# Pre-Analysis Plan

## Monetary and Non-monetary Barriers to Accessing Environmental Public Benefit Programs: Experimental Evidence from California

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**Abstract**

Socioeconomic disparities in exposure to air pollution and in defensive investments raise questions about how the efficiency and distributions of environmental public service programs. This project will address how pecuniary and non-pecuniary application costs affect take-up and targeting of a subsidized air-purifier program. We will conduct a field experiment in which we mail offer letters for discounted or free air purifiers to approximately 90,000 households in California. Across eight treatment arms, we will vary subsidy rates, the length of the application form, documentation requirements, additional information about the application process, and assistance for the application process, and additional information about the health impact of air pollution. We combine the application data with individual-level estimates of income and demographic characteristics, as well as Census Tract-level estimates of pollution exposure. We test whether subsidy rates and higher ordeal costs differentially affect take-up, and whether it varies by socioeconomic status and exposure, allowing us to identify whether pecuniary and non-pecuniary costs improve or worsen targeting toward vulnerable households. We will also address whether information and assistance mitigate behavioral and informational frictions. Our results inform optimal program design when standard neoclassical targeting assumptions may fail in environmental contexts.

**JEL:** C93, I38, Q53

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# 1 Introduction

Exposure to poor air quality and the willingness to pay for defensive investments vary significantly by socioeconomic status (SES) and other demographic factors (e.g., Colmer et al. 2024; Ito and Zhang 2020). On the one hand, the differences may be preference-based; income and preferences for clean air may drive where people reside, how much environmental pollution to tolerate, and whether to purchase air purifiers (e.g., Banzhaf and Walsh 2013; Freeman et al. 2019). On the other hand, exposure to polluted air may not be fully internalized due to behavioral biases and information frictions about the costs of exposure and of engaging in avoidance behaviors (e.g., Hausman and Stolper 2021). Policymakers interested in reducing socioeconomic and demographic disparities in exposure to air pollution may implement public benefit programs—government-funded subsidies for goods and services for vulnerable individuals to meet their basic needs—in order to encourage avoidance and adaptation strategies. Such public benefit programs may also improve welfare if individuals do not fully internalize the cost of poor air quality, particularly in lower SES and high-pollution areas with higher barriers to accessing avoidance and adaptation strategies.

Yet, it remains an open question as to how policymakers should set the costs of accessing public benefit programs to improve targeting. Existing public benefit programs in the United States, such as the Supplemental Nutrition Assistance Program (SNAP), require documentation to verify applicants' eligibility and time to fill out applications, inducing opportunity costs to applicants. Such non-pecuniary costs, to which some refer as "ordeal" costs, may affect both application rate and demographic compositions of applicants. On the one hand, the neoclassical intuition tells us that such ordeal costs should help target low-income beneficiaries if the opportunity cost of time is positively correlated with income; only low-income individuals whose personal benefits from the program exceed the application costs apply (Finkelstein and Notowidigdo 2019). On the other hand, if information frictions, concerns around trust for public programs, and behavioral biases are larger for lower-income individuals, then ordeal costs may be regressive. Combined with the higher tendency of low-income individuals to be exposed to air pollution, ordeal costs may lead to less socially desirable allocations of public assistance services (e.g., Hsiang et al. 2019).

In this study, we will ask the following research questions. First, do consumers respond to pecuniary and non-pecuniary costs of application to environmental public benefit programs? Second, do consumers respond to those pecuniary and non-pecuniary costs differentially by SES, other demographic characteristics, or their air pollution exposure? Third, what mechanisms, such as differences in opportunity cost, differential exposure to pollution, information

asymmetries, or differential (perceived) costs of providing documentation, explain the differences in applications by SES and other factors? With these questions, we hope to identify how a consumption decision for environmental goods may deviate from a neoclassical intuition and how policymakers can design environmental public benefit programs to improve environmental outcomes across all demographics.

We will conduct a field experiment to send offer letters for discounted portable air purifiers to a sample of approximately 90,000 addresses in California. We will assign the addresses into eight treatment arms in which we experimentally vary the content of the letters in a) the pecuniary costs through subsidies, b) time costs and documentary requirements, and c) messaging that improves the perceived benefits of the program and costs of application. The letter recipients will apply for the subsidized air purifiers through the study's website, hosted by UC Davis. We will observe whether a letter recipient begins and completes the application form at the individual level. We will also have estimates of household income levels and demographic characteristics through the mailer data.

Based on the application and mailer data, we will test the following hypotheses. First, we evaluate whether variations in pecuniary costs affect application rates. Second, we test whether lower pecuniary costs differentially affect application rates by income and demographic factors, i.e., whether the demand elasticity differs by SES, and whether higher subsidy rates improve targeting toward lower-income individuals. Third, we will test whether additional non-pecuniary costs—such as longer application forms and requiring proof of residence—affect application rates, and whether such costs increase the share of low-income applicants. In other words, we will test whether non-pecuniary costs improve targeting toward lower-income individuals, as predicted under neoclassical assumptions. Fourth, we will test whether additional assistance and information improve targeting, and whether improved targeting occurs by removing frictions that may lead non-pecuniary costs to worsen targeting, if at all. For instance, we will evaluate whether and to what extent additional information about the application process will negate the potential effects on the application rate and demographic composition of requiring proof of residence.

# 2 Experimental Design

This study aims to distribute a small number of portable residential air purifiers to residents in California. We sample a subset of California addresses and send an offer letter to purchase air purifiers at a discount. In the offer letter, we randomize the subsidy rate, the ordeal

cost of application, and the amount of information pertaining to air quality and mitigation strategies. We will observe whether each letter recipient applies to the program through our online portal.

## 2.1 Sampling

The sampling frame is based on a mailing list purchased from a direct mailing company, containing approximately 12 million individuals from the State of California.[1] We access the list of addresses, excluding those who either a) opted not to receive any direct mail via the Direct Mail Association (DMA), b) no longer reside at the address via the National Change of Address (NCOA) suppression, or c) are missing household IDs in the mailer data.

The mailing list contains estimates of income and demographics at the individual level, GPS coordinates, and the Census Tract ID. The annual income estimates are in the 5,000-dollar increment up to $65,000 and larger increments thereafter. These estimates are available for 91% of the addresses. Figure 1 shows the distribution of estimated income bins. The mailing list also contains other demographic estimates, such as household size, ethnicity, and language spoken at home.

We also access data on air quality and merge it with the mailing list. First, we use a measure of average PM2.5 concentration from CARB for stratified sampling. We use the underlying data input CARB uses for CalEnviroScreen, a report on the environment, health, and SES to identify environmentally disadvantaged communities.[2] We use the 2021-2023 estimates for the latest CalEnviroScreen (Version 5.0). The average PM2.5 concentration is estimated at the 1-kilometer grid level, which we aggregate into the Census Tract level. We construct the tract-level ranking of average PM2.5 concentrations and group the tracts into deciles. Second, we access the U.S. EPA's AQI reports on the number of days at each AQI category for each county, and merge with the mailing list at the county level. We use the AQI report data as part of the information provided in one of the treatment arms.

We further restrict the mailing list prior to sampling if addresses lack the following variables needed for stratified sampling or information needed for the intervention. First, we exclude addresses for which estimated household sizes are zero or missing. Second, we exclude addresses for which estimated household incomes are missing or less than or equal to $250,000, in order to improve the identification of effects on income distribution and to

[1] Total population of California is 39.5 million according to the 2020 Decennial Census.

[2] CalEnviroScreen is used to identify if a Census Tract is a Disadvantaged Community (DAC) as per SB-535, a classification by which the state's revenue from the Cap-and-Trade program is directed to improve environmental quality and economic opportunity.

improve targeting, respectively. Third, we exclude addresses from Census Tracts for which we do not have the PM2.5 concentration measure, which we need for stratified sampling. Fourth, we exclude addresses from counties for which we do not have the U.S. EPA AQI report, which we use as part of an information intervention. Table 3 shows the shares of addresses meeting each of the exclusion restrictions, plus the overall restriction rate (of 16.4%).

We stratify the restricted mailing list based on the estimated income, household size, and county-level PM2.5 concentration. We use the binned measure for estimated income. We group the household size into 1, 2, 3, and 4 or larger. We aggregate the PM2.5 measures into quartiles at the county level. The strata are interactions of the income, household, and PM2.5 bins. We sample 90,179 addresses from the stratified list, and twice as large a sampling probability for strata with household income less than $75,000. We employ differential weights so that the program targets lower-income households, as per the policy objective of our subsidized air purifier program.

