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THE ROLE OF BEHAVIOR IN THE EFFECTIVENESS OF INDOOR AIR POLLUTION INTERVENTIONS:

RESULTS FROM THE ARTIS STUDY

By

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B.A., University of Montana, Missoula, Montana, 2014

Thesis

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The Role of Behavior in the Effectiveness of Indoor Air Pollution Interventions: Results from the ARTIS Study

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Using panel data from a randomized placebo-controlled trial of a wood stove changeout and air filter interventions, this study addresses the role of behavior in the efficacy of air quality interventions. The effectiveness of an intervention in improving air quality depends on how households respond to and use them. Two important responses are whether the target population complies with the requirements of the intervention and whether users adjust other behaviors that can affect air quality.

This paper's results are consistent with prior studies in finding that in the absence of interventions, a number of behaviors can affect indoor air pollution, and that the air filter, but not the wood stove changeout intervention, improved air quality. This paper looks at whether the intervention a home receives impacts its behavior, and whether the air quality outcomes for those who change behavior in response to the interventions differ from those who do not. There is not enough evidence to conclude that household response varied by treatment assignment. However, I did find that the filter was associated with significant reductions in pollution among homes that worsened behavior and among homes that did not. Another important finding was that among homes that reported constant or improving wood-burning practices, and among homes that kept the devices running, the placebo filter was effective in reducing pollution levels. I also find that among homes that report constant or improving wood-burning practices, the placebo filter was also effective in pollution reduction.

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1. Introduction

Today, 50% of the global population – approximately 3.5 billion people – still heat and light their homes, cook their meals, or satisfy general domestic energy requirements using wood, coal, or other solid fuels (Desai, Mehta, and Smith, 2004). Burning these organic materials contributes to ambient and indoor air pollution, which has negative consequences for public health and the environment. Specifically, use of these fuels can contribute to acute lower respiratory infections and chronic obstructive pulmonary disease, as well as to deforestation and climate change (World Health Organization, 2016; Smith, 2006). Air pollution levels tend to be higher indoors, where without proper ventilation, small particles can be trapped. In fact, the World Health Organization reports that this type of pollution was associated with an estimated 4.3 million deaths in 2012 (WHO, 2014).

Reducing both reliance on solid fuels and indoor air pollution has become a policy priority for many governments, aid agencies, and nonprofit organizations. Potential solutions include heating oil subsidies, ventilation, training programs, wood stove changeouts (in which the existing stove is replaced with a more efficient model), and air filters. The cost effectiveness of each of these strategies depends to some degree on user response. How the household manages division of labor (i.e., who is tasked with spending most time near the stove), how it values the intervention in terms of appropriate use and maintenance, and how members of the household adapt their behavior will play a role in the intervention's success or failure in reducing air pollution and/or improving health. This paper examines the role of household behavior in the efficacy of a wood stove changeout and an air filter treatment in a randomized controlled trial in the Northern Rockies region of the United States.

This study uses data from the Asthma Randomized Trial of Indoor Wood Smoke, or ARTIS: a placebo-controlled randomized trial of three interventions carried out in wood-stove-heated homes in Montana, Idaho, and Alaska (Noonan and Ward, 2012b). Eligible households used a wood stove as a primary or supplemental source of heat, were non-tobacco-smoking, and had at least one asthmatic child. Prior to intervention, the average concentration of particulate matter less than 2.5 microns in diameter ($PM_{2.5}$) in the sample was 29.58 $\mu g/m^3$ and the pre-intervention mean one-minute maximum was 795.82 $\mu g/m^3$. The World Health Organization recommends indoor PM below 25 $\mu g/m^3$ (Ward, Semmens, Weiler, Harrar, and Noonan, 2017).

As anticipated, the placebo air filter did not reduce air pollution overall (Ward et al., 2017). Relative to the placebo, the air filter treatment resulted in a significant reduction in $PM_{2.5}$, a finding also in line with expectations. The wood stove changeout was not associated with significant reductions in air pollution relative to the placebo. The changeout intervention was discontinued prior to the final cohort, resulting in only 16 homes receiving this treatment. Existing findings from the ARTIS program are reported in Semmens, Noonan, Allen, Weiler, and Ward (2015) and Ward et al. (2017).

The results of the changeout arm are unexpected, but not unprecedented. Wood stove changeout studies have seen varying results. Most changeouts have reduced air pollution or improved health, but several have had little to no impact on these outcomes. Duflo, Greenstone, and Hanna (2008b) suggest that household behavior plays a role in the effectiveness of a wood stove changeout. Indoor PM is composed of not just wood smoke, but also house dust, endotoxins, mold spores, and other combustion products (Clark et al., 2010). Therefore, households can affect indoor air pollution by engaging in polluting or pollution-mitigating behaviors. Cleaning, cooking, or burning candles or incense can increase indoor air pollution. Furthermore, the stove itself requires correct use. Households must properly maintain the stove, stoke and load it periodically, adequately season firewood, and occasionally open windows or doors (or close them, depending on ambient pollution levels). Receiving a stove or air filter may cause people to change these behaviors by affecting their perception of risk. In fact, behavioral changes of this nature have been observed in response to implementation of other health and safety technologies. For example, drivers have been shown to increase their "driving intensity" in response to government-mandated automobile safety features (Peltzman, 1975).

The subject of interest to this paper is the extent to which household behavioral response to intervention affects air pollution, and whether this plays a role in the efficacy of stove and filtration interventions. This research question is twofold. The first part is whether receiving an intervention causes households to change air pollution-related behavior. The second is whether these changes, if they do occur, impact air quality, and by extension, the effectiveness of the filtration unit or the high-efficiency device. In theory, household responses could totally offset the benefits of an intervention, partially offset them (for all or a subset of participants), or could enhance the intervention's benefits.

The hypothesis tested in this paper is that receiving an intervention affects household behaviors, and these changes in behavior impact air pollution levels, affecting treatment effects of interventions. Data for a number of wood-burning practices (burning intensity, amount of wood burned, etc.), home activities (opening windows, cleaning), as well as air filter compliance (the unit's recorded energy usage divided by the expected usage) were collected for each household over the course of the study. Therefore, it is possible to identify households whose behaviors changed in ways that would be expected to worsen air quality. For example, a household may switch to improperly dried firewood or do more cleaning during the second winter after the intervention has been installed.

The sample is split into subgroups according to households whose behaviors changed in ways that would be expected to worsen air quality, and households whose behavior either did not change or changed in ways that would be expected to improve air quality. This allows comparing the proportions of these subgroups between treatment groups to ascertain whether there are significant differences between the placebo, changeout, and filter groups. It also allows comparing the effect of treatments on air quality between those who changed their behavior in ways that should worsen air quality, and those who did not change or changed in ways that should improve air quality. Conducting the analysis separately for each subgroup, a mixed effects model is estimated with a random intercept and slope, air quality as the dependent variable, and a multiplicative interaction term with a factor variable for treatment assignment and an indicator variable for pre- or post-intervention. The model includes controls for socioeconomic variables, meteorological variables during the sampling period, and home characteristics.

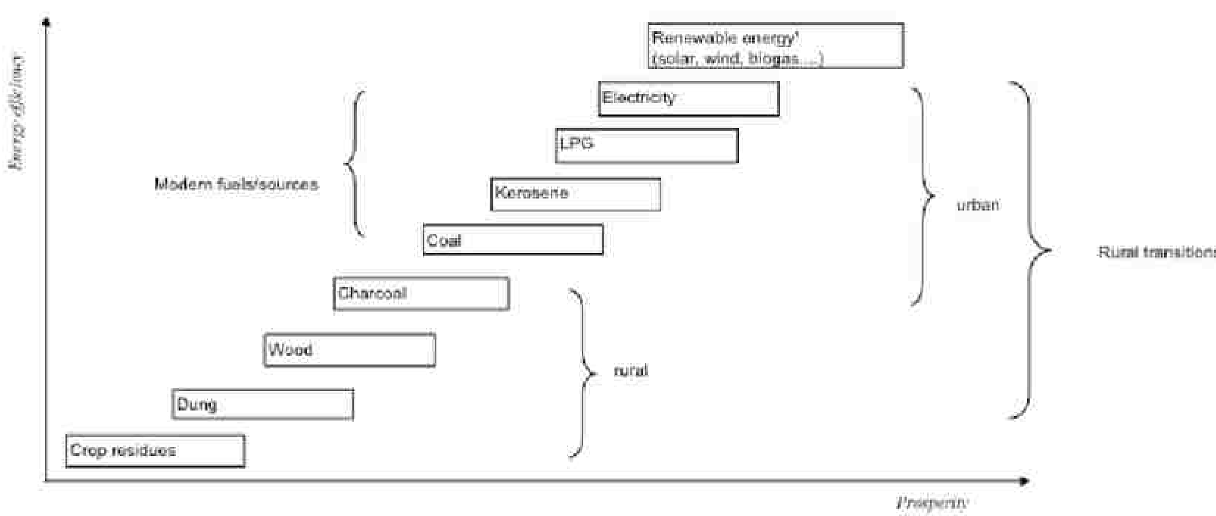
The results do not offer sufficient evidence of compensating behavior for any of the individual treatment groups. However, treatment effects did differ between behavior change subgroups. The results suggest that the placebo was associated with significant reductions in particulate matter in homes that kept the device running, and in homes that reported constant or improving wood-burning practices. Among homes that worsened behavior or did not comply with instructions, the placebo was not associated with significant reductions. The air filter was associated with highly significant reductions in air pollution for homes that did and did not report behavior change, indicating the air filter filtered out additional pollution caused by worsening practices, cancelling the effects of behavior change.

The next section provides an overview of solid fuel use and its effects, contextualizing and informing the design of this study. Section 3 will give an overview of the academic literature regarding wood stove changeouts, air filter interventions, and behavior change models, and will describe this study's contributions. Section 4 outlines the program's design and Section 5 introduces the data. Section 6 will see development of the model. Results are given in Section 7, followed by a discussion in Section 8.

2. Background: Solid fuel use and its implications

Approximately half of the world's population, or 3.5 billion people, continues to rely on biomass fuel. Because clean, reliable energy is a normal good, industrialization and rising incomes tend to carry households up the energy ladder (see Figure 1).[1] As income rises, households exhibit greater preferences for clean, sustainable fuel, and as nations become wealthier, they are able to invest in advanced energy infrastructure, affording residents access to such fuel. Movement up the energy ladder is informed by the determinants of fuel choice and energy use, as described in the International Agency for Research on Cancer (2010). These determinants include availability and access to biomass and modern energy, income, affordability, and traditions or cultural practices. Because it is the poorest nations in the world that have not made these public utility investments, it is largely their residents who suffer the deleterious effects of wood smoke. As Duflo et al. (2008) notes, movement up the ladder has proven unexpectedly slow. The

Figure 1: Energy Ladder



[1] https://www.researchgate.net/figure/216687315_fig8_Figure-11-Energy-transition-ladder-for-developing-countries

percentage of homes relying exclusively on biomass worldwide has remained constant at 25% since 1975 (Duflo et al., 2008).

Despite the disproportionate burden on developing nations, many communities in rural or underserved parts of industrialized nations continue to rely on traditional fuels due to undeveloped natural gas infrastructure and the prohibitive cost of modern energy. It is particularly common for households to use combinations of fuels (a practice known as “fuel stacking,” illustrated in Figure 1 by the overlapping energy boxes and labeled “Rural transitions”). For example, a household may use firewood for supplemental heating, but rely on electricity or liquefied petroleum gas (LPG) to satisfy the rest of its domestic energy requirements. In fact, according to the Environmental Protection Agency, an estimated 12 million American households rely on wood stoves as a primary or supplemental source of heat. Of these, 75% are thought to be inefficient models (Zeller, 2009). Most solid fuel use is in rural communities where lack of infrastructure and high costs make modern energy inaccessible for many families (Ward et al., 2017). This is why use of biomass can remain high well into industrialization (Edwards and Langpap, 2012). However, the nature of biomass use in industrialized countries differs from use of biomass in developing countries. Most wood stove use in the industrialized world is supplemental, and generally for heat rather than cooking. Woodstoves in use in these settings are also typically more efficient and subject to more stringent regulation than those in emerging and developing economies. These differences have important implications. Relative to the U.S. and peer nations, developing countries experience higher levels of indoor air pollution, harvesting of fuel puts more strain on local resources, and households spend a much greater share of their time collecting fuel and dealing with stoves. This also has implications for the meaning of *improved stove*. As World Bank (2011) notes, an improved stove is a relative concept. Programs designed for and carried out in the poorest of communities may promote a stove or add-on device that simply encloses the open flame, costing less than 5 USD. An improved stove in this study is an EPA-certified stove which costs several thousand USD. In this review of existing literature, studies carried out in rich and poor countries will be considered separately due to these important differences.

There are a number of reasons why the international development community prioritizes the transition to clean fuel. Solid fuel use poses a health risk, strains natural resources, and demands time and energy investments that could be spent on more economically productive activities (WHO, 2016). The remainder of this section gives an overview of the effects of solid fuel use on health and the environment, as well as an introduction to the wood stove changeout programs that have been implemented around the world.

2.1 Health and productivity

In toxicological terms, the mechanisms by which wood smoke affects health are varied, as the combustion of biomass fuels generates a number of harmful pollutants, including particulate matter (PM), carbon monoxide (CO), and various carcinogens (Edwards et al., 2012). According to the World Health Organization and the Centers for Disease Control and Prevention, exposure to these particles can lead to increased symptoms of bronchitis, inflammation of airways, headaches, dizziness, vomiting, scratchy eyes, cough, nosebleeds, cardiovascular disease, and cancer. “Inhalable particles” – those with aerodynamic diameters of less than 10 micrometers – are thought to be particularly dangerous. Small particles are generally more toxic, and can be breathed deeper into the lungs (Dockery et al., 1993). In this study, average $PM_{2.5}$ and maximum, coarse and fine particle counts, and carbon monoxide data were collected. The main dependent variable of interest, in this and preceding studies, is average $PM_{2.5}$, as it is the particulate size fraction most injurious to health. Average is preferred over maximum because it is more representative of long-term exposure levels.

Cross-sectional studies have found associations between air pollution measures and respiratory illnesses, hospitalizations, and mortality (Dockery et al., 1993; Lagravinese, Moscone, and Tosetti, 2014; Currie and Neidell, 2005; etc.). More recent studies make use of exogenous shocks and quasi-experimental design. For example, Tanaka (2015) finds that air quality regulations in China are associated with reduced infant mortality. However, the primary source of pollution in China is coal, not wood. Similarly, Chay and Greenstone (2003a,b) find that reductions in industrial pollution caused by regulation and recession also reduce the infant mortality rate.

An emerging body of literature makes use of exogenous shocks in the form of severe forest fires. By comparing high- and low-smoke areas in Indonesia, Frankenberg, McKee, and Thomas (2005), Jayachandran (2009), and Emmanuel (2002) find pollution reduced adults' ability to perform strenuous tasks, increased infant mortality, and increased respiratory hospitalizations. The fact that particulate levels in these studies paralleled those found indoors makes their findings particularly relevant to this study of indoor air pollution. That being said, this does not exactly mimic the effects of indoor air quality because temporarily high outdoor pollution levels may be offset through activity adjustments or the use of protective devices, and limited exposure may not provide needed insight into the effects of long-term, sustained exposure.

Health is important not just out of concern for human welfare, but also as a factor in productive economies. Poor health and poor academic or labor performance go hand in hand, as health helps determine human capital, the principal factor in economic growth (Kaldaru, Kerem, and Vork, 2004). An individual in poor health will miss more days of school or work, will have a more difficult time focusing or performing strenuous tasks, and may be hamstrung in the competition for higher grades or wages. Inadequate income may prevent such an individual from seeking medical care, which will result in continued and worsening illnesses and the perpetuation of poverty. Stafford (2014) finds that performance on standardized tests significantly improved in response to improvements in school air quality. In fact, she proposes that indoor air quality improvements may be more effective in improving student test scores than class size reductions. A study by WHO and the Organisation for Economic Co-operation and Development (2015) reports air pollution costs 1.6 trillion USD per year in diseases and deaths.

In children and adults, the evidence from iron supplementation is instructive. Iron-deficiency anemia presents similarly to respiratory disease, as it limits aerobic capacity and oxygen saturation. Therefore, if iron supplements improve productivity, it would follow that improving air quality would produce similar effects. Indeed, several studies have found randomized interventions of iron supplements result in increased output and wages. Bobonis, Miguel, and Sharma (2004) find iron supplementation increased preschool participation in Delhi, India, by nearly 6 percentage points. Basta, Soekirman, and Scrimshaw (1979) and Thomas et al. (2003, 2006) find that Indonesian iron supplementation programs resulted in gains in wages, productivity, and employment.

2.2 Environment and climate

The most straightforward environmental implications of solid fuel use are its effects on climate and local air quality. Burning wood, plants, or coal releases environmentally damaging particles, such as carbon dioxide, carbon monoxide, methane, and black carbon (Cho, 2016). In less developed countries, biomass and charcoal can emit more greenhouse gases than fossil fuels (Bailis et al., 2003). For example, the United Nations Food and Agriculture Organization reports that the production of fuelwood and charcoal produced 30 million tons of CO_2 emissions in 1996, compared to 6.8 million tons released through fossil fuel use and cement production in the same year (Bailis, Ezzati, and Kammen, 2003). Additionally, solid fuel use is an important source of black carbon, the second largest contributor to climate change after CO_2 (Cho, 2016).

Black carbon can absorb one million times more energy than CO_2, and can stay in the atmosphere for hundreds to thousands of years (Cho, 2016).

Furthermore, the inefficiency of organic combustion makes the use of solid fuels unsustainable. When organic materials are burned, only a small percentage of the energy generated is released as usable heat (Smith, 2006). This has repercussions for local resources, as reliance leads to overuse. Unsustainable harvest contributes to deforestation, which in turn leads to desertification, soil erosion, and degradation of wildlife habitat and watershed functions.[2]

2.3 Wood stove changeouts

By far the most widespread solution to stove-generated indoor air pollution is the wood stove changeout, in which an inefficient wood stove is replaced with a cleaner, more efficient version. These programs have gained traction because they can be inexpensive and scalable, they are customizable to different cultures and settings, and they address not only indoor air pollution, but also ambient air pollution and deforestation by reducing the total amount of wood used through increased efficiency. Wood stove changeouts have been deployed on an impressive scale. During the 1980s and 1990s, the Chinese government's National Improved Stove Program (NISP) distributed 180 million improved stoves (World Bank, 2013). The China Clean Stove Initiative (CSI), which was launched in 2012 in partnership with the World Bank, aims to distribute clean stoves to the entire country by 2030 (World Bank, 2013). India's National Programme on Improved Cookstoves (NPIC) distributed about 35 million stoves from 1983 to 2002 (Kishore and Ramana, 2002). The U.S. Department of State launched the Global Alliance for Clean Cookstoves (GACC) in 2010; the program has distributed 28 million, and plans to reach 100 million by 2020 (it is now a United Nations Foundation program, not a State

[2] https://www.nationalgeographic.com/environment/global-warming/deforestation/

Department program).[3] Non-governmental organizations like Gram Vikas in India, Gambia, and Tanzania, as well as companies like Inyenyeri in Rwanda, offer incentives that nudge communities toward widespread adoption of high efficiency stoves. [4,5] In the United States, the Great American Woodstove Changeout facilitates the transition to new, EPA-approved stoves through promotion and rebate schemes.[6]

Despite the growing popularity of wood stove changeout programs, the empirical evidence remains mixed over whether these improved technologies actually reduce emissions, fuel use and collection time, and whether they improve health and ease pressure on natural resources. Simple extrapolation using engineering estimates to gauge the effectiveness of these interventions is insufficient, as actual outcomes are influenced by household behavior, fuel or stove stacking, etc. Empirical analyses are key due to the myriad factors that can influence air quality.

3. Indoor air pollution intervention studies and behavioral response models

3.1 Wood stove changeout studies carried out in developing and emerging economies

Simple observational field studies have offered evidence that households using improved stoves are healthier, use less fuel, and spend less time cooking and collecting firewood (Bruce, Neufeld, Boy, and West, 1998; Brooks et al., 2016). However, the validity of these findings is undermined by endogeneity as households that independently choose to purchase and use an improved stove may be systematically different from households that do not. They may be wealthier, better informed, or simply more concerned about their family's welfare. For example, Bruce et al. (1998) find that relative to women using an improved stove design, Guatemalan women using an open flame exhibit higher prevalence of cough. They also find strong associations between stove

[3] https://www.state.gov/s/partnerships/cleancookstoves/ (removed under Trump Administration)
[4] https://www.inyenyeri.org
[5] www.gramvikas.org
[6] https://www.hpba.org/Initiatives/Woodstove-Changeouts

design and a number of factors including arrangement of rooms, floor type, possession of a radio and television, and spousal economic activity. Brooks et al. (2016) report associations between clean cookstove use and reductions in fuel use, cook time, and fuel collection time, but they also report that wealthier, smaller, and less marginalized households are more likely to use these stoves. This is supported by Lewis and Pattanayak (2012), who investigate the determinants of improved stove adoption and find income, households headed by a female, head of household education, urban households, and access to credit are positively associated with improved stove adoption.

A more sophisticated identification strategy is required to overcome this endogeneity problem. Certain studies have made use of natural experiments or quasi-random distribution. For example, Adrianzen (2016) exploits a haphazard distribution of improved cook stoves with faulty iron frames during a program in the Northern Peruvian Andes. The NGO responsible for a distribution of improved stoves mistakenly installed a subset of the stoves improperly, resulting in failure of the device and abandonment by households. The distribution of this unintended "treatment" was random and not intended by the NGO; therefore, adoption was not determined by underlying household characteristics. Survey results five years after implementation reveal that households still using the stove (i.e., those that happened to receive a working unit) experience reduced incidence of respiratory diseases and eye discomfort symptoms, relative to households that abandoned the non-functional device.

Additionally, the 1980s Chinese changeout program NISP (National Improved Stove Program) has been the source of academic inquiry, as distribution schemes did offer some exogenous variation. However, studies have faced hurdles in the amount of time elapsed since the program took place, widespread changes that have swept through China in the interim, seasonal and temporal variations in burning practices, and the confounding influence of tobacco smoke. Edwards et al. (2007) selected provinces to represent high, medium, and low adoption rates of improved stoves. Improved stoves reduced air pollution in homes that used combinations of biomass fuels, but produced no effects in homes using coal or LPG in addition to biomass.

Arguably the most salient results are generated by studies that exploit randomized distribution of wood stoves. A randomized distribution is not influenced by confounding factors in patterns of adoption. One success story is that of the random distribution of *Patsari* cookstoves in the Purèpucha region of Mexico given in Garcia-Frapollì et al. (2010). Households that received a stove used less fuelwood, and *patsari* adoption was associated with an 84% reduction in burns, a 44% reduction in acute respiratory disease, and a 62% reduction in eye discomfort (Romieu et al., 2009). Climate benefits were valuated to be a total of 38 hectares of forest cover per year saved, and 3,912 tons of CO_2 per year mitigated (Johnson et al., 2009).

These encouraging findings are supported by those of Ezzati and Kammen (2002), who find an improved stove randomly distributed to homes in Kenya implied significant reductions in high-intensity burning episodes, and reductions in incidence of acute respiratory infections among both genders, but particularly among women, who are disproportionately affected by wood smoke. This effect has been reproduced in other settings; namely, Bensch and Peters (2012) who find randomized distribution of improved stoves in rural Senegal resulted in reduced respiratory and eye infections among women, but did not produce any changes in men's health (who, the authors note, are almost never near the polluting stove). The Senegal study also found that homes that received a stove consumed substantially less firewood. The reduction in fuel used was not supported by Burwen and Levine (2012) who found that randomized construction of stoves in rural Ghana produced no statistically significant difference in fuel used, wood gathering time, or carbon monoxide. On the other hand, this intervention resulted in significant reductions in participants' self-reported health outcomes.

Generally, changeout programs' effects on fuel consumption and cooking and fuel-gathering time vary by study. Self-reported health seems to be consistently responsive to these interventions, but these results may be influenced by Hawthorne or John Henry effects. Some researchers take steps to mitigate these contaminating influences, such as Bensch et al. (2012), who framed the interventions as compensation for participation in a separate study (households who participated in a seemingly separate study were rewarded with either the treatment – a wood stove changeout – or the placebo – a large bag of rice).

One of the most comprehensive studies to date was the Randomized Exposure Study of Pollution Indoors and Respiratory Effects (RESPIRE) study (Smith-Siversten et al., 2004; Diaz et al., 2007), which was carried out in Mayan-Indian communities in the highlands of Guatemala. Beginning in October 2002, popular but expensive indigenously designed stoves called *planchas* were distributed to randomly selected women who were either pregnant or had a child less than four months old. CO levels were significantly lower among the *plancha* group post-intervention, compared to control households. Children in the treatment group experienced reductions in crying and of sore eyes (Duflo et al., 2008b). Women in the treatment group had reductions of sore eyes, of headaches, of sore throats, and of respiratory symptoms as compared to the control (Smith-Siversten et al., 2009). They also experienced lowered blood pressure (3.7 mm Hg lower systolic; 3.0 mm Hg lower diastolic) (McCracken et al., 2007). Infants born to women who received a stove weighed 89 grams more than those born to a control-group mother (Thompson et al., 2011). Additionally, no significant deterioration in these impacts was found over the course of the 18 months of study (Smith et al. 2010). However, no significant effects were found on backache prevalence (Diaz et al., 2007) or lung function (Smith-Siversten et al., 2009).

While the RESPIRE study offers encouraging results, it has important limitations. As Hanna et al. (2012) points out, researchers were heavily involved in the RESPIRE study. It was carried out over a relatively short time period (12 – 18 months), and the stoves were, by regional standards, quite expensive and otherwise infeasible for most families in the area, implying that families who received stoves may have been inclined to value them more than readily available, realistic, and scalable options. Fieldworkers associated with the study periodically inspected the stoves, instructed households on their proper use, and if necessary, made arrangements for repairs. According to Hanna et al. (2012), this involvement in the study prevented households from revealing their true valuation of the stoves. Through this monitoring and support, Hanna et al. (2012) argue, program administrators undermined the study's ability to predict how the interventions would perform in actuality.

Studies detached from program implementation – or that leave upkeep and maintenance investments to households – may see more realistic results. The outcomes of such a study are given in Hanna et al. (2012). The authors find that take-up and usage of randomly subsidized stoves in the Orissa province in India declined rapidly over time, as households failed to make ongoing investments in upkeep and maintenance. In fact, most households kept their existing stoves and cooked only 25 percent of their meals with the improved model (this was halved by the third year). Additionally, reductions in indoor air pollution were significant only during the first year (and were still smaller than laboratory results would predict). There was no appreciable effect on a range of measured and reported health outcomes. Finally, treatment households experienced *declines* in living standards and there was no evidence of any environmental co-benefits (i.e., reductions in deforestation or emissions). The disparity between these findings and those of previous studies underscores the importance of households' valuation and proper usage of a technology intervention.

3.2 Wood stove changeout studies carried out in industrialized economies

While it is true that the use of solid fuels is more widespread in the developing world, many homes in developed countries still rely on solid fuels, most commonly as a heat source. Certain wood stove changeout programs in rural communities in the Western United States have showed encouraging results overall, but puzzling findings lurk in the details. A changeout program consisting of 16 homes on the Nez Perce Reservation in Idaho (Ward, 2009; Ward et al., 2011) found significant reductions in $PM_{2.5}$ averages (56%) and maximum spike concentrations (60%). However, five homes that received a stove actually experienced higher concentrations following changeout. The authors suspect some of this can be attributed to changes in activity, and they refer to notations in the household activity logs kept as part of the study. A widespread, 2-year changeout of 1,200 stoves in Libby, Montana, found ambient $PM_{2.5}$ to be 27.6% lower in winters following changeout (relative to baseline winters; Ward, Palmer, Hooper, Bergauff, and Noonan, 2013). This was associated with reductions in reported wheeze and respiratory infections, including cold, bronchitis, influenza, and throat infection. However, findings across homes and years were highly variable, and 24% did not experience a reduction in $PM_{2.5}$ at all.

