The Cost-Effectiveness of Air Pollution Information Provision Programs

Department of Research and Chief Economist

Karla Hernández
Bridget Lynn Hoffmann
Cristóbal Ruiz-Tagle
Alejandra Schueftan

TECHNICAL NOTE Nº IDB-TN-2236

July 2021

The Cost-Effectiveness of Air Pollution Information Provision Programs

Karla Hernández*
Bridget Lynn Hoffmann**
Cristóbal Ruiz-Tagle***
Alejandra Schueftan****

* University of Wisconsin-Madison
** Inter-American Development Bank
*** London School of Economics and Political Science
**** Universidad Austral de Chile and Instituto Forestal, Chile

July 2021

Inter-American Development Bank

Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library

The cost-effectiveness of air pollution information provision programs / Karla Hernandez, Bridget Lynn Hoffmann, Cristóbal Ruiz-Tagle, Alejandra Schueftan.
p. cm. — (IDB Technical Note ; 2236)
Includes bibliographic references.
1. Indoor air pollution-Mexico. 2. Indoor air pollution-Chile. 3. Stoves, Wood-Mexico. 4. Stoves, Wood-Chile. 5. Air quality management-Cost effectiveness-Mexico. 6. Air quality management-Cost effectiveness-Chile. I. Hernandez, Karla. II. Hoffmann, Bridget. III. Ruiz-Tagle, J. Cristobal. IV. Schueftan, Alejandra. V. Inter-American Development Bank. Department of Research and Chief Economist. VI. Series.
IDB-TN-2236

http://www.iadb.org

Abstract

Air pollution is one of the primary causes of premature death worldwide. This paper examines the cost-effectiveness of two different air quality information programs that were implemented as part of randomized control trials. In the case of the SMS air quality alerts in Mexico City, we find that the program was not cost-effective in the experimental sample, but it would likely be cost-effective if the program were extended to all of Mexico City. In the case of real-time feedback on wood stove emissions in Valdivia, we find that the program was cost-effective in both the experimental sample and at scale.

JEL classifications: Q53, Q52, D83
Keywords: Air pollution, Information, Behavioral nudges, Cost-Effectiveness

1 Introduction

Air pollution is one of the primary causes of premature death worldwide. According to the World Health Organization (WHO, 2016), approximately 7 million people die every year due to air pollution exposure. In 2016, 4.2 million died from ambient air pollution and an additional 3.8 million died due to indoor air pollution generated by cooking with polluting fuels.

Developing countries -including Mexico and Chile- tend to have higher air pollution and suffer the majority of the negative health effects. Approximately 9 out of 10 inhabitants of low and middle income countries are exposed to high levels of air pollution (WorldBank, 2016). Higher exposure leads to greater mortality and morbidity. In 2013, more than 90 percent of deaths and illnesses associated with air pollution occurred in developing countries. Furthermore, air pollution is associated with a significant economic burden through reductions in labor supply and productivity and worse quality of life (WHO, 2016; Hanna and Oliva, 2015; Chen et al., 2018; Chang et al., 2019; Luechinger, 2009).

The Metropolitan Area of Mexico City has historically been one of the most polluted urban centers in the world. High vehicle density and meteorological and topographical factors contribute to high levels of sulfur dioxide (SO_2), particulate matter (PM), carbon monoxide (CO) and ozone (O_3). On the other hand, Valdivia is located in southern Chile where air pollution is primarily caused by burning wood fuel for cooking and heating, which leads to particularly high levels of air pollution during the autumn and winter months. As of 2018, 8 of the 10 most polluted cities by fine particulate matter ($\text{PM}_{2.5}$) in South America were in the south of Chile.[1]

Exposure to high levels of air pollution is causally linked to negative health effects in the general population. Children, whose lungs are still developing, and the elderly, who are generally more frail, are particularly vulnerable to air pollution (Cifuentes et al., 2005; Arigoni Ortiz et al., 2009; Sanhueza et al., 2009). Among the commonly regulated air pollutants, particulate matter (PM), particularly fine particulate matter ($\text{PM}_{2.5}$), represents the greatest health risk. Fine particulate matter causes a broad range of health impacts because it can penetrate the lungs and travel through the bloodstream to other organs (Liu et al., 2017). PM causes respiratory and cardiovascular illness, including lung cancer and COPD, and premature death (Mardones and Cornejo, 2020; Hunt et al., 2016; Agency, 2009). It may also have negative effects on the reproductive system and nervous system (Cifuentes et al., 2005; Awe et al., 2015; Agency, 2009). Exposure to ground-level ozone causes respiratory illness and may additionally negatively impact the cardiovascular system, central nervous system and reproductive system (Hunt et al., 2016; Agency, 2013).