## 2.2 Randomization

We assign each of the 90,179 sampled addresses to eight groups via stratified randomization. We use the same stratifying variables as in sampling. To identify the optimal sample split across treatment arms, we specify 6 broad hypotheses that we test based on which of the 9 treatment groups, as follows:

- price variations in the positive price range (T0, T1, T2, and T3, as specified in Section 2.4)
- non-zero prices v.s. zero price (T3 and T4)
- additional time costs (T4 and T5)
- proof of residency (T4 and T6)
- additional information pertaining to proof of residency (T6 and T7)
- additional information about air pollution and its health impact (T4 and T8)

We then count the "uses" per treatment group, as shown in Table 1. The resulting sample sizes by treatment group are shown in Table 2. We then follow the square-root allocation rule to convert the uses to the sample allocation ratio (Neuhäuser and Ruxton 2025).

## 2.3 Intervention: The offer letter

The intervention for this study is the delivery of an offer letter for subsidized air purifiers. We will send a bi-fold letter to each of the 90,179 selected addresses. The letter indicates that the recipient can apply for a chance to purchase (or receive for free, depending on the treatment arm) an air purifier as part of a UC Davis study. The letter also describes the application process and documentary requirements. Interested recipients can use the QR code in the letter with individual access codes to file their applications. In some of the treatment arms, the letter also contains additional information about air pollution and the health consequences of exposure to high PM2.5 concentration levels, and further details on the application process. The letter designs are shown in Appendix Figures B.1 to B.9. We also provide translations of the letters in 7 popular languages in California, including Spanish, via a separate QR code.

## 2.4 Treatment groups

In the seven treatment and control groups, we will vary a) subsidy amounts, b) time costs in the application process, c) a documentary requirement, d) information about the application process and additional assistance, and e) information about air pollution and its health effects in the offer letter. The following list and Table 4 summarize the features of the treatment arms.

- T0 (Appendix Figure B.1): "Control" arm. The letter will encourage recipients to apply for an air purifier through our website. They will not be offered a subsidy, except for free shipping.
- T1 (Appendix Figure B.2): 50% subsidy treatment. The letter will encourage recipients to apply through our website for a 50% discount on an air purifier, plus free shipping.
- T2 (Appendix Figure B.3): 75% subsidy treatment. The letter will encourage recipients to apply through our website for a 75% discount on an air purifier, plus free shipping.
- T3 (Appendix Figure B.4): 95% subsidy treatment. The letter will encourage recipients to apply through our website for a 95% discount on an air purifier, plus free shipping.
- T4 (Appendix Figure B.5): 100% subsidy treatment. The letter will encourage recipients to apply through our website for a free (100% discount) air purifier, plus free shipping.

- T5 (Appendix Figure B.6): 100% subsidy treatment with time costs. The letter will encourage recipients to apply through our website for a free air purifier. Applicants will be asked to fill out a longer form on the application portal that we expect to take approximately 15 minutes, as opposed to 5 minutes in other treatment arms.

- T6 (Appendix Figure B.7): 100% subsidy treatment with proof of residence. The letter will encourage recipients to apply through our website for a free air purifier. Applicants will be asked to upload proof of residence, such as a bill delivered to them with their name and address on it. The treatment is otherwise identical to T3.

- T7 (Appendix Figure B.8): 100% subsidy treatment with proof of residence and information about the application process. The information is identical to T5, except for the following. First, the letter includes additional details about the types of forms that are required as proof of residence. Second, the letter also contains a link to our website that gives additional information about the application process.

- T8 (Appendix Figure B.9): 100% subsidy treatment with information about air quality. The letter will encourage recipients to apply through our website for a free air purifier. They also receive additional information about the health impact of air pollution, summary statistics on poor air quality days in California overall and for their county based on the U.S. EPA AQI Report, and a link on our website for additional information about the health impact of air pollution and mitigation strategies.

## 2.5 Application process and disbursement

Interested recipients can apply by scanning a QR code or typing the URL listed below the "Apply today!" schematics on the top right part of the letter. The letter also provides recipients with a personal code. Once on the website, they will be asked to provide their personal code as shown in Figure 2. Parts of the personal code are keys that identify which treatment arm they are in. Based on these keys, the application form takes applicants to the set of questions assigned to their treatment arm.[3] For instance, only those assigned to T5 and T6 are taken to the step requiring proof of residence, as shown in Figure 3. Once applicants provide all the required information, they can submit their application by clicking "submit" at the end of the sequence, as shown in Figure 4. Clicking the submit button and providing all required information constitutes a successful application.

[3]The application form is also translated into seven other popular languages of California

The application form does not ask for payment information from the applicants, and they are informed as such. The letter recipients are also notified, and applicants consent to the understanding that not all applicants will necessarily receive the air purifier. This is because we will likely get more applications than air purifiers that the research budget can accommodate. After the deadline, we will randomly draw winners from the applications and process shipping from the distributor, a major manufacturing company of home appliances. They handle payment information, if required, and process it securely through their payment systems.

# 3 Data sources

The project will rely on the following data sources.

First, we will use the mailer data that contains socioeconomic and demographic estimates for a large fraction of California's residential addresses. The list contains the address, income estimate bins, and demographic estimates for each address. This database allows us to compare the distributions of the applicants' income and demographics against the population.

Second, we will identify whether a letter recipient starts and completes their application at the individual level based on the Prolific database, which collects responses to our application form. The database logs an entry when a respondent types in their personal code on the first page of the application form, allowing us to identify whether an individual started their application. We also record whether an individual completes each page of the application form, including whether they submit the form after providing all required information. The application form asks questions about the applicants' address, gender, age, race, and ethnicity. The form also asks applicants to state their 2025 income, whether they have household members susceptible to air pollution, and whether they already own an air purifier. Furthermore, we use Google Analytics to collect an aggregate measure of how many users access the application page (prior to filing their forms) by the treatment arm and a dummy for estimated household income above $75,000.

Third, we will collect data from those selected for subsidized or free air purifiers out of the applicant pool. We will identify whether the selected applicant redeems the air purifier through transaction reports from the supplier. We will also conduct a short telephone survey of those who received the air purifiers. We will ask questions about usage and respiratory symptoms.

# 4 Hypotheses

We design this experiment to test whether pecuniary and non-pecuniary costs affect the targeting of an environmental public benefit program to lower SES recipients. Our design also allows us to identify mechanisms behind possible deviations from a neoclassical assumption that higher ordeal costs should improve targeting to lower SES recipients.

To discipline our hypotheses, we introduce a conceptual framework that describes a consumer's utility from applying for a subsidized air purifier program in Appendix Section A. In the model, individual types with differing preferences for environmental amenities and earnings choose to live in a location with a level of exposure to air pollution. They then decide whether to apply for a subsidized air purifier based on a) the perceived benefit of an air purifier, b) the pecuniary cost, and c) the non-pecuniary costs of application. The non-pecuniary costs may include factors related to the cumbersomeness and the opportunity costs of filing an application (i.e., "ordeal" costs). Recipients may also experience frictions and biases that are specific to their types, such as information friction, behavioral biases in interpreting the extent of air pollution at their location, perceived benefit of an air purifier, ordeal costs of application, and trust in the program. Under a neoclassical assumption in which there are no frictions or biases, consumers would make optimal choices on program application, and higher time costs would shift the composition of applicants toward a low-income group due to their lower opportunity costs.

We test for the following general groups of hypotheses, and discuss how the experimental variation in letter design allows us to test them.

## Pecuniary costs affect the application rate

We introduce T0, T1, T2, and T3 to test how variations in pecuniary cost affect application rate against T4. With T0, we measure the application rate in response to an offer letter without a subsidy except for free shipping. Although the setting may be somewhat unnatural, i.e., asking recipients to apply to pay the full price, T0 allows us to measure the propensity to apply in response to receiving the letter alone. As such, T0 identifies the baseline application rate given all other common features of the letter versions.

Variations in the subsidy rates between T0 through T3 allow us to estimate the application response to pecuniary cost. The subsidy rate is made salient consistently across treatment arms; the subsidy rates are highlighted on the front page, in the title, and in the main body of the letter (e.g., "Congratulations! You are selected to apply for an air purifier

at $YY, a ZZ% discount!" for T1 and T2).

Comparing T3 to T4 also allows us to identify the discontinuous effect of being offered a purifier for free, as opposed to at a cost, on the application rate. In T3, the out-of-pocket cost is small enough that we do not expect the application rate to differ from T4, unless there is a discontinuous effect of positive price against zero. In T4, the price of $0 will be highlighted on the front page, in the title, and in the main body of the letter (e.g., "Congratulations! You are selected to apply for a chance to purchase an air purifier for free (original price of $ZZ)." The letters in T4 are otherwise identical to those of T1 through T3. [4]. The letter design in T4 is otherwise identical to that of T1 through T3.

## Non-pecuniary costs affect the application rate

We introduce T5 and T6 to test how variations in the type and amount of non-pecuniary costs affect the application rate. In T5, we introduce additional time costs by asking more questions in the application form than in T4 and other arms. With the additional questions, the application will take approximately 15 minutes to complete, compared to about 5 minutes in T4. These additional questions in T5 are meant to increase only the time costs and not other costs and constraints, such as trust in the program or access to additional help and resources, of the application process. As such, the additional questions are on detailed time use indoors and outdoors on representative days under various air quality conditions, exposures to, and avoidance from, poor air quality events and activities, knowledge about other state- and local governments' environmental programs that are not about free or subsidized air purifiers. The letters in T5 are otherwise identical to those of T4.

