MPC, total welfare is negative. This analysis further supports the finding that welfare impacts of the subsidy are likely to be negative under reasonable assumptions about the MPC. Adjusting current CARE and non-CARE prices to include a social cost of carbon (SCC) of \$40/ton results in a gain of \$5.9 million.

To compute the welfare change for moving prices to the MPC, we start with equation (A17) and redefine the upper limits of integration. Specifically, define $Q_{2n} = Q_{2n}(\text{MPC})$ as the upper limit for n and $Q_{2c} = Q_{2c}(\text{MPC})$ as the upper limit for c.[49]

As equation (A17) suggests, this will depend on the relationship between existing prices for N and C, the marginal private cost and marginal social cost.

Figure A10 shows the welfare effects of moving prices for CARE and non-CARE households to the marginal private cost of \$0.47/therm used in the base case. This would amount

[48] For these values of the SCC, the MSC is \$0.50, \$0.68, and \$0.86 per therm respectively.

[49] Note that the counterfactual here is the welfare associated with existing prices, \$0.75/therm for C and \$0.95/therm for N, with the subsidy in place.

to a reduction in the price for N of \$0.48/therm and a reduction in the price for C of about \$0.28/therm.

Figure A10 presents three curves, the welfare gains associated with N, the welfare gains associated with C, and the total welfare gains, which represents the vertical sum of the gains for N and C at a given MSC. The benchmark for the welfare comparison is the welfare associated with the current prices offered to CARE and non-CARE households.

The welfare change is a function of the distance of the specified MSC from both the MPC and the existing prices for CARE and non-CARE households. If the MSC is at the low end of the range (\$0.50/therm in the base case), then there is a gain in moving prices to the MPC of about \$36 million in total welfare (about \$6 million associated with CARE households and about \$30 million associated with non-CARE households). The welfare change associated with C households just equals zero when the MSC is precisely halfway between the MPC and the current price for C households (an MSC value of \$0.61/therm). In contrast if the MSC equals the current price for C (\$0.75/therm), moving prices to the MPC for C households results in a \$17 million welfare loss.

Total welfare declines as the MSC moves toward existing prices and away from the MPC. The welfare decline is linear because the welfare function is a linear function of the MSC. The key message of the figure is that welfare gains will not necessarily be positive in moving prices to the MPC.

B.3.8 Comparing the welfare impact of CARE vouchers with a CARE price subsidy

An alternative approach to a subsidy would be to provide vouchers to low-income customers for natural gas purchases instead of CARE price subsidies. Vouchers are of interest because they are sometimes viewed as a mechanism that will not distort consumption patterns. In this sense, they may yield greater benefits than price subsidies if prices were initially set optimally to reflect marginal social costs.

We wish to compare the welfare effects of vouchers for the purchase of natural gas versus a price subsidy when the amount of the voucher is set equal to the subsidy that a representative CARE customer receives.[50] We will distinguish between two types of agents in how they respond to vouchers. The case of *standard vouchers* will refer to a situation when the agent follows standard neoclassical assumptions in reacting to a voucher.[51] The case of *behavioral vouchers* will refer to a situation in which the agent consumes more or less than a standard neoclassical agent would with a voucher.[52] We introduce behavioral vouchers because there is evidence that vouchers may change an individual's observed

[50]We thank the editors Liran Einav and Thomas Lemieux for encouraging us to conduct this analysis.

[51]We analyze the case in which the cash value of vouchers received does not exceed the total expenditures on natural gas for the CARE customer when price equals P_0. This case is the relevant one in our empirical estimation.

[52]We will assume the agent consumes more, in line with empirical work discussed below. For an instructive review of some of the economic issues with using vouchers see Bradford and Shaviro (2000).

demand curve. Hastings and Shapiro (2018) find, for example, that vouchers used in a food program – SNAP (Supplemental Nutrition Assistance Program) – increase consumption compared with cash transfers. If a similar phenomenon arises in the case of energy, this raises the question of how to assess the welfare implications.

We will assume there are three instruments: a standard price subsidy, a standard voucher, and a behavioral voucher. We wish to know whether vouchers will be better or worse for C and for social welfare compared with the price subsidy. The benchmark for comparison is a situation in which CARE customers do not receive any subsidy. For C, a standard voucher is generally preferred to a price subsidy. The reason is that a representative CARE household could consume the same bundle she consumed with the subsidy. Under our assumptions of downward sloping demand, she chooses a different bundle, and is therefore better off using a revealed preference argument. A standard voucher is also preferred to a behavioral voucher if C does not choose a utility maximizing bundle with a behavioral voucher.[53]

A more interesting question from a social perspective is whether these vouchers increase or decrease total economic welfare compared with the CARE price subsidy. For a given MSC, the welfare associated with N's choices do not change because N picks the same quantity. For C, the three policy instruments affect the quantity selected differently. In general, the relationship between the total welfare associated with standard vouchers, behavioral vouchers, and the price subsidy is ambiguous.[54] This underscores the need for empirical work to assess the welfare implications of vouchers.[55]

To estimate the quantitative impact of vouchers, we will assume that the true willingness to pay is given by the demand curve we have estimated for c. To carry out the analysis, we need an estimate of the how much vouchers change consumption, beyond that of an equivalent cash transfer. We will use a crude approach to estimating this bias. Hastings and Shapiro suggest that the marginal propensity to consume using vouchers for SNAP is in the neighborhood of 0.5-0.6 and for cash it was much less – on the order of 0.1 (see also Hoynes and Schanzenbach, 2009). This yields an upper bound estimate of bias of 0.5 (0.6-0.1) for additional expenditures out of each voucher dollar on food. Expenditure on food at home represented about 18% of total expenditures for this group (Mabli and Malsberger, 2013). In contrast, the natural gas customers enrolled on CARE spend about 2% percent of their income on natural gas.[56] Assuming the extra expenditure on gas vouchers is proportionate to income, we multiply the 0.5 estimate by (2/18) to get about 0.06 for the amount of bias.

[53] See appendix section B.2.6 for a more in-depth comparison of standard and behavioral vouchers.

[54] See appendix section B.3 for a more in-depth analysis that links this instrument choice comparison to the marginal social cost.

[55] In principle, we can apply this welfare analysis to any policy intervention, provided that we know the true demand and the observed demand (Chetty et al., 2009).

[56] Gas expenditures are about \$350 per year and the cut-off for CARE income for a two-person household is about \$30,000, yielding 1%. If the average income were half that for CARE households, this would imply that 2% of expenditures were made on natural gas.

In the sensitivity analysis below, we vary the bias over the range 0 to 0.2.

Figure A13 shows the impact of replacing the CARE price subsidy with vouchers, and also shows the impact of varying the degree of bias for SoCalGas customers for three values of the SCC: \$6/ton, \$40/ton, and \$74/ton. The figure shows that the welfare effect of standard vouchers and behavioral vouchers can be positive or negative compared with the subsidy. This is shown by noting that the SCC = 6 and the SCC = 40 curves have a negative value when bias equal zero – the standard voucher case. In contrast, the SCC = 74 curve has a positive value when bias equals 0. Similar results obtain when bias is positive – the behavioral voucher case. The impact of vouchers on welfare compared with a subsidy depends on whether the quantity chosen by CARE customers under vouchers is closer to or further away from the optimal quantity.[57]

B.3.9 Computing an "optimal" subsidy

This section describes how we compute the subsidy that maximizes net benefits as defined by equation (3), which we call the optimal subsidy. We define this subsidy as the percentage decrease from P_0. We consider all percentage decreases from P_0, including zero, that result in a positive price for CARE customers. We assume that P_0 is given by our base case assumptions, and is the same across the three utilities. We also assume that non-CARE customers pay for both the subsidy and administrative costs.

We consider values for P_{1n} and P_{1c} that satisfy equation (4) for each of the three utilities. Note that Q_{1n} and Q_{1c} must also lie on the demand curves for non-CARE and CARE customers, respectively.