Perhaps the most comprehensive study in this setting to date was the Asthma Randomized Trial of Indoor Wood Smoke (Noonan et al., 2012b), which is the subject of this paper. This was a three-arm, randomized control trial consisting of a placebo treatment (sham air filter), wood stove changeout treatment, and working air filter treatment. The wood stove changeout was discontinued prior to the enrollment of the final cohort, as it did not significantly reduce PM concentrations or particle number concentrations (PNCs). The air filter did function as expected, significantly reducing air pollution in treated homes. ARTIS has already been the subject of two key studies. The determinants of indoor air quality are given in Semmens et al. (2015), and the effects of treatment (placebo, stove changeout, and active air filter) on indoor air quality are given in Ward et al. (2017). These will be discussed at greater length in Section 4.

3.3 Air filters

There is very little academic research regarding the efficacy of air filter interventions in reducing indoor air pollution. Reisman, Mauriello, Davis, Georgitis, and DeMasi (1990) present the results of a placebo-controlled trial that, like ARTIS, tested the efficacy of a sham filter and a working air filter in alleviating allergy symptoms. Outcomes were self-reported symptoms, and the study resulted in no significant differences between the placebo and control treatments. Hart et al. (2011) find that portable air purifiers reduced particulate matter and particle counts by as much as 85% in homes using wood stoves as a primary or supplemental source of heat. Similarly, a study of 31 Canadian homes found that those with air filters in active filtration mode experienced significant reductions in $PM_{2.5}$ as compared to homes with air filters in placebo mode (Wheeler et al., 2014). Barn et al. (2008) found that use of high-efficiency particulate air (HEPA; similar to those used in ARTIS) filter cleaners was correlated with lower indoor $PM_{2.5}$ in Canadian homes (during both summer and winter, when sources of PM were forest fires and wood stoves, respectively). Finally, Ward et al. (2017), reports that the air filter intervention in ARTIS was significantly more effective in reducing air pollution that the placebo filter and the wood stove changeout.

There is a growing body of literature that looks at the overall impacts of air pollution interventions on indoor air quality in homes where wood-burning stoves are used. Duflo et al. (2008b), as well as Ward et al. (2017), have speculated that behavioral responses to these interventions might affect their efficacy, but there has not been formal investigation into the merits of this hypothesis. However, behavioral response to health and safety interventions has been addressed in the economics literature. In order to develop these models, the next section reviews the literature on responses to other health and safety interventions.

3.4 Household behavioral response models

The first behavioral response model is the competing mortality risk model, developed extensively by Dow, Philipson, and Sala-I-Martin (1999), which addresses the spillovers of health investments. This model is characterized by relative probabilities of survival. Specifically, an intervention, by reducing one source of mortality, increases the odds of survival and incentivizes an individual to invest in other means to reduce mortality. Competing risks of mortality offer a disincentive to invest in health because, if an individual is exposed to many sources of risk, investing in reductions in one of them will not substantially improve life expectancy (Dow et al., 1999). By reducing the risk of death, an intervention reduces the risk that non-targeted health investments will be wasted, generating spillovers that are observed as indirect behavioral responses (i.e., increases in clinically unrelated health investments). Under this model, health investments are perceived as complements, and the change in behavior will enhance treatment effects.

There is empirical evidence to support the hypothesis that complementarities in health investments lead to spillovers. Dow et al. (1999) examined the effect of tetanus vaccinations given to pregnant women on birth weight. There is no direct medical pathway through which prenatal tetanus vaccinations could affect birth weight, but researchers found that the program had a significant positive effect on birth weights. The effect was attributed to behavioral changes in complementary input demands. Oster (2009) analyzed the impact of life expectancy on investments in AIDS prevention (which was proxied by number of sexual partners) and found that increases in expected longevity reduced the number of partners. That is to say, longer life expectancy increased preventive behavior. Carneiro, Locatelli, Gebremeskel, and Keating (2011) explored the effects of an anti-malarial indoor residual spray program on insecticide treated net usage and other risk mitigating factors in Eritrea. They found no reduction in either behavior, and households who received the treatment were more aware of the risk of mosquitoes and the susceptibility of children. Yarnoff (2010) found that households respond to vitamin A supplementation by increasing investments in another health input: insecticide treated bed nets.

The next model is the offsetting behavior model. This dictates the response when a health intervention or a new strategy is perceived as a substitute to existing health inputs. In these cases, individuals respond to an intervention or subsidy by reducing their investments in non-targeted health inputs, potentially muting the treatment effects of the intervention. Perhaps the most well-known example is provided by Peltzman (1975), whose seminal paper deals with the impact of government-mandated automobile safety equipment on highway safety. Mandated safety regulations had little impact on highway deaths, demonstrating, as Peltzman argued, that these regulations probably made cars safer, but reduced the cost of reckless speed, to which drivers responded by raising their "driving intensity."

There is empirical support for this in a number of contexts. Using randomized levels of encouragement outreach, Nikolov (2011) found that HIV positive patients being treated with antiretroviral medication who received increased support (in the form of peer adherence supporter visits, nutritional supplementation, etc.) had significantly more sexual partners and were significantly less likely to use a condom during these encounters (compared to those who did not receive such support). Mancino and Kuchler (2009) find that although people diagnosed with high cholesterol consume less cholesterol and fat and smoke less; those using cholesterol-lowering drugs (statins, etc.) have increased fat intake and larger waist size (using instrumental variables to control for endogeneity of taking medication).

Whether a household health intervention is perceived as a complement or substitute to other health inputs helps determine household response. If they are perceived as complements, the competing mortality risk model predicts that a family receiving an intervention will increase other health inputs. If they are substitutes, the offsetting behavior model predicts they will decrease other health investments. In the case of wood-burning stoves (and more specifically, the ARTIS study), the wood stove changeouts and filters likely have an imperceptible effect on life expectancy, so the resulting impacts on behavior may also be too small to detect. Based on these models, and the context of this study, it is more likely that behavior change in this case is attributable to the offsetting behavior model.

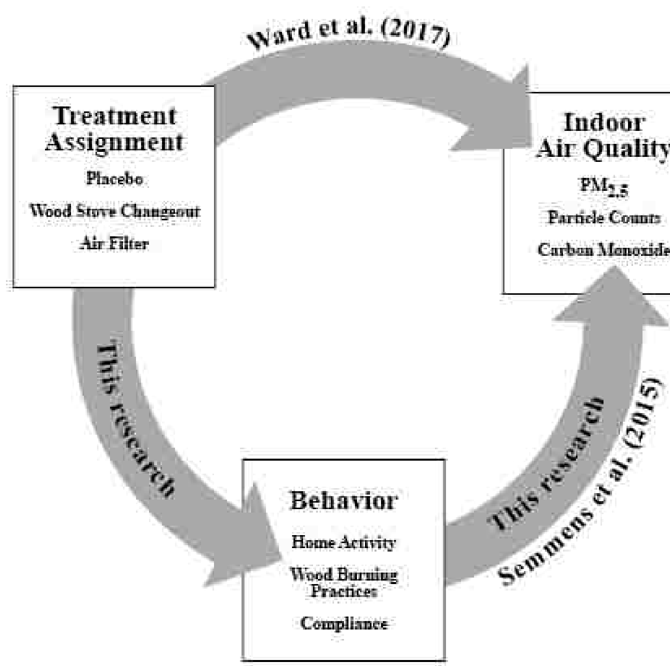
3.5 Contribution to literature

Overall, the existing body of literature indicates that woodstove changeouts can be effective in reducing pollution and fuel usage, and in improving health. This is especially true of studies with substantial administrative support (i.e., interventions in which researchers remain heavily involved in monitoring). Hanna et al. (2012) cast doubt on positive findings from previous randomized trials, and showed that, when left to their own devices, households undervalue improved stoves, which limits their effectiveness. Hanna et al. (2012) advise further study into the role of household behavior in similar intervention studies (a call echoed by Ward et al., 2017). Furthermore, evidence exists of post-intervention behavior change in a number of health-related interventions, but these behavioral models have not been applied to woodstove or air filtration interventions. This paper also adds to existing research by addressing the nature of behavior change in response to an air filter intervention, in addition to the changeout treatment. There is very little rigorous inquiry into the effects of air filters.

Additionally, there is a relatively small amount of research into the use of solid fuels and the effectiveness of interventions in rural communities within industrialized countries. Many state governments offer rebates and incentive schemes to encourage rural residents to exchange their stoves, but little has been done to characterize the nature of indoor air pollution in these communities and to analyze the effectiveness of these programs.[7] This study addresses this deficiency by expanding on the analysis of an intervention study carried out in rural communities in the United States.

Two previous studies feature prominently in this analysis: Semmens et al. (2015) and Ward et al. (2017). The former looked at whether home activity and wood-burning practices impact indoor air quality. The latter looked at whether treatment assignment impacted indoor air quality. In fact, most of the existing studies in this field look at the pathway from treatment assignment to air quality. My research concerns the pathway by which treatment assignment affects air quality (i.e., whether treatment assignment affects behavior, and that, in turn, affects air quality). This is diagrammed in Figure 2.

Figure 2: Contribution to literature



[7] https://www.hpba.org/Consumer-Education/Woodstove-Changeouts

4. The ARTIS Program

This study uses data from the Asthma Randomized Trial of Indoor Wood Smoke (ARTIS), a placebo-controlled, randomized study of wood stove changeouts and air filtration units. This section covers study design and existing findings.

4.1 Study site and population

The study was carried out in semi-urban and rural communities in the Northern Rockies and Alaska. Eligible families were non-tobacco-smoking, included at least one asthmatic child, and resided in homes heated by older model wood stoves (older model wood stoves are wood-fueled and lack the means for emissions control). The six treatment sites were Hamilton, Butte, Missoula, and the Missoula outskirts (all in Montana), the Nez Perce Indian Reservation in Idaho, and Fairbanks, Alaska. These locations were selected due to existing partnerships. The first cohort was enrolled for the winter of 2008-09; the final cohort for the winter of 2011-12. A summary of the cohorts is given in Table 1. Note that only one cohort was enrolled for each site.

Table 1: Community, cohort summary

	COHORT				
Community	Winter 08-09	Winter 09-10	Winter 10-11	Winter 11-12	Winter 12-13
Hamilton	Placebo: 4 WS: 4 Air filter: 4 **Total: 12**	Placebo: 4 WS: 4 Air filter: 3 **Total: 11**			
Missoula		Placebo: 7 WS: 6 Air filter: 7 **Total: 20**	Placebo: 7 WS: 5 Air filter: 6 **Total: 18**		
Nez Perce Reservation		Placebo: 2 WS: 2 Air filter: 2 **Total: 6**	Placebo: 2 WS: 2 Air filter: 1 **Total: 5**		
Butte			Placebo: 3 WS: 2 Air filter: 3 **Total: 8**	Placebo: 2 WS: 2 Air filter: 3 **Total: 7**	
Fairbanks			Placebo: 3 WS: 2 Air filter: 3 **Total: 8**	Placebo: 3 WS: 2 Air filter: 3 **Total: 8**	
Western Montana				Placebo: 21 WS: --- Air filter: 22 **Total: 43**	Placebo: 20 WS: --- Air filter: 18 **Total: 38**

4.2 Recruitment, study design, and interventions

Active recruitment was done through administration of a survey to identify potential candidates for the study.[8] Passive recruitment occurred through advertisement of the program by way of flyers and posters. Both forms of recruitment were administered in local schools. Households identified by the survey, or those that contacted researchers upon learning of the program, were then screened through a phone interview prior to enrollment. The sample size was 98 homes, or 114 children (as several households included multiple children eligible for the study).

[8] ISAAC: International Study of Asthma and Allergy in Children, 5th – 11th grades

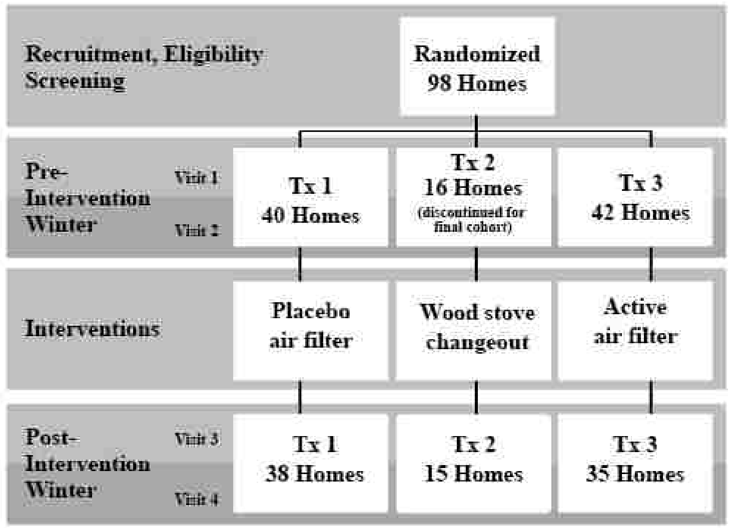
Households were randomly sorted into one of three treatment groups. The three-treatment design allowed researchers to scrutinize the efficacy of both high- and low-cost means for reducing in-home smoke; the high-cost intervention being the wood stove (2500 – 4500 USD per home) and the low-cost being the air filtration unit (500 USD per home, including the unit, yearly filter replacement, and energy usage costs). The treatments were as follows:

Placebo: Two units fitted with non-functioning filter material were placed in homes assigned to the placebo treatment. A large unit was placed in the same room as the wood stove, while a smaller one was located in the child's bedroom. Both were set to the "high" setting and the sham filters were changed monthly. Compliance was monitored by recording the filter's energy usage in kilowatt hours, and then comparing this figure with expected energy output. Households assigned to the placebo were given functioning filtration materials upon completion of the study. These homes kept their existing stoves (i.e., received no changeout).

Wood stove changeout: Old wood stoves were exchanged for high-efficiency, EPA-certified wood-burning stoves. These stoves were installed by certified technicians, and successful installation was verified by a wood stove expert, who also provided guidance to households on the appliance's maintenance needs. No air filters were provided. This treatment was discontinued prior to the final cohort (Western Montana; Winter 2012-2013).

Air filter: A large unit fitted with functioning filter material was placed in the stove room; a small unit placed in the child's room, as was the procedure for the placebo households. Filters were changed periodically in accordance with manufacturer's recommendations, and compliance was monitored. As with the placebo treatment, these households kept their original stoves (did not receive a changeout). The study design is given in Figure 3.

Figure 3: Study Design



Exposure and health outcome evaluations were completed over two visits during the pre- and post-intervention winters (as wood stoves are used more frequently during the winter). Details of data collection are given in Section 5.

4.3 Semmens et al. (2015)

The main objective of Semmens et al. (2015) is to characterize indoor particulate matter in homes using wood stoves as a primary heat source. Therefore, the dependent variable is log-transformed air quality, and right-hand side variables include demographics, home characteristics, weather, and wood-burning and home activities (see Table 7). Restricting the analysis to pre-intervention winter, Semmens et al. (2015) use generalized estimating equations with exchangeable correlation structure and robust standard errors to account for repeated measures within households and the effects of temporal variations on indoor air quality. Due to sample size constraints, community indicators are not included; instead, the analysis was done separately for each community in the sensitivity analysis.

Semmens et al. (2015) report that income, living in a house (relative to a mobile home, duplex, or other), and square footage are negatively associated with PM concentration and PNC, while number of children in the home is positively associated with PM and PNC. Of most relevance to this study were the behavioral findings. The number of times the wood stove was opened and the intensity of burning were not associated with air quality. However, length of seasoning was negatively associated with PM and PNC, and use of a supplemental heating source, burning of any type, and having an open door or window were positively associated with air pollution. The effects of meteorological variables were insignificant.

These results help inform this study by giving the determinants of indoor air quality. Not only do these findings offer evidence that behavior does impact air quality, which motivates this research, they also help inform the inclusion of covariates in subsequent models.

4.4 Ward et al. (2017)

Ward et al. (2017) is the most comprehensive analysis of the ARTIS study's effects on air quality. This paper provides the model for analyzing the impact of treatment assignment and winter (pre- or post-intervention) on PM concentrations, coarse and fine particle counts, and carbon monoxide concentration. The experimental design solves problems of endogeneity and selection bias. Therefore, the authors begin by estimating the effect of treatment on air quality measures without additional covariates. Analysis for each air quality variable was done separately, and air quality variables were log-transformed. The authors used linear mixed models to account for repeated measurements of indoor air quality on the same home. This preliminary model includes only sampling winter (an indicator for pre- or post-), treatment group assignment (a three-level factor variable), and finally, a multiplicative interaction term with both.

Ward et al. (2017) further specified a model adjusted for a number of factors to account for the possibility of unequal distribution of potentially confounding factors between treatment groups. Burwen et al. (2012) note that the experimental design of a randomized controlled trial allows simply comparing the differences in mean values post-intervention. However, controlling for household characteristics and heating patterns increases precision by reducing the variance of the estimator (see Duflo et al., 2008b). Ward et al. (2017) includes a set of covariates similar to the right-hand side variables in the model from Semmens et al. (2015). A comparison of covariates between studies is given in Table 8.

They find that the placebo treatment resulted in insignificant reductions in $PM_{2.5}$, fine particles, and carbon monoxide, but it did result in a highly significant reduction of coarse particles. This is addressed in Ward et al. (2017), who note that the porous nature of the placebo filter was likely efficient at "scrubbing" out coarse fraction particles, while allowing fine particles to pass through.

Only 16 homes received the stove changeout treatment before this intervention was discontinued. This treatment saw no significant reductions in PM or PNCs, but did reduce carbon monoxide by 87% relative to the placebo.

Finally, the air filter treatment group experienced significant reductions in PM and PNCs.

Household activity and wood-burning practices were included as covariates in this paper. This does not address the present study's research question: To what extent does household response affect household air quality and efficacy of treatments? Ward's model addresses the impact of treatment given a fixed level of behavior. In this analysis, Ward's model is modified to address the variable impacts of treatment on households that modified their behavior.

5. Data

5.1 Data Collection

Data collection occurred over the course of two visits during each of the pre- and post-intervention winters. A small number of households were visited a third time to collect samples unrelated to this inquiry; therefore, these visits are not included in this analysis. Each of the four visits included exposure sampling and health outcome collection. Health-related data were collected at the individual level, but this research will only make use of household-level variables.

Air pollution measures were collected over a 48-hour sampling period. Three air samplers were used to continuously monitor air quality, including $PM_{2.5}$ concentrations, particle counts per cubic centimeter (fine and coarse), carbon dioxide, temperature, and relative humidity. The monitors were placed together at a consistent height of three to five feet off of the ground.

Households kept an activity log and a wood-burning record during the 48-hour exposure sampling. In the activity log, households recorded events that could affect the data collection including cooking, cleaning, other burning, or opening of windows or doors. The wood-burning record kept track of the families' use of the stove during exposure sampling: how frequently the wood stove was stoked or loaded, burn intensity, amount burned, source of wood burned, and age and seasoning time of the wood. Air filter compliance is the final behavior variable. The filtration devices (placebo and active) recorded energy usage in kilowatt hours. These usage figures were compared with the expected usage to determine to what extent the filter was 'on.' It is important to note that keeping the filters running was somewhat of a burden, as the devices reportedly made an irritating sound and affected household energy costs. Compliance data were of course only collected for the placebo and active filtration treatment groups, as households in the changeout group did not receive a filtration device. These data were only available for the second (post-intervention) sampling winter, so rather than change in behavior as the variable of interest, in this case, degree of compliance is the variable of interest. Note that despite not being a 'change' variable, air filter compliance still represents a response to intervention.

5.2 Summary statistics

5.2.1 Baseline characteristics and balance testing

The initial sample was 98 households. One was dropped due to missing carbon monoxide data, so 97 are included in this analysis.

Households completed demographic and home surveys prior to sampling. This included household income, education, ethnicity and race, age and square footage of the home, number of children, presence of pets, and age of the wood stove. Selected demographic variables and home characteristics are given in Table 2. Over 40% of caregivers reported having a college degree, and 38% of households earn at least $50,000 per year. The average number of children in household is 2.47, and 68% live in a house (as opposed to a mobile home, apartment, duplex, or other). More than 80% of wood stoves were installed after 1988, and 58% use another source of heat in addition to the wood stove.

Table 2: Baseline summary statistics

	Overall	Placebo	Changeout	Filter
		Mean (SD)		
Humidity (%)	73.42 (11.58)	73.10 (10.57)	74.74 (15.28)	73.20 (10.93)
Temperature (F)	26.80 (14.71)	26.08 (13.69)	25.78 (18.55)	27.95 (14.09)
Average wind speed (mph)	3.448 (2.431)	3.807 (2.439)	2.906 (2.506)	3.306 (2.368)
Precipitation (in)	0.0242 (0.0536)	0.0249 (0.0562)	0.0339 (0.0677)	0.0196 (0.0438)
Number of children in home	2.468 (1.274)	2.400 (1.208)	2.667 (1.561)	2.456 (1.215)
Home square footage (hundreds)	20.16 (8.896)	20.97 (9.836)	16.61 (6.070)	20.33 (8.461)
		Frequency (%)		
Caregiver's education level (0-1)				
0 No college degree	49 (56.32)	21 (53.85)	9 (64.29)	19 (55.88)
1 College degree or higher	38 (43.68)	18 (46.15)	5 (35.71)	15 (44.12)
Household yearly income (0-1)				
0 Less than $49,999	55 (61.80)	25 (64.10)	9 (60.00)	21 (60.00)
1 $50,000 or more	34 (38.20)	14 (35.90)	6 (40.00)	14 (40.00)
Home type				
0 Mobile home, apartment, or other	31 (31.96)	13 (32.50)	7 (43.75)	11 (26.83)
1 House	66 (68.04)	27 (67.50)	9 (56.25)	30 (73.17)
Pet in home				
0 No pet	17 (17.53)	7 (17.50)	2 (12.50)	8 (19.51)
1 Dog, cat, or bird	80 (82.47)	33 (82.50)	14 (87.50)	33 (80.49)
Year home built				
0 Before 1978	46 (47.42)	20 (50.00)	9 (56.25)	17 (41.46)
1 After 1978	51 (52.58)	20 (50.00)	7 (43.75)	24 (58.54)
Year wood stove built				
0 Before 1988	16 (16.49)	6 (15.00)	4 (25.00)	6 (14.63)
1 After 1988	81 (83.51)	34 (85.00)	12 (75.00)	35 (85.37)
Other heat source				
0 No other heat source	40 (41.67)	15 (38.46)	4 (25.00)	21 (51.22)
1 Gas, electricity, propane, or oil	56 (58.33)	24 (61.54)	12 (75.00)	20 (48.78)
n	97	40	16	41

Baseline home activity and wood burning variables are given in Table 3. The mean number of times the stove was opened during the first visit was 3.2, and the average number of cords burned was 5.6. More than 70% reported average to heavy burning during the first sampling period, and 59% reported using wood aged longer than one year. 31% report having opened a door or window during the sampling period, and the same percentage reported other burning. High and low compliance is divided by the median.

Table 3: Baseline home activity and wood-burning (behavior) summary statistics

	Overall	Placebo	Changeout	Filter
	Mean (SD)			
Number of times the stove was stoked or loaded	3.225 (4.162)	2.987 (4.250)	4.812 (4.915)	2.808 (3.608)
Amount of wood used (cords)	9.503 (55.45)	4.614 (1.955)	5.250 (2.427)	5.701 (2.751)
Mean compliance (post-intervention)	79.05 (33.86)	79.82 (30.27)	. (.)	78.18 (37.72)
	Frequency (%)			
Burning intensity (0-1)				
0 None – light	28 (28.87)	11 (27.50)	3 (18.75)	14 (34.15)
1 Average – heavy	69 (71.13)	29 (72.50)	13 (81.25)	27 (65.85)
Wood age (0-1)				
0 Less than 1 year	38 (40.86)	16 (42.11)	7 (43.75)	15 (38.46)
1 1 year or longer	55 (59.14)	22 (57.89)	9 (56.25)	24 (61.54)
Doors or windows opened during sampling				
0 No open doors or windows	66 (68.75)	27 (69.23)	8 (50.00)	31 (75.61)
1 Door or window opened	30 (31.25)	12 (30.77)	8 (50.00)	10 (24.39)
Other burning during exposure sampling				
0 No other burning	66 (68.75)	26 (66.67)	10 (62.50)	30 (73.17)
1 Smoke, incense, candle, or lamp	30 (31.25)	13 (33.33)	6 (37.50)	11 (26.83)
Cleaning during exposure sampling				
0 No cleaning	33 (34.38)	13 (33.33)	5 (31.25)	15 (36.59)
1 Vacuuming, sweeping, or dusting	63 (65.62)	26 (66.67)	11 (68.75)	26 (63.41)
Compliance (post-intervention)				
Low compliance	35 (48.61)	17 (44.74)	(.)	18 (52.94)
High compliance	37 (51.39)	21 (5.26)		16 (47.06)
n	97	40	32	41

Both Semmens et al. (2015) and Ward et al. (2017) log-transformed air quality variables. This has been confirmed to be appropriate for this analysis. The original data are right-skewed, but the log-transformed data fit normal distributions. Kernel density plots for original and log-transformed data are given in the Appendix (Figures 4 and 5). The original (non-log-transformed) baseline data are presented in Table 4.

Table 4: Baseline air quality summary statistics

	Overall	Placebo	Changeout	Filter
		Mean (SD)		
$PM_{2.5}$ concentration average ($\mu g/m^3$)	29.58 (30.41)	23.92 (24.31)	41.02 (27.75)	30.32 (35.30)
$PM_{2.5}$ concentration maximum ($\mu g/m^3$)	795.8 (1797.2)	437.4 (609.7)	894.5 (1065.5)	1100.0 (2584.8)
Coarse particle count (millions)	0.491 (0.643)	0.531 (0.843)	0.574 (0.558)	0.420 (0.418)
Fine particle count (millions)	69.75 (62.36)	64.04 (63.77)	105.7 (69.99)	60.75 (52.81)
Carbon monoxide concentration average ($\mu g/m^3$)	0.809 (2.574)	0.422 (1.526)	1.257 (3.110)	1.007 (3.102)
n	186	76	32	78

mean coefficients; sd in parentheses

Households were randomly assigned into treatment groups. To check the balance of household characteristics and baseline measurements between treatment groups, tests of proportion, Wilcoxon Rank Sum tests, and t-tests are used. Note that this tests balance, not randomness. The only way to ensure randomization is to observe the randomization process itself. However, an imbalance of characteristics across treatment groups could bias estimates, and models would be adjusted to include baseline measurements to increase precision. However, bias is mitigated in this study by the use of panel data (dependent variables are first-differenced values).

Tests of proportion are used to compare the distribution of indicator variables across treatment groups. A Wilcoxon Rank Sum test was used to compare the number of children across treatment groups, and t-tests were used for continuous variables. Tables given in the Appendix report only p-values from these tests (Tables 22-24). These tables indicate that demographic, home, weather, and baseline behavior values were comparable between treatment groups. However, baseline air quality was significantly worse in the changeout group compared to the rest of the sample.

5.2.2 Behavior variables

One of the main variables of interest in this paper is change in behavior from the pre-intervention sampling winter to the post-intervention sampling winter. Behavior change was determined by subtracting pre-intervention averages from post-intervention averages, as reported in the following table (Table 5). These changes are also illustrated in the Appendices (Figures 6-12).

Table 5: Mean changes in individual behavior measures

Δ Individual behavior measures (Post-intervention average – pre-intervention average)	Overall	Placebo	Changeout	Filter
Δ Stoking and loading the stove	-1.355	-1.338	-2.643	-0.812
	(4.071)	(4.664)	(4.194)	(3.185)
Δ Burning intensity	0.141	0.0294	0.0357	0.317
	(0.683)	(0.651)	(0.796)	(0.650)
Δ Wood age	0.0921	0.0909	0.107	0.0862
	(1.012)	(1.128)	(1.163)	(0.814)
Δ Wood usage	-0.216	0.400	-0.525	-0.808
	(2.421)	(2.730)	(1.805)	(2.136)
Δ Opening of doors/windows	-0.182	-0.153	-0.367	-0.132
	(0.392)	(0.411)	(0.297)	(0.395)
Δ Other burning	-0.0176	0	-0.0667	-0.0147
	(0.419)	(0.463)	(0.320)	(0.417)
Δ Cleaning	-0.0765	-0.0694	-0.167	-0.0441
	(0.485)	(0.599)	(0.408)	(0.377)
n	87	38	15	34

mean coefficients; sd in parentheses

For this analysis, two index variables capture how household behavior changed overall. The four behaviors related to wood-burning practices were combined into one variable, and the three behaviors related to home activities were combined into one variable. These are summarized in Table 6.