[1] www.airvisual.com/world-most-polluted-cities

In the last few decades, policies to address air pollution problems have been implemented around the globe, generating a number of benefits to human health (WHO, 2016). Developing countries have established different programs and regulations to reduce air pollution. For example, an ex-post evaluation of the Critical Episodes Management program in Temuco, Chile found that restrictions on the use of firewood heaters reduces $PM_{2.5}$ and PM_{10} (Mardones and Cornejo, 2020). Also, beginning in the 1990s, Mexico City increased its efforts to improve air quality by implementing several policies to curtail air pollution, such as *Hoy no circula* (a program that allowed cars to circulate only on certain days of the week), with mixed results reported in the evaluation literature (Molina, 2014; Davis, 2008).

Policy makers continue to recognize air pollution as a top environmental concern. Although many policies and programs have been implemented to limit air pollution emissions, there is still substantial room for improvement. Public programs that provide air pollution information to the public are low cost, and because they depend on voluntary behavior changes to avoid exposure to reduce emissions, they are relatively easy to implement.

Exploring the cost effectiveness of policies and programs to reduce citizens' exposure to air pollution is essential to determining whether these policies deliver greater benefits than their costs. Further, cost-benefit analysis can help policymakers garner support for allocating scare budget resources to programs that help to tackle air pollution and its health impacts.

Different methodologies have been used to study the cost-effectiveness of environmental policies that aim to reduce air pollution. Golub et al. (2014) study the effects of using wood and other biomass for cooking. Among other indicators, they use the Cost of Illness (COI) approach, which takes into account time losses due to changes in productivity and willingness to pay (WTP) to avoid mortality and morbidity risks. Arigoni Ortiz et al. (2009) and Hammitt and Ibarraran (2002) use contingent valuation methods to estimate the WTP to reduce the mortality risks of air pollution in Sao Paulo and Mexico City, respectively. Bowland and Beghin (2001), on the other hand, use a value-of-statistical-life (VSL) approach to calculate the WTP for a reduction in mortality related to air pollution exposure in Santiago, Chile.

This technical note examines the cost-effectiveness of two different air quality information programs described in Hanna et al. (2021) and Ruiz-Tagle and Schueftan (2019). These programs were implemented as part of randomized control trials that studied the effectiveness of the provision of air quality information in adaptation to and mitigation of air pollution. First, we explore a SMS air quality alert system in Mexico City that informed the population when either ozone or particulate matter (PM) reached (or was projected to reach) harmful levels at the monitoring stations nearest to their home. Second, we analyze an information sign placed on households' wood stoves in Valdivia, Chile for the purpose of delivering real-time feedback on wood stoves' pollution emissions.

In the case of the SMS air quality alerts in Mexico City, we find that the program was not cost-effective in the experimental sample, but it would likely be cost-effective if the program were extended to all of Mexico City. In the case of real-time feedback on wood stove emissions in Valdivia, in comparison to a government subsidy program to replace inefficient wood stoves, we find that the program was cost-effective in the experimental sample, and it also would be cost-effective at scale.

2 SMS Air Quality Alerts in Mexico City

This randomized control trial consisted of an SMS system that provided air quality alerts to participants in Mexico City.[2] The RCT was designed to study the effects of real-time air quality alerts on air pollution knowledge and avoidance behavior. Participants in the treatment group received a one-year subscription to the SMS alerts system that notified participants of elevated levels of ozone (O_3), proxied by the IMECA, or particulate matter (PM) in the household's neighborhood.[3] Specifically, participants in the treatment group received an alert at 7am if at 6am the IMECA was projected to reach harmful levels that day or $PM_{2.5}$ or PM_{10} reached abnormally high levels at any of the four air pollution monitoring stations nearest to the household's AGEB.[4] The PM alert read *"Suspended particles near your house are high and likely will remain high for the rest of the day. Take precautions. Remember: the mask DOES protect against suspended particles."*. The O3 alert read *"It is forecasted that the IMECA, and likely ozone, will be high near your house today. Take precautions. Remember: the mask DOES NOT protect against ozone."*. In our analysis, the control group was assigned to the same stations as the treatment group in that AGEB.