Consider the three utilities: SoCalGas, SDG&E and PG&E. Figure A14 shows how welfare varies with the subsidy for these three utilities, and California as a whole. The figure also shows that the welfare values are always negative for the subsidy for SoCalGas and SDG&E. We conclude that welfare would be maximized by having no subsidy for CARE customers for these two utilities (i.e., a corner solution). This solution would avoid the administrative costs of CARE for SoCalGas and SDG&E, which total \$ 8 million. For PG&E, the optimal CARE subsidy is 23 percent, with a social welfare increase of \$2.4 million. See the curve labeled PG&E in the figure. The curve labeled California sums the three curves for the utilities and multiplies by 1.25 to reflect that these utilities represent about 80 percent of the natural gas supply. The California curve shows that net benefits would be maximized with a zero subsidy (a corner solution), because that would result in a welfare change of zero as opposed to the negative values shown in the figure.

The results are summarized in Table A15. This analysis shows that the socially optimal CARE subsidy may differ across utilities, and policy makers may want to take this into account.

[57] For the cases in which the SCC is \$6/ton and \$40/ton, the MSC is less than P_{1c}, which means that increasing the the price of natural gas to P_0 unambiguously reduces welfare for CARE customers because it represents a movement away from the MSC.

B.4 Programs used to implement welfare models

This section summarizes the programs that implement the formulas in the text. The six different programs and the sensitivities we run are outlined below. The programs can be found in the online appendix. See README.md for related file names.

B.4.1 Welfare results for introducing CARE

This program calculates welfare changes when moving to a CARE subsidy for low-income households. Welfare changes are aggregated across different sectors (welfare associated with non-CARE households, CARE households, and administrative costs), presented at an aggregate level. The file defines the base welfare calculation, creating a table of parameters and model results used in section B.3.2.

B.4.2 Welfare results for introducing CARE: Sensitivities

This program takes the welfare calculation defined in program B.4.1 and performs a number of sensitivities for different parameter values used in the model, which include: simulations for a range of E_c from -0.2 to -0.5 in Figure 3; simulations for a range of E_n from -0.35 to 0 in figure A6; simulations for a range of SCC values from \$6/ton to \$74/ton in A7, and simulations for a range of MPC from \$0/therm to \$1/therm in Figure A11.

B.4.3 Welfare analysis across California

This program takes the welfare calculation defined in program B.4.1 and extends the model to the three largest natural gas utilities in California, representing 80% of natural gas consumption. It then creates the table of the individual and total results of our model in section B.3.1.

B.4.4 Welfare analysis when moving to a cap-and-trade regime

This program calculates changes in welfare for CARE and non-CARE agents when moving from CARE pricing to a scenario where all customers have to pay the allowance price for a cap and trade scheme. Welfare changes are disaggregated by changes that are associated with CARE households and changes that are associated with non-CARE households. The sum of both values represents the total changes in welfare. The file simulates the model across a range of allowance prices from \$0 to \$20, generating Figures A12 and A8.

B.4.5 Welfare analysis when moving to a voucher system

This program calculates changes in welfare associated with CARE households when moving from CARE pricing to a scenario where CARE households receive a voucher instead of the subsidy and pay the pre-CARE price. Welfare changes are shown as changes that are associated with CARE households. These are calculated using equations (A17) and (A3). The file contains simulations for a range of bias from 0 to 0.3 for three different values of MSC: \$0.50/therm, \$0.68/therm, and \$0.86/therm (corresponding to the bounds and mid-point of the SCCs values we consider), creating Figure A13.

B.4.6 Welfare analysis when prices are moved to MPC and MSC

This program calculates changes in welfare when moving from CARE pricing to a scenario where all customers pay a price equal to either the MPC, or MSC. Welfare changes are disaggregated by changes that are associated with CARE households and changes that are associated with non-CARE households. The aggregation of both values represents the total changes in welfare. The file generates Figures A10 and A9, simulations of setting price to the MPC and MSC, respectively, across a range of MSC values (corresponding to SCC values from \$6 to \$74/ton).

B.4.7 Computing an "optimal" subsidy

This program estimates the optimal CARE discount from P_0 that maximizes total welfare for the three utilities in our sample, as well for the state of California.

B.4.8 Welfare analysis

This program takes the welfare calculation defined in program B.4.1 and calculates the percent by which benefits to CARE households, B_C, would need to increase to just offset net cost to others. It concisiders a range of elasticities for CARE and non-CARE households and a range of values for the SCC.

C Appendix: Additional Tables and Figures

Table A1: The Income Eligibility for CARE for 2015-2016

CARE Income Guidelines	
Household Size	**Income Eligibility Upper Limit**
1-2	$31,860
3	$40,180
4	$48,500
5	$56,820
6	$65,140
7	$73,460
8	$81,780
Each Additional Person	$8,320
Effective June 1, 2015 to May 31, 2016	

Notes: This is publicly available information from both Southern California Gas (SoCalGas) and the CPUC.

Table A2: Eligibility and Expenditures for the 2015 CARE Program

	Expected Eligible Households (million)	**Actual Households (million)**	**Expected Cost (million)**	**Actual Cost (million)**
SoCalGas	1.9	1.557	$147	$109
SCE	1.499	1.282	$424	$377
PG&E	1.636	1.424	$622	$573
SDG&E	0.37	0.271	$89	$82
Total	5.405	4.534	$1,282	$1,141

Notes: Southern California Gas (SoCalGas) customers receive a subsidy of 20% for gas consumption, Southern California Edision (SCE) customers only receive a subsidy of 35% for electricity consumption, and both Pacific Gas and Electric (PGE) and San Diego Gas and Electric (SDGE) customers receive a 20% subsidy for gas and a 35% subsidy for electricity. The eligible households column is estimated by each utility. Source: CPUC (2016).

Table A3: Timeline of the Experiment for the Five Different Waves

	Wave 1	**Wave 2**	**Wave 3**	**Wave 4**	**Wave 5**
(1) Consumption data started	Jan-12	Jan-14	Jan-14	Jan-14	Jan-14
(2) Customers came off CARE	Feb-Apr-14	May-15	Jun-15	Jul-15	Aug-15
(3) Randomized letter encouraged re-certifying for CARE sent out	May-14	Jun-15	Jul-15	Aug-15	Sep-15
(4) CARE letters processed and customers first notified of being on CARE	Aug-14	Aug-15	Sep-15	Oct-15	Nov-15
(5) Consumption data ended	Dec-15	Dec-15	Dec-15	Dec-15	Dec-15

Table A4: Baseline Usage of the Experimental Population

	Experiment 1		**Experiment 2**	
	Pre-Experiment Usage		**Pre-Experiment Usage**	
Treatment	**N**	**Mean Use (therms)**	**N**	**Mean Use (therms)**
0	7,366	29.04	8,496	26.30
1	7,329	29.03	8,499	26.44
2	7,363	28.95	8,496	26.31
3	7,368	28.92	8,497	26.20
4	7,370	29.14		

Notes: We present summary statistics by experiment. N describes the number of households in a given treatment cell.

Table A5: Balance for Pre-experimental Gas Use in Experiment 1

		t-tests [p-value]			
Treatment	**Average Use**	**0**	**1**	**2**	**3**
0	29.04	-			
1	29.03	0.97	-		
2	28.95	0.75	0.79	-	
3	28.92	0.67	0.71	0.92	-
4	29.14	0.72	0.70	0.52	0.44

Notes: Average use is defined as average number of therms per month before the letters were sent to households.

Table A6: Balance for Pre-experimental Gas Use in Experiment 2

		t-tests [p-value]		
Treatment	**Average Use**	**0**	**1**	**2**
0	26.30	-		
1	26.44	0.59	-	
2	26.31	0.97	0.61	-
3	26.20	0.67	0.34	0.65

Notes: Average use is defined as average number of therms per month before the letters were sent to households.

Table A7: Summary Statistics across Waves

	Wave 1	Wave 2	Wave 3	Wave 4	Wave 5	Overall
Very low-income	23%	24%	30%	30%	29%	25%
Opower	10%	9%	9%	7%	6%	9%
Paperless	27%	32%	31%	29%	29%	29%
Total N	36,796	8,548	9,720	8,969	6,751	70,784

Notes: Very low-income households are defined as underprivileged in our income data. Opower refers to whether the customer is part of the Opower HER treatment group. Paperless refers to whether the customer receives their bills online and not on paper format sent to their home address.