Table 6: Behavior index composition

Wood-burning practices		Home activities	
Variable	**Description**	**Variable**	**Description**
Activity	Number of times the stove was stoked or loaded during the sampling period	Open doors/windows	0 No open doors or windows 1 Any open doors or windows
Burn Intensity	0 None/light 1 Average/heavy	Other burning	0 No other burning 1 Smoke, incense, candle, or lamp
Wood age	0 Less than 1 year 1 1 year or longer	Cleaning	0 No cleaning 1 Vacuuming, sweeping, or dusting
Wood usage	Amount of wood burned over the course of the sampling period, cords		

The composite variables are indicators for whether a household's behavior got worse (i.e., they exhibited more polluting behaviors during the post-intervention sampling winter). So, for the wood-burning index, a household receives a value of one if two or more of their wood-burning behaviors got worse over the course of the study. A household receives a value of zero for this index if one or fewer wood-burning practices got worse. For the home activity index, a household receives a value of one if one or more of their home activity behaviors got worse after the interventions were distributed; it receives a value of zero otherwise. Variables for each behavior – as well as for summary or index variables – are summarized below.

Table 7: Behavior change indicators

	Overall	Placebo	Changeout	Filter
Activity increase				
0 (No Δ)	68	31	13	24
	(78.16)	(81.58)	(86.67)	(70.59)
1(Δ)	19	7	2	10
	(21.84)	(18.42)	(13.33)	(29.41)
Burning intensity increase				
0	47	23	9	15
	(54.02)	(60.53)	(60.00)	(44.12)
1	40	15	6	19
	(45.98)	(39.47)	(40.00)	(55.88)
Wood age decrease				
0	63	26	12	25
	(72.41)	(68.42)	(80.00)	(73.53)
1	24	12	3	9
	(27.59)	(31.58)	(20.00)	(26.47)
Wood usage increase				
0	49	23	8	18
	(56.32)	(60.53)	(53.33)	(52.94)
1	38	15	7	16
	(43.68)	(39.47)	(46.67)	(47.06)
Wood index				
0	47	22	9	16
	(54.02)	(57.89)	(60.00)	(47.06)
1	40	16	6	18
	(45.98)	(42.11)	(40.00)	(52.94)
Open doors/windows increase				
0	78	32	15	31
	(89.66)	(84.21)	(100.00)	(91.18)
1	9	6	0	3
	(10.34)	(15.79)	(0.00)	(8.82)
Other burning increase				
0	68	27	13	28
	(78.16)	(71.05)	(86.67)	(82.35)
1	19	11	2	6
	(21.84)	(28.95)	(13.33)	(17.65)
Cleaning increase				
0	68	27	13	28
	(78.16)	(71.05)	(86.67)	(82.35)
1	19	11	2	6
	(21.84)	(28.95)	(13.33)	(17.65)
Home index				
0	53	21	11	21
	(60.92)	(55.26)	(73.33)	(61.76)
1	34	17	4	13
	(39.08)	(44.74)	(26.67)	(38.24)
Median compliance				
Low	35	17	(.)	18
	(48.61)	(44.74)		(52.94)
High	37	21		16
	(51.39)	(5.26)		(47.06)
Observations	87	38	15	34

Behavior indices are constructed in this manner due to the nature of the component behavior variables. Wood-burning and home activity behaviors (stoking and loading the stove, burning intensity, wood age, etc.) were measured in varying units, so their nominal values could not be combined. For example, wood usage was a count variable, whereas burning intensity was an ordered factorial variable. As indicator variables, households can be scored based on the number of behaviors they improved or did not improve over the course of the study. The cutoffs for whether a household is categorized as a behavior-changer or not were chosen to be at approximately the 50^{th} percentile to achieve even populations of behavior-changers and non-behavior-changers, as the sample will be stratified by these distinctions in the second part of the behavior analysis. These cutoffs will be subjected to scrutiny in Section 7.

The final behavior variable (for the placebo and air filter treatment groups) is air filter compliance. Compliance was a response to the devices themselves, so it is not a 'change' variable. Rather, compliance is classified as 'low' and 'high,' according to percentile (high compliers are in the upper 50^{th} percentile of compliance; low compliers fall below the 50^{th} percentile of compliance).

5.3 Attrition

Attrition may pose a threat to the study's validity if certain types of households are systematically leaving the study. If certain characteristics make a household less likely to complete the study, it can bias estimates. In this study, 10 households (10.20%) were lost to attrition. The distribution by treatment group was as follows: two (5.00%) attritors from the placebo block, one (6.25%) from the changeout block, and seven (16.67%) from the filter block. A higher proportion of homes assigned to the air filter treatment left the study. To investigate this further, a probit model is estimated in which the dependent variable takes on a value of one if the household dropped out of the sample (zero otherwise). Explanatory variables include treatment assignment, community, and a set of demographic variables. Results are reported in the Appendix (Table 25). When the regression includes treatment assignment as the sole independent variable and community effects are included, the results indicate that a household assigned the air filter is much more likely to leave the study compared to the placebo. However, this does not hold with the inclusion of the rest of the community and demographic variables. Full regression results indicate participants who live in a house were significantly more prone to attrition, those with more children were more prone to attrition, and that for each additional hundred square feet of home, a participant is less prone to attrition.

According to Duflo, Greenstone, and Hanna (2008a), an important consideration is the possibility that attritors were selected differently in the treatment and control groups. For example, in a medical study, attrition due to death and attrition due to feeling healthier would not be viewed interchangeably. In this case, the study was a two-period panel, so it is unlikely households would have left due to effects of the treatment. According to Semmens et al. (2015), two households did not complete post-intervention sampling due to a change in residence, and eight did not wish to proceed with sampling. These figures were not separated by treatment, so it is not possible to compare the reason for attrition between treatment groups. As attrition seems to be associated with home type and size, as well as number of children, and these are not key determinants of household air quality, attrition can be considered ignorable.

It is also important to comment on how attritors were defined for the purposes of this study. Following Ward et al. (2017), attritors are those for whom no post-intervention data are available. This means that households that completed the third data collection visit (the first post-intervention) but did not complete the fourth visit, are not considered attritors. Rather than leaving the study early, this is seen as a missing observation, as some households missed – for example – the second visit, but were not considered attritors. If a household had data available before and after the intervention was installed, that household is not considered an attritor.

6. Models

The aim of this paper is to determine to what extent behavioral responses to treatment affect household air quality. Consider the production function for household air quality:

(1)

$$Y_{ij} = f(P)$$

where Y_{ij} is the outcome, air quality, and P is a vector if inputs that contribute to household air quality, including the determinants from Semmens et al. (2015), as well as stove efficiency, presence of a filter, etc. Section 6.1.1 investigates this vector of inputs.

To estimate the overall impact of ARTIS program interventions, consider the expression below, from Duflo et al. (2008b), which gives the expected average effect of treatment on air quality:

(2)

$$E[Y_{ij}^{C,F} - Y_{ij}^{P}]$$

where $Y_{ij}^{C,F}$ is average air quality for households that have received a given intervention (changeout or filter), and Y_{ij}^{P} is average air quality for households that received the placebo. The model for overall treatment effects is given in Section 6.1.2, following Ward et al. (2017).

Some of the determinants of indoor air quality are directly impacted by intervention (e.g., stove efficiency for changeout homes, or filtration, depending on compliance). Interventions may also indirectly impact air quality by affecting other inputs, particularly pollution-related behavioral factors. Section 6.1.2 estimates the impact of treatment on air quality all else constant (i.e., the partial derivative of the outcome). Section 6.2.1 and 6.2.2 approximate the total derivative of air quality with respect to treatment, by investigating the effects of treatment on other inputs in the air quality production function (1). If pollution-reducing behaviors are complements or substitutes for treatment, changes in the vector of inputs P will lead to changes in pollution-reducing behaviors. These effects are covered in Sections 6.2.1 and 6.2.2.

6.1 Initial regressions

6.1.1 Pre-intervention determinants of indoor air quality

The first step, following Semmens et al. (2015), is to estimate the determinants of indoor air quality. This information will be used in later models. To account for repeated sampling within households, a multilevel mixed effects model is estimated. Following Noonan et al. (2017), random effects account for repeated sampling during each period (as each home was visited twice both pre- and post-intervention). Inclusion of random effects resolves non-independence by assuming a different baseline, or intercept, for each household. Random intercepts are included in the model, but random slope is not, as this analysis is restricted to pre-intervention data. Following previous ARTIS studies, robust standard errors are used.

The household characteristics and behaviors included in this model are summarized in the following table. The inclusion of these controls is informed by existing studies (namely, Semmens et al., 2015) and the theoretical determinants of household air quality (as given in IARC, 2010 and Clark et al., 2010).

Table 8: Comparison of covariates between ARTIS papers

	Ward et al. (2017)	Semmens et al. (2015)	This paper
Demographic characteristics, home characteristics, ambient meteorology	Household income Caregiver's education Children in home, mean Home type Indoor temperature Indoor humidity Temperature Humidity Precipitation	Household income Caregiver's education Children in home, mean Home type Indoor temperature Indoor humidity Home square footage, mean Dog Cat Other heat source Temperature Humidity Precipitation Wind % of day spent in home by child, mean	Household income Caregiver's education Children in home, mean Home type Home square footage, mean Pet Year wood stove built Other heat source Temperature Humidity Precipitation Wind
Activities in or near the home	Open door or window Burning	Open door or window Burning	Open door or window* Burning* Cleaning*
Wood, wood stove, and usage	Method of acquiring wood Wood age Burn intensity	Method of acquiring wood Wood age Woodstove opened, mean Burn intensity	Wood age* Woodstove opened, mean* Burn intensity* Amount of wood used*

*Variables used in determinants of air quality model; not used in treatment effects model

In addition to characteristics included in previous studies' models, this paper's model includes an indicator variable for the year the wood stove was installed, which takes on a value of one for stoves installed after 1988; zero otherwise. The EPA's New Source Performance Standards (NSPS) set new regulations governing the manufacture and sale of new wood stoves and certain wood burning fireplace inserts after 1988.[9] The model also includes an indicator for cleaning that took place, and an indicator for presence of a pet (dog, cat, or bird).

The model – modified from Semmens et al. (2015) – is given below. This analysis is restricted to the first sampling winter (pre-intervention):

[9] https://www.gpo.gov/fdsys/pkg/CFR-2013-title40-vol7/pdf/CFR-2013-title40-vol7-part60-subpartAAA.pdf

(3)

$$Y_{ij} = \beta_0 + \beta_1 H_{ij} + \beta_2 W_{ij} + \beta_3 X_{ij} + \varphi_j + \mu_i + \varepsilon_i$$

where Y_{ij} is the set of air quality outcome variables (particulate matter, coarse and fine particle counts, and carbon monoxide concentration) in household i and community j. H_{ij} is a set of household activity variables, W_{ij} is a set of wood-burning variables, and X_{ij} is a set of control variables, including demographics, home characteristics, and ambient meteorology (see Table 8). The model includes dummy variables for community (φ_j) and household random effects (μ_i). This paper differs from Semmens et al. (2015) in its approach to community effects. Semmens et al. (2015) did not include indicators for community, instead running the models separately for each community due to sample size concerns. For this analysis, the sample is going to be stratified by behavior change, and to stratify it further by community would result in unworkably small sample sizes. Instead, in this paper's models, dummy variables account for community-level variation. This also captures variation by year, as each community included only one cohort.

6.1.2 Effect of air quality interventions on air quality

The second step in the initial analysis is determining the effect of three air quality interventions (placebo filter, stove changeout, and active filter) on indoor air pollution. The model – adapted from Ward et al. (2017) – is given below:

(4)

$$Y_{ij} = \beta_0 + \sum_{m=0}^{2} \sum_{k=0}^{1} \left(\alpha_{m \times k}\left(T_{ijm} \times I_k\right)\right) + \varphi_j + \mu_i + \varepsilon_i$$

where Y_{ij} is the same set of air quality variables, T_{ijm} is the treatment assignment in household i and I_k is winter (pre- or post-intervention). m takes on values from 0 to 2, representing the three treatment assignments (0 being placebo; 1, changeout; and 2, air filter), and k takes on values from 0 to 1 representing both sampling winters. The multiplicative interaction term calculates treatment effects ($\alpha_{m \times k}$).

Controlling for baseline covariates that are likely to impact the outcome does not affect the value of the estimator, but it can reduce variance. However, controlling for covariates affected by treatment can lead to bias. This is because including these covariates can cause the model to underestimate treatment effects. At this point, it is not clear whether treatment affected pollution-related behaviors, H_{ij} and W_{ij}. In model (5) – this paper's model – they are not included, but, following the methods presented in Ward et al. (2017), model (6) includes home activity and wood-burning variables as covariates: With the inclusion of covariates from (3), this becomes:

(5)

$$Y_{ij} = \beta_0 + \sum_{m=0}^{2} \sum_{k=0}^{1} \left(\alpha_{m \times k}(T_{ijm} \times I_k)\right) + \beta_1 X_{ij} + \varphi_j + \mu_i + \varepsilon_i$$

(6)

$$Y_{ij} = \beta_0 + \sum_{m=0}^{2} \sum_{k=0}^{1} \left(\alpha_{m \times k}(T_{ijm} \times I_k)\right) + \beta_1 H_{ij} + \beta_2 W_{ij} + \beta_3 X_{ij} + \varphi_j + \mu_i + \varepsilon_i$$

where the multiplicative interaction term is the same as in (4) and H_{ij} is the same set of household activity variables, W_{ij} the same set of wood-burning variables, and X_{ij} the same set of control variables, including demographics, home characteristics, and ambient meteorology. In these models, random intercept and random coefficient for slope are included, following Noonan et al. (2017), which initially included random effects for intercept and slope. This approach allows each treatment unit to have its own intercept and slope describing change in air quality from pre-intervention to post-intervention winter.

6.2 Behavior analysis

6.2.1 Effects of treatment assignment on behavior change

To determine the effect of treatment assignment on household polluting behavior, proportions of each treatment block that changed behavior are compared using tests of proportion. These results are confirmed using probit models, with whether a household changed behavior as the dependent variable, and treatment assignment as the sole independent variable. Due to the randomized design of the study, the simple comparison of proportions is adequate. Whether or not a household adjusted its behavior – unlike air quality – is unlikely to be influenced by demographic variables or weather (in short, the determinants of indoor air quality included in previous models as controls), so a full regression analysis is not needed.

6.2.2 Effects of behavior change on air quality

Finally, to determine whether household response impacts the effectiveness of the air quality interventions themselves, the model from Ward et al. (2017) is modified. Due to the small sample size of the changeout block (16 homes received the wood stove changeout before its discontinuation), this stage of the analysis is restricted to placebo and active filtration homes. Here, the sample is stratified by each behavior variable:

(7)

$$(Y_{ij}|\{\Delta B\} = 0) = \beta_0 + \sum_{m=0}^{2} \sum_{k=0}^{1} \left(\alpha_{m \times k}\left(T_{ijm} \times I_k\right)\right) + \beta_1 H_{ij} + \beta_2 W_{ij} + \beta_3 X_{ij} + \varphi_j + \mu_i + \varepsilon_i$$

(8)

$$(Y_{ij}|\{\Delta B\} = 1) = \beta_0 + \sum_{m=0}^{2} \sum_{k=0}^{1} \left(\alpha_{m \times k}\left(T_{ijm} \times I_k\right)\right) + \beta_1 H_{ij} + \beta_2 W_{ij} + \beta_3 X_{ij} + \varphi_j + \mu_i + \varepsilon_i$$

where Y_{ij} is air quality in household i and community j. $\{\Delta B\}$ is the set of three behavior indicator variables (wood index, home index, and compliance).

This approach allows comparing the treatment effects ($\alpha_{m \times k}$) for households that did and did not change their behavior, and is discussed in the context of randomized controlled trials in Duflo et al. (2008b). They note that because interventions often have heterogeneous effects on populations, researchers who are interested in testing the effect separately for different subgroups can stratify the randomization of subjects into treatment and control groups by subgroups. This is not a novel strategy, and has been applied in the literature in cases where interventions have heterogeneous effects on the population. For example, Glewwe, Kremer, and Moulin (2004) find no evidence that distribution of textbooks to rural Kenyan schools increased test scores at the mean. However, they report that the textbooks raised test scores for higher-achieving students.

To avoid data mining, researchers should know about their subgroup designations *ex ante*. However, if the reasoning is sound, it is permissible to conduct this type of analysis *ex post.* In the case of Glewwe et al. (2004), the rationale for subgroup stratification was that the textbooks were written in English; therefore, only more advanced students received a benefit. In this case, because the subgroups are defined by how they responded to treatment, it would not be possible to define them before the analysis. Additionally, while designations are specified *ex post* in this analysis, the reasoning and theoretical basis for this approach are clear.

7. Results

Section 7.1 gives the results of the initial regressions (determinants of indoor air quality and effects of interventions), and 7.2 presents the results of this paper's models (behavior analysis).

7.1 Initial regressions

7.1.1 Pre-intervention determinants of air quality

The results of the first initial regression are given in Table 9. Only the results for behavior variables are reported here; full results can be found in the Appendix (Table 26). Because the left-hand side variables are log-transformed, the coefficients result in $\left(e^{\beta_n} - 1\right) \times 100$ percentage changes in air quality. These results show that increasing frequency of opening the stove and burning intensity only significantly contribute to coarse particle count. Each additional time the stove was opened was associated with a 4.60% increase in coarse particle count, and burning reported as average to heavy was associated with a 40.07% increase in coarse particle count (relative to burning reported as none to light). Properly dried firewood was consistently associated with statistically significant reductions in pollution across air quality measures. Burning wood aged longer than one year was associated with a 30.02% reduction in average $PM_{2.5}$ and a 64.08% reduction in fine particles. Opening a door or window is consistently positively correlated with air pollution. Other home activities (other burning and cleaning) had little to no effect on air quality. Household income, caregiver education, home square footage, and using another heating source are also negatively associated with air pollution.

Table 9: Pre-intervention determinants of indoor air quality regression results

	(1) $PM_{2.5}$ Average (log)	(2) $PM_{2.5}$ Maximum (log)	(3) Coarse particle count (log)	(4) Fine particle count (log)	(5) Carbon monoxide average (log)
main					
Number of times the stove was stoked or loaded	0.015 (0.019)	0.027 (0.042)	0.045** (0.018)	0.021 (0.023)	0.028 (0.133)
Burning intensity dummy	0.151 (0.148)	0.010 (0.300)	0.337** (0.152)	0.037 (0.170)	-0.585 (1.194)
Wood age	-0.357*** (0.127)	-0.042 (0.291)	-0.273 (0.196)	-0.445*** (0.146)	-0.674 (1.221)
Amount of wood used (cords)	-0.034 (0.031)	0.025 (0.059)	-0.022 (0.038)	0.028 (0.037)	-0.098 (0.182)
Doors or windows opened during exposure sampling	0.542*** (0.149)	0.648** (0.325)	0.324** (0.150)	0.459** (0.199)	0.803 (0.968)
Other burning during exposure sampling	-0.091 (0.147)	-0.179 (0.268)	-0.017 (0.189)	0.005 (0.168)	0.774 (0.906)
Cleaning during exposure sampling	-0.039 (0.134)	0.164 (0.321)	0.223 (0.147)	-0.120 (0.188)	-2.218** (0.938)
N	96.000	96.000	88.000	88.000	52.000
chi2	181.666***	71.335***	112.256***	116.391***	92.459***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Some of these findings are straightforward, such as the effects of wood age. Freshly cut wood has a high moisture content, which reduces the temperature in the stove and prevents the wood from burning completely. Incomplete combustion contributes significantly to indoor air pollution.[10] Properly aged and dried firewood, therefore, would be expected to reduce particulate matter and particle counts, and this expectation is borne out in these results. One finding ran counter to intuitive expectations. Opening a door or window during the exposure sampling would seem as if it would have a mitigating effect on indoor air pollution, but in fact, opening a door or window was associated with increases in all of the pollution measures but carbon monoxide. This may be explained by

[10] https://www.epa.gov/sites/production/files/2017-02/documents/moisture_meter_v1_01-04-2017final.pdf

the inclination to open a door or window only when the home becomes uncomfortably smoky. That is, opening a door or window may be a response to air pollution rather than one of its predictors. Bear in mind that these sampling periods took place during the winter months in Montana, Idaho, and Alaska. Doors and windows are unlikely to be opened without a reason.

Household income and caregiver education are associated with significant reductions in indoor air pollution (see Appendix; Table 26). The effect of income could be attributed to the ability to make investments in better ventilation, construction, and even original stove technology. Those who are better educated may be more informed about the risks posed by air pollution and may have already taken steps to limit particulate matter in their homes. Square footage of the home was also negatively associated with indoor air pollution, which may speak to better construction of large homes, or simply more space by which to diffuse particles. Finally, using another heating source was associated with reductions in air pollution as well. Using another heating source may reduce reliance on the wood stove as a heat source, resulting in less intense wood stove use. These results are in line with those reported by Semmens et al. (2015).

7.1.2 Effect of air quality interventions on air quality

The estimation results for the impact of treatment on air quality are given in Table 10, and support the findings given in Ward et al. (2017). Results for $PM_{2.5}$ maximum, fine and coarse particle counts, and carbon monoxide, as well as the complete results for average $PM_{2.5}$ are reported in the Appendix (Tables 27-31).

Table 10: Intervention treatment effects

	(1) No controls	(2) No behavior controls	(3) Full model
$PM_{2.5}$ Average (log)			
Stove changeout, pre-intervention	0.615***	0.716***	0.825***
	(0.221)	(0.266)	(0.223)
Air filter, pre-intervention	0.146	0.118	0.137
	(0.180)	(0.186)	(0.184)
Placebo, post-intervention	-0.114	-0.297*	-0.293
	(0.130)	(0.165)	(0.182)
Stove changeout, post-intervention	-0.004	-0.062	-0.203
	(0.184)	(0.300)	(0.332)
Air filter, post-intervention	-1.126***	-0.670***	-0.669**
	(0.196)	(0.237)	(0.264)
N	350.000	190.000	169.000
chi2	86.682***	150.002***	340.684***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

The first result reported is for the simplest model, including just a multiplicative interaction term with treatment assignment and sampling winter. The second includes demographic, meteorological, and home characteristic variables as controls. The third includes not just demographic, meteorological, and home characteristic variables, but also wood-burning and home activity variables. The justification for including these separate models is given in Section 6.

As noted in Section 5, baseline air pollution was significantly higher among those assigned to the wood stove changeout; this is reflected in Table 10.

The placebo performed as expected, with some important exceptions. The first is that is that the placebo was highly effective in reducing coarse particles (see Appendix Table 29). As noted in Section 4, this may be due to the “porous” filter material “scrubbing” out larger size fraction particles (Ward et al., 2017). Table 10 also reveals that, according to the first and third models (those used by Ward et al., 2017), the placebo was not associated with significant reductions in PM. However, according to this paper’s model (2), which includes demographic, weather, and home controls, but does not include behavioral variables to avoid over-controlling, the placebo is associated with a significant 25.70% reduction in particulate matter. This may be evidence of the placebo treatment's impact on PM through a behavioral pathway. This is addressed further in Section 7.2.

The stove changeout was not associated with significant reductions in any of the air pollution measures relative to the placebo. Ward et al. (2017) had found that the wood stove changeout reduced carbon monoxide. In this analysis, the changeout did reduce carbon monoxide (with the inclusion of controls), but this effect was not statistically significant.

The air filter, post-intervention, implied significant reductions in average $PM_{2.5}$ and fine particles relative to the placebo according to each model. Although the air filter, post-intervention did not imply a significant reduction in coarse particle count, this is relative to the placebo's reduction from baseline, which was already highly significant.

7.2 Behavioral analysis

7.2.1 Effects of treatment assignment on behavior change

The relative frequencies and proportions of households that did and did not change behavior (or were high or low compliers) are given in the following tables. According to Table 11, a higher proportion of households in the air filter group exhibited worsened wood-burning practices, as compared to the placebo and changeout groups (52.94% of air filter homes got worse, as opposed to placebo homes and changeout homes, 42.11% and 40.00% of whom got worse, respectively). In terms of home activity, only 26.67% of the changeout group got worse, where 44.74% of the placebo group and 38.24% of the filter group got worse, respectively (Table 12). The proportions of households who were high- and low-compliers were relatively similar between the placebo and active filter treatment groups (Table 13).

Table 11: Changes in wood-burning between treatment groups

Wood index	Placebo	Changeout	Filter	Total
0 No change/improvement				
Frequency	22	9	16	47
(Column percentage)	(57.89)	(60.00)	(47.06)	(54.02)
1 Worsened				
Frequency	16	6	18	40
(Column percentage)	(42.11)	(40.00)	(52.94)	(45.98)
Total				
Frequency	38	15	34	87
(Column percentage)	(100)	(100)	(100)	(100)

Table 12: Changes in home activity between treatment groups

Home index	Placebo	Changeout	Filter	Total
0 No change/improvement				
Frequency	21	11	21	53
(Column percentage)	(55.26)	(73.33)	(61.76)	(60.92)
1 Worsened				
Frequency	17	4	13	34
(Column percentage)	(44.74)	(26.67)	(38.24)	(39.08)
Total				
Frequency	38	15	34	87
(Column percentage)	(100)	(100)	(100)	(100)

Table 13: Compliance between treatment groups

Compliance	Placebo	Filter	Total
0 Low compliance			
Frequency	17	18	35
(Column percentage)	(44.74)	(52.94)	(48.61)
1 High compliance			
Frequency	21	16	37
(Column percentage)	(55.26)	(47.06)	(51.39)
Total			
Frequency	38	34	72
(Column percentage)	(100)	(100)	(100)

Tests of proportion are used to compare the proportion of each treatment group that changed a given behavior measure. The test was restricted to one post-intervention visit to count each household only once. As this is panel data, each home has multiple observations. In regression analysis, panel data methods allow grouping observations by home such that four visits for 97 households is not interpreted as 388 independent observations. However, these simple tests do not allow for this, so the sample is limited to the third visit. Index variables include information from all periods of the study in their construction, so this method does not result in loss of information; it just prevents repeat counting of the same households.

The results of the tests of proportion between treatment groups are given in Table 14. The mean difference in proportion is reported for each pairing (e.g., the proportion of the placebo group that worsened wood-burning, .4211, minus the proportion of the active filter group that worsened wood-burning, .5294, gives -.108, as reported in the table), as well as the t-statistics in parentheses.

Table 14: Comparing proportions of households that changed behavior between treatment groups

	(1) Stove changeout – Air filter	(2) Placebo – Air filter	(3) Placebo – Stove changeout
Wood index	-0.129	-0.108	0.0211
	(-0.85)	(-0.92)	(0.14)
Home index	-0.116	0.0650	0.181
	(-0.82)	(0.56)	(1.29)
Compliance		0.0820	
		(0.70)	
N	49	72	53

t statistics in parentheses
* p<0.10, ** p<0.05, *** p<0.01

The proportion of homes in the active filter group that exhibited changes in wood-burning practices was higher than the proportion in the placebo and changeout groups, although this was not significant. In terms of wood-burning, there was very little difference between the placebo and changeout groups. A smaller proportion of homes in the changeout group increased home activity than the placebo group or the active filter group, although this was also insignificant. The placebo and active filter groups contained approximately equal distributions of those who changed home activity, as well as of high- and low-compliers. Proportion comparison tables for each individual wood-burning and home activity variable are reported in the Appendices (Tables 35-41).

According to Table 14, there were no significant differences between the proportions of each treatment group that changed behavior, which may be due to small sample size. In order to confirm these results, a set of probit models are estimated, in which the dependent variable is each behavior index (results for individual behaviors are again reported in the Appendices, Tables 35-41), and the independent variable is a three-level factor variable for treatment assignment. Again, the analysis is restricted to one visit to avoid double-counting of households.