In T6, we introduce another form of non-pecuniary costs by asking recipients to provide proof of residence. In T5, the costs are the additional time required to fill out the application questionnaire. T6, on the other hand, imposes non-pecuniary costs that are related to the ability to produce specific types of proof of residence, such as bills and official documents with the applicant's name and address. The applicants are asked to upload a digital copy to the application form and submit it. In addition to the time and hassle costs of finding the documents and uploading them, we hypothesize that this additional step introduces an additional cost in terms of trust that applicants may have for the program. We will test whether these additional costs affect the application rate relative to T4, and how the impact differs from that of T5against T4. The letter design is identical to that of T4 otherwise.

[4]We will also set the price to be free for the remainder of our treatment arms to improve the odds of detecting potentially smaller and noisier effects

## Additional information affects the application rate

We introduce T7and T8 to test whether respondents face information friction regarding the health impact of air pollution, and how providing more information about air quality and the application process affects the application rate. We address the effect of information about the application process in T7, and about air quality more generally in T8.

T7 is identical to T6, except we provide additional services and information related to the proof of residence requirement. First, the letter provides additional information about the required proof of residence by specifying what document types and forms are acceptable. Second, we provide a web link on our program website that contains step-by-step instructions for the application form and FAQs.

In T8, we provide additional information about the adverse health effects of wildfire smoke and poor air quality. The letter highlights the general health impact of air pollution and states that many in California are exposed to unhealthy air. The letter also provides localized information about exposure by providing the number of days the address's county experienced air quality levels that are moderate, unhealthy for sensitive groups, and unhealthy or worse. We use the U.S. EPA's Air Quality Index Report from 2023 as inputs. Furthermore, the letter includes a link to a page on our website that provides a CARB video on the health effects of air pollution, as well as additional resources on how to interpret air quality data and avoid exposure. The letter design is identical to that of T4 otherwise.

## Pecuniary and non-pecuniary costs and information affect the socioeconomic composition of the applicant pool

Beyond the average treatment effect on the application rate, we are interested in understanding how pecuniary and non-pecuniary costs screen out applicants based on their willingness to pay or their opportunity costs, both of which we presume would be correlated with income. Under neoclassical assumptions, lower pecuniary costs should differentially increase applications from low-income individuals. Under such assumptions, higher non-pecuniary costs should also deter higher-income individuals from applying more than lower-income ones, given their relative differences in opportunity costs. As such, higher non-pecuniary costs should *improve* the program's targeting to lower-income individuals.

To test the hypothesis above, we will identify how T0 through T6 differentially affect the application rate by the applicants' SES. Specifically, we will identify the heterogeneous treatment effects (HTEs) of varying pecuniary (T0 through T4) as well as non-pecuniary

(T4 through T6) costs by the estimated household income level. We define the measures of SES in Section 5.3. We will identify whether lower pecuniary costs (e.g., T3 against T2) increase applications differentially by lower SES applicants, and higher non-pecuniary costs (T5 and T6 against T4) reduce applications differentially by higher SES ones.

Furthermore, we hypothesize that possible deviations from neoclassical expectations, as stated above, may be due to limited information and other frictions. Furthermore, exposures to information and other frictions may differ by the SES. To test such hypotheses, we will identify heterogeneous treatment effects of additional information about the application process (T7) and exposures to air pollution (T8) by SES, and evaluate to what extent information interventions may "correct for" deviations from neoclassical expectations, if any.

# 5 Key variables

## 5.1 Primary outcomes

We define the primary application outcomes as follows:

- 1 if a letter recipient provides all required information and clicks "submit" on the application form described in Section 2.5 and zero otherwise.
- Natural log of self-reported annual household income of the applicant from 2025. The measure is collected as part of the application questionnaire.

The application measure captures the letter recipient's choice after being exposed to the terms of the offer and information conveyed in the letter, and incurring the ordeal costs associated with the application process. This outcome measure will be collected prior to the lottery draw for the winners among the applicants. As such, the applicants will not have paid for or received the air purifier at the point we capture the primary outcome. We define the outcome variable as such to capture the full application outcome, rather than restricting it to the subset, in case there are more applicants than the number of available subsidized air purifiers.

The income measure allows us to identify whether treatment conditions affect application decisions differentially by SES. To do so, we will test for differences in applicants' average income by treatment conditions. We expect the potential noise and bias in this measure to be similar to any other survey outcomes, as we make clear in the survey form that their stated income does not affect their probability of receiving an air purifier. We will trim extreme

values (below $10,000 and above $1,000,000) to account for typos that may be typos, and test alternative variable cleaning processes for robustness.

We will also use alternative outcome variable definitions for robustness checks as follows.

- 1 if the recipient starts the application form by typing in their personal code and clicking "next," and zero otherwise. This measure captures the first instance in which we capture the recipient's intent to apply, while they have not yet fully incurred the opportunity costs, such as filling the rest of the form or providing proof of residence.
- Alternative versions of the self-reported income, such as alternative trimming/winsorizing thresholds, and without log transformation.

## 5.2 Secondary outcomes

We specify the secondary outcomes to test whether treatment conditions affect application probability differentially by recipients' air pollution exposure and demographic characteristics. We will also define household income measures based on the alternative data source: binned income estimates in the mailer data. The secondary outcomes are as follows:

- average PM2.5 concentration between 2021-2023 for the address' Census Tract, based on CARB's estimates
- 1 if White non-Hispanic, zero otherwise, based on the race and ethnicity estimates in the mailer data
- 1 if language at home is English, zero otherwise, based on the language estimates in the mailer data
- 1 if the household's estimated income is at or below $75,000, and 0 otherwise and non-missing, based on the binned income estimates from the mailer data
- Several thresholds (below 100%, 138%[5], 200%[6], 300%, and 400%) against the federal poverty line (FPL), based on the binned income and household size estimates from the mailer data

[5]This corresponds to the Medi-Cal eligibility threshold. https://www.dhcs.ca.gov/Medi-Cal/Pages/eligibility-chart.aspx

[6]This corresponds to the CalFresh eligibility threshold. https://dpss.lacounty.gov/en/food/calfresh/gross-income.html

### 5.3 Dimension of heterogeneity

Another way to test whether treatment conditions affect applicantion probability differentially by recipients' air pollution exposure and demographic characteristics, as well as alternative definitions of income, is to identify heterogeneous treatment effects by interacting the treatment variables with dimensions of heterogeneity. We primarily focus on the following dimensions across which to focus on heterogeneous responses, as well as other demographic and income measures as specified in Section 5.2.

- 1 if the Census Tract is above median in their average PM2.5 concentration between 2021-2023, based on CARB's estimates, zero otherwise.
- 1 if the household's estimated income is higher than $75,000, and 0 otherwise, and non-missing. This binary measure is based on the binned estimates from the mailer data.
- Interaction of the two variables above to divide respondents into four groups.

We select income and air pollution as the two key dimensions of heterogeneity to identify the following: a) which of the treatment conditions draw in more economically vulnerable or more pollution-exposed applicants, and b) is there a trade-off between the income and pollution margins? Identifying such effects will provide insights into the extent to which differential exposure to air pollution is preference-based, and the relative efficacies of subsidy programs that target beneficiaries based on their locations or income levels.

## 6 Empirical specifications

### 6.1 Intent-to-treat (ITT) effects

We identify the intent-to-treat (ITT) effects of the specific treatment features as described in Section 2.4 on the application rate and log income.

For the binary application outcome, we will use the Linear Probability Model (LPM) with robustness checks using logistic regression. The most common potential challenge to using the LPM is unreasonable probability estimates stemming from large variances in the covariates (Horrace and Oaxaca 2006). This concern is likely limited in our context, as we only include randomization strata dummies as covariates. The coefficients on those dummy variables would estimate their average application rate for the strata, and would be unlikely

to generate extreme values outside of 0 to 1. The empirical specification for an individual $i$ assigned to T$j$ is as follows:

$$Y_{i,j,k} = \sum_{n \in \{0,1,2,3,5,6,7,8\}} \beta_n \mathbf{1}[j = n]_i + \gamma_k + \varepsilon_{i,j,k} \tag{1}$$

$Y_{i,j}$ is the outcome variable. We create an indicator for each treatment arm and estimate $\beta_n$ against T4, the treatment arm with 100% subsidy and no additional non-pecuniary costs or information. $\mathbf{1}[j = n]_i$ is a dummy variable for whether individual $i$ is assigned to Treatement Group T$n$, i.e., whether $n = j$. $\gamma_k$ is a fixed effect of $i$'s stratum $k$, identified through a combination of their income estimate, household size, and the Census Tract's average PM2.5 concentration. Given that we are agnostic as to which treatment arms are likely to increase the application rate, our hypothesis tests are two-tailed.