Table A8: Heterogeneity in enrollment in CARE

	(1)	(2)	(3)	(4)	(5)
Encouragement letter	0.1024***	0.0997***	0.1054***	0.1086***	0.0997***
	(0.0023)	(0.0028)	(0.0021)	(0.0025)	(0.0035)
Very low-income household	0.0115***				0.0120***
	(0.0034)				(0.0035)
Very low income household x letter	0.0092*				0.0107**
	(0.0049)				(0.0050)
High gas user		0.003			0.0048
		(0.0028)			(0.0029)
High gas user x letter		0.0103**			0.0142***
		(0.0041)			(0.0043)
Opower treatment group			0.0032		0.0019
			(0.0051)		(0.0053)
Opower treatment group x letter			-0.0064		-0.0113
			(0.0073)		(0.0075)
Paperless				-0.0068**	-0.0056**
				(0.0030)	(0.0030)
Paperless x letter				-0.0134***	-0.0125***
				(0.0043)	(0.0043)
Constant	0.0422***	0.0434***	0.0446***	0.0474***	0.0417***
	(0.0036)	(0.0038)	(0.0035)	(0.0037)	(0.0040)
R2	0.21	0.20	0.20	0.21	0.22
N	70,784	70,784	70,784	70,784	70,784

Notes: Dependent variable is a binary variable indicator whether the household successfully signed up to CARE. We define low-income household as being in the bottom groups of the Prizm segmentation codes. We define high gas user as being in the upper half of the sample for our overall dataset. Opower treatment group households are defined as those who have been randomly paced in the Opower Home Energy Report treatment group. Paperless billing are those households who receive their bill online and not delivered to their home address. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Table A9: Comparison of Nonparticipants in the Control and Encouragement Groups

	(1)
	Gas use
Receive encouragement	0.092
	(0.077)
Monthly usage control	0.709***
	(0.016)
Control usage (therms)	21.11
R2	0.53
N	440,615

Notes: Dependent variable is household-level monthly natural gas usage in therms. The analysis is restricted to the post-recertification period only, i.e. the period after households got off the CARE rates initially. The regression utilizes observations from the year of the experiment (2014 for experiment 1 and 2015 for experiment 2). Receive Encouragement is an indicator equal to one in the month of treatment letters for all of those who are in the encouragement group but do not take-up the CARE subsidy. Month-of-sample and wave fixed effects are included in all specifications. Monthly Usage Control is a variable capturing the average usage in the same month-of-year prior to the year of the experiment (2012 and 2013 for experiment 1, 2012 to 2014 for experiment 2). Standard errors are clustered at the household level. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Table A10: Summer and Winter ITT and LATE estimates of CARE

Summer Months	(1) (FS)	(2) (ITT)	(3) (LATE)
	Take-up CARE	**Gas consumption**	**Gas consumption**
Receive encouragement	0.0640***	0.1208*	
	(0.0013)	(0.0654)	
Monthly usage control	0.0001***	0.6725***	0.6722***
	(0.0000)	(0.0261)	(0.0261)
Post-CARE-Take-Up			1.8443*
			(0.9992)
Control usage (Therms)	N	N	N
F-stat in first-stage	2018		
R2	0.063	0.424	0.412
N	318,747	310,0337	310,0337

Winter Months	(4) (FS)	(5) (ITT)	(6) (LATE)
	Take-up CARE	**Gas consumption**	**Gas consumption**
Receive encouragement	0.1011***	0.2331*	
	(0.0020)	(0.1355)	
Monthly usage control	0.0001***	0.7378***	0.7376***
	(0.000)	(0.0109)	(0.0109)
Post-CARE-Take-Up			2.2251*
			(1.2929)
Control usage (Therms)	N	N	23
F-stat in first-stage	2040		
R2	0.043	0.538	0.501
N	174,644	167,399	167,399

Notes: Dependent variable is household-level monthly natural gas usage in therms for columns (2), (3), (5), and (6), and a binary indicator for household program take-up in columns (1) and (4). The analysis is restricted to the post-recertification period only, i.e. the period after households got off the CARE rates initially. Columns (1)-(3) only utilize observations for Summer months only, and columns (4)-(6) also utilize observations Winter months only. Receive Encouragement is an indicator equal to one in the month of treatment letters and thereafter for all households assigned to a treatment group. Post-Take-Up is an indicator equal to one in the month of take-up and thereafter for households who re-sign successfully for CARE. Columns (2) and (5) present the ITT, Columns (1) and (4) the first-stage, and Columns (3) and (6) the LATE estimates where we instrument for program take-up (Post-Take-Up) with random assignment to treatment (Receive Encouragement). Month-of-sample and wave fixed effects are included in all specifications. Monthly Usage Control is a variable capturing the average usage in the same month-of-year prior to the year of the experiment. Standard errors are clustered at the household level. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Table A11: Comparison of our sample with the rest of the CARE and non-CARE populations

	Field Experimental Sample	**Rest of CARE in SCG**	**Non-CARE in SCG**
Overall monthly gas use pre-experiment	26.67	26.46	41
Summer months gas use pre-experiment	18.97	18.26	25
Winter months gas use pre-experiment	34.15	34.65	56
Very low income	0.25	0.49	0.10
Paperless	0.29	0.25	0.35
Opower	0.09	0.09	0.09
LA area	0.17	0.17	0.24
Total number of households	70,784	1,198,191*	3,843,707

Notes: The gas use variables (first three rows) are average therms per month. The very low income, paperless, Opower, and LA variables are in fractions. The data for the Non-CARE in SCG sample comes from SCG. The Opower nummber in the second column comes from the utility. The sample size is those who were on CARE for twelve months before the experiment started and so is lower than the 1.5 million customers who are on CARE on any given month.

Table A12: Reweighted ITT and LATE estimates of CARE

	(1) (FS)	(2) (ITT)	(3) (LATE)
	Take-up CARE	**Gas consumption**	**Gas consumption**
Receive encouragement	0.0810***	0.1789**	
	(0.0018)	(0.0717)	
Monthly usage control	0.0002***	0.7343***	0.7340***
	(0.0000)	(0.0097)	(0.0097)
Post-CARE-Take-Up			2.1688**
			(0.8693)
Control usage (Therms)	19	19	19
F-stat in first-stage	1084		
2015 data for wave 1			
R2	0.063	0.56	0.51
N	493,391	477,736	477,736

	(4) (FS)	(5) (ITT)	(6) (LATE)
	Take-up CARE	**Gas consumption**	**Gas consumption**
Receive encouragement	0.0960***	0.1707**	
	(0.0025)	(0.0708)	
Monthly usage control	0.0001***	0.7096***	0.7094***
	(0.000)	(0.0071)	(0.0071)
Post-CARE-Take-Up			1.7151**
			(0.7122)
Control usage (Therms)	21	21	21
F-stat in first-stage	773		
2015 data for wave 1	x	x	x
R2	0.046	0.610	0.541
N	920,683	839,106	839,106

Notes: Dependent variable is household-level monthly natural gas usage in therms for columns (2), (3), (5), and (6), and a binary indicator for household program take-up in columns (1) and (4). The analysis is restricted to the post-recertification period only, i.e. the period after households got off the CARE rates initially. Columns (1)-(3) only utilize observations from the year of the experiment (2014 for experiment 1 and 2015 for experiment 2), columns (4)-(6) also utilize 2015 observations for experiment 1. Receive Encouragement is an indicator equal to one in the month of treatment letters and thereafter for all households assigned to a treatment group. Post-Take-Up is an indicator equal to one in the month of take-up and thereafter for households who re-sign successfully for CARE. Columns (2) and (5) present the ITT, Columns (1) and (4) the first-stage, and Columns (3) and (6) the LATE estimates where we instrument for program take-up (Post-Take-Up) with random assignment to treatment (Receive Encouragement). Month-of-sample and wave fixed effects are included in all specifications. Monthly Usage Control is a variable capturing the average usage in the same month-of-year prior to the year of the experiment (2012 and 2013 for experiment 1, 2012 to 2014 for experiment 2). Standard errors are clustered at the household level. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

Table A13: Welfare estimates under different counterfactual price determinants

Price determinant	Tax difference equal across tiers	Subsidy difference equal across tiers	Minimization exercise
Welfare change (millions $):			
Total	-5.3	-3.2	-4.3
Total in base case	-4.8	-4.8	-4.8
% change, compared to base	0.10	-0.34	-0.11

Notes: Parameters are taken from the base case: N_c is 1600000, N_n is 3850000 and A is $7001307.52. Percent on tier 2, C is estimated as 0.27, N as 0.72. P_{1c1} is observed as 0.69, P_{1n1} as 0.86, P_{1c2} as 0.90, P_{1n2} is 1.12. The bottom line is that this analysis suggests that introducing the assumption of two-tiered pricing still yields a loss in welfare when CARE is introduced.