The data used in our analysis comes from the baseline survey, which was conducted between June 18 and August 1, 2019 in Mexico City. The sampling procedure started

[2]The experiment involved a random assignment of households to four different cross-cutting treatment groups: (1) provision of a free reusable N95 mask, (2) 50% higher compensation for participation in the baseline survey, (3) a year-long subscription to monthly pollution trend and avoidance behavior SMS reminders, and (4) a year-long subscription to pollutant-specific SMS air quality alerts. However, for the purpose of this technical note, the first three treatments are not relevant.

[3]The IMECA or Metropolitan Index of Air Quality is used to communicate the levels of air pollution in the Mexico City Metropolitan Area. It is divided into 5 categories: Good, Regular, Bad, Very Bad, and Extremely Bad.

[4]The thresholds for sending a particulate matter alert were 75 $\mu g/m^3$ for PM_{10} and 40 $\mu g/m^3$ for $PM_{2.5}$. An ozone alert was sent if the IMECA was forecast to reach orange, red, or purple.

with all the *Áreas Geoestadísticas Básicas* (AGEBs) in Mexico City that included residential households in the 2010 census.[5] Then, the list of potential AGEBs was restricted to those with an average education level below the median, AGEBs that were not included in previous rounds of data collection, and AGEBs with a homicide rate below the 70th percentile.[6] The remaining AGEBs were randomly ordered and visited by the field team in approximately that order.[7] Prior to surveying an AGEB invitations were distributed to give residents notice of the survey. The field team started in the North-western-most block of the AGEB, and then moved South and East until reaching 500 household interviews attempts.

The survey included information on demographics and health information for all members of the household. Additionally, it collected information on respondents' perceptions about air pollution in the city and the effectiveness of various air pollution avoidance measures.

A key aspect of the RCT and of the data used in the analysis in this technical note is the incentive compatible willingness to pay (WTP) for the air quality alerts service. The survey used a novel variation of Becker-DeGroot-Marshak mechanism Becker et al. (1964) with the goal of recovering the demand curve for the alerts service. The Becker-DeGroot-Marshak mechanism is an incentive compatible method of WTP elicitation that is similar to a second price auction in which the second price is a randomly generated price. If the participant's willingness to pay is equal to or greater than the random price, the participant purchases the good or service and pays the random price. If the participant's willingness to pay is less than the random price then the participant is unable to purchase the good or service and pays nothing. Therefore, the best strategy for participants is to truthfully state their maximum WTP.[8]

The WTP elicitation occurred after the main information in the survey had been collected and after surveyors provided respondents with information on the health impacts of air pollution and the effectiveness of avoidance measures.

The WTP module was implemented as follows. First, participants were asked to state the maximum amount that they would be willing to pay for a one year subscription to the alerts service. Then, surveyors followed up with a series of questions to pin down the participant's WTP. Specifically, surveyors asked if the participant would be willing to

[5]AGEB is an acronym for basic geo-statistical area, which consists on a group of blocks with an average of 1500 inhabitants in urban areas.

[6]AGEBs with a homicide rate above the 70th percentile were exclude for safety reasons. Further, in rare cases, AGEBs could be excluded at the discretion of the field team for safety reasons.

[7]The field team had the discretion to order the AGEBs within the week to reduce logistics efforts.

[8]This is true under a set of common assumptions including expected utility maximization but is not necessarily true under all conditions (Horowitz, 2006).

pay specific prices for the service, starting at 5 pesos below the participant's stated WTP and increasing by 5 peso increments until the participant no longer choose to purchase at the stated price. After the participant's WTP was confirmed, a random number (X) between 0 and the WTP (if the WTP is zero, so is X) was generated using the surveyors' tablets. Then the price was calculated using X according to the following formulas. If the participant was assigned to the treatment group, then the price was calculated using the formula *Price = min[WTP - X, compensation value]*, and if the participant was assigned to the control group the price was calculated using the formula *Price = WTP + X + 1*. *Compensation value* is the compensation received through a debit card for participating in the survey (either 100 or 150 pesos, depending on the compensation treatment group to which the participant was previously assigned). For safety reasons, the compensation value was set as an upper limit to ensure that the surveyors never collected cash as a payment for the service. The amount of compensation loaded on a participant's debit card would be reduced by the amount paid for the alerts service.