Based on Equation 1, we test the following null hypotheses:

- $\hat{\beta}_0 = \hat{\beta}_1 = \hat{\beta}_2 = \hat{\beta}_3$: Subsidy amounts do not affect application outcomes.
- $\hat{\beta}_3 = 0$: Positive price does not affect application outcomes.
- $\hat{\beta}_5 = 0$: Additional time cost does not affect the application outcomes.
- $\hat{\beta}_6 = 0$: Requiring proof of residence does not affect the application outcomes.
- $\hat{\beta}_7 = \hat{\beta}_6$: Additional assistance through a helpline and information about the time cost of the application process do not affect the application outcomes.
- $\hat{\beta}_8 = 0$: Additional information about air quality and health impact does not affect the application outcomes.

We will report Benjamini et al. (2006) sharpened q-values separately for each of the above null hypotheses on the two primary outcomes to account for the false discovery rate from multiple hypothesis testing.

## 6.2 Differential effects by recipients' characteristics

We also test hypotheses on whether pecuniary and non-pecuniary costs, as well as information, differentially affect the application rate by recipients' characteristics, and therefore

change the composition of applicants. To do so, we estimate the following equation for a given recipient characteristic $X_i$:

$$Y_{i,j,k} = \sum_{n \in \{0,1,2,3,5,6,7,8\}} (\beta_n + \delta_n X_i) \, \mathbf{1}[j = n]_i + \mu X_i + \gamma_k + \varepsilon_{i,j,k} \tag{2}$$

Because of potentially limited power in identifying heterogeneous treatment effects, as well as several possible dimensions of heterogeneity, we will not adjust the test statistics for multiple hypothesis testing. Instead, we state the primary dimensions of interest as described in Section 5.3. As a robustness check on whether the treatments affect the distributions of the applicant's demographic attributes, we will also present a visual comparison of the histograms of the distributions and use a Kolmogorov-Smirnov test—a non-parametric test that compares the cumulative distribution functions between groups.

# 7 Power

We calculate the minimum detectable treatment effect sizes for the two primary outcome variables based on the prespecified empirical strategy. We calculate minimum detectable effects (MDEs) on a range of baseline response rates between 0.25% and 5%. When necessary, we pick 0.34% and 2% for low and high response-rate scenarios, based on baseline results. For the log income outcome variable, we assume the baseline mean of 11.07 with the standard deviation of 1.01, based on summary statistics from the pilot data. We calculate these MDEs for a given pair of treatment arms, which could be as small as approximately 6,600 recipients each, or as large as approximately 11,000 and 18,000 recipients. We assume a 0% attrition rate because the outcome of interest is whether a recipient applies and is, by definition, fully captured in the data.

Figures 5 and 6 show MDEs for a range of baseline response rates, with and without Bonferroni corrections, for the pairwise comparisons of 6,600 v.s. 6,600 recipients, and 11,000 v.s. 18,000 recipients, respectively. For the pairwise comparison of 6,600 v.s. 6,600 recipients, we expect the baseline response rate to be around the lower end of the chosen range. At the baseline response rate of 0.25%, the MDE is .27% with Bonferroni correction. We expect the baseline response rate for the pairwise comparison of 11,000 v.s. 18,000 recipients to be relatively large, at around 2%. In that scenario, the MDE is 0.52% with Bonferroni correction. As such, we are well-powered to detect economically meaningful differences in application rates.

For the applicants' log income outcome variable, the MDE is 164% of the mean for the pairwise comparison of treatment groups with the smallest numbers of applicants, and 38% for those with the largest numbers. We take these MDE estimates as speculative, as they rest on additional assumptions about application rates. We plan to test the robustness of the effects of treatment conditions on applicant characteristics through a series of heterogeneous treatment effect estimates, as specified in Section 6.2.

# 8 Timeline

- January-December 2024: Design experimental procedure and draft intervention letters.
- January-November 2025: Intervention design and logistics: websites, letters, and delivery mechanisms.
- December 2025: Small-scale pilot.
- February – March 2026: Project launch.
- March-2026: Collection of the primary outcome, i.e., application.
- March 2026: Shipment of devices.
- April – June 2026: Follow-up survey, analysis, write-up.