Table A14: Extrapolating the welfare results to California

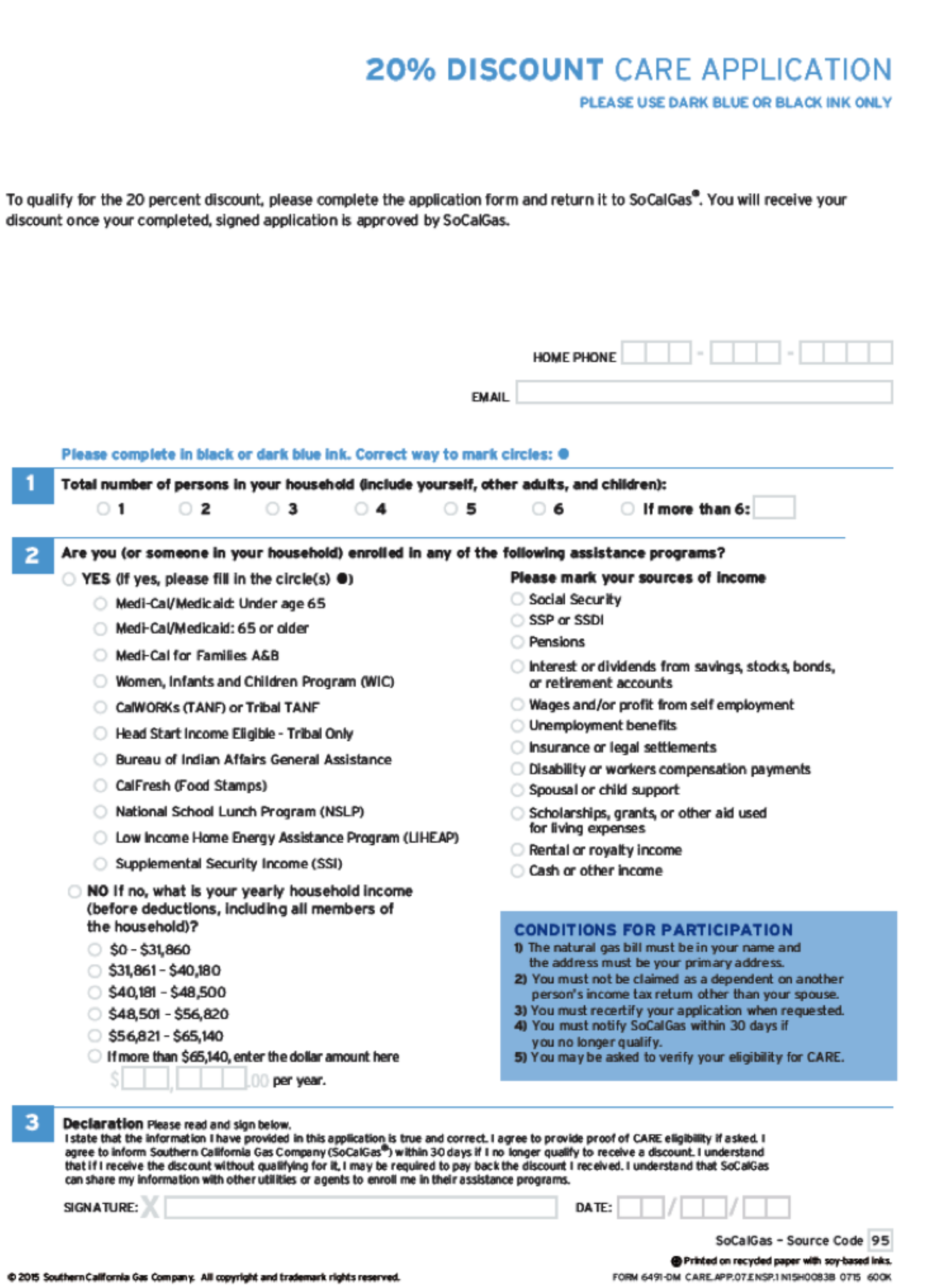
	SoCalGas	PG&E	SDG&E	Total
E_c	-0.35	-0.35	-0.35	
E_n	-0.14	-0.14	-0.14	
SCC	39.95	39.95	39.95	
MEC	0.21	0.21	0.21	
MPC	0.47	0.47	0.47	
MSC	0.68	0.68	0.68	
N_c	1,600,000	1,076,000	176,000	
N_n	3,850,000	3,124,000	1,024,000	
P_0	0.9	1.10	1.22	
P_{1c}	0.75	0.91	1.0	
P_{1n}	0.95	1.14	1.25	
Q_{0c}	289.51	338.82	222.34	
Q_{0n}	495.31	576.96	380.44	
Q_{1c}	312.84	364.96	241.17	
Q_{1n}	492.0	573.97	379.29	
A	7,000,000.00	3,000,000.0	1,000,000.00	
Welfare estimates:				
ΔW, total welfare change ($ mill)	-4.8	2.0	-0.23	-3.0
CO_2, extra emissions tons	130,000	99,000	11,000	241,000

Sources: Authors calculations and the California Public Utilities Commission (CPUC).

Table A15: Optimal CARE subsidy for the three California utilities and the State of California

	SoCalGas	PG&E	SDG&E	California
% change in subsidy	0%	22%	0%	0%
Welfare change	$0	$2.4M	$0	$0

Notes: With a subsidy of zero percent, we assume that there are no administrative costs of CARE. The table shows that the optimal subsidy is zero for two of the three utilities, as well as for California as a whole. See the text for details.



20% DISCOUNT CARE APPLICATION

PLEASE USE DARK BLUE OR BLACK INK ONLY

To qualify for the 20 percent discount, please complete the application form and return it to SoCalGas®. You will receive your discount once your completed, signed application is approved by SoCalGas.

HOME PHONE

EMAIL

Please complete in black or dark blue ink. Correct way to mark circles: ●

1 **Total number of persons in your household (include yourself, other adults, and children):**

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ If more than 6:

2 **Are you (or someone in your household) enrolled in any of the following assistance programs?**

○ **YES** (If yes, please fill in the circle(s) ●)
- ○ Medi-Cal/Medicaid: Under age 65
- ○ Medi-Cal/Medicaid: 65 or older
- ○ Medi-Cal for Families A&B
- ○ Women, Infants and Children Program (WIC)
- ○ CalWORKs (TANF) or Tribal TANF
- ○ Head Start Income Eligible - Tribal Only
- ○ Bureau of Indian Affairs General Assistance
- ○ CalFresh (Food Stamps)
- ○ National School Lunch Program (NSLP)
- ○ Low Income Home Energy Assistance Program (LIHEAP)
- ○ Supplemental Security Income (SSI)

○ **NO** If no, what is your yearly household income (before deductions, including all members of the household)?
- ○ $0 - $31,860
- ○ $31,861 - $40,180
- ○ $40,181 - $48,500
- ○ $48,501 - $56,820
- ○ $56,821 - $65,140
- ○ If more than $65,140, enter the dollar amount here $, .00 per year.