Table 15: Behavior change probit regression results

	(1) Worsened wood-burning	(2) Worsened home activities	(3) High compliance
Stove changeout	-0.054	-0.491	0.000
	(0.388)	(0.405)	(.)
Air filter	0.273	-0.167	-0.206
	(0.299)	(0.301)	(0.299)
Constant	-0.199	-0.132	0.132
	(0.206)	(0.205)	(0.205)
N	87.000	87.000	72.000
chi2	1.094	1.487	0.477

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 15 reports the results of these probit tests, which corroborate the results of the proportion tests given in Table 14. Indeed, homes in the air filter treatment group were more likely to exhibit more polluting wood-burning practices after the interventions were installed, although this effect was still insignificant. Homes in the air filter group were more likely to increase stoking and loading of the stove, burning intensity, and wood usage, relative to the placebo and changeout groups (although the effects were again insignificant).

These results give limited evidence of compensating behavior. It seems that households that received the air filter were slightly more likely to exhibit worsening behavior, but, perhaps due to sample size, these effects are insignificant. Therefore, based on the data available, the null hypothesis that treatment assignment did not affect behavior change cannot be rejected. This conclusion is based on comparisons between the placebo, changeout, and filter treatment groups. The fact that behavior change did not significantly differ between the filter and placebo treatment groups is expected, as these interventions are equivalent from the perspective of participants. Participating households were not made aware of the type of filter (active or placebo) they had received. Therefore, they would be expected to modify their behavior similarly, as both types of households had reason to believe they had received a device that would improve their air quality and health. This is true of each treatment group in the study, in that every household received a device. Furthermore, simply being involved in the study could have changed their behavior in response to new information posed by the risks of wood smoke. For a true difference-in-difference model, one treatment group would have had to receive no intervention at all. Table 5 (given again below) gives the average change in each behavior overall, and shows that for the entire sample, frequency of stoking and loading the stove decreased, average burning intensity increased, wood usage decreased, and opening of doors or windows increased. Although these absolute changes are small in magnitude, they indicate that simply receiving an intervention and participating in the program may have affected household behavior.

Table 5: Mean changes in individual behavior measures

Δ Individual behavior measures (Post-intervention average – pre-intervention average)	Overall	Placebo	Changeout	Filter
Δ Stoking and loading the stove	-1.355	-1.338	-2.643	-0.812
	(4.071)	(4.664)	(4.194)	(3.185)
Δ Burning intensity	0.141	0.0294	0.0357	0.317
	(0.683)	(0.651)	(0.796)	(0.650)
Δ Wood age	0.0921	0.0909	0.107	0.0862
	(1.012)	(1.128)	(1.163)	(0.814)
Δ Wood usage	-0.216	0.400	-0.525	-0.808
	(2.421)	(2.730)	(1.805)	(2.136)
Δ Opening of doors/windows	-0.182	-0.153	-0.367	-0.132
	(0.392)	(0.411)	(0.297)	(0.395)
Δ Other burning	-0.0176	0	-0.0667	-0.0147
	(0.419)	(0.463)	(0.320)	(0.417)
Δ Cleaning	-0.0765	-0.0694	-0.167	-0.0441
	(0.485)	(0.599)	(0.408)	(0.377)
n	87	38	15	34

mean coefficients; sd in parentheses

7.2.2 Effects of behavior change on air quality

Due to the small sample size of the stove changeout treatment, the following analysis is restricted to the placebo and active air filter treatment groups. The following regression output table presents comparisons of treatment effects for the placebo and air filter between levels of compliance and whether a household changed wood-burning and home behavior. In addition to subgroup stratification according to overall wood-burning and home activity behavior change, a final subgroup is defined according to whether households reduced the age of wood burned from pre- to post-intervention. Wood aged properly (more than one year) was associated with significantly lower levels of air pollution, relative to wood aged improperly (less than one year), according to results presented in Section 7.1.1. This was the most consistent and significant effect of an individual measure of behavior. Results for average $PM_{2.5}$ are given here; results for the rest of the air pollution measures can be found in the Appendix (Tables 42-46).

Table 16: Comparing treatment effects between behavior subgroups

	Compliance		Wood index		Home index		Wood age	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	High	Low	No change	Worsened	No change	Worsened	No change	Worsened
$PM_{2.5}$ Average (log)								
Air filter, pre-intervention	0.008	-0.271	0.161	0.306	0.198	-0.041	0.074	1.091***
	(0.190)	(0.250)	(0.238)	(0.209)	(0.236)	(0.245)	(0.207)	(0.274)
Placebo, post-intervention	-0.323**	-0.098	-0.457*	-0.018	0.074	-0.627**	-0.410*	-0.066
	(0.150)	(0.430)	(0.251)	(0.241)	(0.201)	(0.246)	(0.217)	(0.225)
Air filter, post-intervention	-0.851***	-0.787	-0.437	-1.076***	-0.928***	-1.131***	-0.443	-1.271***
	(0.295)	(0.492)	(0.293)	(0.341)	(0.244)	(0.367)	(0.279)	(0.316)
N	90.000	73.000	85.000	80.000	90.000	75.000	123.000	42.000
chi2	1111.809***	2410.764***	514.173***	224.496***	514.067***	1260.083***	145.498***	161.395***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

The ‘Hamilton’ community indicator is excluded from the regression given in column (2) in Table 16. The reason for this was that it was a singleton dummy; a regressor that is nonzero for only one observation for one cluster. In the restricted sample (namely; low-compliance, and in either the placebo or filter treatment groups), there was only one household (cluster) for which the ‘Hamilton’ community indicator was nonzero. Because cluster-robust standard errors are used in these models, the derivative of the likelihood function with respect to the community parameter was zero for all observations, implying a singular robust variance matrix. This observation was dropped for these analyses.

In the final column of Table 16, robust standard errors are not used due to the small size of the restricted sample. The number of constraints must be less than the number of clusters (households), and only 18 households are in this subgroup compared with 22 constraints. This is resolved by estimating the model parameters without the *vce (robust)* option used for the rest of the subgroup analyses.

These models include the demographic and weather controls from Section 7.1. Component behavioral variables (stoking and loading the stove, opening of doors and windows, etc.) are not included as covariates. However, for each of these models, the excluded $\{\Delta B\}$ variables are included as covariates. For example, compliance regressions include wood and home indices as controls. As wood age was the most significant determinant of indoor air quality according to the results from 7.1.1, it was included as another $\{\Delta B\}$. Columns (7) and (8) report separate treatment effects for homes that do not decrease age of wood (7) and homes that do decrease age of wood (8).

The results for compliance are unexpected. Because the placebo is not designed to impact air quality, one would expect negligible treatment effects for both high- and low-compliers (i.e., keeping the filter running should not improve air quality, as the filter itself is designed to be ineffective). Instead, homes in the placebo group that complied with directed use actually experienced a statistically significant 27.60% reduction in $PM_{2.5}$ relative to pre-intervention levels, while those that received a placebo and did not keep the device running did not experience a significant reduction. Perhaps the most straightforward explanation for this result is an unobserved characteristic or practice among high-compliers that influenced air quality independent of the placebo filter. Although the wood-burning and home activity indices were included as controls, there could be other behaviors associated with homes that reliably kept their placebo filters 'on.' Maybe households that were motivated to run the filter also exhibited behaviors that simply were not measured: perhaps they kept their pets outside, or dusted more frequently, or underwent inspections for mold. However, this explanation is undermined by the pairwise correlations between compliance and measured behavioral variables. If high compliance was correlated with unobserved behavioral factors (as this postulated explanation suggests), it might also be correlated with observed behavioral factors, such as change in wood-burning or home activities. However, the results show that compliance is not correlated with change in wood burning or home activity. The Pearson's correlation coefficient between compliance and the wood index is 0.029; the correlation coefficient between compliance and the home index is 0.033.

Homes that were compliant with filter instructions in the active filter treatment group experienced an 57.30% reduction in particulate matter relative to the placebo's reduction, which was also significant, while low-compliers did not see a reduction of statistical significance (a 54.62% reduction) relative to the placebo. This result withstands practical scrutiny. For the active filtration group, the expectation is to see a difference in treatment effects between those who kept the device running and those who did not. The active air filter treatment is expected to affect air quality, so whether the device is in use or not would, in theory, determine its efficacy. However, although the reduction associated with the filter was not significant among low-compliance homes, its magnitude was comparable with that of the reduction for corresponding high-compliance homes.

In terms of wood-burning behaviors, among the placebo group, the theoretical expectation is that those who change behavior would experience worse air quality (increased pollution), and those who did not adjust their wood-burning practices would experience no change in air quality. This was not realized. The effect of the placebo treatment for those whose behavior got worse was an insignificant increase in PM. The unexpected result was that households that received the placebo and did not adjust wood-burning practices experienced a 36.68% reduction in particulate matter relative to pre-intervention, and this effect was significant. Although the placebo treatment was not expected to and did not reduce PM for the full sample, it seems that the placebo actually implied improved air quality among households that reported consistent or improving behavior. It is important to note that households that *improved* behavior are grouped with those that did not change their behavior. So, it is possible that this result is due to improved, rather than neutral behavior, which would help explain this effect.

The wood index results for those who received the active filter were also unexpected. Among this group, those whose behavior got worse experienced a significant reduction of 65.90% in PM, while those who did not adjust household wood burning did not realize a significant reduction relative to the placebo (a 35.40% reduction). However, these results are relative to the reduction produced by the placebo – which, for those whose behavior remained constant or improved, was significant. Relative to baseline, the active filter was associated with a 66.51% reduction in particulate matter for those whose behavior changed, and a 59.10% reduction in particulate matter for those whose behavior stayed constant or improved. Therefore, the active filter produced similar results for households that exhibited behavior change and households that did not. This implies that even if the stove became more polluting as a result of worsening behavior, the air filter cancelled out this effect by filtering out the additional pollution. This may represent an additional benefit of the air filter intervention, in that its effectiveness may be robust to behavior change.

The effects for the home activity index are given in columns (5) and (6). The air filter was associated with highly significant improvements in air quality regardless of household behavior. Similar to the results for wood-burning, the benefits of the active air filter seem to be robust to changes in home activities.

Among households that received the placebo, households that did not report worsening home activity saw an insignificant increase in pollution. Their counterparts that did report worsening behavior saw a significant 46.58% reduction in particulate matter. This is the opposite of the effect on wood-burning practices, where homes in the placebo group who remained consistent or improved their behavior experienced significant reductions in air pollution, and homes that reported worsening burning practices did not experience reductions. The reasoning for this outcome is not entirely clear.

The final two columns give comparison of treatment effects for households that burned similarly or longer aged wood throughout the study (7) and households that compensated and burned younger, fresher wood upon receiving a device (8). The results are in line with compliance and wood index findings. Among homes that burned fresher wood post-intervention, the effect of the placebo was an insignificant 6.39% reduction in particulate matter, but among homes that burned similarly or longer aged wood throughout, the effect of the placebo was a statistically significant 33.63% reduction. This effect is similar to that of the wood index, in that this positive result may be driven by households that improved (as these are grouped with households that report no change). The effect of the air filter was also consistent with compliance and wood-burning findings, in that it was associated with significant reductions among households that got worse and households that did not. Among homes that reported improving or constant behavior, the filter implied a 57.39% reduction in $PM_{2.5}$ relative to baseline levels. Among homes that reported worsening behavior, the filter implied a 73.74% reduction relative to baseline levels, again implying that the filter is effective in filtering out additional pollution caused by compensating behavior.

The final step in this analysis is testing the designations for subgroup stratification. In constructing behavior change index variables, households were classified as those that changed behavior and those that did not according to how many household air-polluting behaviors were worsened from the pre- to post-sampling winter. There were four wood-burning behaviors. Households that worsened two or more of these were classified as those exhibiting behavior change; households that worsened one or fewer did not show compensating behavior. A similar approach was used in stratifying according to home activity. There were only three home activities measured, so households that reported worse behavior for at least one of these were classified as "worsening home activities." These distinctions were made based on the approximate 50th percentile to achieve similarly sized subgroups. Finally, high- and low-compliers were classified in a similar manner, with the aim of creating similarly sized subgroups. To test this approach, models are run with different cutoffs. Table 17 reports regression results for differing classifications for homes demonstrating behavior change. The first column gives the model as reported in Section 7.2, in which behavior-changing homes were defined as homes that worsened two or more wood-burning practices. The second gives results for the same regression in which they were households that reported one or more worsened wood-burning practices; the third column reports results from when they worsened three or more wood-burning practices.

Table 17: Testing wood index cutoff levels

	Wood index cutoff: 2		Wood index cutoff: 1		Wood index cutoff: 3	
	(1)	(2)	(3)	(4)	(5)	(6)
	No change	Worsened	No change	Worsened	No change	Worsened
$PM_{2.5}$ Average (log)						
Air filter, pre-intervention	0.161	0.306	-1.139	0.219	-0.016	-0.305
	(0.238)	(0.209)	(0.954)	(0.210)	(0.213)	(0.625)
Placebo, post-intervention	-0.457*	-0.018	-0.675***	-0.155	-0.312*	-0.360
	(0.251)	(0.241)	(0.236)	(0.203)	(0.184)	(0.639)
Air filter, post-intervention	-0.437	-1.076***	0.008	-0.938***	-0.580**	-0.783
	(0.293)	(0.341)	(0.445)	(0.278)	(0.271)	(0.701)
N	85.000	80.000	35.000	130.000	134.000	31.000
chi2	514.173***	224.496***	78.292***	97.827***	77.079***	165.649***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01
Due to small sample size, the robust standard errors option is not used for the regressions reported in columns (3) and (6).

Results for the placebo treatment are robust to variations in cutoff levels.

If wood-burning behavior change is classified as changing one or more wood-burning practices, active filter homes that reported behavior change experienced reductions, while those that did not report behavior change did not experience reductions in pollution (the same result as the original specification). When the bar to qualify as a behavior-changer is raised to three modified wood-burning practices, the result for the active filter treatment block is reversed; according to this designation, homes that do not report behavior change experience greater reductions in average $PM_{2.5}$. This effect is in line with the original theoretical predictions. When homes that displayed moderate changes are classified as changing behavior, the results are counterintuitive, but when substantial changes are classified as changing behavior, the results match predictions. This may be due to the cancelling out effect of the stove on moderate behavior change. Households that substantially adjust their behavior may overwhelm the cancellation effect of the filter.

Results for alternate behavior change designations are reported for the home activity variable in Table 18. For this paper's analysis, to demonstrate changing home activity, a home worsened one or more home activities. The second column gives results for the model when home activity change is demonstrated by two or more increased activities.

Table 18: Testing home index cutoff levels

	Home index cutoff: 1		Home index cutoff: 2	
	(1)	(2)	(3)	(4)
	No change	Worsened	No change	Worsened
$PM_{2.5}$ Average (log)				
Air filter, pre-intervention	0.198	-0.041	-0.079	-0.006
	(0.236)	(0.245)	(0.205)	(0.250)
Placebo, post-intervention	0.074	-0.627**	-0.360*	0.054
	(0.201)	(0.246)	(0.193)	(0.292)
Air filter, post-intervention	-0.928***	-1.131***	-0.496*	-2.353***
	(0.244)	(0.367)	(0.260)	(0.381)
N	90.000	75.000	136.000	29.000
chi2	514.067***	1260.083***	101.062***	714.716***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

For the air filter treatment block, the original direction and significance of treatment effects holds for the new specification. According to the original specification, for homes worsening one or more home activities, the placebo implied a 46.58% reduction in average PM relative to pre-intervention. According to the new designation, worsening fewer than two home activities implies a 30.23% reduction in average PM. This indicates that among placebo homes, air quality improvements were concentrated in homes that worsened one home activity.

Finally, results for alternate designations for high- and low-compliers are given in Table 19. The first column is as given in this paper; high-compliers were in at least the 50th percentile of compliance. In practical terms, their energy usage was at least 77.49% of expected. The second column gives results for high-compliers as being in the upper two tertiles of compliance, or above 67.68% of expected energy use. The third gives results for high-compliers being in the upper one tertile of compliance, or above 89.86% of expected energy use. Note that compliance was particularly high in this study, and that several homes recorded higher than expected energy usage (i.e., proportions above 100%).

Table 19: Testing compliance cutoff levels

	High compliance cutoff: 50th percentile		High compliance cutoff: upper two tertiles		High compliance cutoff: upper tertile	
	(1) High	(2) Low	(3) High	(4) Low	(5) High	(6) Low
$PM_{2.5}$ Average (log)						
Air filter, pre-intervention	0.008	-0.271	0.159	-0.496	-0.663	0.161
	(0.190)	(0.250)	(0.217)	(0.440)	(0.439)	(0.217)
Placebo, post-intervention	-0.323**	-0.098	-0.367***	-0.296	-0.386*	-0.132
	(0.150)	(0.430)	(0.126)	(0.350)	(0.234)	(0.232)
Air filter, post-intervention	-0.851***	-0.787	-0.723***	-0.434	-1.714***	-0.749**
	(0.295)	(0.492)	(0.241)	(0.526)	(0.542)	(0.306)
N	90.000	73.000	101.000	49.000	43.000	107.000
chi2	1111.809***	2410.764***	208.871***	44.461***	113.439***	82.885***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01
Singleton community indicators were excluded for regressions given in columns (2), (4), and (5). Robust standard errors are excluded from model results in the final three columns (4), (5), and (6), due to cell size.

Results for the placebo treatment are robust to cutoff designation; those who received the placebo filter, and kept it on, experienced reductions in particulate matter regardless of the cutoff level.

Consider the effects of the active air filter. The second column gives treatment effects when high-compliance homes are defined as being in the upper two tertiles of compliance. This specification re-classifies homes who would have previously been considered low-compliers as high-compliers. For the active air filter, the original finding holds (those who received and kept the filter running experienced its benefits).

The third column reports treatment effects for the most stringent definition of high-complier: those in the sample's upper third of compliance. For both high- and low-compliance homes, the filter was associated with significant reductions. This specification re-classifies homes who would have originally been high-compliers as low-compliers. According to this designation, low-compliers too experienced significant reductions in pollution. This is probably due to many households who were moderate compliers being re-classified as low-compliers. Overall, it seems that homes in the upper tertile of compliance were driving the effects of the placebo, while more moderate compliers were driving the effects of the active filter. In this case, 'moderate' compliance is rather high

7.3 Specification tests

Running alternate models can check the appropriateness of this paper's models' specifications and the robustness of its findings. Because the analysis was based largely on the two initial models, specification tests are run for these.

Specification tests for determinants of indoor air quality are given in Table 20. Four specifications are tested: a random-effects generalized least squares model, a mixed-effects maximum likelihood model, and a mixed-effects maximum likelihood model with community effects, and finally, the model used; mixed-effects maximum likelihood with community effects and robust standard errors. Although robust standard errors were included in previous studies' models, there were concerns regarding sample size in this analysis. Findings are robust to variations in model specification.

Table 20: Pre-intervention determinants of indoor air quality specification testing

	(1) Random-effects GLS	(2) Mixed-effects ML	(3) Mixed-effects ML Community effects	(4) Mixed-effects ML Community effects Robust standard errors
$PM_{2.5}$ average (log)				
Number of times the stove was stoked or loaded	0.002 (0.021)	0.033* (0.020)	0.015 (0.020)	0.015 (0.019)
Burning intensity dummy	0.131 (0.176)	-0.085 (0.160)	0.151 (0.158)	0.151 (0.148)
Wood age	-0.395** (0.174)	-0.420*** (0.158)	-0.357** (0.155)	-0.357*** (0.127)
Amount of wood used (cords)	-0.039 (0.041)	-0.012 (0.028)	-0.034 (0.037)	-0.034 (0.031)
Doors or windows opened during exposure sampling	0.520*** (0.165)	0.198 (0.158)	0.542*** (0.144)	0.542*** (0.149)
Other burning during exposure sampling	-0.025 (0.166)	0.128 (0.155)	-0.091 (0.147)	-0.091 (0.147)
Cleaning during exposure sampling	-0.095 (0.165)	-0.139 (0.143)	-0.039 (0.146)	-0.039 (0.134)
N	96.000	169.000	96.000	96.000
chi2	49.608***	80.338***	70.403***	181.666***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

The second initial regression estimated the impact of treatment on air quality. In Section 7, results are presented for several models: one including no covariates, one including demographic, weather, and home characteristics, and one including the entire set of covariates, including component behavioral variables. Specification tests are conducted for this paper's contribution; the second model (demographic, weather, and home characteristics; not including controls for wood-burning and home activity). Five models are tested, and presented in Table 21: random-effects GLS, mixed-effects ML, mixed-effects ML with community effects, mixed-effects ML with community effects and random effects for sampling winter, and finally, the full model used in the analysis. Findings were robust to these variations in model specification.

Table 21: Treatment effects specification testing

	Random-effects GLS	Mixed-effects ML	Mixed-effects ML Community effects	Mixed-effects ML Community effects Random coefficient (winter)	Mixed-effects ML Community effects Random coefficient (winter) Robust standard errors
$PM_{2.5}$ average (log)					
Stove changeout, pre-intervention	0.657**	0.610**	0.688**	0.716**	0.716***
	(0.312)	(0.280)	(0.291)	(0.300)	(0.266)
Air filter, pre-intervention	0.158	0.169	0.139	0.118	0.118
	(0.201)	(0.169)	(0.168)	(0.181)	(0.186)
Placebo, post-intervention	-0.341**	-0.318*	-0.299*	-0.297	-0.297*
	(0.165)	(0.180)	(0.180)	(0.189)	(0.165)
Stove changeout, post-intervention	-0.034	0.009	0.008	-0.062	-0.062
	(0.347)	(0.379)	(0.377)	(0.393)	(0.300)
Air filter, post-intervention	-0.704***	-0.671**	-0.658**	-0.670**	-0.670***
	(0.237)	(0.261)	(0.258)	(0.275)	(0.237)
N	190.000	190.000	190.000	190.000	190.000
chi2	88.449***	116.899***	124.160***	112.335***	150.002***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

7.4 Key findings

The goal of this research was to identify to what extent behavioral responses to household interventions affect the efficacy of air quality interventions in a randomized controlled trial. This paper is distinguished by not just looking at the impacts of treatment on air quality, but the pathway by which treatments impact air quality, as illustrated on the following page.

The initial analyses established a key set of findings that were used to inform the rest of the study's design. The first stage was establishing the determinants of indoor air quality. Using pre-intervention data, a mixed effects model estimated the effects of a range of demographic and home characteristics, wood-burning practices and home activities, and ambient weather on indoor air quality. Of most interest to this study were the behavioral determinants. The most significant of these were age of wood burned, which was inversely correlated with air pollution, and opening of doors or windows, which was positively correlated with air pollution.

The second stage in the initial analyses was estimating treatment effects for the study's three interventions: the placebo filter, wood stove changeout, and active air filter. This paper reported results for models developed by Ward et al. (2017), as well as for an adapted model. Ward et al. (2017) had found that the air filter was associated with significant reductions in air pollution, but that the placebo and changeout interventions were not associated with significant reductions in air pollution (with a few exceptions for certain air quality measures). These results were verified, but this paper's contribution offered a novel finding. Suspecting that treatment affected air quality at least partially through a behavioral pathway, this paper's model did not include behavioral variables as covariates. The result was that the placebo filter was also associated with a significant reduction in particulate matter.

To determine whether compensating behavior took place, the proportions of each treatment group that changed behavior were compared using simple tests. The proportion of homes that changed wood-burning practices was highest in the air filter treatment group, but perhaps due to small sample size, the differences were not significant. A set of panel probit models was estimated in which dependent variables were whether a household changed behavior, and the independent variable was treatment assignment. The results confirmed the findings from the comparison tests. The null hypothesis that treatment assignment does not affect behavior change cannot be rejected. This may be due to the fact that treatment groups were compared to one another, and that they all may have responded to the interventions. For a true difference-in-difference, a treatment group would have had to receive no intervention.

Comparing the proportions of those that adjusted home activity seemed to indicate that a much smaller proportion of those in the changeout group worsened home activity, compared to the placebo and filter groups. However, again possibly due to sample size, these effects were not significant according to comparison tests of proportion or probit regressions.

The final step in the behavioral analysis was to determine whether behavior change impacted intervention treatment effects. The sample was divided into subgroups according to whether or not behavior changed, and whether or not households complied with instructions regarding filter use. The placebo – although it was not expected to, and did not – reduce air pollution overall, implied significant reductions in particulate matter relative to baseline levels among households that kept the device running, among households that either did not change or improved their wood-burning practices, and among households that either maintained or improved their wood aging practices.

Because the placebo filter material was designed not to filter out particulate matter, it is likely that the effect among high-compliers is due to an unobserved characteristic or practice associated with households that kept the device running (e.g., outdoor pets, frequent dusting, mold inspection, etc.). However, compliance was not correlated with observed behaviors. This does not disprove this theory, but further studies should look at additional factors that may have driven this effect. The effect among homes that did not change or improved wood-burning and wood aging may be driven by homes that actually improved these practices (these homes were grouped with those that did not change behavior at all).

The air filter was associated with significant reductions in particulate matter regardless of whether or not a household changed its wood-burning practices or home activities. It is likely that additional emissions caused by more polluting behavior were cancelled out by the filter.

Finally, the cutoffs used to stratify the sample into subgroups according to behavior change were tested. The treatment effects of the placebo were consistent across designations of wood-burning behavior change. Whether wood-burning behavior change was classified as two, one, or three behaviors changed, households that did not change behavior or reported improved behavior, and received the placebo, experienced reductions in pollution. For the active filter treatment, when behavior change is defined as one or two worsened behaviors, even those that changed behavior still experienced reductions with the active filter. However, under the most stringent definition of behavior change – three worsened behaviors – those who changed behavior did not experience reductions with the filter. This likely means that the air filter compensated for moderate behavior change (one or two worsened practices), but this was overwhelmed by households that reported substantial behavior change (three or more worsened practices).

In terms of home activities, effects of the active filter were robust to two cutoffs considered: one behavior changed and two behaviors changed. As for the placebo, households that worsened one or more activity saw reductions, and households that worsened fewer than two activities saw reductions. It seems that reductions for the placebo were concentrated in homes that worsened one home activity.

The treatment effects of the placebo were robust across three designations for high and low compliance. For each designation, among homes classified as being high-compliers, the placebo was associated with significant improvements in air quality. When households that complied moderately are considered high-compliers, only this group experienced reductions associated with the active filter. However, under a more stringent definition of high-complier where moderate levels of compliance are classified as low, the results show that low-compliers then experience the benefit of the active filter. Therefore, average compliance was adequate for this treatment. However, in this study, even 'moderate' compliance was unusually high. Overall, the level of compliance in this study was higher than in similar studies, according to Semmens et al. (2015).

8. Discussion

The goal of this paper was to investigate the role of behavior in the efficacy of household air quality interventions. This research contributes to the literature meaningfully by applying existing theories of health intervention behavior change to a randomized trial of air quality interventions.

This study could not prove that compensating behavior occurred in this setting. The hypothesis was that receiving a wood stove or air filter would cause households to reduce their efforts and investments in pollution reduction. To test this hypothesis, the proportions of households that exhibited behavior change were compared between treatment groups. The results indicate that households that received the active air filter were more likely to exhibit compensating behavior, although this was not statistically significant. According to the hypothesized nature of behavior change, a household would respond to simply receiving a device. In this case, receiving an active air filter and receiving a placebo filter were equivalent from the perspective of the household, as they were blinded to the type of filter they received. Therefore, it is not surprising that households responded similarly. However, there is some evidence – although far from conclusive – that homes in the air filter may have been more likely to exhibit compensating behavior. Further study should address this, as it may be that households compensate in response to perceived improvements in air quality or health, rather than in response to the interventions themselves.

Another component of the hypothesis was that behavior change would obscure or distort treatment effects. To test this, the effects of the interventions for those who exhibited compensating behavior were compared with the effects for those who did not exhibit this behavior change.

Homes that received the placebo, and worsened their home activities in response to assuming they had a working filter, experienced reductions in air pollution. This was not expected and not easily explained. Among the placebo treatment group, homes that reported constant or improving wood-burning practices and aging experienced significant reductions in air pollution relative to baseline. This effect may be the result of wood-burning behaviors improving on average for this group. This would not be captured in the comparison of proportions from Section 7.2.1, as households that improved behavior were grouped with those that did not change.