This experimental design ensured that the WTP module elicited truthful willingness to pay and also ensured that the random assignment of participants to the air quality alerts treatment and control group were respected. Prior to beginning the WTP dynamic, the participants were told that the surveyor's tablet would generate a random price to serve as the reserve price. Participants were also advised that the best strategy would be to state the true maximum value that they would be willing to pay and that they would not be able to change their mind after the random price was generated. Even though the participants in the control group would not receive the alerts service because the formula to calculate the random price for participants in the control group always generated a random price above the participant's WTP, the participants were not informed of this order to elicit an undistorted measure of WTP.

Table 1: Summary Statistics Mexico City

	Mean	Standard Dev
Number of HH members	3.976	1.778
Number of children in HH	0.955	1.115
Age	41.012	39.316
Gender: female	0.652	0.477
Head of household	0.532	0.499
Level of education:		
Did not complete secondary	0.192	0.394
Completed secondary school	0.376	0.484
Completed post-secondary degree	0.433	0.496
Income:		
Not working	0.452	0.498
0 - 2,000 Pesos	0.117	0.322
2,000 - 6,000 Pesos	0.229	0.420
Above 6,000 Pesos	0.127	0.333
Working, but income unreported	0.071	0.258
Subjective health: bad/very bad	0.135	0.342
Poll. in CDMX a (large) problem	0.945	0.228
Poll. in colonia (much) worse than CDMX	0.569	0.495
WTP	63.446	196.763

Table 1 shows the summary statistics of the sample. The final sample consists of 1,869 households located in 118 different AGEBs. The average number of household members is around 4, with one of them being a child. The mean age of the respondents is 41 years old. Further, around 65% of the respondents are females, 53% are the head of the household, and 56% had completed secondary education or less. Forty-five percent of the respondents were not working at the time of the survey. Ninety-four percent reported that pollution in Mexico City is a problem or a large problem and 57% responded that pollution in their neighborhood is worse or much worse than in the rest of the city. The average WTP for the year subscription to the SMS air quality alerts service was 63 Mexican Pesos or approximately $3.2 USD.

3 Cost Effectiveness of SMS Air Quality Alerts in Mexico City

The number of households receiving the alerts and their WTP for the system was determined through the Becker-DeGroot-Marshak mechanism. The total WTP from all participants adds up to \$ 4,871.[9] In our analysis, we assume that willingness to pay captures the value or benefits of the alerts to households. The fixed cost of the SMS platform was \$2,720. Additionally, each text message had a cost of \$0.05.[10] The total cost of the program was \$10,278.[11] This combination of numbers can be found in the red square in Panel A of Figure 1. In the study sample, the fixed and variable costs could not be covered by the total WTP of the participants indicating that participants' WTP is not sufficient to finance the SMS system. Because there could be a menu of cost structures for a SMS communications system, including one in which the marginal cost of sending an SMS is 0, Figure 1 shows the results for different levels of variable cost on the horizontal axis. For this program to be cost-effective in the study sample the variable cost per message would have to be \$0.014 per message or less. In this case, the red square would have been located between the green and blue lines to the left of the point where they cross.

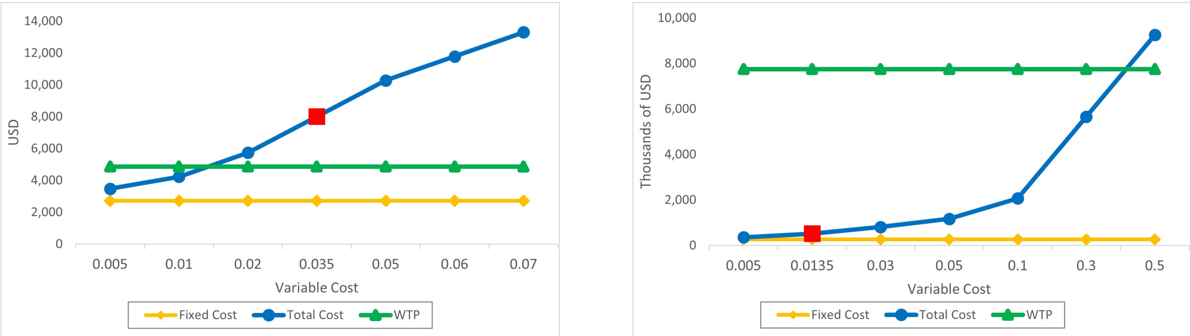
Panel B shows a projection of the results extrapolated to the entire city. We use an estimated number of 2,599,081 households in Mexico City and multiply it by the mean WTP elicited in this project.[12] Furthermore, we assume a fixed cost 10 times larger than that incurred during the RCT, \$271 868. Different values for the marginal cost per message are shown on the horizontal axis of Panel B. In this case, the combination of WTP and costs is shown in the red square in Panel B of Figure 1. In the case when the alerts system is expanded to the entire city, it becomes cost-effective.