Please mark your sources of income
- ○ Social Security
- ○ SSP or SSDI
- ○ Pensions
- ○ Interest or dividends from savings, stocks, bonds, or retirement accounts
- ○ Wages and/or profit from self employment
- ○ Unemployment benefits
- ○ Insurance or legal settlements
- ○ Disability or workers compensation payments
- ○ Spousal or child support
- ○ Scholarships, grants, or other aid used for living expenses
- ○ Rental or royalty income
- ○ Cash or other income

CONDITIONS FOR PARTICIPATION
1) The natural gas bill must be in your name and the address must be your primary address.
2) You must not be claimed as a dependent on another person's income tax return other than your spouse.
3) You must recertify your application when requested.
4) You must notify SoCalGas within 30 days if you no longer qualify.
5) You may be asked to verify your eligibility for CARE.

3 **Declaration** Please read and sign below.
I state that the information I have provided in this application is true and correct. I agree to provide proof of CARE eligibility if asked. I agree to inform Southern California Gas Company (SoCalGas®) within 30 days if I no longer qualify to receive a discount. I understand that if I receive the discount without qualifying for it, I may be required to pay back the discount I received. I understand that SoCalGas can share my information with other utilities or agents to enroll me in their assistance programs.

SIGNATURE: X DATE: / /

SoCalGas – Source Code 95

Printed on recycled paper with soy-based inks.

FORM 6491-DM CARE.APP.07.ENSP.1 N15H0083B 0715 600K

Figure A1: *Application page (in English).*

YOU CAN AVOID LOSING MONEY BY REAPPLYING FOR CARE TODAY

Dear [name],

We are writing because you participated in the California Alternate Rates for Energy (CARE) 20 percent discount program last year and **you saved $XXX.XX**. **Unfortunately, you no longer receive this special discount** because your application is out of date.

The good news is that you can still re-apply. If you or another member of your household is on a public assistance program listed in the enclosed application or meet the income guidelines listed below, you may still be eligible for the program. Once you are re-certified, assuming you still meet the requirements, **you will immediately receive the 20 percent discount.**

MAXIMUM HOUSEHOLD INCOME TO BE ELIGIBLE (effective June 1, 2015 to May 31, 2016)

Number of Persons in Household:	1-2	3	4	5	6	7	8
Total Annual Income[1]	$31,860	$40,180	$48,500	$56,820	$65,140	$73,460	$81,780

For each additional household member, add $8,320

1. Includes current household income from all sources before deductions.

What you NEED to do:

- Complete the attached application form
- Mail the completed form in the postage-paid envelope
- The CARE application can also be completed online at **socalgas.com** (search *"CARE"*).

Did you know? Each year more than 200,000 customers like you re-certify to save money.

If you need more information about this discount, please visit **socalgas.com** (search *"CARE"*) or call us free at 1-800-427-2200.

Sincerely,

Ted Humphrey

Ted Humphrey
CARE Program Senior Market Advisor

 Printed on recycled paper with soy-based inks. FORM 6491-DM CARE.APP.07.ENSP.1 N15H0083B

Figure A2: *Letter from Experiment 2 (in English).*

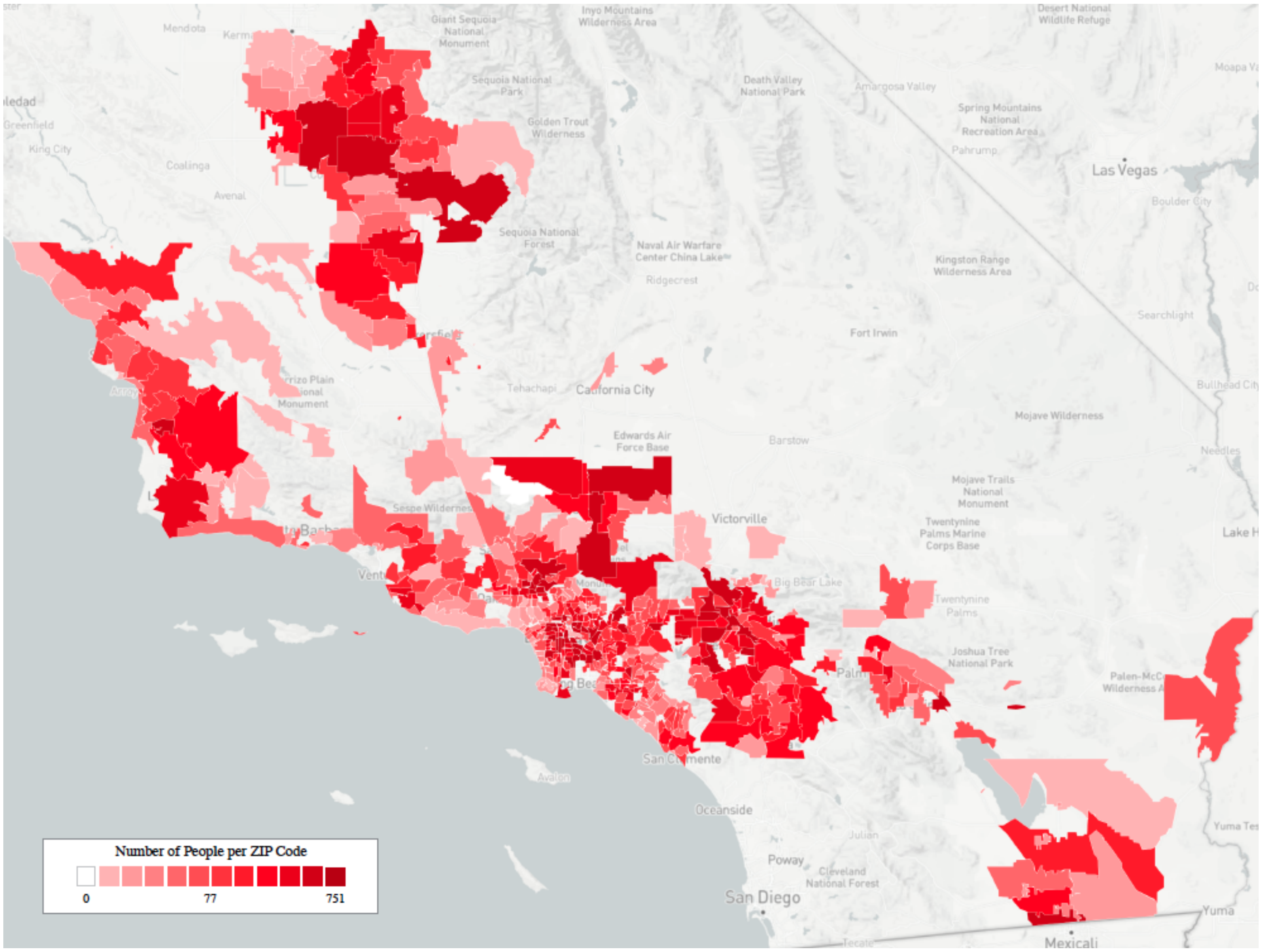


Figure A3: *Heat map of customers in the Southern California Gas districts.*

Notes: This heat map demonstrates the density of households in our experiment in each five-digit zip code. The heat intensity is divided by deciles of the frequency by zip. The declie cut-offs are: 9, 21, 37, 57, 77, 106, 152, 210, 303, 751. The data for this map comes from the utility.