The air filter was consistently associated with significant reductions in air pollution (across models, across air pollution measures, and across behavior change classification). Homes receiving the active filtration device experienced reductions in pollution regardless of changes in wood-burning or home activities. This suggests that the filter can compensate for poor or deteriorating behavior by filtering out additional pollution. This is further supported by cutoff testing, which showed that the air filter compensated for moderate change in burning practices, but was overwhelmed by substantial worsening of burning practices. The filter's ability to offset behavior change – combined with its affordability relative to the changeout – makes the filter, as of this study, the more attractive option.

Compliance was an important determinant of both interventions' efficacy. Households in the placebo treatment group that demonstrated high compliance with filter instructions experienced significant reductions in pollution, despite receiving a nonfunctional filter. This effect held for all designations of compliance in the subgroup analysis. It is postulated that this is due to underlying characteristics or actions taken by households that tend to comply with instructions. Perhaps these households took other steps to reduce pollution that simply were not captured in this data. However, this explanation was investigated by testing the correlation between compliance and observed behavior (if compliance is correlated with unobserved behavior, it may also be correlated with observed behavior). There was no correlation found between compliance and observed behavior change. This does not disprove the explanation, but more research is needed to address this unexpected effect of the placebo.

Compliance was a less important determinant of the active air filter's efficacy. Although air filter treatment effects were insignificant among homes that were low compliance, the magnitude of reductions was comparable to those associated with the filter among homes that were high compliance.

It is important to note caveats imposed by this paper's limits. The primary threat to internal and external validity for this study was sample size. Although 40 and 42 homes received the placebo and active air filters respectively, only 16 received the wood stove changeout, and for this reason, it was not considered for the second part of the behavioral analysis. Even the placebo and filter sample sizes – when stratified by behavior change status – were small.

Another limitation is the lack of a clear counterfactual. The placebo filter served as the base case for this analysis. This is appropriate when the dependent variable is air quality, as the placebo filter presumably does not impact air quality. However, when the dependent variable is behavior change, the placebo does not work as a base case, as receiving a placebo filter is equivalent to receiving an actual filter in a blinded experiment. That is, each treatment group received an intervention they had reason to believe would reduce air pollution. Therefore, there was no true baseline, i.e., a treatment block that received no intervention. Due to this lack of a true counterfactual, this study addressed relative change in behavior by comparing the proportions of each treatment group that changed behavior.

Another consideration is that the key explanatory variable in these models was *reported* behavior. This is limiting for a number of reasons. The first is that it may not be objective. Households were required to make subjective judgments of their behaviors, for example on their burning intensity. Questions of recollection were used to determine wood age, which perhaps could have been more reliably measured through moisture meter readings. Additionally, for count measures, such as how often the stove was stoked or loaded, or how many cords of wood were used, higher figures were associated with more polluting behavior; lower numbers with less polluting behavior. However, it may be that households reporting higher activity and usage were simply more meticulous and earnest compared to their supposedly better-performing counterparts. Increases in these measures, which were interpreted as deteriorating behavior, could actually imply improved dedication to the study.

Additionally, the exposure and sampling periods were relatively short and two 48-hour periods pre- and post-intervention may not be representative of a household's overall behavior and air quality.

Finally, the number of households that changed behavior is likely understated, due to the nature of attrition. To determine behavior change, winter averages were compared between sampling winters (pre-intervention and post-intervention). Four homes receiving the placebo and three receiving the filter did not complete the fourth sampling period. These homes were not considered attritors, as post-intervention data was available for these homes. However, their post-intervention winter averages are likely incomplete.

Other limitations have to do with external validity, and whether these effects would hold if the program were scaled up. A primary concern is maintenance and commitment to ongoing investments. This study was completed over a short time period. Less than one year elapsed from intervention installation to post-intervention sampling, so these results do not capture long-term maintenance and compliance, which has been shown to deteriorate (Hanna et al., 2012).

8.1 Implications and importance of this research

This paper looked at the effect of treatment assignment on behavior change. Relative to the effect of the placebo filter on behavior change, the effects of the changeout and active filter were not significant. This may be due to the fact that households were blinded to the type of filter they received. Therefore, households would theoretically respond to a placebo filter exactly as they would respond to an active filter. Households in each treatment group received an intervention they believed would help them. Lack of a true counterfactual undermined the strength of the difference-in-difference model in this stage of the analysis. Further studies should include a treatment group that receives no intervention.

Another key finding was that the active air filter was effective in reducing air pollution among homes that changed behavior and among homes that did not. This suggests that the filter compensated for additional emissions caused by compensating behavior, which represents another benefit of the air filter. In addition to affordability (relative to the changeout), the filter seems to be robust to changes in wood-burning. This is up to a point; according the subgroup designation testing, the filter compensated for moderate compensating behavior, but the cancelling effect of the filter was overwhelmed by substantial behavior change.

The benefits of the air filter were somewhat limited by compliance. Only homes that used the filter as directed (i.e., kept it on) experienced statistically significant reductions in pollution. Households that did not comply did not experience significant reductions (although the magnitude of this effect was comparable to the effect of the filter for high-compliance homes). This has important implications for policy design. Interventions – like the air filter – that rely on particular actions by the user, are limited by the fact that some users simply won't perform the actions. Types of interventions that do not require action by the user are likely to be more effective than those that rely on users' compliance (including filters, as well as improved woodstoves). For example, an intra-uterine device is likely to be more effective in preventing pregnancy than a daily contraceptive pill.

Overall, the placebo filter was not associated with significant reductions in pollution, which was expected. However, among homes that complied with filter instructions, homes that reported constant or improving wood-burning practices, and homes that reported constant or improving wood aging, the placebo was associated with significant reductions in particulate matter. The effect for homes that reported constant or improving wood-burning practices may be driven by this treatment group, on average, *improving* wood-burning. Households that reported no change and those that reported improvement were grouped together into one classification, as this study was primarily interested in compensating behavior change. Homes that complied with filter directions and received the placebo also experienced benefits in pollution reduction. Due to the fact that the placebo was designed to not filter small particles, it is unlikely that simply keeping the nonfunctional filter running was responsible for this group's reductions. Additionally, these regressions by subgroup included behavioral controls. Perhaps high-compliance homes exhibit certain characteristics or practices that affected air quality independently of the nonfunctional filter. It could be that high-compliance homes are more likely to use air purifiers or dehumidifiers, keep their pets outside, or undergo mold inspections. These unexpected results support the hypothesis that household behavior affects air quality. Even those who received a nonfunctional device experienced a reduction if they reported good wood-burning practices and complied with instructions. The practical implication of this finding is that user behavior is very important in these interventions. Further studies could address the effects of a behavioral or training intervention.

In 1307, King Edward I decreed that coal should no longer be burned, as it was injuring his subjects' "bodily health" (Boyd, 2015). More than 700 years later, wood and coal are still commonly burned around the world, and the evidence of injury to bodily health has grown. In developing and developed countries, use of biomass is highest in rural areas, where access to clean fuels is often limited by infrastructure, cost, and tradition. Wood stove changeouts and air filters may be effective in improving air quality and health. However, rural communities face many challenges and limited resources, and before these interventions are deployed on a large scale, it is wise to scrutinize their effectiveness, and consider the best approach to implementation. Additional training or behavioral tools for households could help them realize maximum benefit from these devices and optimize the cost-effectiveness of changeouts or other intervention programs.

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Appendix

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Figure 4: Original air quality kernel density plots

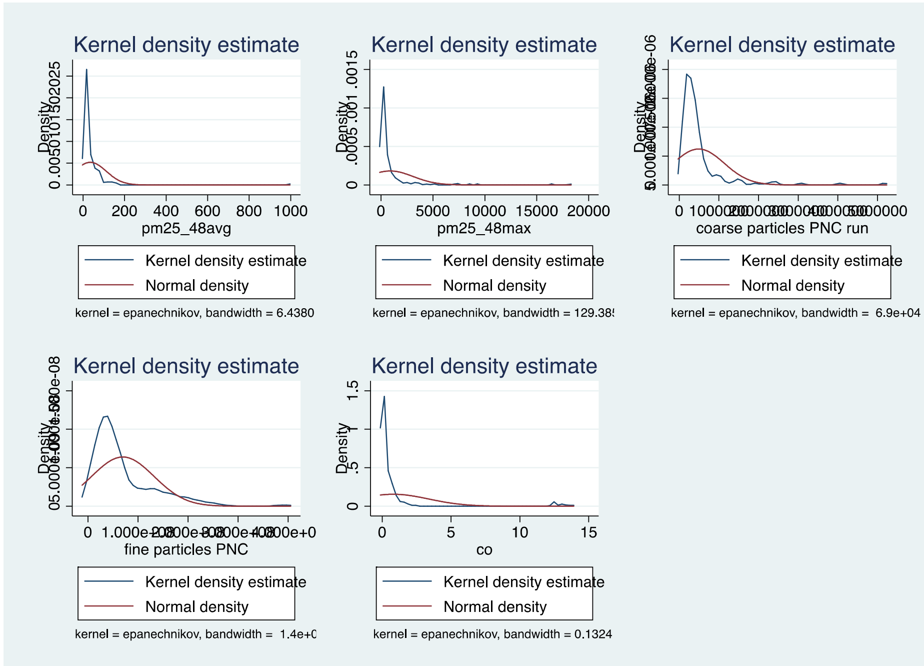

Figure 5: Log-transformed air quality kernel density plots

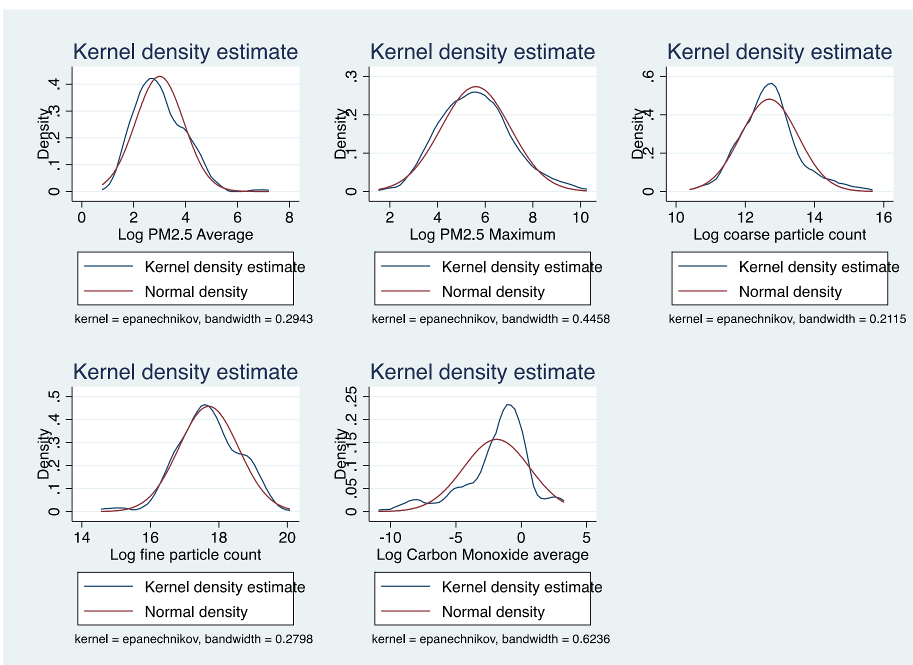

Table 22: Comparison of demographics and baseline weather between treatment groups (p-values)

	Placebo	Changeout	Filter
T-tests			
Humidity (%)	0.692	0.430	0.853
Temperature (F)	0.632	0.534	0.347
Average wind speed (mph)	0.118	0.186	0.561
Precipitation (in)	0.250	0.678	0.144
Home square footage (hundreds)	0.681	0.201	0.605
Wilcoxon Rank Sum			
Number of children in home	0.8197	0.7704	0.9932
Tests of proportion			
Caregiver's education level (0-1)	0.675	0.512	0.947
Household yearly income (0-1)	0.693	0.875	0.779
Home type	0.924	0.268	0.354
Pet in home	0.996	0.563	0.660
Year home built	0.670	0.439	0.315
Year wood stove built	0.740	0.316	0.673
Other heat source	0.598	0.139	0.101

Table 23: Comparison of baseline behavior between treatment groups

	Placebo	Changeout	Filter
T-tests			
Number of times the stove was stoked or loaded	0.681	0.375	0.798
Amount of wood used (cords)	0.111	0.814	0.153
Mean compliance	0.874		0.874
Tests of proportion			
Burning intensity (0-1)	0.804	0.328	0.326
Wood age (0-1)	0.839	0.796	0.689
Doors or windows opened during exposure sampling	0.933	0.076	0.211
Other burning during exposure sampling	0.716	0.555	0.420
Cleaning during exposure sampling	0.859	0.773	0.694
Median compliance	0.899		0.899

Table 24: Comparison of baseline air quality between treatment groups

	Placebo v. Sample	Changeout v. Sample	Filter v. Sample
T-tests			
$PM_{2.5}$ Average	0.0827	0.00281**	0.592
$PM_{2.5}$ Maximum	0.0841	0.0175*	0.928
Coarse particle count	0.867	0.208	0.429
Fine particle count	0.328	0.000309***	0.0836
Carbon monoxide average	0.248	0.0716	0.697

Figure 6: Change in number of times the stove was stoked or loaded (post-intervention winter average minus pre-intervention winter average)

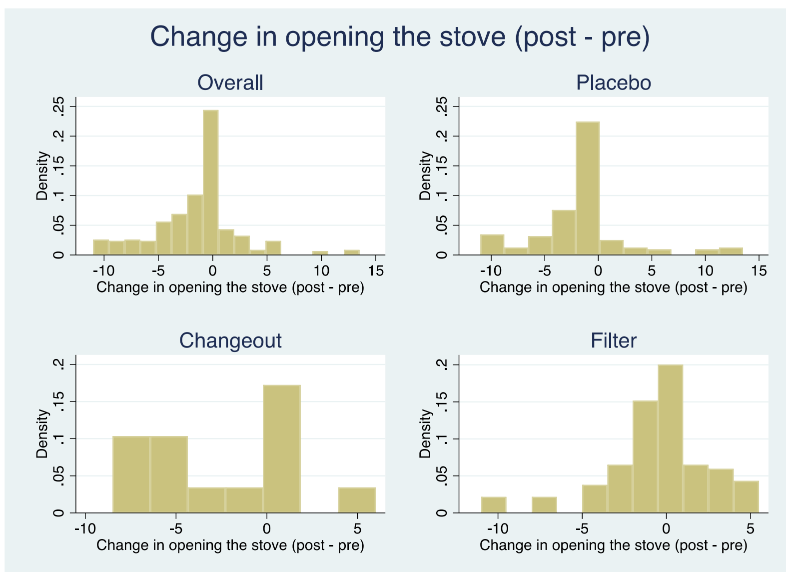

Figure 7: Change in burning intensity (post-intervention winter average – pre-intervention winter average)

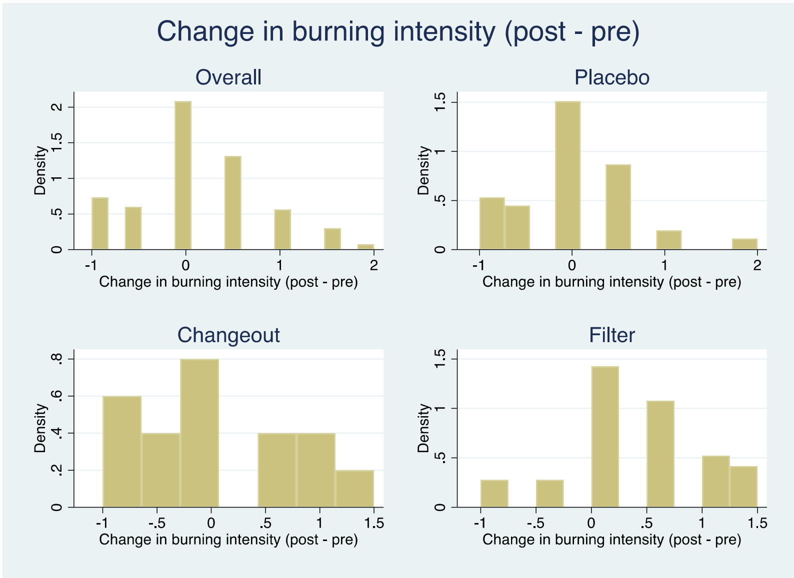

Figure 8: Change in age of wood burned

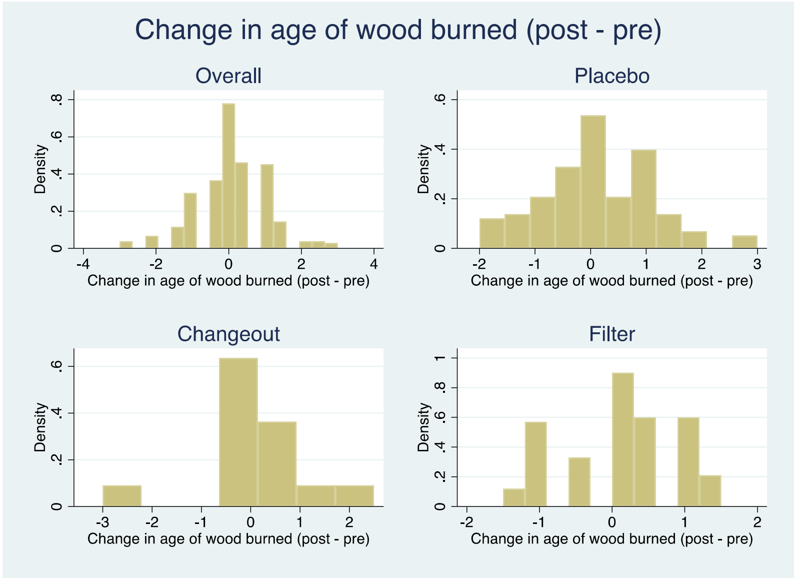

Figure 9: Change in wood usage

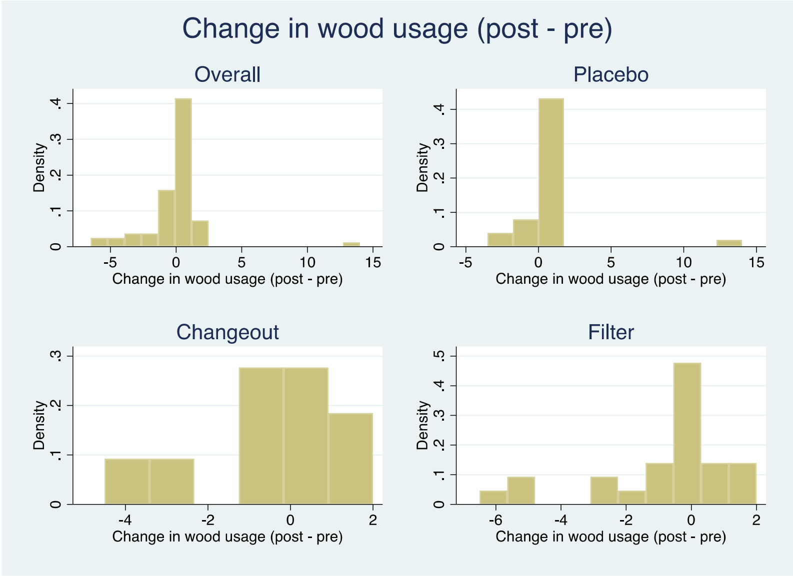

Figure 10: Change in opening of doors or windows

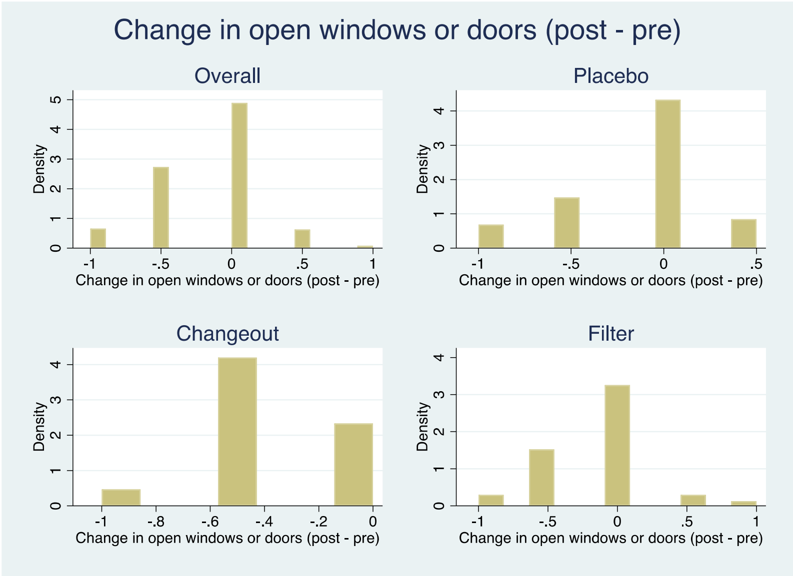

Figure 11: Change in other burning

Figure 12: Change in cleaning

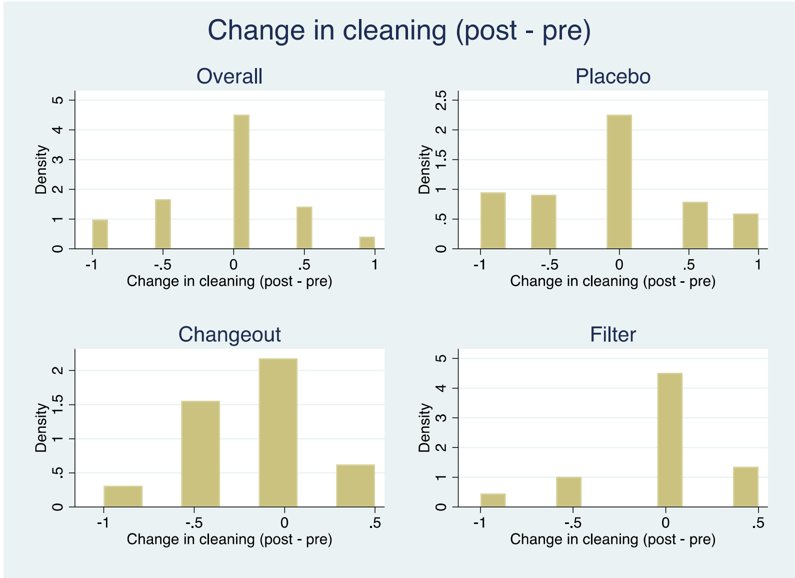

Table 25: Attrition probit tests

	(1) No controls	(2) Community FE	(3) Some controls	(4) Full model
Attrition				
Stove changeout	0.111	1.161	0.736	5.671
	(1.608)	(84.625)	(1.873)	(6.041)
Air filter	1.117	4.769***	1.330	-1.529
	(1.135)	(1.620)	(1.717)	(2.389)
Missoula		0.957	0.218	0.882
		(2.154)	(1.838)	(5.876)
Nez Perce Reservation		4.333*	0.000	0.000
		(2.563)	(.)	(.)
Butte		0.108	0.500	-2.529
		(2.410)	(2.083)	(3.451)
Western Montana		3.243*	0.000	0.000
		(1.812)	(.)	(.)
Household yearly income			0.203	-0.580
			(1.493)	(2.523)
Caregiver's education level			-0.994	-4.650
			(1.543)	(3.376)
Number of children in home				2.022**
				(0.870)
Pet in home				4.808
				(4.255)
Home type				12.744**
				(5.132)
Home square footage (hundreds)				-1.143***
				(0.443)
Year home built				-5.234
				(3.259)
Year wood stove built				-0.630
				(2.959)
Other heat source				-2.044
				(2.951)
Constant	-9.725***	-30.408***	-11.730***	-8.072
	(0.910)	(2.346)	(2.389)	(6.856)
/				
lnsig2u	4.038***	6.338***	4.561***	4.023***
	(0.294)	(0.166)	(0.338)	(0.559)
N	354.000	322.000	236.000	148.000
chi2	1.136	13.628**	1.145	12.963

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 26: Pre-intervention determinants of indoor air quality (full results)

	(1) Log $PM_{2.5}$ Average	(2) Log $PM_{2.5}$ Maximum	(3) Log coarse particle count	(4) Log fine particle count	(5) Log Carbon Monoxide average
main					
Number of times the stove was stoked or loaded	0.015 (0.019)	0.027 (0.042)	0.045** (0.018)	0.021 (0.023)	0.028 (0.133)
Burning intensity dummy	0.151 (0.148)	0.010 (0.300)	0.337** (0.152)	0.037 (0.170)	-0.585 (1.194)
Wood age	-0.357*** (0.127)	-0.042 (0.291)	-0.273 (0.196)	-0.445*** (0.146)	-0.674 (1.221)
Amount of wood used (cords)	-0.034 (0.031)	0.025 (0.059)	-0.022 (0.038)	0.028 (0.037)	-0.098 (0.182)
Doors or windows opened during exposure sampling	0.542*** (0.149)	0.648** (0.325)	0.324** (0.150)	0.459** (0.199)	0.803 (0.968)
Other burning during exposure sampling	-0.091 (0.147)	-0.179 (0.268)	-0.017 (0.189)	0.005 (0.168)	0.774 (0.906)
Cleaning during exposure sampling	-0.039 (0.134)	0.164 (0.321)	0.223 (0.147)	-0.120 (0.188)	-2.218** (0.938)
Household yearly income	-0.623*** (0.229)	-0.831** (0.376)	0.140 (0.203)	-0.528** (0.247)	0.553 (0.844)
Caregiver's education level	-0.093 (0.212)	-0.046 (0.372)	-0.574*** (0.209)	-0.043 (0.217)	1.122 (0.937)
Number of children in home	0.078 (0.118)	0.057 (0.177)	-0.056 (0.082)	0.030 (0.113)	0.252 (0.456)
Pet in home	0.222 (0.183)	0.142 (0.580)	0.293 (0.182)	0.132 (0.222)	0.240 (0.933)
Home type	0.070 (0.285)	0.113 (0.371)	0.122 (0.262)	-0.090 (0.291)	-0.731 (1.107)
Home square footage (hundreds)	-0.025* (0.013)	-0.030 (0.022)	-0.022** (0.011)	-0.020 (0.014)	0.040 (0.055)
Year home built	-0.214 (0.227)	-0.393 (0.305)	0.087 (0.228)	0.186 (0.259)	-0.591 (1.065)
Year wood stove built	-0.002 (0.245)	-0.184 (0.473)	0.081 (0.197)	0.151 (0.241)	-3.096** (1.363)
Other heat source	-0.112 (0.164)	-0.366 (0.378)	-0.551*** (0.173)	-0.445** (0.183)	-0.214 (0.895)
Temperature (F)	0.021** (0.010)	0.013 (0.017)	0.012 (0.008)	-0.000 (0.012)	-0.014 (0.048)
Humidity (%)	-0.005 (0.008)	-0.034** (0.014)	-0.003 (0.006)	0.000 (0.009)	-0.017 (0.068)
Precipitation (in)	-1.613 (1.457)	1.140 (3.055)	-1.668 (1.371)	-0.775 (1.800)	9.181 (7.812)
Average wind speed (mph)	-0.088** (0.040)	-0.029 (0.093)	0.064 (0.048)	-0.068 (0.056)	-0.439 (0.323)
Missoula	0.326 (0.356)	1.100** (0.555)	0.781* (0.415)	-0.107 (0.353)	4.097 (4.069)
Butte	-0.335 (0.593)	-0.854 (1.098)	-0.296 (0.477)	-0.393 (0.650)	5.075* (3.057)
Fairbanks	0.959* (0.549)	1.671* (0.931)	0.670 (0.461)	0.010 (0.546)	2.466 (4.810)
Western Montana	0.179 (0.262)	0.475 (0.429)	0.072 (0.249)	-0.153 (0.272)	3.932 (2.660)

Constant	3.623***	7.958***	12.533***	18.603***	0.066
	(0.811)	(1.359)	(0.650)	(0.973)	(4.129)
lns1_1_1					
Constant	-0.423***	-0.289	-0.569**	-0.485***	0.008
	(0.164)	(0.610)	(0.263)	(0.144)	(1.504)
lnsig_e					
Constant	-1.051***	-0.091	-0.892***	-0.859***	0.698*
	(0.181)	(0.323)	(0.245)	(0.148)	(0.403)
N	96.000	96.000	88.000	88.000	52.000
chi2	181.666***	71.335***	112.256***	116.391***	92.459***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 27: Treatment effects (full results) – Average $PM_{2.5}$