[9]Because costs were measured in USD, we convert from pesos to USD.

[10]All values in this section are in US dollars. The exchange rate is 19.6165 Mexican Pesos per US dollar, and it was taken from Bloomberg.com for June 1, 2019.

[11]These costs do not include approximately \$3,630 USD of costs that were incurred during the project to update the SMS system in response to updates to the website where we scraped the data. Further, these cost estimates assume that that there is a costless process to enroll and unenroll participants in the SMS service. However, it includes sending SMS alerts to both the treatment and control group for 12 months.

[12]http://cuentame.inegi.org.mx/monografias/informacion/df/poblacion/vivienda.aspx?tema=mee=09



(a) RCT (b) Projection CDMX

Figure 1: Cost-Effectiveness

We also consider the cost-effectiveness of adding a marginal user to the SMS service. For the marginal user, we take into account only the variable cost and the SMS system is still not cost-efficient. However, conducting the analysis station by station shows that the alerts system is cost-effective for some neighborhoods (i.e. air pollution stations).

Figure 2 shows that, for the households assigned to the stations Gustavo A. Madero (GAM) and Merced (MER), the WTP exceeds the costs. If we rank household responses by station according to the average level of income, level of education, perception of health, and perception of air quality in their colonia and in Mexico City, MER ranks second by health perception, air quality in their colonia, and air quality in CDMX; and it is the third wealthiest. GAM contains the households that have the worst self-perception of health and air quality.

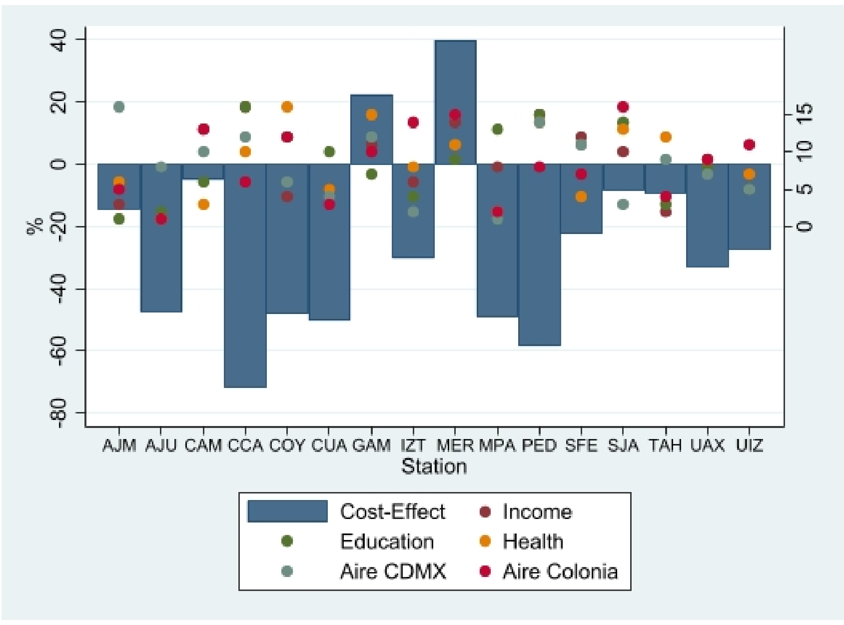


Figure 2: Cost-Effectiveness by station

4 Real-Time Emissions Feedback in Valdivia

The field experiment in Valdivia provided a group of treated households with an information sign placed on their wood stove that delivered real-time feedback on wood stove air pollution emissions. In choosing the position of the wood stove's damper, users face a trade-off. Users can choose to choke their wood-stove's damper to save fuel expenditure but this causes greater emissions. In contrast, opening the damper increases the airflow in the combustion chamber to decrease emissions. Households can choose either of these damper positions or any combination in between at all times their wood stoves are in operation. In contrast, households in the control group were not provided with the information sign.