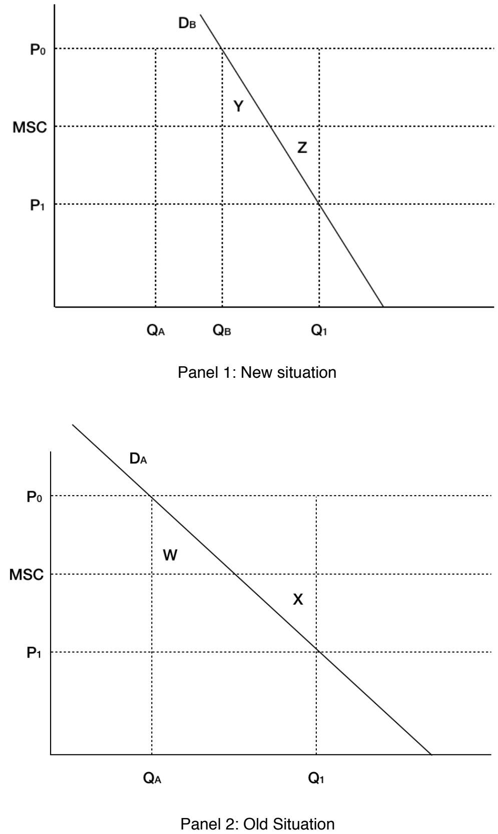


Figure A4: *Effect of Varying the Elasticity with Introducing CARE*

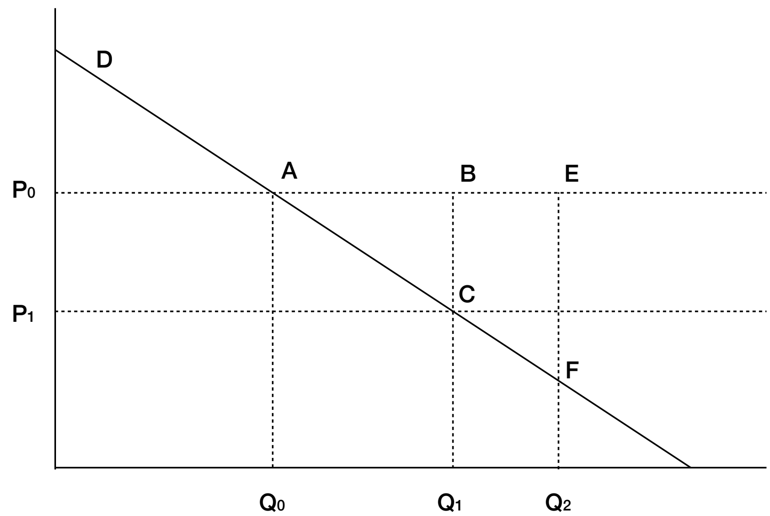


Figure A5: *Explanation for Standard and Behavioral voucher welfare analysis for the group receiving the subsidy.*

Notes: This figure compares the welfare for CARE households of a subsidy with standard vouchers and behavioral vouchers. With the subsidy the CARE household chooses C at the subsidized price P_1. With the voucher, she chooses A. She prefers a standard voucher to a subsidy by a revealed preference argument. A behavioral voucher may or may not be preferred to a subsidy or a standard voucher from the perspective of a CARE household.

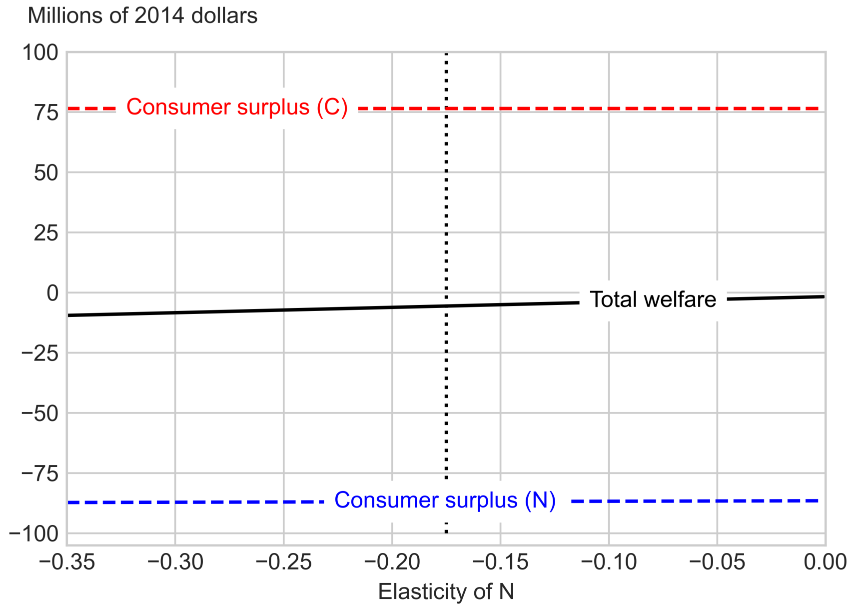


Figure A6: *Effect of Varying Elasticity of non-CARE households on Welfare Associated with Introducing CARE*

Notes: The figure shows the welfare effects of varying the elasticity for SoCalGas non-CARE customers. Total welfare is negative over the range of elasticities and increases slightly as the demand by non-CARE customers becomes more inelastic.

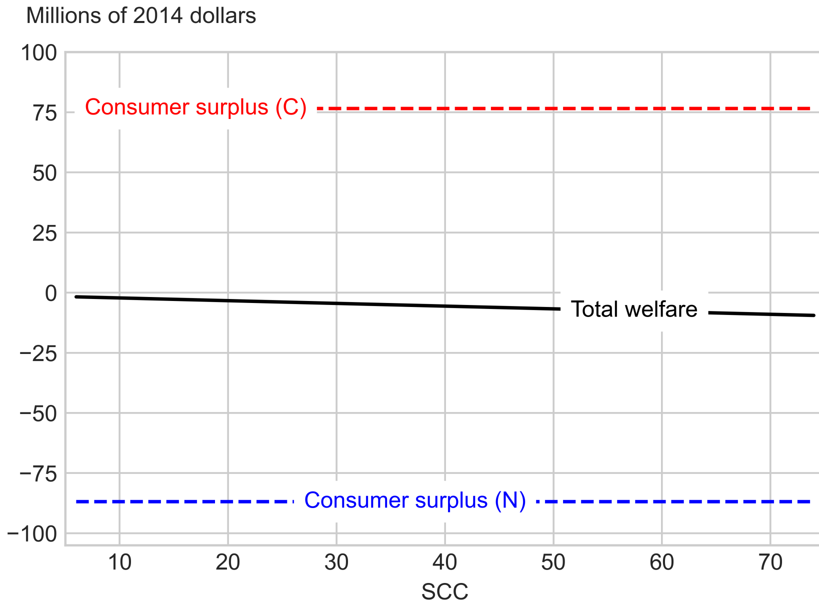


Figure A7: *Effect of Varying the SCC on Welfare Associated with Introducing CARE*

Notes: Total welfare from introducing CARE is negative when the SCC is $6/ton and continues to decrease as the SCC increases. The only impact of the change in the SCC on welfare is the effect of pollution damages, shown as the Environment curve in the figure.

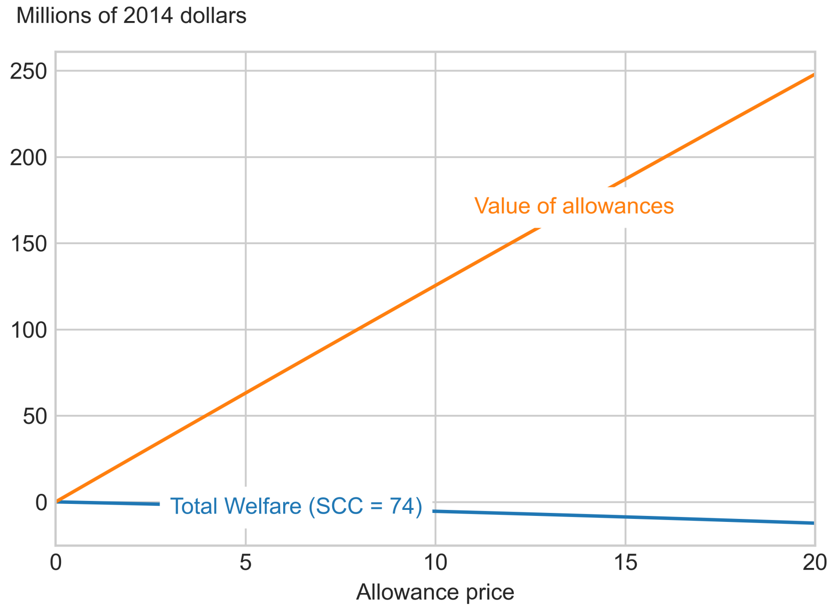


Figure A8: *The Value of Allowances with Varying the Allowance Price*

Notes: The figure shows that there is an increasing gap between the value of allowances and the welfare change with a high value for the SCC as the allowance price increases.