	(1) No controls	(2) No behavior controls	(3) Full model
$PM_{2.5}$ Average (log)			
Stove changeout, pre-intervention	0.615***	0.716***	0.825***
	(0.221)	(0.266)	(0.223)
Air filter, pre-intervention	0.146	0.118	0.137
	(0.180)	(0.186)	(0.184)
Placebo, post-intervention	-0.114	-0.297*	-0.293
	(0.130)	(0.165)	(0.182)
Stove changeout, post-intervention	-0.004	-0.062	-0.203
	(0.184)	(0.300)	(0.332)
Air filter, post-intervention	-1.126***	-0.670***	-0.669**
	(0.196)	(0.237)	(0.264)
Household yearly income		-0.786***	-0.601***
		(0.169)	(0.188)
Caregiver's education level		0.092	0.106
		(0.155)	(0.170)
Number of children in home		0.063	0.029
		(0.069)	(0.079)
Pet in home		0.242*	0.198
		(0.146)	(0.158)
Home type		0.347	0.130
		(0.237)	(0.221)
Home square footage (hundreds)		-0.034***	-0.033***
		(0.012)	(0.011)
Year home built		0.104	-0.021
		(0.167)	(0.178)
Year wood stove built		0.055	0.206
		(0.196)	(0.195)
Other heat source		-0.208	-0.254*
		(0.136)	(0.132)
Temperature (F)		-0.001	0.006
		(0.006)	(0.007)
Humidity (%)		0.010	0.005
		(0.008)	(0.008)
Precipitation (in)		-1.354	-0.677
		(1.383)	(1.550)
Average wind speed (mph)		0.047	-0.011
		(0.041)	(0.048)
Missoula		0.458**	0.525**
		(0.222)	(0.249)
Nez Perce Reservation		-0.133	0.006
		(0.581)	(0.672)
Butte		0.282	0.418
		(0.538)	(0.452)
Fairbanks		0.324	0.626*
		(0.359)	(0.338)
Western Montana		0.387**	0.386**
		(0.182)	(0.179)
Number of times the stove was stoked or loaded			0.036*
			(0.021)
Burning intensity dummy			-0.027
			(0.135)
Wood age			-0.423***
			(0.147)
Amount of wood used (cords)			-0.004
			(0.024)
Doors or windows opened during exposure sampling			0.136
			(0.177)
Other burning during exposure sampling			0.068

			(0.133)
Cleaning during exposure sampling			-0.119
			(0.129)
Constant	2.828***	2.026***	2.740***
	(0.125)	(0.741)	(0.784)
lns1_1_1			
Constant	-0.276***	-0.891**	-0.949*
	(0.084)	(0.378)	(0.485)
lnsig_e			
Constant	-0.547***	-0.379***	-0.441***
	(0.094)	(0.130)	(0.167)
N	350.000	190.000	169.000
chi2	86.682***	150.002***	340.684***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 28: Treatment effects (full results) – Maximum $PM_{2.5}$

	(1) No controls	(2) No behavior controls	(3) Full model
$PM_{2.5}$ Maximum (log)			
Stove changeout, pre-intervention	0.815***	0.854**	0.770*
	(0.306)	(0.377)	(0.442)
Air filter, pre-intervention	0.271	0.385	0.347
	(0.292)	(0.288)	(0.260)
Placebo, post-intervention	-0.078	-0.372	-0.400
	(0.188)	(0.236)	(0.267)
Stove changeout, post-intervention	-0.187	-0.077	-0.085
	(0.274)	(0.424)	(0.499)
Air filter, post-intervention	-0.791***	-0.100	0.059
	(0.279)	(0.329)	(0.346)
Household yearly income		-0.983***	-0.750**
		(0.320)	(0.338)
Caregiver's education level		0.137	0.076
		(0.276)	(0.305)
Number of children in home		0.079	0.072
		(0.112)	(0.128)
Pet in home		0.111	0.218
		(0.361)	(0.382)
Home type		0.438	0.276
		(0.309)	(0.315)
Home square footage (hundreds)		-0.036**	-0.040**
		(0.017)	(0.017)
Year home built		0.094	-0.130
		(0.226)	(0.247)
Year wood stove built		0.013	0.075
		(0.370)	(0.363)
Other heat source		-0.485**	-0.544**
		(0.228)	(0.247)
Temperature (F)		-0.005	-0.003
		(0.008)	(0.010)
Humidity (%)		-0.002	-0.014
		(0.011)	(0.012)
Precipitation (in)		-0.333	0.869
		(2.261)	(2.419)
Average wind speed (mph)		0.095*	0.024
		(0.056)	(0.065)
Missoula		0.784**	0.941**
		(0.365)	(0.445)
Nez Perce Reservation		-0.506	-0.172
		(0.686)	(0.786)
Butte		0.247	0.343
		(0.770)	(0.779)
Fairbanks		0.648	0.983*
		(0.495)	(0.549)
Western Montana		0.525	0.563
		(0.324)	(0.361)
Number of times the stove was stoked or loaded			0.023
			(0.028)
Burning intensity dummy			-0.269
			(0.209)
Wood age			-0.286
			(0.225)
Amount of wood used (cords)			0.034
			(0.041)
Doors or windows opened during exposure sampling			0.159
			(0.269)

Other burning during exposure sampling			0.053
			(0.191)
Cleaning during exposure sampling			-0.061
			(0.219)
Constant	5.345***	5.414***	6.652***
	(0.187)	(1.050)	(1.089)
lns1_1_1			
Constant	0.010	-0.604	-1.140
	(0.104)	(0.500)	(1.668)
lnsig_e			
Constant	-0.001	0.093	0.129
	(0.060)	(0.128)	(0.145)
N	350.000	190.000	169.000
chi2	28.934***	76.644***	91.973***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 29: Treatment Effects (full results) – Coarse particle count

	(1) No controls	(2) No behavior controls	(3) Full model
Coarse particle count (log)			
Stove changeout, pre-intervention	0.194 (0.238)	-0.079 (0.311)	-0.064 (0.414)
Air filter, pre-intervention	-0.034 (0.169)	0.033 (0.227)	-0.036 (0.230)
Placebo, post-intervention	-1.196*** (0.349)	-1.328*** (0.354)	-1.094*** (0.363)
Stove changeout, post-intervention	0.948** (0.397)	0.494 (0.443)	0.286 (0.571)
Air filter, post-intervention	-0.530 (0.515)	-0.565 (0.653)	-0.890 (0.650)
Household yearly income		-0.300 (0.282)	-0.488 (0.417)
Caregiver's education level		-0.158 (0.315)	0.221 (0.298)
Number of children in home		0.076 (0.120)	0.067 (0.107)
Pet in home		0.577 (0.353)	0.580 (0.429)
Home type		0.566** (0.287)	0.553 (0.354)
Home square footage (hundreds)		0.001 (0.012)	-0.002 (0.012)
Year home built		0.015 (0.255)	0.062 (0.295)
Year wood stove built		0.056 (0.395)	0.274 (0.412)
Other heat source		-0.183 (0.222)	-0.238 (0.297)
Temperature (F)		-0.007 (0.014)	0.011 (0.012)
Humidity (%)		0.022 (0.018)	0.008 (0.018)
Precipitation (in)		0.554 (1.672)	0.517 (1.880)
Average wind speed (mph)		0.142* (0.073)	0.030 (0.084)
Missoula		0.180 (0.303)	0.381 (0.335)
Nez Perce Reservation		0.463 (0.485)	0.495 (0.583)
Butte		0.195 (0.456)	0.342 (0.475)
Fairbanks		-0.081 (0.516)	0.559 (0.558)
Western Montana		-0.610** (0.308)	-0.351 (0.308)
Number of times the stove was stoked or loaded			-0.031 (0.036)

Burning intensity dummy			-0.042
			(0.357)
Wood age			-0.589**
			(0.237)
Amount of wood used (cords)			0.007
			(0.045)
Doors or windows opened during exposure sampling			0.227
			(0.220)
Other burning during exposure sampling			-0.283
			(0.363)
Cleaning during exposure sampling			0.216
			(0.260)
Constant	12.666***	10.240***	11.216***
	(0.133)	(1.310)	(1.584)
lns1_1_1			
Constant	0.024	-2.036	-11.978
	(0.260)	(12.164)	(18.543)
lnsig_e			
Constant	0.264*	0.370**	0.316**
	(0.144)	(0.182)	(0.132)
N	323.000	173.000	154.000
chi2	36.116***	85.476***	122.546***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 30: Treatment Effects (full results) – Fine particle count

	(1) Treatment	(2) Demographic, weather, and home characteristic controls	(3) Full model
Fine particle count (log)			
Stove changeout, pre-intervention	0.567*** (0.212)	0.477 (0.300)	0.624** (0.316)
Air filter, pre-intervention	-0.069 (0.176)	-0.045 (0.251)	-0.015 (0.245)
Placebo, post-intervention	-0.581** (0.243)	-0.606** (0.261)	-0.452 (0.294)
Stove changeout, post-intervention	0.479* (0.285)	0.207 (0.408)	-0.150 (0.492)
Air filter, post-intervention	-1.154*** (0.412)	-1.083** (0.552)	-1.247** (0.561)
Household yearly income		-0.928*** (0.257)	-1.070*** (0.362)
Caregiver's education level		0.234 (0.262)	0.478* (0.282)
Number of children in home		0.025 (0.099)	0.033 (0.104)
Pet in home		0.321 (0.272)	0.325 (0.327)
Home type		0.254 (0.325)	0.069 (0.349)
Home square footage (hundreds)		-0.008 (0.015)	-0.009 (0.015)
Year home built		-0.143 (0.229)	-0.050 (0.268)
Year wood stove built		0.095 (0.318)	0.389 (0.349)
Other heat source		-0.183 (0.187)	-0.120 (0.227)
Temperature (F)		-0.020* (0.011)	-0.004 (0.009)
Humidity (%)		0.024* (0.015)	0.017 (0.016)
Precipitation (in)		-0.892 (1.648)	-0.486 (1.988)
Average wind speed (mph)		0.072 (0.062)	-0.031 (0.077)
Missoula		0.021 (0.317)	-0.004 (0.348)
Nez Perce Reservation		0.070 (0.674)	-0.055 (0.799)
Butte		0.291 (0.581)	0.494 (0.576)
Fairbanks		-0.224 (0.489)	0.054 (0.447)
Western Montana		-0.361 (0.306)	-0.331 (0.357)

Number of times the stove was stoked or loaded			0.016
			(0.037)
Burning intensity dummy			-0.125
			(0.306)
Wood age			-0.574***
			(0.223)
Amount of wood used (cords)			-0.017
			(0.042)
Doors or windows opened during exposure sampling			0.067
			(0.208)
Other burning during exposure sampling			-0.027
			(0.291)
Cleaning during exposure sampling			-0.146
			(0.197)
Constant	17.632***	16.358***	17.150***
	(0.124)	(1.197)	(1.509)
lns1_1_1	-0.124	-0.658	-0.239
Constant	(0.250)	(0.683)	(0.440)
lnsig_e	0.104	0.138	-0.113
Constant	(0.136)	(0.196)	(0.362)
N	323.000	173.000	154.000
chi2	48.865***	74.421***	132.739***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 31: Treatment Effects (full results) – Carbon monoxide

	(1) Treatment	(2) Demographic, weather, and home characteristic controls	(3) Full model
Carbon Monoxide average (log)			
Stove changeout, pre-intervention	1.165** (0.544)	0.353 (1.008)	-0.657 (1.163)
Air filter, pre-intervention	0.218 (0.611)	-0.066 (0.784)	0.179 (0.780)
Placebo, post-intervention	0.577 (0.516)	0.769 (0.775)	0.928 (0.810)
Stove changeout, post-intervention	-2.194** (0.934)	-0.857 (1.311)	-0.474 (1.291)
Air filter, post-intervention	-0.146 (0.690)	0.104 (1.035)	-0.212 (1.099)
Household yearly income		-0.443 (0.519)	-0.163 (0.464)
Caregiver's education level		1.062** (0.497)	0.964** (0.474)
Number of children in home		0.162 (0.205)	0.211 (0.210)
Pet in home		-0.237 (0.602)	-0.457 (0.583)
Home type		-0.604 (0.644)	-1.055* (0.617)
Home square footage (hundreds)		0.026 (0.028)	0.036 (0.033)
Year home built		-0.675 (0.543)	-1.248* (0.659)
Year wood stove built		-0.578 (0.634)	-0.557 (0.782)
Other heat source		0.080 (0.435)	-0.105 (0.457)
Temperature (F)		-0.005 (0.020)	0.009 (0.021)
Humidity (%)		0.019 (0.022)	0.004 (0.029)
Precipitation (in)		-2.394 (2.746)	-2.478 (3.298)
Average wind speed (mph)		-0.136 (0.195)	-0.368* (0.216)
Missoula		-0.149 (0.717)	-0.725 (1.267)
Nez Perce Reservation		2.192** (0.900)	2.297** (0.948)
Butte		2.111* (1.185)	2.659** (1.147)
Fairbanks		-1.462 (1.136)	-1.237 (1.508)
Western Montana		0.132 (0.545)	-0.487 (0.823)

Number of times the stove was stoked or loaded			0.004
			(0.090)
Burning intensity dummy			0.210
			(0.622)
Wood age			-0.898
			(0.589)
Amount of wood used (cords)			-0.018
			(0.062)
Doors or windows opened during exposure sampling			0.567
			(0.440)
Other burning during exposure sampling			0.516
			(0.462)
Cleaning during exposure sampling			-0.493
			(0.532)
Constant	-2.265***	-3.020	-0.246
	(0.412)	(1.862)	(2.870)
lns1_1_1			
Constant	0.220	0.128	0.132
	(0.210)	(0.628)	(0.557)
lnsig_e			
Constant	0.643***	0.612***	0.546**
	(0.094)	(0.218)	(0.242)
N	249.000	123.000	110.000
chi2	9.880*	137.212***	150.699***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Effect of treatment assignment on behavior change {B}
Probit tests
Comparison tables

Table 32: Effect of treatment assignment on wood index, home index, compliance

	(1) Worsened wood-burning	(2) Worsened home activities	(3) High compliance
Stove changeout	-0.054	-0.491	0.000
	(0.388)	(0.405)	(.)
Air filter	0.273	-0.167	-0.206
	(0.299)	(0.301)	(0.299)
Constant	-0.199	-0.132	0.132
	(0.206)	(0.205)	(0.205)
N	87.000	87.000	72.000
chi2	1.094	1.487	0.477

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 33: Effect of treatment assignment on wood-burning variables

	(1) Activity increase	(2) Burning intensity increase	(3) Wood age decrease	(4) Wood usage increase
Stove changeout	-0.211	0.014	-0.362	0.183
	(0.474)	(0.389)	(0.428)	(0.386)
Air filter	0.358	0.415	-0.149	0.193
	(0.329)	(0.300)	(0.315)	(0.300)
Constant	-0.899***	-0.267	-0.480**	-0.267
	(0.238)	(0.207)	(0.213)	(0.207)
N	87.000	87.000	87.000	87.000
chi2	1.992	2.172	0.756	0.480

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 34: Effect of treatment assignment on home activity variables

	(1) Open doors/windows increase	(2) Other burning increase	(3) Cleaning increase
Stove changeout	0.000	-0.556	-0.556
	(.)	(0.464)	(0.464)
Air filter	-0.349	-0.374	-0.374
	(0.393)	(0.333)	(0.333)
Constant	-1.003***	-0.555**	-0.555**
	(0.247)	(0.216)	(0.216)
N	72.000	87.000	87.000
chi2	0.785	2.071	2.071

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 35: Comparison of proportions of households that adjusted stove stoking or loading by treatment group

Activity	Placebo	Changeout	Filter	Total
0 No change/improvement				
Frequency				
(Column percentage)	31	13	24	68
	(81.58)	(86.67)	(70.59)	(78.16)
1 Worsened				
Frequency	7	2	10	19
(Column percentage)	(18.42)	(13.33)	(29.41)	(21.84)
Total				
Frequency	38	15	143	87
(Column percentage)	(100)	(100)	(100)	(100)

Table 36: Comparison of proportions of households that adjusted burning intensity by treatment group

Intensity	Placebo	Changeout	Filter	Total
0 No change/improvement				
Frequency				
(Column percentage)	23	9	15	47
	(60.53)	(60.00)	(44.12)	(54.02)
1 Worsened				
Frequency	15	6	19	40
(Column percentage)	(39.47)	(40.00)	(55.88)	(45.98)
Total				
Frequency	38	15	34	87
(Column percentage)	(100)	(100)	(100)	(100)

Table 37: Comparison of proportions of households that adjusted wood age by treatment group

Wood age	Placebo	Changeout	Filter	Total
0 No change/improvement				
Frequency				
(Column percentage)	26	12	25	63
	(68.42)	(80.00)	(73.53)	(72.41)
1 Worsened				
Frequency	12	3	9	24
(Column percentage)	(31.58)	(20.00)	(26.47)	(27.59)
Total				
Frequency	38	15	34	87
(Column percentage)	(100)	(100)	(100)	(100)

Table 38: Comparison of proportions of households that adjusted wood usage by treatment group

Wood usage	Placebo	Changeout	Filter	Total
0 No change/improvement				
Frequency				
(Column percentage)	23	8	18	49
	(60.53)	(53.33)	(52.94)	(56.32)
1 Worsened				
Frequency	15	7	16	38
(Column percentage)	(39.47)	(46.67)	(47.06)	(43.68)
Total				
Frequency	38	15	34	87
(Column percentage)	(100)	(100)	(100)	(100)

Table 39: Comparison of proportions of households that adjusted opening of doors or windows by treatment group

Open doors/windows	Placebo	Changeout	Filter	Total
0 No change/improvement				
Frequency				
(Column percentage)	32	15	31	78
	(84.21)	(100.00)	(91.18)	(85.59)
1 Worsened				
Frequency	6	0	3	9
(Column percentage)	(15.79)	(0.00)	(8.82)	(14.41)
Total				
Frequency	38	15	34	87
(Column percentage)	(100)	(100)	(100)	(100)

Table 40: Comparison of proportions of households that adjusted other burning by treatment group

Other burning	Placebo	Changeout	Filter	Total
0 No change/improvement				
Frequency				
(Column percentage)	27	13	28	68
	(71.05)	(86.67)	(82.35)	(78.16)
1 Worsened				
Frequency	11	2	6	19
(Column percentage)	(28.95)	(13.33)	(17.65)	(21.84)
Total				
Frequency	38	15	34	87
(Column percentage)	(100)	(100)	(100)	(100)

Table 41: Comparison of proportions of households that adjusted cleaning by treatment group

Cleaning	Placebo	Changeout	Filter	Total
0 No change/improvement				
Frequency				
(Column percentage)	27	13	28	68
	(71.05)	(86.67)	(82.35)	(78.16)
1 Worsened				
Frequency	11	2	6	19
(Column percentage)	(28.95)	(13.33)	(17.65)	(21.84)
Total				
Frequency	38	15	34	87
(Column percentage)	(100)	(100)	(100)	(100)

Effect of behavior change on change in air quality
Comparison tables
Regression output

Table 42: Treatment effects by behavior change subgroup ($PM_{2.5}$ average)

	Compliance		Wood index		Home index		Wood age	
	(1) High	(2) Low	(3) No change	(4) Worsened	(5) No change	(6) Worsened	(7) No change	(8) Worsened
$PM_{2.5}$ Average (log)								
Air filter, pre-intervention	0.008	-0.271	0.161	0.306	0.198	-0.041	0.074	1.091***
	(0.190)	(0.250)	(0.238)	(0.209)	(0.236)	(0.245)	(0.207)	(0.274)
Placebo, post-intervention	-0.323**	-0.098	-0.457*	-0.018	0.074	-0.627**	-0.410*	-0.066
	(0.150)	(0.430)	(0.251)	(0.241)	(0.201)	(0.246)	(0.217)	(0.225)
Air filter, post-intervention	-0.851***	-0.787	-0.437	-1.076***	-0.928***	-1.131***	-0.443	-1.271***
	(0.295)	(0.492)	(0.293)	(0.341)	(0.244)	(0.367)	(0.279)	(0.316)
Household yearly income	-1.048***	-0.153	-0.412	-0.962***	-0.549**	-0.360	-0.736***	-0.556
	(0.161)	(0.260)	(0.276)	(0.197)	(0.255)	(0.328)	(0.176)	(0.533)
Caregiver's education level	0.146	-0.465*	0.713***	0.179	0.496**	0.054	0.399*	0.153
	(0.178)	(0.263)	(0.205)	(0.148)	(0.218)	(0.173)	(0.235)	(0.679)
Number of children in home	-0.061	0.123	0.468***	-0.139**	0.436***	0.038	0.092	0.124
	(0.086)	(0.108)	(0.094)	(0.066)	(0.082)	(0.082)	(0.079)	(0.136)
Pet in home	0.159	0.259	0.329*	0.331	-0.386	0.575***	0.343**	0.000
	(0.157)	(0.308)	(0.176)	(0.343)	(0.261)	(0.209)	(0.174)	(.)
Home type	0.523**	0.588**	-0.867***	0.609**	-0.270	0.582**	0.144	0.079
	(0.237)	(0.297)	(0.325)	(0.245)	(0.379)	(0.286)	(0.322)	(0.321)
Home square footage (hundreds)	-0.042***	-0.054***	0.007	-0.037***	-0.049***	-0.040***	-0.017	-0.033**
	(0.012)	(0.013)	(0.015)	(0.011)	(0.014)	(0.013)	(0.017)	(0.015)
Year home built	0.193	0.442**	-0.530***	0.209	0.485**	-0.208	-0.008	-0.471
	(0.212)	(0.179)	(0.166)	(0.181)	(0.229)	(0.206)	(0.221)	(0.399)
Year wood stove built	0.693***	-0.476	-0.219	0.936***	0.162	0.092	-0.113	0.953**
	(0.178)	(0.346)	(0.220)	(0.329)	(0.214)	(0.277)	(0.250)	(0.409)
Other heat source	-0.101	-0.101	-0.109	-0.698***	0.161	-0.513***	-0.382**	-0.245
	(0.145)	(0.207)	(0.201)	(0.171)	(0.168)	(0.199)	(0.176)	(0.250)
Temperature (F)	0.013	0.011	0.011	-0.008	0.012	-0.002	0.006	-0.003
	(0.012)	(0.008)	(0.010)	(0.008)	(0.009)	(0.012)	(0.010)	(0.010)

Humidity (%)	0.008	0.011	-0.008	0.021*	0.001	-0.012	0.006	0.011
	(0.010)	(0.013)	(0.012)	(0.011)	(0.009)	(0.015)	(0.009)	(0.014)
Precipitation (in)	-1.010	-1.040	-1.548	-3.060	-2.994	-3.166**	-2.036	-1.345
	(1.273)	(2.001)	(1.117)	(2.412)	(2.657)	(1.547)	(1.438)	(3.889)
Average wind speed (mph)	-0.022	0.098	-0.102**	0.039	0.027	-0.078	0.012	-0.161**
	(0.048)	(0.071)	(0.048)	(0.043)	(0.062)	(0.058)	(0.041)	(0.079)
Worsened 2 or more wood-burning behaviors pre-post intervention	-0.006	-0.346			0.421*	-0.508**		
	(0.189)	(0.286)			(0.227)	(0.198)		
Worsened 1 or more home activities	-0.086	-0.724***	0.111	-0.131			-0.368**	-0.598
	(0.134)	(0.190)	(0.170)	(0.177)			(0.183)	(0.393)
Missoula	0.717**	0.000	0.073	0.654**	0.345	0.749***	0.747***	0.597
	(0.290)	(.)	(0.321)	(0.310)	(0.259)	(0.273)	(0.248)	(0.392)
Nez Perce Reservation	0.927**	-1.697***	1.721***		-0.316	1.889***	0.993**	
	(0.444)	(0.512)	(0.301)		(0.498)	(0.621)	(0.418)	
Butte	0.000	-0.183	0.062	1.379***	0.995	-0.871	0.135	3.095***
	(0.775)	(0.614)	(0.448)	(0.447)	(0.648)	(0.772)	(0.554)	(0.913)
Fairbanks	-0.219	0.106	0.622	0.630	-0.142		0.795	-1.169*
	(0.467)	(0.441)	(0.406)	(0.614)	(0.400)		(0.552)	(0.685)
Western Montana	0.571**	-0.540*	0.530**	0.283	0.738***	0.088	0.922***	-0.585
	(0.287)	(0.290)	(0.259)	(0.306)	(0.238)	(0.231)	(0.209)	(0.509)
High/low compliance			0.417*	0.317*	0.021	0.360	0.232	-0.078
			(0.215)	(0.189)	(0.269)	(0.222)	(0.213)	(0.293)
Constant	1.894**	3.172***	2.268**	0.836	1.674*	4.381***	1.675*	2.945**
	(0.907)	(1.203)	(1.030)	(1.399)	(1.017)	(1.384)	(0.886)	(1.178)
lns1_1_1								
Constant	-22.803	-1.380	-22.111	-26.789	-17.600	-23.060	-1.136	-20.970
	(18.317)	(2.153)	(23.843)	(22.865)	(18.144)	(22.202)	(0.852)	(7324.708)
lnsig_e								
Constant	-0.403***	-0.410	-0.454***	-0.456***	-0.423***	-0.425***	-0.329*	-0.853***
	(0.084)	(0.267)	(0.093)	(0.069)	(0.088)	(0.075)	(0.177)	(0.109)
N	90.000	73.000	85.000	80.000	90.000	75.000	123.000	42.000
chi2	1111.809***	2410.764***	514.173***	224.496***	514.067***	1260.083***	145.498***	161.395***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 43: Treatment effects by behavior change subgroup ($PM_{2.5}$ maximum)

	Compliance		Wood index		Home index		Wood age	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	High	Low	No change	Worsened	No change	Worsened	No change	Worsened
$PM_{2.5}$ Maximum (log)								
Air filter, pre-intervention	0.123	-0.025	0.888**	0.723**	0.694*	0.136	0.270	1.682***
	(0.272)	(0.329)	(0.350)	(0.337)	(0.371)	(0.427)	(0.301)	(0.404)
Placebo, post-intervention	-0.406	0.111	-0.265	-0.218	0.148	-0.620*	-0.512*	0.428
	(0.266)	(0.539)	(0.323)	(0.343)	(0.271)	(0.351)	(0.274)	(0.331)
Air filter, post-intervention	-0.550	-0.406	-0.012	-0.737	-0.796**	-0.681	0.318	-1.805***
	(0.453)	(0.627)	(0.412)	(0.467)	(0.378)	(0.561)	(0.356)	(0.465)
Household yearly income	-1.532***	0.653	-0.389	-0.854**	-0.371	-0.511	-0.849**	-1.627**
	(0.254)	(0.468)	(0.482)	(0.338)	(0.378)	(0.613)	(0.334)	(0.786)
Caregiver's education level	0.411	-1.099**	1.225***	0.398	0.999***	-0.092	0.267	2.015**
	(0.280)	(0.486)	(0.310)	(0.305)	(0.346)	(0.366)	(0.408)	(1.001)
Number of children in home	-0.115	0.013	0.766***	-0.181	0.743***	-0.104	0.067	0.489**
	(0.127)	(0.170)	(0.144)	(0.116)	(0.148)	(0.137)	(0.140)	(0.201)
Pet in home	0.417	-1.088*	-0.064	0.722	-0.904*	0.280	0.181	0.000
	(0.333)	(0.597)	(0.348)	(0.681)	(0.534)	(0.283)	(0.495)	(.)
Home type	0.591	-0.016	-1.985***	0.480	-0.967*	0.587	-0.020	-0.487
	(0.369)	(0.428)	(0.456)	(0.391)	(0.542)	(0.425)	(0.497)	(0.472)
Home square footage (hundreds)	-0.034*	-0.048***	0.020	-0.030	-0.042**	-0.048*	-0.019	-0.030
	(0.020)	(0.017)	(0.022)	(0.019)	(0.019)	(0.025)	(0.026)	(0.022)
Year home built	0.249	0.427*	-0.886**	0.408	0.424	-0.296	-0.126	-0.376
	(0.273)	(0.250)	(0.356)	(0.326)	(0.404)	(0.403)	(0.339)	(0.588)
Year wood stove built	1.179***	-1.322**	-0.403	1.418**	0.519	-0.107	-0.125	1.611***
	(0.291)	(0.563)	(0.439)	(0.563)	(0.355)	(0.517)	(0.498)	(0.603)
Other heat source	-0.403*	-0.006	-0.526*	-0.880***	-0.177	-0.589	-0.845**	-0.159
	(0.226)	(0.353)	(0.269)	(0.301)	(0.235)	(0.388)	(0.329)	(0.368)
Temperature (F)	0.012	0.014	0.016	-0.019	0.006	-0.005	0.005	-0.009
	(0.015)	(0.014)	(0.014)	(0.012)	(0.013)	(0.027)	(0.014)	(0.015)
Humidity (%)	-0.004	-0.011	-0.046***	0.017	-0.018*	-0.035	-0.015	0.012
	(0.018)	(0.019)	(0.018)	(0.018)	(0.011)	(0.024)	(0.014)	(0.021)
Precipitation (in)	1.910	1.523	-0.425	-2.228	-0.403	-3.153	-0.231	-6.452
	(2.709)	(2.666)	(2.261)	(4.059)	(4.439)	(2.610)	(2.744)	(5.731)