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# 9 Figures

Figure 1: Distribution of estimated income bins

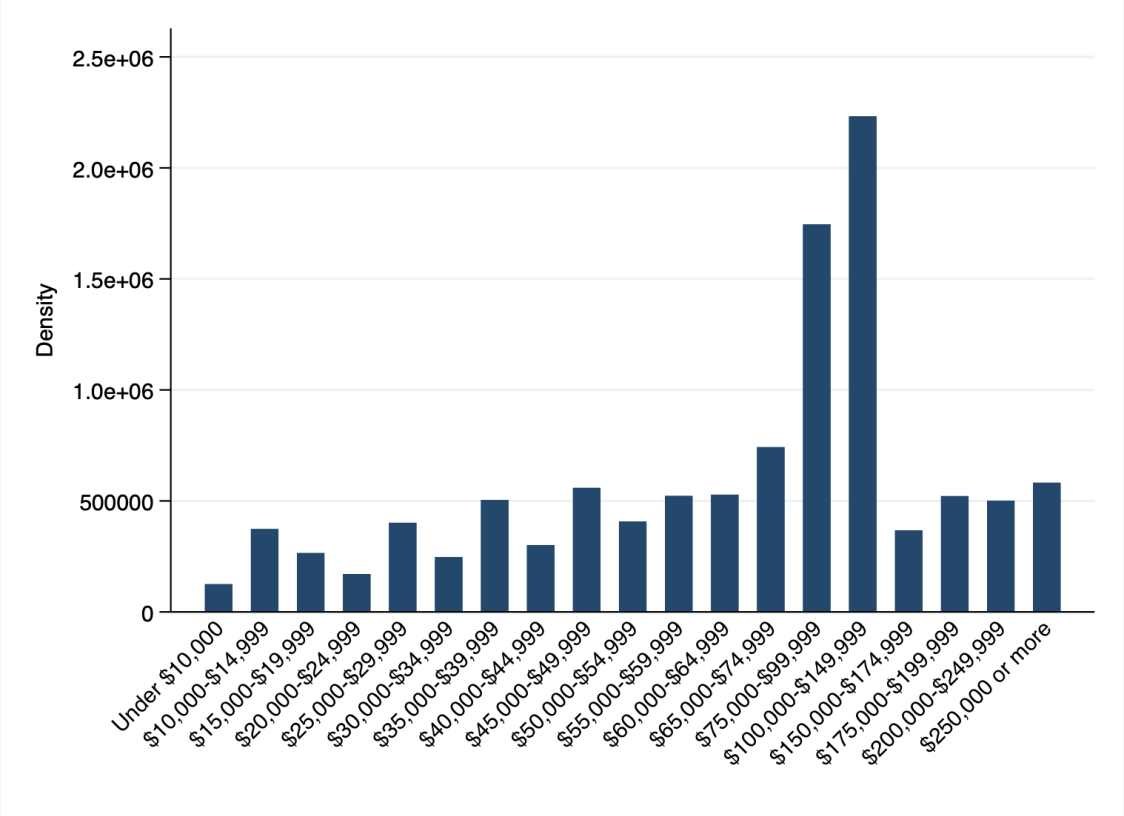


Figure 2: Application form: Validating personal code

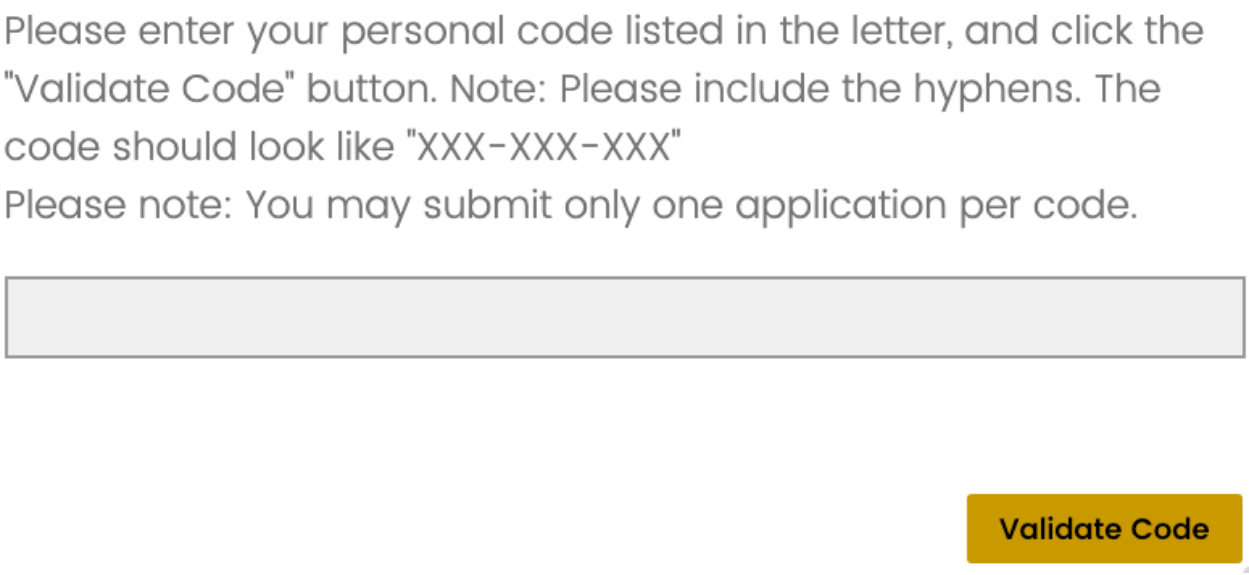


Figure 3: Application form: Uploading proof of residence

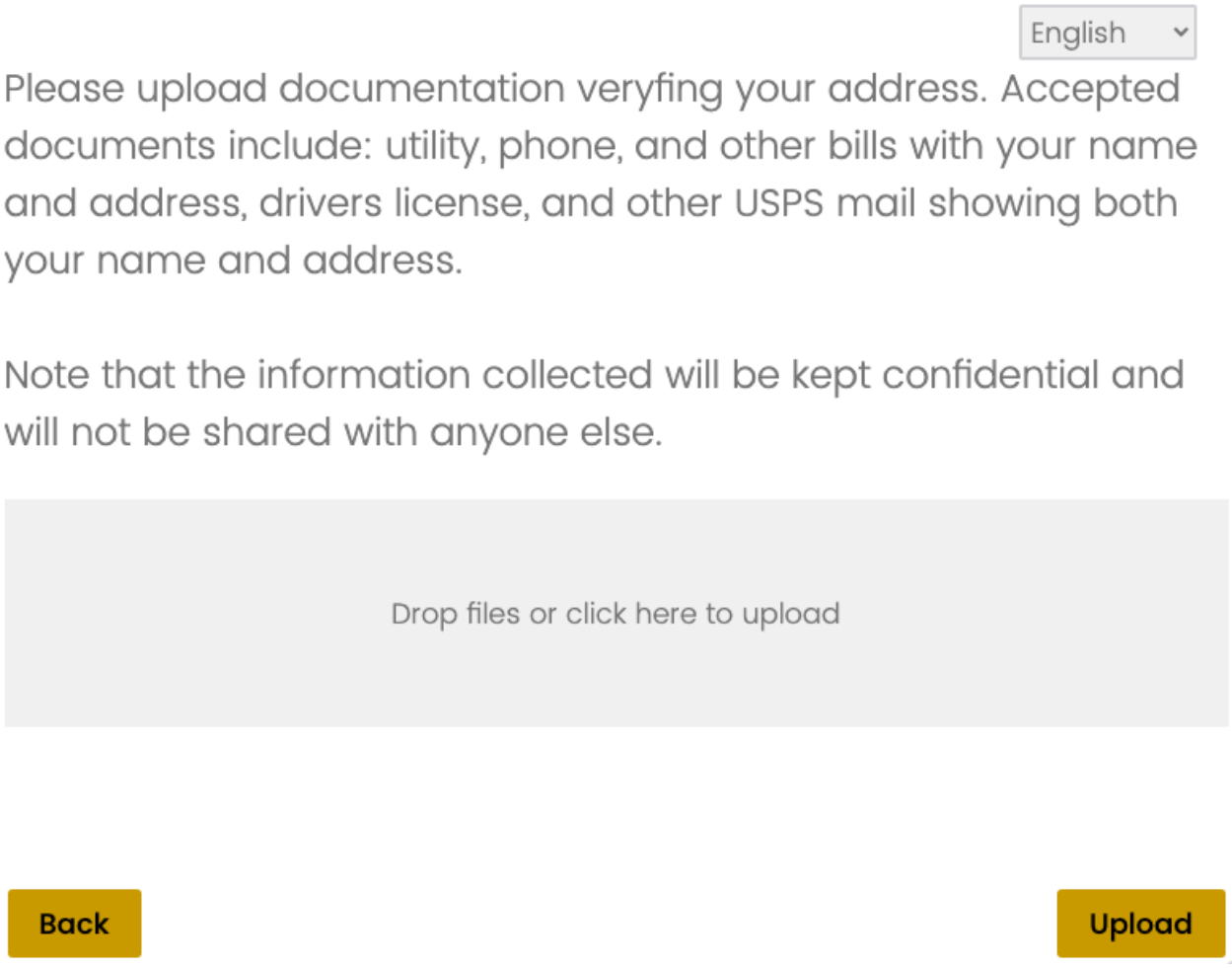


Figure 4: Application form: Submit

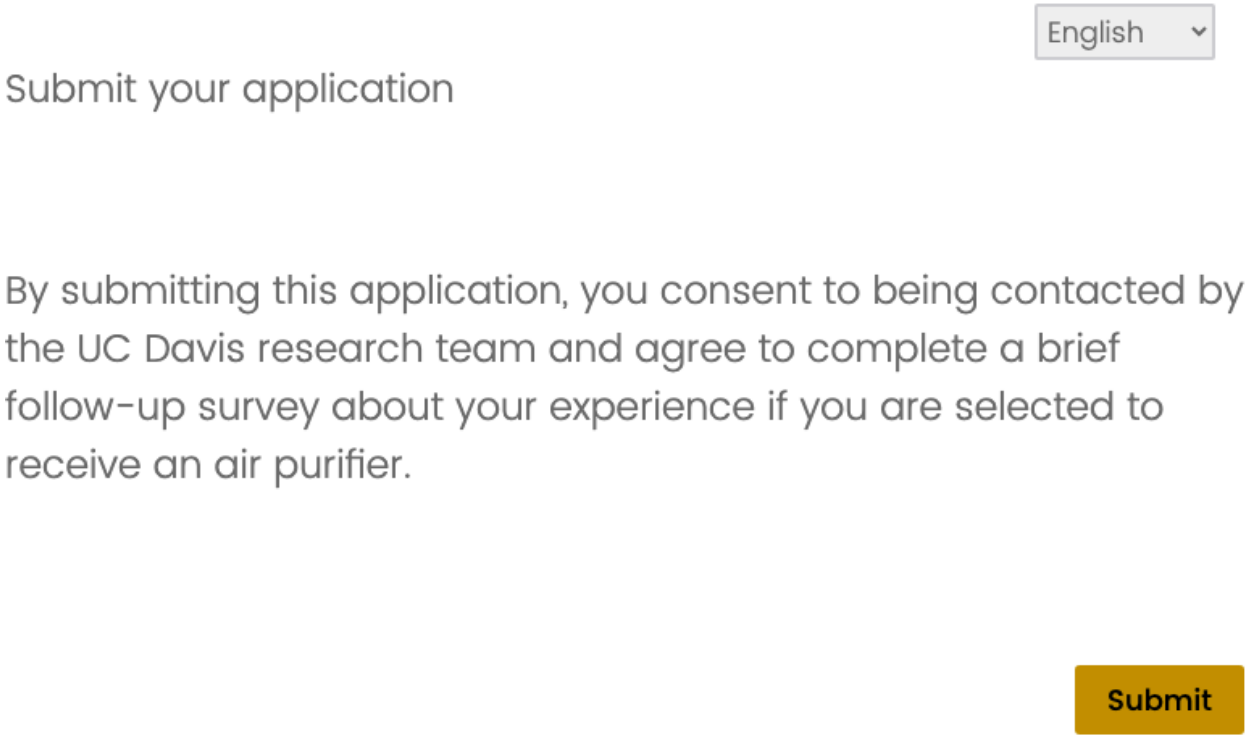


Figure 5: MDEs with a pairwise comparisons of treatment groups with 6,600 recipients each