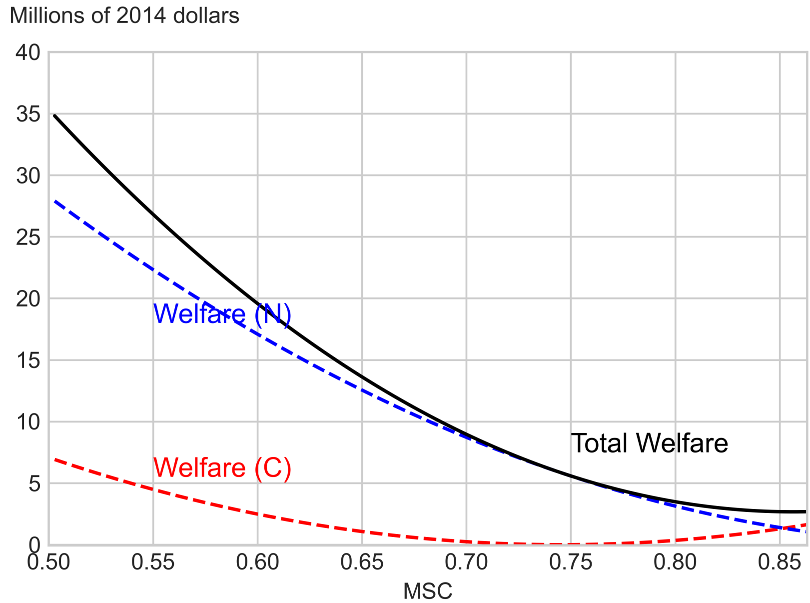


Figure A9: *The Impact of Varying the Social Cost of Carbon on the Welfare Increase associated with setting Energy Prices equal to Marginal Social Cost*

Notes: The figure shows the welfare effects of moving prices for CARE and non-CARE households to the marginal social cost (the two dashed curves). The total welfare change is the solid curve. The key message of this figure is that welfare gains will always be positive as prices are moved to the MSC, but gains exhibit substantial variation depending on which MSC is selected. The differences in the welfare gains can be explained by the extent to which existing prices deviate from the assumed MSC.

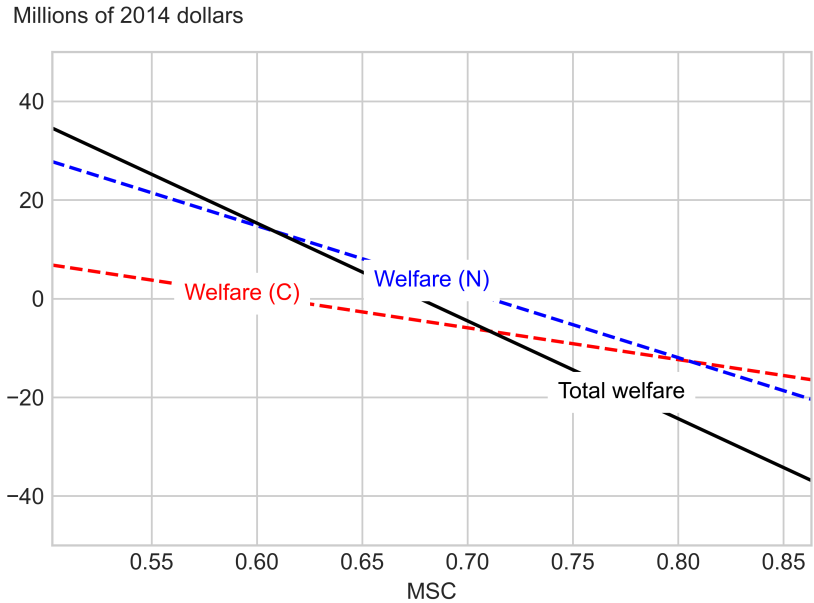


Figure A10: *Welfare Impacts of setting prices equal to the MPC with different values of the Marginal Social Cost.*

Notes: The figure shows the welfare effects of moving prices for CARE and non-CARE households to the marginal private cost (the two dashed lines) for different values of the marginal social cost. The total welfare change is the solid line. The welfare change associated with a change in the price for C and the welfare change with a change in the price for N are dashed lines. The change in welfare declines as the MSC increases (for plausible values of the SCC). The total welfare change can be positive or negative.

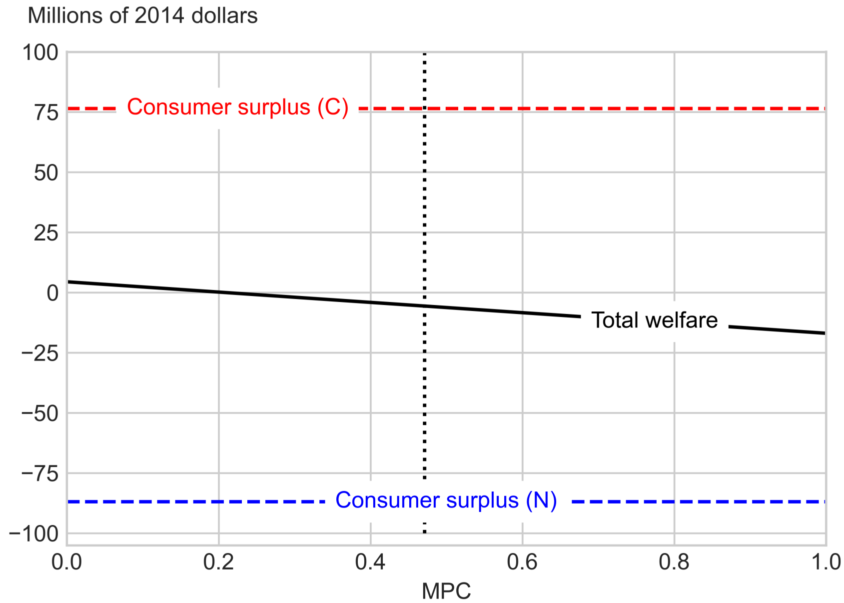


Figure A11: *Effect of Varying the MPC on Welfare Associated with Introducing CARE*

Notes: The figure shows the effect of varying the MPC on the welfare associated with introducing CARE for SoCalGas customers. In general, as the MPC increases, utility profits decline, and overall welfare decreases.

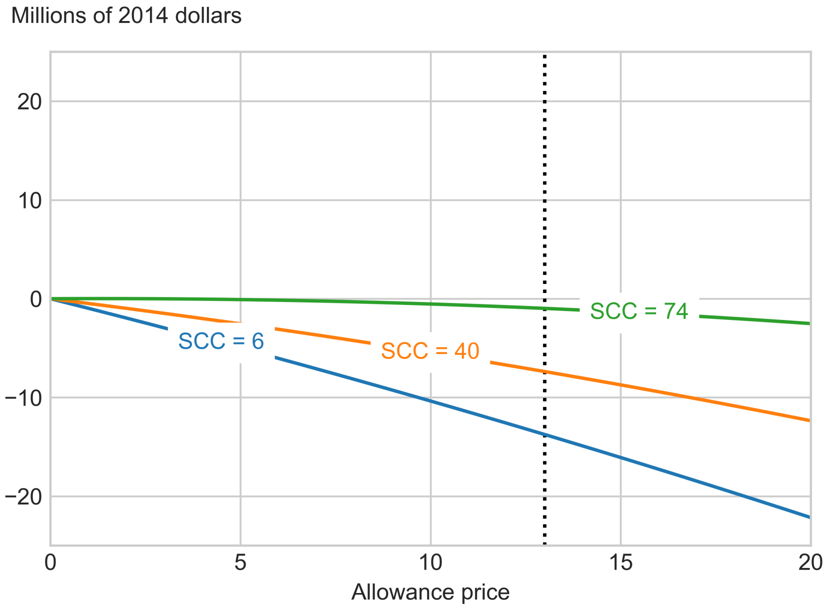


Figure A12: *How the Welfare Impacts of a Cap-and-Trade Policy Vary with the SCC*

Notes: This figure shows how the change in welfare from introducing cap-and trade varies with the allowance price and the level of the SCC for SoCalGas customers. The welfare change from introducing cap-and-trade is negative for the values of the SCC considered here.