The information sign was attached to the wood-stoves of participants in the treatment group, aligned with the damper's lever. The damper could be set at one of five different positions according to the choking level, and the information sign displayed emissions information for this position of the damper. When the lever was set all the way to the left, the user would be setting the damper at the "Choked" position and the corresponding pollution level is "very high". By slightly moving the damper to the right, the user would allow more airflow into the combustion chamber and the pollution emissions would decrease until reaching the "ignition only" ("open") damper position all the way to the right.

A device to monitor damper settings, which was developed for this project, was placed in the wood stoves of all participating households. The device saves the position of the damper setting every 10 minutes into a flash memory card.

The sample consists of 80 households with their own wood stove as the only source of heating in their dwelling.[13] The only requirement was that the damper setting monitoring device could be installed in their wood stove. The experiment was conducted in two phases of 40 households each (26 assigned to treatment and 14 to control). The phases were implemented during the months of August and September of 2017, and each phase lasted for one month. After the first two weeks, the information sign was installed in the treated households. The technician in charge of the installation also provided a detailed explanation of the use of the device and supplemented this information with a flyer in the form of a refrigerator magnet. Additionally, an indoor temperature monitoring device was installed in both treated and control households to record indoor temperature and, by contrasting it with outdoor temperature, determine when the wood stove was in use.

Surveyors conducted households surveys to gather information on socio-economic characteristics, characteristics of the house, health-related problems, participants' perception on air pollution, frequency of use of the wood stove, and quality of wood fuel. At the end

[13]The households in the sample use wood stoves only for heating, not for cooking.

of the experiment, a follow-up survey was also conducted and all monitoring devices were collected. As compensation for participating in the study, the participants received one cubic meter of certified-dry wood fuel at the start of the experiment, which also controlled the quality of the fuel used throughout the experiment.

Table 2: Summary Statistics Valdivia

	Mean	Standard Dev
Number of HH members	3.273	1.361
Number of children	0.640	0.871
Age	44.310	13.996
Gender: female	0.610	0.490
Level of Education:		
Did not complete secondary school	0.170	0.378
Completed secondary school	0.360	0.482
Completed post-secondary degree	0.470	0.502
Respiratory or cardiovascular problem in HH	0.260	0.441
Reports burning wood fuel pollutes	0.830	0.378

Table 2 presents summary statistics for the 80 households in the sample. On average, households are composed of 3.2 members. The average age of respondents was 44 years old. Sixty percent of respondents are female and around 19% had not completed secondary school. Twenty-six percent of the households had a member with respiratory or cardiovascular problems. Eight out of 10 respondents reported that cooking with firewood causes pollution.

5 Cost Effectiveness of Real-Time Emissions Feedback in Valdivia

We compare the cost-effectiveness of the information signage to the cost-effectiveness of a government wood stove replacement program. The double-combustion wood stoves used in the replacement program have an average cost of approximately \$700 USD. Under the Chilean government's replacement program, selected households co-pay \$50 USD to upgrade from their current wood stove to one of these double-combustion wood stoves provided that they dispose of their old (highly polluting) wood stove, while the government subsidizes the remaining \$650 USD. According to official figures from Chile's Ministry for the Environment, these double-combustion wood stoves emit 3,540 mg of $PM_{2.5}$ per KWh. This compares to the estimated average emissions of the old wood stoves, at 14,862 mg of $PM_{2.5}$ per KWh. That is, as compared to old wood stoves, double-combustion wood stoves emit 76% less $PM_{2.5}$ pollutants. Therefore, the $650 USD subsidy to upgrade to double-combustion wood stoves can potentially reduce emissions at a rate of $8.53 USD per each percentage point of reduction in $PM_{2.5}$ pollutants.

Nonetheless, the estimates of emissions presented above are a result of 'optimal' usage of these double-combustion wood stoves. That is, usage that involves burning dry wood fuel with a fully efficient air flow in the stoves' combustion chamber. As shown in the study for Valdivia, households' actual usage of these wood stoves is far from optimal. Indeed, households tend to choke the air flow in the wood stoves' combustion chamber, thus generating a highly polluting combustion process. Moreover, household surveys show that about 25 percent of users burn wood fuel with a high moisture content, which is significantly more polluting than burning dry wood fuel Instituto Forestal (2015).