Average wind speed (mph)	0.016	0.214**	-0.130	0.133**	0.028	-0.046	0.072	-0.313***
	(0.084)	(0.105)	(0.087)	(0.054)	(0.075)	(0.119)	(0.058)	(0.117)
Worsened 2 or more wood-burning behaviors pre-post intervention	-0.393	-0.174			0.791**	-0.889***		
	(0.297)	(0.427)			(0.396)	(0.330)		
Worsened 1 or more home activities	-0.441	-0.976***	0.068	-0.548*			-0.753**	-0.906
	(0.294)	(0.186)	(0.289)	(0.313)			(0.302)	(0.580)
Missoula	0.952**	0.000	0.165	0.317	-0.107	0.896	0.770	-0.074
	(0.464)	(.)	(0.732)	(0.477)	(0.511)	(0.628)	(0.506)	(0.578)
Nez Perce Reservation	0.571	-3.565***	1.336		-1.898**	2.026*	0.126	
	(1.057)	(0.698)	(0.824)		(0.839)	(1.203)	(0.943)	
Butte	-0.680	0.243	-0.224	0.810	1.214	-1.598	-0.520	3.960***
	(0.830)	(0.864)	(0.970)	(0.721)	(0.819)	(1.530)	(0.962)	(1.346)
Fairbanks	-0.680	0.829	0.775	0.858	-0.894		0.802	-2.835***
	(0.724)	(0.839)	(0.669)	(0.803)	(0.633)		(0.908)	(1.009)
Western Montana	0.572	-0.076	0.563	0.136	0.525	0.158	0.718*	-1.327*
	(0.442)	(0.400)	(0.622)	(0.478)	(0.440)	(0.561)	(0.419)	(0.751)
High/low compliance			0.944***	0.608*	0.483	0.340	0.270	-0.068
			(0.308)	(0.333)	(0.383)	(0.435)	(0.369)	(0.431)
Constant	5.112***	8.564***	7.475***	2.779	5.245***	9.672***	6.661***	5.201***
	(1.465)	(1.982)	(1.689)	(2.204)	(1.601)	(2.230)	(1.458)	(1.736)
lns1_1_1								
Constant	-26.287*	-27.239	-30.576	-0.581*	-1.235	-14.301	-19.921	-26.840***
	(15.311)	(18.956)	(19.718)	(0.319)	(1.531)	(16.175)	(16.956)	(2.648)
lnsig_e								
Constant	-0.042	0.038	0.068	-0.295**	-0.023	0.086	0.244*	-0.465***
	(0.054)	(0.080)	(0.079)	(0.124)	(0.174)	(0.080)	(0.143)	(0.109)
N	90.000	73.000	85.000	80.000	90.000	75.000	123.000	42.000
chi2	429.642***	1700.829***	546.705***	116.031***	1871.924***	770.114***	96.769***	96.629***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 44: Treatment effects by behavior change subgroup (Coarse particle count)

	Compliance		Wood index		Home index		Wood age	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	High	Low	No change	Worsened	No change	Worsened	No change	Worsened
Coarse particle count (log)								
Air filter, pre-intervention	-0.217	0.665	0.048	0.816*	-0.494	0.603	0.140	-1.718***
	(0.389)	(0.539)	(0.263)	(0.490)	(0.319)	(0.711)	(0.265)	(0.590)
Placebo, post-intervention	-1.661***	-1.396**	-0.846**	-2.178***	-0.730*	-2.268***	-1.652***	0.008
	(0.473)	(0.543)	(0.418)	(0.545)	(0.421)	(0.563)	(0.411)	(0.502)
Air filter, post-intervention	0.261	-1.268*	-0.494	-0.688	-0.813	0.057	-0.133	-2.330***
	(0.967)	(0.736)	(0.577)	(1.092)	(0.712)	(1.185)	(0.661)	(0.708)
Household yearly income	-0.360*	-1.079	-0.598	-0.512	-0.489	-2.092**	-0.200	-2.438**
	(0.212)	(0.738)	(0.612)	(0.386)	(0.392)	(0.943)	(0.384)	(1.092)
Caregiver's education level	-0.634**	0.778	0.727*	-0.422	0.151	-0.269	0.064	2.443*
	(0.287)	(0.714)	(0.422)	(0.353)	(0.264)	(0.448)	(0.476)	(1.409)
Number of children in home	-0.101	0.377**	0.410***	-0.032	0.437***	0.149	-0.009	0.180
	(0.150)	(0.191)	(0.143)	(0.171)	(0.134)	(0.192)	(0.128)	(0.301)
Pet in home	1.555***	0.467	0.307**	3.705***	0.858*	1.689**	0.670	0.000
	(0.481)	(0.657)	(0.147)	(0.958)	(0.447)	(0.672)	(0.604)	(.)
Home type	1.006*	-0.364	-0.801*	0.581	1.229	1.159*	-0.076	1.570**
	(0.550)	(0.891)	(0.456)	(0.613)	(0.936)	(0.632)	(0.666)	(0.657)
Home square footage (hundreds)	-0.016	0.064**	0.033	0.053**	-0.018	0.023	0.039	-0.094***
	(0.025)	(0.029)	(0.025)	(0.025)	(0.018)	(0.038)	(0.029)	(0.031)
Year home built	-0.132	-0.063	0.065	0.417	-0.053	0.752	-0.515	1.878**
	(0.348)	(0.396)	(0.497)	(0.397)	(0.255)	(0.520)	(0.398)	(0.816)
Year wood stove built	-0.385	0.943	0.297	0.252	-0.907	1.504**	0.291	-0.522
	(0.590)	(0.839)	(0.351)	(0.430)	(0.671)	(0.696)	(0.667)	(0.880)
Other heat source	0.059	-0.587	0.057	-0.389	0.188	-0.301	-0.108	1.493***
	(0.261)	(0.367)	(0.097)	(0.397)	(0.240)	(0.506)	(0.297)	(0.539)
Temperature (F)	0.019	-0.048**	0.008	-0.062**	0.014	-0.042	0.001	-0.020
	(0.023)	(0.022)	(0.006)	(0.026)	(0.016)	(0.048)	(0.019)	(0.023)
Humidity (%)	0.036*	0.023	-0.010**	0.049	-0.019	0.066**	0.038*	-0.119***
	(0.019)	(0.037)	(0.005)	(0.041)	(0.016)	(0.032)	(0.020)	(0.030)
Precipitation (in)	-0.294	-3.469	0.736	-3.399	4.674	-5.380*	-1.059	-10.734
	(2.955)	(2.771)	(0.696)	(3.983)	(3.330)	(3.034)	(1.656)	(8.271)
Average wind speed (mph)	0.200**	-0.025	-0.105***	0.295***	-0.072	0.189*	0.183**	-0.252

	(0.100)	(0.126)	(0.035)	(0.095)	(0.063)	(0.102)	(0.078)	(0.167)
Worsened 2 or more wood-burning behaviors pre-post intervention	-0.557**	-0.693			-0.353	-1.456***		
	(0.271)	(0.621)			(0.415)	(0.556)		
Worsened 1 or more home activities	0.580***	0.270	0.251	1.115***			0.260	3.077***
	(0.208)	(0.409)	(0.411)	(0.412)			(0.255)	(0.865)
Missoula	0.429	0.000	-1.275***	-0.045	0.116	-0.522	-0.637	1.471
	(0.434)	(.)	(0.462)	(0.608)	(0.483)	(0.948)	(0.536)	(0.944)
Nez Perce Reservation	-0.399	2.212	0.756		-0.261	0.810	1.078	
	(1.367)	(1.348)	(0.485)		(1.060)	(1.549)	(0.702)	
Butte	-0.852	2.176**	-0.136	1.012	0.928	0.946	-0.778	-0.672
	(0.914)	(0.881)	(0.658)	(1.034)	(0.596)	(1.866)	(0.816)	(1.881)
Fairbanks	1.057	-1.126	-0.538*	-0.921	0.134		-0.217	-0.078
	(0.889)	(1.161)	(0.288)	(1.217)	(0.701)		(1.076)	(1.474)
Western Montana	-0.918**	0.277	-0.351	-0.876	-1.028***	-1.624**	-1.106**	0.499
	(0.365)	(0.587)	(0.564)	(0.555)	(0.292)	(0.808)	(0.498)	(1.075)
High/low compliance			0.764**	0.449	-0.772	0.397	-0.012	-1.485**
			(0.362)	(0.546)	(0.480)	(0.551)	(0.547)	(0.616)
Constant	8.537***	9.176***	11.698***	4.419	13.453***	6.905**	8.895***	21.802***
	(1.302)	(3.518)	(0.878)	(4.292)	(1.489)	(2.810)	(1.518)	(2.641)
lns1_1_1								
Constant	-16.579	-18.363	0.120	-26.084	-1.556	-25.587	-17.882	-23.649***
	(1.548e+08)	(24.335)	(0.254)	(18.024)	(3.848)	(18.202)	(17.363)	(2.904)
lnsig_e								
Constant	0.336	0.364*	-1.385***	0.452***	-0.025	0.511***	0.429***	-0.149
	(1.746)	(0.200)	(0.156)	(0.125)	(0.239)	(0.134)	(0.143)	(0.115)
N	84.000	66.000	79.000	72.000	82.000	69.000	113.000	38.000
chi2	131.092***	217.318***	159.766***	1231.801***	941.497***	101.258***	361.790***	100.296***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 45: Treatment effects by behavior change subgroup (Fine particle count)

	Compliance		Wood index		Home index		Wood age	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	High	Low	No change	Worsened	No change	Worsened	No change	Worsened
Log fine particle count								
Air filter, pre-intervention	-0.247	-0.360	-0.127	0.484	-0.728*	0.442	-0.224	-0.585
	(0.369)	(0.474)	(0.313)	(0.420)	(0.380)	(0.510)	(0.284)	(0.391)
Placebo, post-intervention	-0.802**	-0.693	-0.625*	-0.817**	-0.018	-1.449***	-1.037***	0.371
	(0.366)	(0.463)	(0.346)	(0.365)	(0.327)	(0.368)	(0.297)	(0.320)
Air filter, post-intervention	-0.465	-1.757**	-0.686	-1.603*	-1.322**	-0.539	-0.582	-2.261***
	(0.827)	(0.685)	(0.523)	(0.887)	(0.606)	(0.924)	(0.590)	(0.473)
Household yearly income	-1.100***	-0.796	-1.178***	-1.034***	-1.143***	-2.542***	-0.882***	-2.349***
	(0.265)	(0.625)	(0.407)	(0.354)	(0.413)	(0.666)	(0.272)	(0.693)
Caregiver's education level	-0.080	0.143	1.094***	-0.092	0.684**	0.414	0.616	1.883**
	(0.295)	(0.636)	(0.263)	(0.313)	(0.325)	(0.309)	(0.377)	(0.863)
Number of children in home	-0.167	0.167	0.537***	-0.173	0.641***	0.075	0.030	0.248
	(0.148)	(0.200)	(0.099)	(0.136)	(0.128)	(0.138)	(0.106)	(0.182)
Pet in home	1.040**	0.099	0.504**	1.956***	0.206	1.310***	0.411	0.000
	(0.425)	(0.674)	(0.232)	(0.729)	(0.483)	(0.469)	(0.370)	(.)
Home type	0.587	0.363	-1.146***	0.859*	0.876	1.050**	-0.320	1.555***
	(0.454)	(0.737)	(0.400)	(0.462)	(0.917)	(0.496)	(0.456)	(0.476)
Home square footage (hundreds)	-0.006	-0.016	0.047***	0.004	-0.063**	0.032	0.035	-0.090***
	(0.029)	(0.026)	(0.017)	(0.025)	(0.025)	(0.031)	(0.029)	(0.017)
Year home built	-0.072	0.141	-0.965**	0.391	0.082	0.534	-0.761**	1.141**
	(0.331)	(0.369)	(0.418)	(0.304)	(0.364)	(0.388)	(0.385)	(0.490)
Year wood stove built	0.145	0.272	0.490	0.162	-0.530	1.361***	0.437	-0.444
	(0.429)	(0.704)	(0.462)	(0.476)	(0.399)	(0.410)	(0.398)	(0.563)
Other heat source	-0.171	-0.410	0.175	-0.836***	0.272	-0.718**	-0.291	0.822***
	(0.253)	(0.286)	(0.174)	(0.296)	(0.197)	(0.310)	(0.241)	(0.174)
Temperature (F)	0.009	-0.041**	0.002	-0.058***	0.013	-0.064*	-0.008	-0.013
	(0.019)	(0.017)	(0.012)	(0.022)	(0.011)	(0.034)	(0.016)	(0.009)
Humidity (%)	0.032*	0.021	-0.002	0.046	-0.010	0.055*	0.033*	-0.070***
	(0.018)	(0.030)	(0.013)	(0.031)	(0.014)	(0.029)	(0.017)	(0.009)
Precipitation (in)	-2.712	0.104	-0.282	-3.867	-2.329	-7.543***	-1.380	-10.914**
	(2.388)	(2.990)	(1.135)	(3.074)	(3.469)	(2.728)	(1.631)	(5.313)
Average wind speed (mph)	0.072	0.011	-0.166***	0.153**	-0.059	-0.030	0.073	-0.190***
	(0.079)	(0.110)	(0.064)	(0.076)	(0.089)	(0.076)	(0.058)	(0.058)
Worsened 2 or more wood-burning behaviors pre-post intervention	-0.677***	-0.503			0.004	-1.565***		

	(0.248)	(0.656)			(0.448)	(0.333)		
Worsened 1 or more home activities	0.214	-0.772*	0.192	0.264			-0.235	1.926***
	(0.239)	(0.397)	(0.309)	(0.340)			(0.268)	(0.584)
Missoula	0.363	0.000	-1.089**	0.126	0.908**	-1.202	-0.008	0.278
	(0.467)	(.)	(0.504)	(0.531)	(0.459)	(0.767)	(0.488)	(0.648)
Nez Perce Reservation	0.477	-0.636	1.891***		-0.856	0.935	1.766***	
	(1.038)	(1.172)	(0.464)		(1.045)	(1.298)	(0.669)	
Butte	-0.219	1.485*	-0.144	1.144	1.496**	1.267	-0.007	0.523
	(1.277)	(0.829)	(0.855)	(1.013)	(0.712)	(1.289)	(0.717)	(0.904)
Fairbanks	0.069	-0.614	-0.016	-0.806	0.149		0.543	-1.134
	(0.881)	(1.011)	(0.583)	(1.054)	(0.545)		(0.917)	(0.941)
Western Montana	-0.297	-0.132	-0.425	-0.372	-0.108	-1.481**	-0.127	-0.307
	(0.428)	(0.497)	(0.605)	(0.474)	(0.389)	(0.655)	(0.484)	(0.749)
High/low compliance			0.680**	0.370	-1.154**	0.786***	0.250	-1.438***
			(0.323)	(0.362)	(0.561)	(0.301)	(0.361)	(0.356)
Constant	14.902***	17.732***	16.505***	13.184***	18.313***	14.455***	14.693***	23.993***
	(1.519)	(3.221)	(1.412)	(3.355)	(1.689)	(2.451)	(1.352)	(1.089)
lns1_1_1								
Constant	-18.338	-1.285	-0.241	-24.252	-0.335	-26.602***	-20.651	-0.671***
	(.)	(4.691)	(0.225)	(15.384)	(0.279)	(0.005)	(16.141)	(0.151)
lnsig_e								
Constant	0.234	0.105	-0.729***	0.281**	-0.463*	0.227	0.281***	-1.734***
	(0.153)	(0.387)	(0.205)	(0.120)	(0.279)	(0.149)	(0.109)	(0.250)
N	84.000	66.000	79.000	72.000	82.000	69.000	113.000	38.000
chi2	162.983***	106.162***	1133.493***	1111.889***	427.022***	1062.716***	49.877***	169.434***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 46: Treatment effects by behavior change subgroup (Carbon monoxide)

	Compliance		Wood index		Home index		Wood age	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	High	Low	No change	Worsened	No change	Worsened	No change	Worsened
Carbon monoxide average (log)								
Air filter, pre-intervention	-1.471**	-0.834	2.055*	-1.741*	-0.242	-0.035	-0.548	-0.942
	(0.712)	(1.546)	(1.237)	(0.901)	(1.258)	(0.967)	(0.677)	(1.172)

Placebo, post-intervention	-0.273	1.588	1.881**	-0.391	0.612	1.561*	0.444	2.053**
	(0.986)	(1.139)	(0.868)	(1.285)	(1.266)	(0.876)	(1.056)	(0.854)
Air filter, post-intervention	1.538	-0.496	-1.698	2.532	0.771	-0.859	0.015	1.205
	(1.213)	(1.552)	(1.089)	(1.632)	(1.666)	(1.104)	(1.182)	(1.092)
Household yearly income	-0.076	-0.888	0.983	-0.666	-1.011	1.886*	-1.025*	-2.485
	(0.636)	(1.396)	(0.851)	(0.953)	(0.836)	(0.983)	(0.582)	(3.775)
Caregiver's education level	1.924***	-0.536	2.384***	2.375***	1.649**	0.405	-0.220	2.608
	(0.574)	(1.018)	(0.675)	(0.835)	(0.686)	(0.558)	(0.870)	(4.535)
Number of children in home	0.336	0.075	0.588**	0.298	0.431	0.214	0.351	-0.138
	(0.336)	(0.400)	(0.265)	(0.312)	(0.315)	(0.425)	(0.230)	(0.687)
Pet in home	-0.026	-1.919	-1.477	-2.159	-1.135	-1.622	-0.337	0.000
	(0.786)	(1.311)	(1.024)	(2.038)	(1.177)	(1.005)	(0.574)	(.)
Home type	0.094	-0.324	-3.945**	-1.184	-1.520	-1.314	2.406**	-1.099
	(0.781)	(1.438)	(1.593)	(1.058)	(1.325)	(1.117)	(0.959)	(1.173)
Home square footage (hundreds)	-0.014	0.049	0.007	0.051	0.066	-0.027	-0.129***	0.111
	(0.043)	(0.062)	(0.048)	(0.044)	(0.052)	(0.049)	(0.042)	(0.073)
Year home built	-0.397	0.581	-0.283	-0.389	-0.166	-0.966	2.334***	-2.088
	(0.479)	(0.719)	(0.717)	(0.619)	(0.964)	(0.705)	(0.733)	(2.008)
Year wood stove built	-1.600***	-1.293	-1.794***	0.016	0.911	-1.020*	-1.630***	5.330***
	(0.590)	(1.284)	(0.514)	(1.351)	(1.611)	(0.549)	(0.578)	(2.033)
Other heat source	0.808	-0.813	-1.248*	0.773	-0.297	0.607	-0.492	0.788
	(0.970)	(0.850)	(0.702)	(1.078)	(0.792)	(0.636)	(0.733)	(1.389)
Temperature (F)	-0.005	-0.015	0.063**	-0.039	0.037	0.024	0.021	-0.068**
	(0.033)	(0.039)	(0.027)	(0.037)	(0.027)	(0.047)	(0.023)	(0.031)
Humidity (%)	0.051	0.041	-0.071**	0.094*	-0.028	0.026	0.011	0.083*
	(0.037)	(0.061)	(0.028)	(0.048)	(0.042)	(0.040)	(0.026)	(0.044)
Precipitation (in)	-6.930	6.304	-0.033	-10.363	-0.511	6.012	-1.482	-33.200*
	(5.555)	(7.136)	(4.368)	(8.167)	(10.862)	(3.679)	(3.935)	(19.566)
Average wind speed (mph)	-0.054	0.091	-0.634**	0.386	-0.598*	0.329	-0.307	0.394
	(0.252)	(0.468)	(0.274)	(0.356)	(0.336)	(0.370)	(0.223)	(0.360)
Worsened 2 or more wood-burning behaviors pre-post intervention	0.978	-0.918			0.416	-0.100		
	(0.600)	(1.250)			(0.697)	(0.953)		
Worsened 1 or more home activities	0.371	0.071	0.451	0.787			-0.509	-1.628
	(0.434)	(0.674)	(0.442)	(0.781)			(0.487)	(1.721)
Missoula	0.004	0.000	0.891	0.241	-0.740	0.739	1.273	-4.113*
	(1.381)	(.)	(1.788)	(1.598)	(1.149)	(1.541)	(1.453)	(2.322)
Nez Perce Reservation	2.152	2.034	0.517		3.901*	-1.392	-0.255	
	(1.351)	(2.664)	(1.335)		(2.359)	(1.938)	(1.362)	
Butte	0.124	4.194***	0.215	1.676	4.484**	-0.847	4.477***	-8.282*
	(2.041)	(1.488)	(1.924)	(2.985)	(1.909)	(2.644)	(1.535)	(4.397)
Fairbanks	-2.737*	0.863	0.443	-2.385	0.146		-0.124	-8.882***
	(1.604)	(2.152)	(1.010)	(3.205)	(1.519)		(1.800)	(2.924)

Western Montana	0.356	1.520	0.493	0.682	1.658	-0.749	0.901	-5.631**
	(1.270)	(1.018)	(1.084)	(1.842)	(1.341)	(1.459)	(0.941)	(2.473)
High/low compliance			1.090	1.113	2.134*	0.181	-0.713	1.279
			(0.766)	(0.915)	(1.203)	(0.696)	(0.599)	(1.241)
Constant	-5.623**	-4.276	3.935*	-9.691	-3.136	-3.360	-1.544	-8.074
	(2.540)	(6.714)	(2.383)	(6.660)	(4.417)	(4.682)	(2.690)	(5.480)
lns1_1_1								
Constant	-26.872	0.329	-0.213	-15.676*	0.624**	-26.967	-17.742	-22.613
	(20.767)	(0.219)	(0.429)	(9.336)	(0.281)	(25.109)	(19.463)	(13684.684)
lnsig_e								
Constant	0.658***	0.157	0.088	0.793***	0.241	0.422***	0.668***	0.103
	(0.137)	(0.144)	(0.161)	(0.111)	(0.289)	(0.153)	(0.141)	(0.129)
N	59.000	48.000	55.000	52.000	61.000	46.000	77.000	30.000
chi2	558.521***	1684.728***	.	1181.510***	1520.848***	685.197***	179.737***	99.425***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 47: Comparing air pollution reductions between wood-burning practice subgroups

	Placebo No change	Placebo Behavior change	Placebo Difference (SE)	Filter No change	Filter Behavior change	Filter Difference (SE)
ΔPM2.5 average (log)	-0.116	-0.185	0.0696	-1.010	-1.195	0.185
	(0.781)	(0.769)	(0.133)	(0.729)	(0.908)	(0.145)
ΔPM2.5 maximum (log)	-0.128	-0.0603	-0.0676	-0.484	-0.939	0.456*
	(1.008)	(1.264)	(0.192)	(1.180)	(1.312)	(0.220)
ΔCoarse Particle Count (log)	-0.879	-1.212	0.333	-0.925	-2.196	1.271***
	(1.959)	(2.273)	(0.364)	(0.731)	(2.780)	(0.374)
ΔFine Particle Count (log)	-0.439	-0.675	0.236	-1.056	-1.939	0.883**
	(1.329)	(1.790)	(0.266)	(0.880)	(2.349)	(0.326)
ΔCO (log)	1.423	0.107	1.317*	0.229	1.149	-0.920
	(2.430)	(3.960)	(0.595)	(2.025)	(2.726)	(0.493)
n	86	59	145	62	68	130

mean coefficients; sd in parentheses; differences: se in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 48: Comparing air pollution reductions between home activity subgroups

	Placebo			Filter		
	No change	Behavior change	Difference (SE)	No change	Behavior change	Difference (SE)
ΔPM2.5 average (log)	-0.00174	-0.325	0.324*	-1.073	-1.164	0.0910
	(0.787)	(0.723)	(0.129)	(0.704)	(1.009)	(0.150)
ΔPM2.5 maximum (log)	0.00477	-0.238	0.243	-0.768	-0.646	-0.122
	(1.112)	(1.107)	(0.188)	(1.049)	(1.571)	(0.230)
ΔCoarse Particle Count (log)	-1.085	-0.909	-0.176	-1.440	-1.798	0.358
	(2.027)	(2.163)	(0.356)	(1.592)	(2.828)	(0.402)
ΔFine Particle Count (log)	-0.451	-0.625	0.174	-1.504	-1.516	0.0118
	(1.281)	(1.777)	(0.260)	(1.489)	(2.314)	(0.346)
ΔCO (log)	0.711	1.203	-0.492	0.426	0.961	-0.535
	(3.609)	(2.370)	(0.604)	(2.698)	(1.871)	(0.506)
n	80	65	145	81	49	130

mean coefficients; sd in parentheses; differences: se in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 49: Comparing air pollution reductions between compliance subgroups

	Placebo			Filter		
	High	Low	Difference (SE)	High	Low	Difference (SE)
ΔPM2.5 average (log)	-0.109	-0.189	-0.0799	-1.055	-1.151	-0.0957
	(0.701)	(0.868)	(0.132)	(0.789)	(0.866)	(0.146)
ΔPM2.5 maximum (log)	-0.197	0.0297	0.227	-0.662	-0.774	-0.112
	(1.081)	(1.150)	(0.189)	(1.299)	(1.245)	(0.223)
ΔCoarse Particle Count (log)	-0.936	-1.108	-0.172	-1.619	-1.542	0.0763
	(2.087)	(2.091)	(0.360)	(2.493)	(1.833)	(0.394)
ΔFine Particle Count (log)	-0.328	-0.817	-0.490	-1.381	-1.611	-0.229
	(1.458)	(1.571)	(0.260)	(2.080)	(1.624)	(0.337)
ΔCO (log)	0.311	1.741	1.430*	0.588	0.691	0.103
	(3.134)	(3.059)	(0.587)	(2.112)	(2.630)	(0.502)
n	82	63	145	60	70	130

mean coefficients; sd in parentheses; differences: se in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 50: Change in air quality, stoking and loading stove

Placebo	Filter

	No change	Behavior change	Difference (SE)	No change	Behavior change	Difference (SE)
Δ$PM_{2.5}$ average (log)	-0.0877	-0.445	0.357	-0.978	-1.420	0.442**
	(0.814)	(0.399)	(0.178)	(0.620)	(1.145)	(0.156)
Δ$PM_{2.5}$ maximum (log)	-0.0252	-0.516	0.491	-0.536	-1.172	0.635**
	(1.126)	(0.952)	(0.256)	(1.113)	(1.500)	(0.239)
ΔCoarse Particle Count (log)	-0.795	-2.129	1.334**	-0.920	-3.189	2.268***
	(1.748)	(3.170)	(0.472)	(0.700)	(3.350)	(0.378)
ΔFine Particle Count (log)	-0.353	-1.463	1.111**	-0.980	-2.806	1.827***
	(1.206)	(2.460)	(0.341)	(0.821)	(2.791)	(0.330)
ΔCO (log)	1.284	-0.680	1.964**	0.839	0.142	0.697
	(2.815)	(4.068)	(0.732)	(2.433)	(2.273)	(0.552)
n	120	25	145	92	38	130

mean coefficients; sd in parentheses; differences: se in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 51: Change in air quality, burning intensity