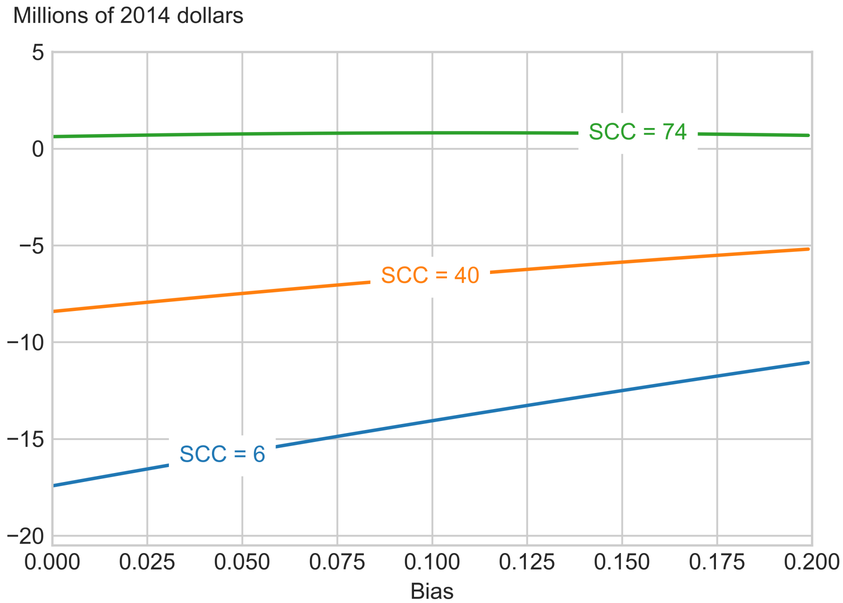


Figure A13: *Change in economic welfare compared with subsidy for standard vouchers and behavioral vouchers*

Notes: This figure shows the impact of varying the degree of bias for three values of the SCC for SoCalGas customers. The figure shows that the welfare effect of standard vouchers and behavioral vouchers can be positive or negative compared with the subsidy. This is shown by noting that the SCC=6 and SCC=40 curves have a negative value when the bias equal zero – the standard voucher case; in contrast, the SCC=74 curve has a positive value when bias equals 0. Similar results obtain when bias is positive – the behavioral voucher case. The general point for policy makers is that the welfare associated with a voucher is quite sensitive to what is assumed about the degree of bias and the SCC.

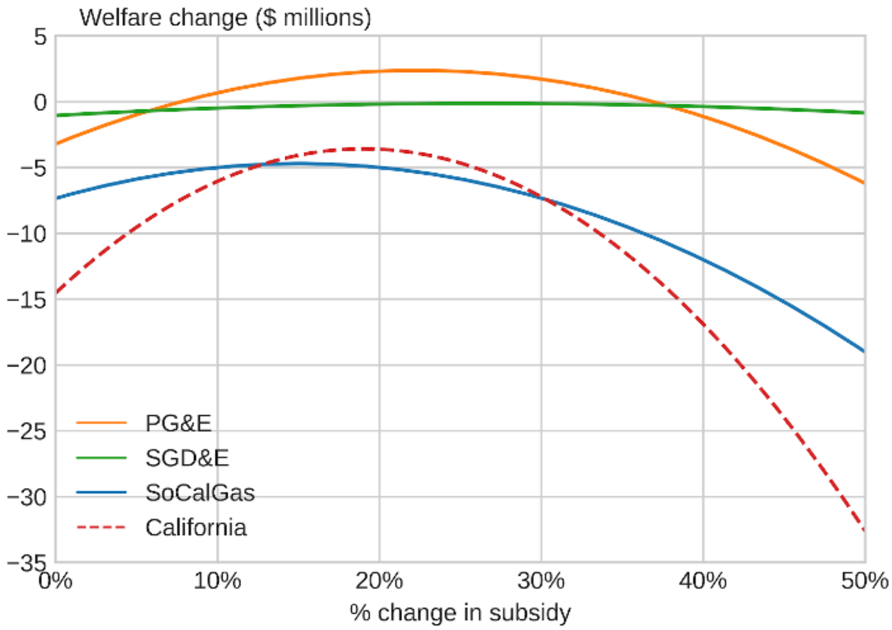


Figure A14: *Optimal CARE subsidy for the three California utilities and the State of California*

Notes: All of the points in these four curves include administrative costs. If the subsidy is zero, these costs could be avoided. See discussion in the text for details.

Appendix Reference List

Allcott, Hunt, Dmitry Taubinsky (2015). Evaluating behaviorally motivated policy: Experimental evidence from the lightbulb market. American Economic Review, 105 (8): 2501-38.

Angrist, Joshua D., Guido W. Imbens, Donald B. Rubin (1996) Identification of causal effects using instrumental variables. Journal of the American Statistical Association 91.434: 444-455.

Baumol, William J., Wallace E. Oates (1998). The Theory of Environmental Policy. Cambridge University Press.

Bertanha, Marinho, Guido W. Imbens (2019). External validity in fuzzy regression discontinuity designs. Journal of Business Economic Statistics, 1-39.

Borenstein, Severin, James Bushnell (2019). Do Two Electricity Pricing Wrongs Make a Right? Cost Recov- ery, Externalities, and Efficiency. Energy Institute at Haas Working Paper No. 274R.

Borenstein, Severin, James Bushnell, Frank A. Wolak, Matthew Zaragoza-Watkins (2019). Expecting the Unexpected: Emissions Uncertainty and Environmental Market Design. American Economic Review, 109 (11): 3953-77.

Bradford, David F., Daniel N. Shaviro (2000). The Economics of Vouchers. In Vouchers and the Provision of Public Services (Eds. C. Eugene Steuerle, Van Doorn Ooms, George Peterson and Robert D. Reischauer), Brookings Institution Press.

Chetty, Raj, Adam Looney, and Kory Kroft (2009). Salience and taxation: Theory and evidence. American Economic Review, 99 (4): 1145-77.

Chetty, Raj (2015). Behavioral economics and public policy: A pragmatic perspective. American Economic Review, 105 (5): 1-33.

Einav, Liran, Amy Finkelstein, Mark R. Cullen (2010). Estimating welfare in insurance markets using variation in prices. Quarterly Journal of Economics 125 (3): 877-921.

Hastings, Justine, Jesse M. Shapiro (2018). How are SNAP benefits spent? Evidence from a retail panel. American Economic Review, 108 (12): 3493-3540.

Hoynes, Hilary W., Diane Whitmore Schanzenbach (2009). Consumption responses to in-kind transfers: Evidence from the introduction of the food stamp program. American Economic Journal: Applied Economics, 1 (4): 109-39.

Kowalski, Amanda E. (2016). Doing More When You're Running LATE: Applying Marginal Treatment Effect Methods to Examine Treatment Effect Heterogeneity in Experiments. NBER Working Paper No. 22363.

Mabli, James, Rosalie Malsberger (2013). Recent trends in spending patterns of Supplemental Nutrition Assistance Program participants and other low-income Americans. Monthly Labor Review, 136: 1.

Mogstad, Magne, Andres Santos, Alexander Torgovitsky (2018). Using instrumental variables for inference about policy relevant treatment parameters. Econometrica, 86 (5): 1589-1619.

Ramsey, Frank P. (1927). A Contribution to the Theory of Taxation. Economic Journal, 37: 47–61.

Stuart, Elizabeth A., Stephen R. Cole, Catherine P. Bradshaw, Philip J. Leaf (2011). The use of propensity scores to assess the generalizability of results from randomized trials. Journal of the Royal Statistical Society: Series A (Statistics in Society), 174 (2): 369-386.