Table 3 below presents frequency of damper setting usage in Valdivia together with associated $PM_{2.5}$ emissions according to the type of wood fuel used Díaz-Robles (2014). As shown in Table 3, actual operating conditions and use of fuel wood are far from optimal. Households tend to set the wood stove's damper to Mostly Open only 19% of the time, whereas they set it to Mid-Level or Mostly Choked 34% and 47% of the time, respectively. Because of the departures from optimal operating conditions, these double-combustion wood stoves fail to achieve their maximum potential reduction in $PM_{2.5}$ emissions under real-world operating conditions.

Based on the figures presented in Table 3, $PM_{2.5}$ emissions from these double-combustion wood stoves are in fact 2.35 times larger than under "optimal" conditions. This means that, under real-world usage, double-combustion wood stoves emit only 44 percent less $PM_{2.5}$ emissions than old wood stoves. Taking this into account, the $650 USD subsidy for upgrading to double-combustion wood stoves effectively achieves a reduction in $PM_{2.5}$ emissions at a rate of $14.78 USD per each percentage point of reduction.

In contrast, the intervention in Valdivia suggests that an information sign that provides real-time feedback on emissions can induce a behavioral change in usage of the damper setting of these double-combustion wood stoves that results in 17% less $PM_{2.5}$ emissions. That is, a $5 USD information sign can induce emission reductions at a rate of $0.19 USD per each percentage point of reduction. This is only a fraction of the cost of upgrading to newer wood stove technologies.

Table 3: Actual Usage and Emissions of Double-Combustion Wood Stoves in Valdivia

	Mostly Open	Mid-Level	Mostly Choked
Frequency of Usage of Damper Setting	19%	34%	47%
Emissions (mg of $PM_{2.5}$ per hour):			
Dry wood fuel (used by 75% of HHs)	4.8	5.9	12.3
High Moist wood fuel (used by 25% of HHs)	9.3	9.5	29.0

Note: The type of wood fuel consumed by households is calculated from the Encuesta Residencial Urbana sobre Consumo de Energía, Uso de Combustibles Derivados de la Madera, Estado Higrotérmico de las Viviendas y calefacción en las ciudades de Valdivia, La Unión y Panguipulli (Instituto Forestal, 2015).

Because the study in Valdivia measured outcomes only in the short-term, it is uncertain how long reductions in emission due to the informational nudges will persist. However, there are also indications that scaling up this program could have large impacts. Eighty-nine percent of participants reported that they would choke their wood stoves less frequently if there were a large-scale government led campaign that educates and encourages the community to choke their wood stoves less frequently. The cost-effectiveness of the informational nudges and the ease of deploying them clearly demonstrates that they are worthwhile.

6 Conclusion

The two studies discussed in this technical note demonstrate the value of air pollution information. In this technical note, we find that these programs are cost-effective at scale.

The information provision studied in Mexico City was designed to allow households to adapt to a high pollution environment by engaging in avoidance behavior on days with elevated levels of air pollutants. In contrast, the information provision in Valdivia had the objective of mitigating households' emissions of air pollution by changing their behavior. These two programs also had different cost structures. An SMS service is characterized by a relatively high fixed cost and very low or even 0 marginal cost per participant. In contrast, the information signage program in Valdivia had nearly 0 fixed cost but a relatively large marginal cost per participant.

These disparate contexts, information programs, and cost structures demonstrate the cost-effectiveness of air pollution information provision in a range of situations. Policymakers in Latin America and the Caribbean should view information provision as an additional tool to address high levels of air pollution.

References

Agency, U. E. P. (2009). Integrated science assessment for particulate matter. *US Environmental Protection Agency Washington, DC*.

Agency, U. E. P. (2013). Integrated science assessment for ozone and related photochemical oxidants. *US Environmental Protection Agency Washington, DC*.

Arigoni Ortiz, R., A. Markandya, and A. Hunt (2009). Willingness to pay for mortality risk reduction associated with air pollution in são paulo. *Revista Brasileira de Economia 63*(1), 3–22.