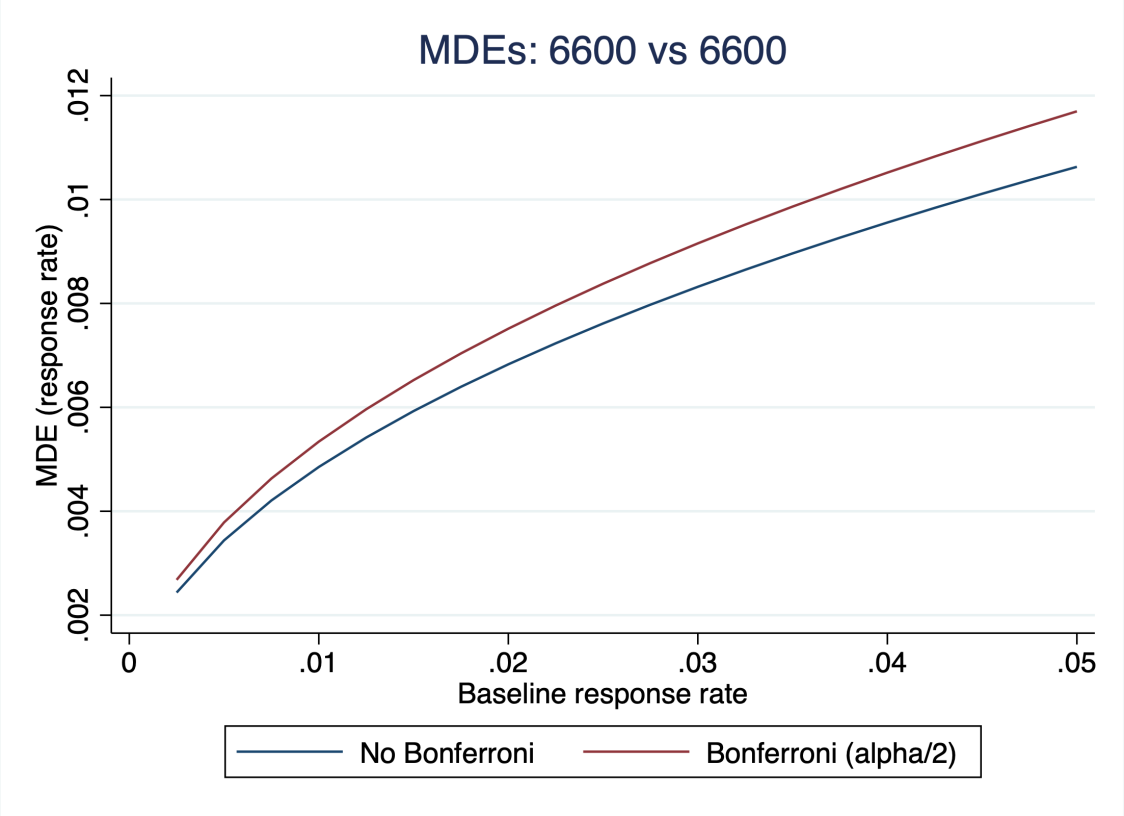


Figure 6: MDEs with a pairwise comparisons of treatment groups with 11,000 and 18,000 recipients

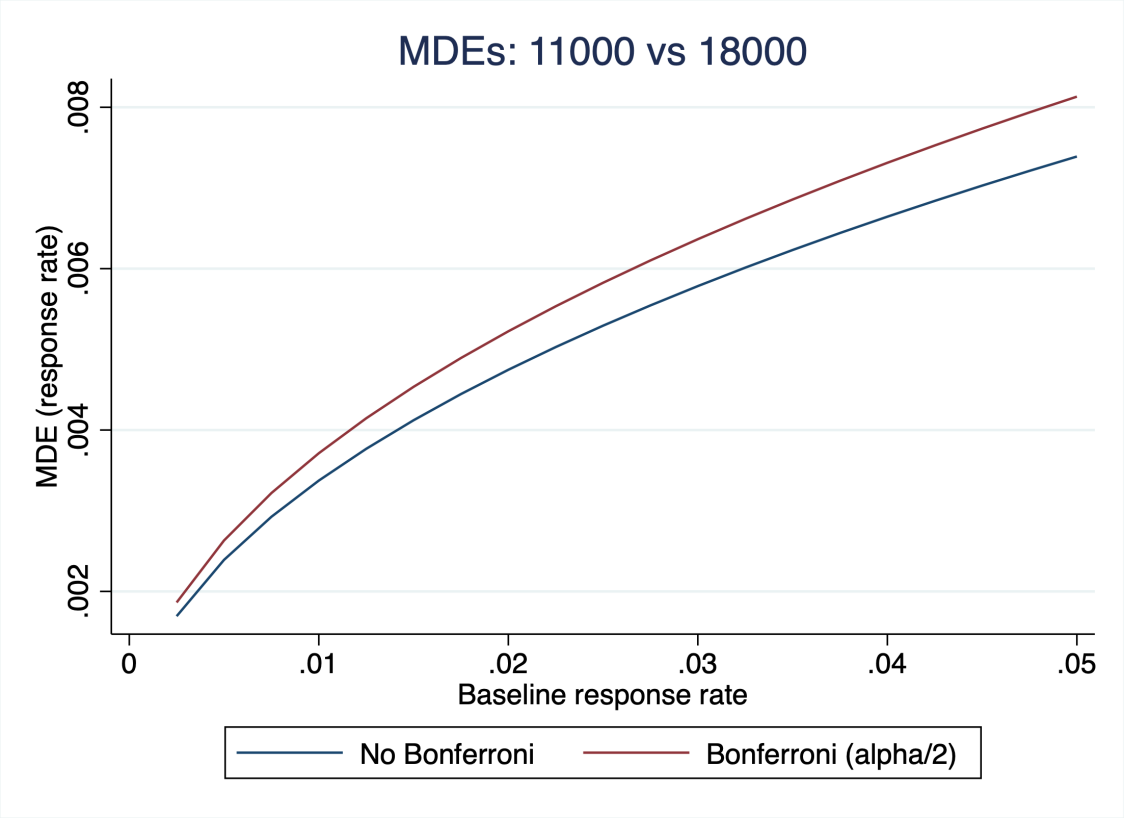


Table 1: Sample split across tratment groups based on "uses"

| Treatment Arm | Name | Uses | Percent |
|---|---|---|---|
| T0 | 0% subsidy | 0.50 | 7.2% |
| T1 | 50% subsidy | 0.50 | 7.2% |
| T2 | 75% subsidy | 0.50 | 7.2% |
| T3 | 95% subsidy | 1.50 | 12.5% |
| T4 | 100% subsidy | 4.00 | 20.5% |
| T5 | Time cost | 1.00 | 10.2% |
| T6 | Proof of residency | 2.00 | 14.5% |
| T7 | Proof of residency with salience/additional info | 1.00 | 10.2% |
| T8 | Health info | 1.00 | 10.2% |

*Notes*: This table shows treatment arms, the associated number of "uses," and the sample allocation share. A "use" is defined as the number of times a treatment arm is used as tests of differences between two groups. The use count is discounted when there are more than two groups per hypothesis. E.g., Because there are four treatment arms to test the effect of positive price variation (T0 through T3), they each get 0.5 use as opposed to 1.

Table 2: Sample sizes by treatment groups

| Treatment Group | Frequency | Percent (%) |
|---|---|---|
| T0 | 6,575 | 7.29 |
| T1 | 6,590 | 7.31 |
| T2 | 6,579 | 7.3 |
| T3 | 11,293 | 12.52 |
| T4 | 18,483 | 20.5 |
| T5 | 9,194 | 10.2 |
| T6 | 13,067 | 14.49 |
| T7 | 9,203 | 10.21 |
| T8 | 9,195 | 10.2 |
| Total | 90,179 | 100.00 |

*Notes*: This table shows the number of sampled addresses by treatment group.

Table 3: Share of addresses excluded from sampling

| | (1) | | |
|---|---|---|---|
| | mean | sd | count |
| Missing household size | .0271939 | .1626482 | 1.18e+07 |
| Household size 0 | 3.47e-06 | .0018634 | 1.18e+07 |
| Missing estimated income | .1109563 | .3140781 | 1.18e+07 |
| Estimated income USD 250k or above | .0457839 | .209016 | 1.18e+07 |
| Missing CES V5.0 PM2.5 measure | .0289467 | .1676566 | 1.18e+07 |
| Missing US EPA pollution day measure | .0333434 | .1795318 | 1.18e+07 |
| Excluded from sample | .1635769 | .3698912 | 1.18e+07 |

*Notes*: This table shows the share of addresses qualifying for one of the sample exclusion conditions, after NCOA and DMA suppressions. "Missing household size": The mailer data does not provide an estimate of household size for the address. "Household size 0": The estimated household size for the address is 0. "Missing estimated income"; The mailer data does not provide an estimate of household annual income. "Estimated income USD 250k or above": the estimated household annual income is $250,000 or greater. "Missing CES V5.9 PM2.5 measure": The Census Tract level estimate of average PM2.5 concentration from 2021 to 2023 is missing for the address's tract. "Missing US EPA polution day measure": The U.S. EPA's AQI Report, which shows the number of days in each AQI category, is missing or reported for the minority of the year for the address's county in 2023. "Excluded from sample": The address is excluded from the sampling frame for one or more of the reasons above.