Awe, Y., J. Nygard, S. Larssen, H. Lee, H. Dulal, and R. Kanakia (2015). Clean air and healthy lungs: enhancing the world bank's approach to air quality management.

Becker, G. M., M. H. DeGroot, and J. Marschak (1964). Measuring utility by a single-response sequential method. *Behavioral science 9*(3), 226–232.

Bowland, B. J. and J. C. Beghin (2001). Robust estimates of value of a statistical life for developing economies. *Journal of Policy Modeling 23*(4), 385–396.

Chang, T. Y., J. Graff Zivin, T. Gross, and M. Neidell (2019). The effect of pollution on worker productivity: evidence from call center workers in china. *American Economic Journal: Applied Economics 11*(1), 151–72.

Chen, S., P. Oliva, and P. Zhang (2018). Air pollution and mental health: evidence from china. Technical report, National Bureau of Economic Research.

Cifuentes, L. A., A. J. Krupnick, R. O'Ryan, M. A. Toman, et al. (2005). Urban air quality and human health in latin america and the caribbean. *Inter American Development Bank*.

Davis, L. W. (2008). The effect of driving restrictions on air quality in mexico city. *Journal of Political Economy 116*(1), 38–81.

Díaz-Robles, L. (2014). Investigación y generación de factores de emisión de contaminantes atmosféricos para artefactos residenciales que combustionan biomasa de relevancia nacional. proyecto fondef d08i1147. temuco, chile. Technical report, Universidad Católica de Temuco (UCT).

Golub, E., I. Klytchnikova, G. Sanchez-Martinez, and J. C. Belausteguigoitia (2014). Environmental health costs in colombia: the changes from 2002 to 2010.

Hammitt, J. and M. Ibarraran (2002). Estimating the economic value of reducing health risks by improving air quality in mexico city ". *Newsletter on Integrated Program on Air Pollution 2*.

Hanna, R., B. Hoffmann, P. Olivia, and J. Schneider (2021). The power of perceptions: Limitations of information in reducing air pollution exposure. *IRB Working Paper Series IDB-WP-01260*.

Hanna, R. and P. Oliva (2015). The effect of pollution on labor supply: Evidence from a natural experiment in mexico city. *Journal of Public Economics 122*, 68–79.

Horowitz, J. K. (2006). The becker-degroot-marschak mechanism is not necessarily incentive compatible, even for non-random goods. *Economics Letters 93*(1), 6–11.

Hunt, A., J. Ferguson, F. Hurley, and A. Searl (2016). Social costs of morbidity impacts of air pollution.

Instituto Forestal, C. (2015). Encuesta residencial urbana sobre consumo de energía, uso de combustibles derivados de la madera, estado higrotérmico de las viviendas y calefacción en las ciudades de valdivia, la unión y panguipulli. Unpublished database.

Liu, Q., C. Xu, G. Ji, H. Liu, W. Shao, C. Zhang, A. Gu, and P. Zhao (2017). Effect of exposure to ambient pm2. 5 pollution on the risk of respiratory tract diseases: a meta-analysis of cohort studies. *Journal of biomedical research 31*(2), 130.

Luechinger, S. (2009). Valuing air quality using the life satisfaction approach. *The Economic Journal 119*(536), 482–515.

Mardones, C. and N. Cornejo (2020). Ex-post evaluation of a program to reduce critical episodes due to air pollution in southern chile. *Environmental Impact Assessment Review 80*, 106334.

Molina, C. M. (2014). Evaluación del programa hoy no circula. *línea].¡ http://centromariomolina. org/wp-content/uploads/2014/06/RE_HNC_20141. pdf*.

Ruiz-Tagle, C. and A. Schueftan (2019). Reducing air pollution through behavioral change of wood-stove users: Evidence from an rct in valdivia, chile. *IRB Working Paper Series IDB-WP-959*.

Sanhueza, P. A., M. A. Torreblanca, L. A. Diaz-Robles, L. N. Schiappacasse, M. P. Silva, and T. D. Astete (2009). Particulate air pollution and health effects for cardiovascular and respiratory causes in temuco, chile: a wood-smoke-polluted urban area. *Journal of the Air & Waste Management Association 59*(12), 1481–1488.

WHO (2016). Ambient air pollution: A global assessment of exposure and burden of disease.

WorldBank (2016). The cost of air pollution: Strengthening the economic case for action.