Table 4: Treatment features

| **Treatment arm** | **0% subsidy** | **50% subsidy** | **95% subsidy** | **100% subsidy** | **Time cost** | **Proof of residence** | **App. process info + helpline** | **Enhanced AQ + health info** |
|---|---|---|---|---|---|---|---|---|
| T0 | ✓ | | | | | | | |
| T1 | | ✓ | | | | | | |
| T2 | | | ✓ | | | | | |
| T3 | | | | ✓ | | | | |
| T4 | | | | ✓ | ✓ | | | |
| T5 | | | | ✓ | | ✓ | | |
| T6 | | | | ✓ | | ✓ | ✓ | |
| T7 | | | | ✓ | | | | ✓ |

*Notes*: This table summarizes the difference in the letter features between treatment arms. Each row is a treatment arm, which includes corresponding features in checkmarks. "X% subsidy": The subsidy rate on offer, on top of free shipping. "Time cost": A longer application form that we expect will take 15 minutes, as opposed to 5. "Proof of residence": Applicants are asked to provide proof of residence during the application process. "App. process info + helpfine": The letter provides additional information on about the application process, a link for further information, and a phone number they can call. "Enhanced AQ + health info": The letter provides additional information about the health costs of ambient air pollution and the U.S. EPA's AQI report for their county.

# A Conceptual Framework

We model the discrete choice of consumers with heterogeneous preference for environmental goods and of differing income types. We specify individual utility as a function of exposure to air pollution, gains from consuming a unit of air purifier, the pecuniary cost, and non-pecuniary cost of application. We incorporate factors that affect consumer choice with and without perfect information and behavioral biases, the magnitudes of which depend on their types. We derive comparative statics on consumers' application choice to pecuniary and non-pecuniary costs and information. We also characterize the social planner's problem and draw policy implications in terms of both efficiency and equity of the distribution of air purifiers.

## A.1 Set-up

We denote an individual consumer with $i$. There are two dimensions to consumer types. First, we denote consumers' preferences for better environmental amenities as $a \in \{Y, N\}$; those with $Y$ have preference for better environmental amenities while others with $N$ do not. Second, there are high- and low-income types, i.e., $y \in \{H, L\}$. Based on these two dimensions, consumers choose to reside in location $l$, which determines their exposure to air pollution as follows:

$$E(a, y) = F(a, y) + \gamma_y + \mu_i \tag{3}$$

A consumer's exposure is a function $F(a, y)$, a rational choice based of their income and preferences for environmental amenities. It is also a function of $\gamma_y$, a combination of non-neoclassical factors that differ by income types, and $\mu_i$ an i.i.d. error term. $\gamma_y = 0$ under the neoclassical assumptions, i.e., locational choice and exposure to air pollution are made rationally under full information based on income, preferences for environmental quality, and an individual stochastic shock.

## A.2 Utility function

Consumer's utility from applying for an air purifier is determined by a) the benefit of consuming an air purifier as a function of exposure, preference for air quality, and income, b) the pecuniary cost of purchasing an air purifier at a subsidized rate through the program, and c) the non-pecuniary cost of applying for an air purifier through the program. The following

is the utility function:

$$U(i,a,y) = B(E(a,y),a,y,\eta_y) - C^P(\Theta) - C^N(\Lambda\kappa_y, \Phi\tau_y) + \epsilon_i \tag{4}$$

The benefit function is defined as $B(E(a,y),a,y,\eta_y)$, i.e., a function of environmental exposure $E(a,y)$, preference term $a$, earnings $y$, and type-specific biases and information friction $\eta_y$. The pecuniary cost $C^P()$ is a function of $\Theta$, the price set by the program. $C^N()$ a function of non-pecuniary ordeal costs experienced by an applicant of type $y$. The parameter $\Lambda$ expresses the amount of time and effort to file an application, as determined by the program administrator. $\kappa_y$ is the opportunity cost of a type-$t$ individual per unit of time or effort. $C^N()$ also depends on factors that opportunity costs but may vary by type, such as structural barriers or trust costs that may vary by SES. We denote the amount of such barriers and concerns that programs may impose as $\Phi$, and the unit cost for a given type as $\tau_y$. $\epsilon_i$ is an i.i.d. error term.

Under the neoclassical assumptions, the benefit and costs of application should only depend on exposure under full information, pecuniary costs of the program, and non-pecuniary costs based only on the opportunity cost of time. In other words, the applicant's utility should not depend on $\eta_y$ or $\tau_y$, and there is no information asymmetry about their exposure $E(a,y)$. In other words, the model highlights several ways in which applicants' utility could deviate from that under neoclassical assumptions; they may misestimate exposure or the benefit from an air purifier, or experience non-pecuniary costs beyond the opportunity cost.

## A.3 Welfare function

We normalize the level of the utility function such that a consumer decides to apply if and only if $U(i,a,y) \geq 0$. We assume that there is a unit mass of consumers of given characteristics $a$ and $y$. We denote the share of consumers with characteristics $a$ and $y$ facing price $p$ and the non-pecuniary cost of application $\Lambda$ as $S(a,y,p,\Lambda)$. This section is in development, but we plan to identify whether and where there may be equity-efficiency tradeoffs.

## A.4 "Basic" predictions

The conceptual framework allows us to make predictions on primary empirical hypotheses under assumptions.

1. Higher pecuniary and non-pecuniary costs weakly reduce application rates. In other words, $\frac{dS(a,y,p,\bar{\Lambda})}{dp} \leq 0$ and $\frac{dS(a,y,p,\bar{\Lambda})}{d\bar{\Lambda}} \leq 0$.

2. Under neoclassical assumptions, higher pecuniary costs would reduce the share of low-earning applicants iff $\frac{dS(a,H,p,\bar{\Lambda})}{dp} \geq \frac{dS(a,L,p,\bar{\Lambda})}{dp}$.

3. Under neoclassical assumptions under which higher earners have higher opportunity cost, higher non-pecuniary costs would reduce the share of high-earning applicants iff $\frac{dS(a,H,p,\bar{\Lambda})}{d\bar{\Lambda}} \leq \frac{dS(a,L,p,\bar{\Lambda})}{d\bar{\Lambda}}$

## A.5 Deviations from neoclassical assumptions

1. We deviate from neoclassical assumptions if $\frac{dS(a,H,p,\bar{\Lambda})}{d\bar{\Lambda}} > \frac{dS(a,L,p,\bar{\Lambda})}{d\bar{\Lambda}}$. If so, we want to identify mechanisms.

    - Could it be that the bias in the benefit from air purifiers ($epsilon_i$) is correlated with consumer characteristics $a$ and $y$? Would an information intervention about the benefit of air purifier, and the extent of environmental degradation in location $l$, i.e., $e(l(a,i))$, help reduce deviation of $epsilon_i$ from zero?
    - Could it be that the extent of bias in the perceived ordeal costs ($\kappa_y$) differ by earning types $H$ and $L$?

## A.6 Predictions related to Environmental Justice

We plan to discuss how and whether:

1. pecuniary and non-pecuniary costs affect application by geographies with different exposure levels;

2. the relationship above is driven by residential sorting by type (i.e., "basic" results 2 and 3);

## A.7 Welfare implications

We plan to discuss how pecuniary and non-pecuniary costs shift the share of low- vs. high-income individuals in the application pool, and how there may be distortions created by biases in the perceptions of costs and benefits of the program.

# B Additional figures

Figure B.1: Letter design: T0



Figure B.2: Letter design: T1

# CONGRATULATIONS!

## YOU ARE SELECTED TO APPLY FOR AN AIR PURIFIER AT *$74.97, A 50% DISCOUNT!*

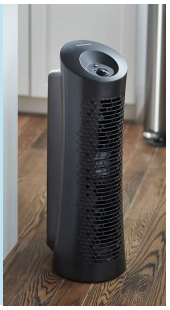
### Be part of Prepare Clean Air, a UC Davis study to improve air quality in homes across California!

Air pollution from industrial production, burning of fossil fuels, and wildfires affects the health of many Californians each year. Portable air purifiers improve indoor air quality and help protect yourself and your family from air pollution.

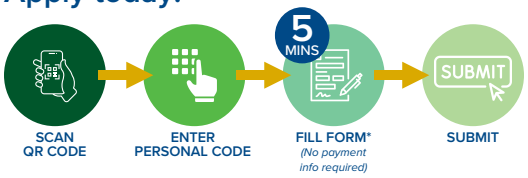
We invite you to apply for an air purifier at a 50% discount. If selected, you will receive a link for a high-quality indoor portable air purifier listed below.

**Honeywell Allergen Plus HEPA Tower Air Purifier - Black, HPA030**
*~~(Retail: $149.95)~~ $74.97, a 50% discount, and shipping fee waived!*

- This silent and energy-efficient (ENERGY STAR label) purifier removes dust, smoke, pollen, pet dander, and mold spores.
- It removes more than 90% of allergens and particles in medium to large rooms (independently tested and verified by AHAM).
- This product is certified by the State of California's Air Resource Board.



## Apply today!




Apply by scanning the QR code or go to https://pcair.ucdavis.edu/application-air
Personal code:
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If you are selected, we will contact you via email and phone. Then, you can pay the discounted amount to Honeywell directly and securely. The device will be shipped directly to your home. You will be asked to complete short surveys on your use and experience with the air purifier after you receive it.

Limited availability. Apply by February 28th. Your confidential data will be kept safe. To read more about this study, visit https://pcair.ucdavis.edu.

*The application may ask questions about your demographics, information related to air quality, and California's environmental programs.

Figure B.3: Letter design: T2

# CONGRATULATIONS!

## YOU ARE SELECTED TO APPLY FOR AN AIR PURIFIER AT *$37.49, A 75% DISCOUNT!*

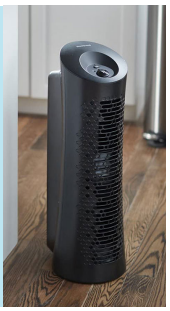
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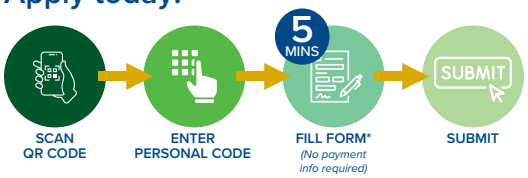
We invite you to apply for an air purifier at a 75% discount. If selected, you will receive a link for a high-quality indoor portable air purifier listed below.

**Honeywell Allergen Plus HEPA Tower Air Purifier - Black, HPA030**
*~~(Retail: $149.95)~~ $37.49, a 75% discount, and shipping fee waived!*

- This silent and energy-efficient (ENERGY STAR label) purifier removes dust, smoke, pollen, pet dander, and mold spores.
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## Apply today!




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https://pcair.ucdavis.edu/application-launch
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If you are selected, we will contact you via email and phone. Then, you can pay the discounted amount to Honeywell directly and securely. The device will be shipped directly to your home. You will be asked to complete short surveys on your use and experience with the air purifier after you receive it.

Limited availability. Apply by February 28th. Your confidential data will be kept safe. To read more about this study, visit https://pcair.ucdavis.edu.

*The application may ask questions about your demographics, information related to air quality, and California's environmental programs.

Figure B.4: Letter design: T3

# CONGRATULATIONS!

## YOU ARE SELECTED TO APPLY FOR AN AIR PURIFIER AT *$7.49, A 95% DISCOUNT!*

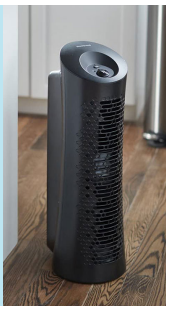
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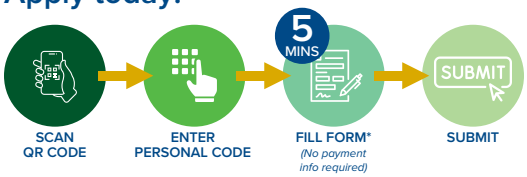
We invite you to apply for an air purifier at a 95% discount. If selected, you will receive a link for a high-quality indoor portable air purifier listed below.

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*The application may ask questions about your demographics, information related to air quality, and California's environmental programs.

Figure B.5: Letter design: T4

# CONGRATULATIONS!

## YOU ARE SELECTED TO APPLY FOR A *FREE* AIR PURIFIER!

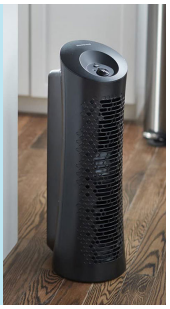
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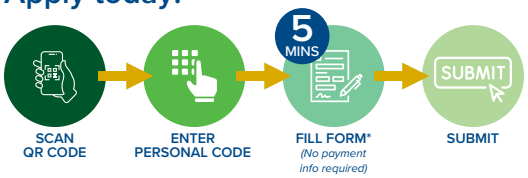
We invite you to apply for a free air purifier. If selected, you will receive a link for a high-quality indoor portable air purifier listed below.

**Honeywell Allergen Plus HEPA Tower Air Purifier - Black, HPA030**
*~~(Retail: $149.95)~~ free and shipping fee waived!*

- This silent and energy-efficient (ENERGY STAR label) purifier removes dust, smoke, pollen, pet dander, and mold spores.
- It removes more than 90% of allergens and particles in medium to large rooms (independently tested and verified by AHAM).
- This product is certified by the State of California's Air Resource Board.



### Apply today!




Apply by scanning the QR code or go to https://pcair.ucdavis.edu/application-clean
Personal code:
000-AAA-AAA

If you are selected, we will contact you via email and phone. Then, you can redeem the air purifier from Honeywell directly and securely. The device will be shipped directly to your home. You will be asked to complete short surveys on your use and experience with the air purifier after you receive it.

Limited availability. Apply by February 28th. Your confidential data will be kept safe. To read more about this study, visit https://pcair.ucdavis.edu.

*The application may ask questions about your demographics, information related to air quality, and California's environmental programs.

Figure B.6: Letter design: T5

# CONGRATULATIONS!

## YOU ARE SELECTED TO APPLY FOR A *FREE* AIR PURIFIER!

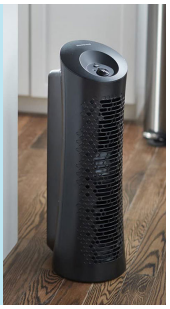
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Air pollution from industrial production, burning of fossil fuels, and wildfires affects the health of many Californians each year. Portable air purifiers improve indoor air quality and help protect yourself and your family from air pollution.

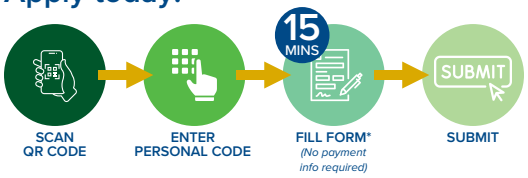
We invite you to apply for a free air purifier. If selected, you will receive a link for a high-quality indoor portable air purifier listed below.

**Honeywell Allergen Plus HEPA Tower Air Purifier - Black, HPA030**
*~~(Retail: $149.95)~~ free and shipping fee waived!*

- This silent and energy-efficient (ENERGY STAR label) purifier removes dust, smoke, pollen, pet dander, and mold spores.
- It removes more than 90% of allergens and particles in medium to large rooms (independently tested and verified by AHAM).
- This product is certified by the State of California's Air Resource Board.



### Apply today!




Apply by scanning the QR code or go to https://pcair.ucdavis.edu/application-enviro
Personal code:
000-AAA-AAA

If you are selected, we will contact you via email and phone. Then, you can redeem the air purifier from Honeywell directly and securely. The device will be shipped directly to your home. You will be asked to complete short surveys on your use and experience with the air purifier after you receive it.

Limited availability. Apply by February 28th. Your confidential data will be kept safe. To read more about this study, visit https://pcair.ucdavis.edu.

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Figure B.7: Letter design: T6

# CONGRATULATIONS!

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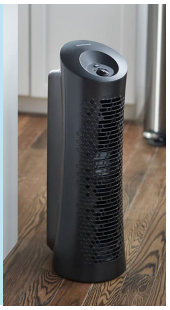
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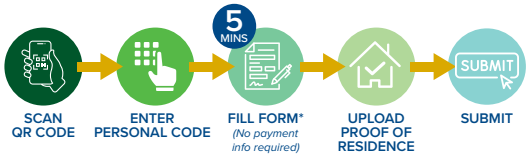
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Figure B.8: Letter design: T7

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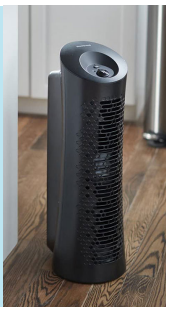
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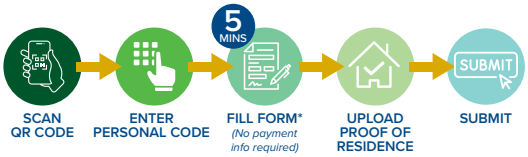
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- **You will be asked to provide proof of residence at this address.**
- **We accept any pictures of bills (such as utility or phone) and other official documents with your name and address.**
- **For additional information about the application process, go to https://pcair.ucdavis.edu/instructions.**

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Figure B.9: Letter design: T8

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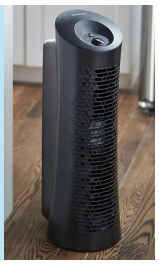
Air pollution from industrial production, burning of fossil fuels, and wildfires affects the health of many Californians each year. Exposures can cause **heart and lung disease, including asthma, and even premature death**.

**Did you know?**

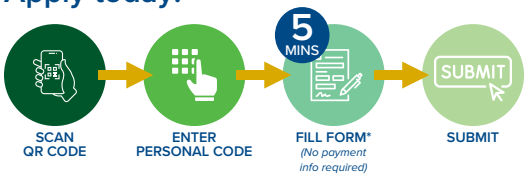
- **Over 90%** of California residents are exposed to unhealthy air at some point in the year.
- Yolo County had many days with poor air quality, including 117 moderate days and 2 days that were unhealthy for sensitive groups in 2023.
- To learn more about air quality and how to protect your health, go to pcair.ucdavis.edu/https://pcair.ucdavis.edu/aq-guide.

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