	Placebo			Filter		
	No change	Behavior change	Difference (SE)	No change	Behavior change	Difference (SE)
Δ$PM_{2.5}$ average (log)	-0.0855	-0.240	0.154	-1.198	-1.036	-0.162
	(0.713)	(0.867)	(0.134)	(0.878)	(0.788)	(0.146)
Δ$PM_{2.5}$ maximum (log)	0.105	-0.447	0.552**	-0.803	-0.659	-0.145
	(0.968)	(1.255)	(0.188)	(1.222)	(1.305)	(0.224)
ΔCoarse Particle Count (log)	-0.873	-1.223	0.350	-1.154	-1.917	0.764
	(1.844)	(2.424)	(0.364)	(1.476)	(2.518)	(0.387)
ΔFine Particle Count (log)	-0.329	-0.852	0.523*	-1.351	-1.635	0.283
	(1.312)	(1.772)	(0.263)	(1.381)	(2.138)	(0.336)
ΔCO (log)	1.251	0.290	0.961	0.226	0.989	-0.762
	(3.093)	(3.249)	(0.613)	(2.253)	(2.480)	(0.496)
n	89	56	145	57	73	130

mean coefficients; sd in parentheses; differences: se in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 52: Change in air quality, wood age

	Placebo			Filter		
	No change	Behavior change	Difference (SE)	No change	Behavior change	Difference (SE)
Δ$PM_{2.5}$ average (log)	-0.317	0.219	-0.536***	-0.938	-1.583	0.645***
	(0.775)	(0.641)	(0.132)	(0.841)	(0.582)	(0.156)
Δ$PM_{2.5}$ maximum (log)	-0.455	0.636	-1.091***	-0.464	-1.450	0.986***
	(1.025)	(0.915)	(0.178)	(1.240)	(1.051)	(0.238)
ΔCoarse Particle Count (log)	-1.337	-0.267	-1.071**	-1.480	-1.822	0.342
	(2.359)	(0.921)	(0.372)	(2.121)	(2.213)	(0.434)

ΔFine Particle Count (log)	-0.876 (1.671)	0.246 (0.615)	-1.122*** (0.263)	-1.322 (1.797)	-1.983 (1.880)	0.661 (0.368)
ΔCO (log)	0.936 (3.301)	0.854 (2.937)	0.0817 (0.627)	0.354 (2.124)	1.530 (2.969)	-1.176* (0.566)
n	99	46	145	96	34	130

mean coefficients; sd in parentheses; differences: se in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 53: Change in air quality, wood usage

	Placebo			Filter		
	No change	Behavior change	Difference (SE)	No change	Behavior change	Difference (SE)
$\Delta PM_{2.5}$ average (log)	-0.145 (0.769)	-0.140 (0.791)	-0.00466 (0.135)	-1.059 (0.731)	-1.161 (0.932)	0.102 (0.146)
$\Delta PM_{2.5}$ maximum (log)	0.0589 (1.033)	-0.172 (1.241)	0.113 (0.193)	-0.629 (1.249)	-0.828 (1.288)	0.199 (0.223)
ΔCoarse Particle Count (log)	-1.033 (2.399)	-0.958 (1.369)	-0.0755 (0.369)	-1.237 (1.370)	-1.983 (2.764)	0.746 (0.387)
ΔFine Particle Count (log)	-0.630 (1.720)	-0.349 (1.065)	-0.281 (0.268)	-1.359 (1.346)	-1.688 (2.293)	0.329 (0.335)
ΔCO (log)	0.739 (3.066)	1.201 (3.359)	-0.462 (0.615)	0.829 (2.593)	0.378 (2.089)	0.451 (0.506)
n	89	56	145	69	61	130

mean coefficients; sd in parentheses; differences: se in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 54: Change in air quality, opening doors or windows

	Placebo			Filter		
	No change	Behavior change	Difference (SE)	No change	Behavior change	Difference (SE)
ΔPM2.5 average (log)	-0.163 (0.790)	-0.0148 (0.669)	-0.148 (0.191)	-1.014 (0.789)	-2.222 (0.367)	1.209*** (0.252)
ΔPM2.5 maximum (log)	-0.148 (1.127)	0.201 (0.984)	-0.349 (0.274)	-0.579 (1.190)	-2.437 (0.844)	1.857*** (0.385)
ΔCoarse Particle Count (log)	-0.914 (1.840)	-1.587 (3.235)	0.673 (0.513)	-1.689 (2.188)	-0.330 (0.925)	-1.358 (0.700)

ΔFine Particle Count (log)	-0.468	-0.913	0.445	-1.553	-1.015	-0.538
	(1.242)	(2.707)	(0.375)	(1.904)	(0.639)	(0.607)
ΔCO (log)	0.789	1.411	-0.623	0.629	0.833	-0.204
	(3.475)	(1.140)	(0.752)	(2.491)	(0.448)	(0.947)
n	123	22	145	120	10	130

mean coefficients; sd in parentheses; differences: se in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 55: Change in air quality, other burning

	Placebo			Filter		
	No change	Behavior change	Difference (SE)	No change	Behavior change	Difference (SE)
ΔPM2.5 average (log)	-0.0073	-0.502	0.494**	-1.090	-1.187	0.0976
	(0.783)	(0.631)	(0.140)	(0.776)	(1.062)	(0.191)
ΔPM2.5 maximum (log)	0.0425	-0.481	0.524*	-0.719	-0.735	0.0158
	(1.165)	(0.863)	(0.205)	(1.281)	(1.223)	(0.292)
ΔCoarse Particle Count (log)	-0.992	-1.041	0.0488	-1.182	-3.568	2.386***
	(2.001)	(2.305)	(0.395)	(1.493)	(3.504)	(0.479)
ΔFine Particle Count (log)	-0.398	-0.863	0.465	-1.259	-2.766	1.507***
	(1.343)	(1.878)	(0.285)	(1.396)	(3.011)	(0.430)
ΔCO (log)	0.545	1.937	-1.392*	0.532	1.082	-0.550
	(3.345)	(2.366)	(0.663)	(2.420)	(2.321)	(0.617)
n	103	42	145	107	23	130

mean coefficients; sd in parentheses; differences: se in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 56: Change in air quality, cleaning

	Placebo			Filter		
	No change	Behavior change	Difference (SE)	No change	Behavior change	Difference (SE)
ΔPM2.5 average (log)	-0.141	-0.149	0.00862	-1.123	-1.037	-0.0853
	(0.821)	(0.640)	(0.147)	(0.805)	(0.944)	(0.188)
ΔPM2.5 maximum (log)	-0.114	-0.0668	-0.0470	-0.854	-0.141	-0.712*
	(1.119)	(1.109)	(0.212)	(1.189)	(1.452)	(0.280)
ΔCoarse Particle Count (log)	-0.959	-1.130	0.171	-1.439	-2.131	0.691
	(1.823)	(2.679)	(0.398)	(1.585)	(3.617)	(0.487)
ΔFine Particle Count (log)	-0.481	-0.654	0.173	-1.444	-1.767	0.323
	(1.200)	(2.167)	(0.290)	(1.374)	(3.106)	(0.420)
ΔCO (log)	0.969	0.762	0.207	0.579	0.885	-0.306
	(3.387)	(2.620)	(0.650)	(2.625)	(1.285)	(0.608)
n	104	41	145	106	24	130

mean coefficients; sd in parentheses; differences: se in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Specification and robustness checks

Table 57: Pre-intervention determinants of indoor air quality specification testing (full results)

	(1) Random-effects GLS	(2) Mixed-effects ML	(3) Mixed-effects ML Community fixed-effects	(4) Mixed-effects ML Community fixed-effects Robust standard errors
$PM_{2.5}$ average (log)				
Number of times the stove was stoked or loaded	0.002	0.033*	0.015	0.015
	(0.021)	(0.020)	(0.020)	(0.019)
Burning intensity dummy	0.131	-0.085	0.151	0.151
	(0.176)	(0.160)	(0.158)	(0.148)
Wood age	-0.395**	-0.420***	-0.357**	-0.357***
	(0.174)	(0.158)	(0.155)	(0.127)
Amount of wood used (cords)	-0.039	-0.012	-0.034	-0.034
	(0.041)	(0.028)	(0.037)	(0.031)
Doors or windows opened during exposure sampling	0.520***	0.198	0.542***	0.542***
	(0.165)	(0.158)	(0.144)	(0.149)
Other burning during exposure sampling	-0.025	0.128	-0.091	-0.091
	(0.166)	(0.155)	(0.147)	(0.147)
Cleaning during exposure sampling	-0.095	-0.139	-0.039	-0.039
	(0.165)	(0.143)	(0.146)	(0.134)
Household yearly income	-0.633**	-0.610***	-0.623**	-0.623***
	(0.280)	(0.182)	(0.244)	(0.229)
Caregiver's education level	-0.088	0.018	-0.093	-0.093
	(0.261)	(0.172)	(0.234)	(0.212)
Number of children in home	0.134	0.059	0.078	0.078
	(0.089)	(0.065)	(0.086)	(0.118)
Pet in home	0.163	0.261	0.222	0.222
	(0.283)	(0.213)	(0.254)	(0.183)
Home type	0.073	0.014	0.070	0.070
	(0.295)	(0.196)	(0.259)	(0.285)
Home square footage (hundreds)	-0.027*	-0.029***	-0.025*	-0.025*
	(0.015)	(0.010)	(0.013)	(0.013)
Year home built	-0.122	-0.180	-0.214	-0.214
	(0.246)	(0.153)	(0.228)	(0.227)
Year wood stove built	0.100	0.222	-0.002	-0.002
	(0.252)	(0.201)	(0.228)	(0.245)
Other heat source	-0.103	-0.198	-0.112	-0.112
	(0.172)	(0.149)	(0.151)	(0.164)
Temperature (F)	0.011	-0.000	0.021**	0.021**
	(0.007)	(0.006)	(0.008)	(0.010)
Humidity (%)	-0.003	0.007	-0.005	-0.005
	(0.008)	(0.009)	(0.007)	(0.008)

Precipitation (in)	-1.436	-1.399	-1.613	-1.613
	(1.879)	(1.311)	(1.690)	(1.457)
Average wind speed (mph)	-0.103**	0.013	-0.088**	-0.088**
	(0.043)	(0.043)	(0.041)	(0.040)
Missoula			0.326	0.326
			(0.401)	(0.356)
Butte			-0.335	-0.335
			(0.522)	(0.593)
Fairbanks			0.959*	0.959*
			(0.533)	(0.549)
Western Montana			0.179	0.179
			(0.329)	(0.262)
Constant	3.952***	3.029***	3.623***	3.623***
	(0.879)	(0.819)	(0.794)	(0.811)
lnsig_e				
Constant		-0.160***	-1.051***	-1.051***
		(0.054)	(0.160)	(0.181)
lns1_1_1				
Constant			-0.423***	-0.423***
			(0.134)	(0.164)
N	96.000	169.000	96.000	96.000
chi2	49.608***	80.338***	70.403***	181.666***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 58: Treatment effects specification testing (full results)

	(1) Random-effects GLS	(2) Mixed-effects ML	(3) Mixed-effects ML Community fixed-effects	(4) Mixed-effects ML Community fixed-effects Random coefficient (winter)	(5) Mixed-effects ML Community fixed-effects Random coefficient (winter) Robust standard errors
$PM_{2.5}$ Average (log)					
Stove changeout, pre-intervention	0.657**	0.610**	0.688**	0.716**	0.716***
	(0.312)	(0.280)	(0.291)	(0.300)	(0.266)
Air filter, pre-intervention	0.158	0.169	0.139	0.118	0.118
	(0.201)	(0.169)	(0.168)	(0.181)	(0.186)
Placebo, post-intervention	-0.341**	-0.318*	-0.299*	-0.297	-0.297*
	(0.165)	(0.180)	(0.180)	(0.189)	(0.165)
Stove changeout, post-intervention	-0.034	0.009	0.008	-0.062	-0.062
	(0.347)	(0.379)	(0.377)	(0.393)	(0.300)
Air filter, post-intervention	-0.704***	-0.671**	-0.658**	-0.670**	-0.670***
	(0.237)	(0.261)	(0.258)	(0.275)	(0.237)
Household yearly income	-0.806***	-0.737***	-0.751***	-0.786***	-0.786***
	(0.204)	(0.152)	(0.153)	(0.162)	(0.169)
Caregiver's education level	0.065	0.070	0.084	0.092	0.092
	(0.194)	(0.143)	(0.142)	(0.151)	(0.155)
Number of children in home	0.067	0.077	0.054	0.063	0.063
	(0.071)	(0.055)	(0.057)	(0.060)	(0.069)
Pet in home	0.153	0.248	0.238	0.242	0.242*
	(0.218)	(0.185)	(0.189)	(0.195)	(0.146)
Home type	0.219	0.250	0.353**	0.347*	0.347
	(0.212)	(0.169)	(0.179)	(0.189)	(0.237)
Home square footage (hundreds)	-0.024**	-0.030***	-0.034***	-0.034***	-0.034***
	(0.010)	(0.008)	(0.009)	(0.009)	(0.012)
Year home built	0.084	0.035	0.073	0.104	0.104
	(0.171)	(0.132)	(0.142)	(0.150)	(0.167)
Year wood stove built	0.108	0.100	0.040	0.055	0.055
	(0.203)	(0.177)	(0.179)	(0.186)	(0.196)
Other heat source	-0.198	-0.222*	-0.246*	-0.208	-0.208
	(0.141)	(0.130)	(0.131)	(0.132)	(0.136)
Temperature (F)	0.001	-0.002	-0.002	-0.001	-0.001
	(0.006)	(0.005)	(0.007)	(0.007)	(0.006)
Humidity (%)	0.008	0.012	0.010	0.010	0.010
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Precipitation (in)	-1.275	-1.420	-1.102	-1.354	-1.354
	(1.256)	(1.185)	(1.263)	(1.262)	(1.383)

Average wind speed (mph)	0.037	0.060	0.059	0.047	0.047
	(0.037)	(0.037)	(0.040)	(0.040)	(0.041)
Missoula			0.468*	0.458*	0.458**
			(0.247)	(0.256)	(0.222)
Nez Perce Reservation			-0.127	-0.133	-0.133
			(0.500)	(0.516)	(0.581)
Butte			0.181	0.282	0.282
			(0.375)	(0.379)	(0.538)
Fairbanks			0.333	0.324	0.324
			(0.344)	(0.355)	(0.359)
Western Montana			0.367	0.387*	0.387**
			(0.226)	(0.235)	(0.182)
Constant	2.428***	2.125***	2.073***	2.026***	2.026***
	(0.735)	(0.695)	(0.728)	(0.727)	(0.741)
lnsig_e					
Constant		-0.218***	-0.229***	-0.379***	-0.379***
		(0.051)	(0.051)	(0.104)	(0.130)
lns1_1_1					
Constant				-0.891***	-0.891**
				(0.301)	(0.378)
N	190.000	190.000	190.000	190.000	190.000
chi2	88.449***	116.899***	124.160***	112.335***	150.002***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 59: Testing wood index cutoff levels (full results)

	Wood index cutoff: 2		Wood index cutoff: 1		Wood index cutoff: 3	
	(1)	(2)	(3)	(4)	(5)	(6)
	No change	Worsened	No change	Worsened	No change	Worsened
$PM_{2.5}$ Average (log)						
Air filter, pre-intervention	0.161	0.306	-1.139	0.219	-0.016	-0.305
	(0.238)	(0.209)	(0.954)	(0.210)	(0.213)	(0.625)
Placebo, post-intervention	-0.457*	-0.018	-0.675***	-0.155	-0.312*	-0.360
	(0.251)	(0.241)	(0.236)	(0.203)	(0.184)	(0.639)
Air filter, post-intervention	-0.437	-1.076***	0.008	-0.938***	-0.580**	-0.783
	(0.293)	(0.341)	(0.445)	(0.278)	(0.271)	(0.701)
Household yearly income	-0.412	-0.962***	-2.478	-0.505**	-0.615***	-1.303*
	(0.276)	(0.197)	(2.047)	(0.228)	(0.211)	(0.758)
Caregiver's education level	0.713***	0.179	-0.504	0.127	0.343	0.624
	(0.205)	(0.148)	(1.278)	(0.220)	(0.243)	(0.536)
Number of children in home	0.468***	-0.139**	1.698	0.051	0.236**	-0.312*
	(0.094)	(0.066)	(1.255)	(0.079)	(0.102)	(0.161)
Pet in home	0.329*	0.331	-2.034	0.043	0.235	0.137
	(0.176)	(0.343)	(1.904)	(0.166)	(0.169)	(1.417)
Home type	-0.867***	0.609**	0.000	0.176	0.183	0.739
	(0.325)	(0.245)	(.)	(0.262)	(0.420)	(0.548)
Home square footage (hundreds)	0.007	-0.037***	0.100	-0.040***	-0.032**	-0.032
	(0.015)	(0.011)	(0.120)	(0.013)	(0.016)	(0.031)
Year home built	-0.530***	0.209	-0.035	0.108	0.192	0.168
	(0.166)	(0.181)	(0.809)	(0.206)	(0.219)	(0.480)
Year wood stove built	-0.219	0.936***	0.019	0.001	-0.049	-0.706
	(0.220)	(0.329)	(0.489)	(0.285)	(0.226)	(0.867)
Other heat source	-0.109	-0.698***	-0.472*	-0.079	-0.056	-0.640
	(0.201)	(0.171)	(0.286)	(0.172)	(0.146)	(0.553)
Temperature (F)	0.011	-0.008	0.013	-0.004	0.003	0.035
	(0.010)	(0.008)	(0.013)	(0.008)	(0.009)	(0.030)
Humidity (%)	-0.008	0.021*	0.013	0.004	-0.003	0.091***
	(0.012)	(0.011)	(0.017)	(0.009)	(0.009)	(0.020)
Precipitation (in)	-1.548	-3.060	0.199	-0.654	-0.925	-14.392
	(1.117)	(2.412)	(3.587)	(1.551)	(1.210)	(17.969)
Average wind speed (mph)	-0.102**	0.039	-0.129*	0.057	-0.039	0.186**
	(0.048)	(0.043)	(0.071)	(0.043)	(0.047)	(0.078)
High/low compliance	0.417*	0.317*	-0.043	0.202	0.256	-0.234
	(0.215)	(0.189)	(1.355)	(0.175)	(0.231)	(0.526)
Worsened 1 or more home activities	0.111	-0.131	-0.281	-0.499**	-0.120	1.053**
	(0.170)	(0.177)	(1.054)	(0.201)	(0.169)	(0.467)
Missoula	0.073	0.654**	-2.487	0.499	0.448	
	(0.321)	(0.310)	(2.402)	(0.326)	(0.317)	
Nez Perce Reservation	1.721***			0.142	0.560	
	(0.301)			(0.577)	(0.434)	
Butte	0.062	1.379***		-0.124	0.834	0.000
	(0.448)	(0.447)		(0.610)	(0.598)	(.)
Fairbanks	0.622	0.630	-2.555	-0.279	0.028	2.629
	(0.406)	(0.614)	(2.210)	(0.575)	(0.493)	(2.154)
Western Montana	0.530**	0.283	0.000	0.396	0.566**	1.344
	(0.259)	(0.306)	(.)	(0.242)	(0.262)	(1.564)
Constant	2.268**	0.836	1.122	3.000***	2.545***	-5.066*
	(1.030)	(1.399)	(2.171)	(0.954)	(0.910)	(2.732)
lns1_1_1						
Constant	-22.120	-17.214*	-18.384***	-0.917	-0.773**	-19.219***

	(24.115)	(10.404)	(3.610)	(0.583)	(0.382)	(3.157)
lnsig_e						
Constant	-0.454***	-0.456***	-0.705***	-0.371**	-0.442**	-0.817***
	(0.093)	(0.069)	(0.120)	(0.178)	(0.173)	(0.127)
N	85.000	80.000	35.000	130.000	134.000	31.000
chi2	514.173***	224.496***	78.292***	97.827***	77.079***	165.649***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 60: Testing home index cutoff levels (full results)

	Home index cutoff: 1		Home index cutoff: 2	
	(1)	(2)	(3)	(4)
	No change	Worsened	No change	Worsened
$PM_{2.5}$ Average (log)				
Air filter, pre-intervention	0.198	-0.041	-0.079	-0.006
	(0.236)	(0.245)	(0.205)	(0.250)
Placebo, post-intervention	0.074	-0.627**	-0.360*	0.054
	(0.201)	(0.246)	(0.193)	(0.292)
Air filter, post-intervention	-0.928***	-1.131***	-0.496*	-2.353***
	(0.244)	(0.367)	(0.260)	(0.381)
Household yearly income	-0.549**	-0.360	-0.557**	-0.897*
	(0.255)	(0.328)	(0.235)	(0.528)
Caregiver's education level	0.496**	0.054	0.206	1.809***
	(0.218)	(0.173)	(0.203)	(0.359)
Number of children in home	0.436***	0.038	0.180**	-0.499***
	(0.082)	(0.082)	(0.087)	(0.078)
Pet in home	-0.386	0.575***	0.097	0.038
	(0.261)	(0.209)	(0.241)	(0.360)
Home type	-0.270	0.582**	0.106	-0.004
	(0.379)	(0.286)	(0.335)	(0.474)
Home square footage (hundreds)	-0.049***	-0.040***	-0.040***	0.012
	(0.014)	(0.013)	(0.013)	(0.028)
Year home built	0.485**	-0.208	0.348*	-0.462
	(0.229)	(0.206)	(0.185)	(0.387)
Year wood stove built	0.162	0.092	-0.009	0.574**
	(0.214)	(0.277)	(0.257)	(0.259)
Other heat source	0.161	-0.513***	-0.132	0.304
	(0.168)	(0.199)	(0.166)	(0.218)
Temperature (F)	0.012	-0.002	0.002	0.052***
	(0.009)	(0.012)	(0.009)	(0.014)
Humidity (%)	0.001	-0.012	0.004	0.078***
	(0.009)	(0.015)	(0.009)	(0.011)
Precipitation (in)	-2.994	-3.166**	0.173	-6.706***
	(2.657)	(1.547)	(1.470)	(1.392)
Average wind speed (mph)	0.027	-0.078	0.010	-0.046
	(0.062)	(0.058)	(0.051)	(0.042)
High/low compliance	0.021	0.360	0.064	0.357
	(0.269)	(0.222)	(0.199)	(0.438)
Worsened 2 or more wood-burning behaviors pre-post intervention	0.421*	-0.508**	0.016	0.539
	(0.227)	(0.198)	(0.215)	(0.394)
Missoula	0.345	0.749***	0.511*	0.000
	(0.259)	(0.273)	(0.289)	(.)
Nez Perce Reservation	-0.316	1.889***	0.118	
	(0.498)	(0.621)	(0.366)	
Butte	0.995	-0.871	0.923	1.910***
	(0.648)	(0.772)	(0.699)	(0.715)
Fairbanks	-0.142		-0.062	
	(0.400)		(0.437)	
Western Montana	0.738***	0.088	0.548**	2.852***
	(0.238)	(0.231)	(0.228)	(0.593)
Constant	1.674*	4.381***	2.350**	-6.735***
	(1.017)	(1.384)	(0.958)	(1.075)
lns1_1_1				
Constant	-16.586	-23.155	-1.012*	-23.033***
	(193.063)	(24.382)	(0.562)	(3.263)
lnsig_e				

Constant	-0.423***	-0.425***	-0.386**	-1.504***
	(0.088)	(0.075)	(0.154)	(0.134)
N	90.000	75.000	136.000	29.000
chi2	514.067***	1260.083***	101.062***	714.716***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 61: Testing compliance cutoff levels (full results)

	High compliance cutoff: 50th percentile		High compliance cutoff: upper two tertiles		High compliance cutoff: upper tertile	
	(1)	(2)	(3)	(4)	(5)	(6)
	High	Low	High	Low	High	Low
$PM_{2.5}$ Average (log)						
Air filter, pre-intervention	0.008	-0.271	0.159	-0.496	-0.663	0.161
	(0.190)	(0.250)	(0.217)	(0.440)	(0.439)	(0.217)
Placebo, post-intervention	-0.323**	-0.098	-0.367***	-0.296	-0.386*	-0.132
	(0.150)	(0.430)	(0.126)	(0.350)	(0.234)	(0.232)
Air filter, post-intervention	-0.851***	-0.787	-0.723***	-0.434	-1.714***	-0.749**
	(0.295)	(0.492)	(0.241)	(0.526)	(0.542)	(0.306)
Household yearly income	-1.048***	-0.153	-0.994***	0.257	-1.054***	-0.673***
	(0.161)	(0.260)	(0.194)	(0.546)	(0.377)	(0.213)
Caregiver's education level	0.146	-0.465*	0.366*	-0.185	0.163	0.234
	(0.178)	(0.263)	(0.192)	(0.405)	(0.540)	(0.175)
Number of children in home	-0.061	0.123	0.091	0.172	0.297*	0.167**
	(0.086)	(0.108)	(0.102)	(0.137)	(0.157)	(0.076)
Pet in home	0.159	0.259	0.027	-0.018	0.386	0.387
	(0.157)	(0.308)	(0.205)	(0.533)	(0.454)	(0.241)
Home type	0.523**	0.588**	0.793**	-0.026	0.239	0.598**
	(0.237)	(0.297)	(0.338)	(0.486)	(0.512)	(0.257)
Home square footage (hundreds)	-0.042***	-0.054***	-0.037***	-0.043**	-0.006	-0.046***
	(0.012)	(0.013)	(0.013)	(0.018)	(0.027)	(0.011)
Year home built	0.193	0.442**	0.140	-0.065	0.285	0.293
	(0.212)	(0.179)	(0.207)	(0.381)	(0.443)	(0.191)
Year wood stove built	0.693***	-0.476	0.127	-0.023	0.058	-0.027
	(0.178)	(0.346)	(0.249)	(0.503)	(0.521)	(0.212)
Other heat source	-0.101	-0.101	-0.196	-0.236	-0.196	-0.292*
	(0.145)	(0.207)	(0.162)	(0.240)	(0.242)	(0.159)
Temperature (F)	0.013	0.011	-0.002	0.012	0.022*	0.005
	(0.012)	(0.008)	(0.011)	(0.012)	(0.011)	(0.010)
Humidity (%)	0.008	0.011	0.006	0.006	0.010	0.008
	(0.010)	(0.013)	(0.011)	(0.016)	(0.017)	(0.010)
Precipitation (in)	-1.010	-1.040	-2.863**	-0.373	-1.415	-2.231
	(1.273)	(2.001)	(1.453)	(2.244)	(2.751)	(1.760)
Average wind speed (mph)	-0.022	0.098	0.019	0.012	-0.141*	0.075
	(0.048)	(0.071)	(0.058)	(0.072)	(0.081)	(0.048)
Worsened 2 or more wood-burning behaviors pre-post intervention	-0.006	-0.346	-0.314	-0.066	-0.014	-0.400**
	(0.189)	(0.286)	(0.202)	(0.409)	(0.451)	(0.190)
Worsened 1 or more home activities	-0.086	-0.724***	0.146	-1.196***	0.689*	-0.508***
	(0.134)	(0.190)	(0.183)	(0.334)	(0.387)	(0.157)
Missoula	0.717**	0.000	0.515	0.000	0.357	1.328**
	(0.290)	(.)	(0.326)	(.)	(0.392)	(0.658)
Nez Perce Reservation	0.927**	-1.697***	0.407	-1.802		0.159
	(0.444)	(0.512)	(0.559)	(1.175)		(1.003)
Butte	0.000	-0.183		0.181		1.237
	(0.775)	(0.614)		(0.927)		(0.788)
Fairbanks	-0.219	0.106	-0.575	0.098	0.492	1.209
	(0.467)	(0.441)	(0.519)	(0.929)	(0.566)	(0.754)
Western Montana	0.571**	-0.540*	0.185	-0.208	0.664*	1.086*
	(0.287)	(0.290)	(0.270)	(0.560)	(0.391)	(0.627)
Constant	1.894**	3.172***	2.516**	3.821**	0.714	1.178
	(0.907)	(1.203)	(1.041)	(1.783)	(1.561)	(1.135)
lns1_1_1						

Constant	-22.803	-1.380	-31.731**	-0.654***	-18.509***	-26.251***
	(18.317)	(2.153)	(15.479)	(0.246)	(2.533)	(1.710)
lnsig_e						
Constant	-0.403***	-0.410	-0.374***	-0.757***	-0.644***	-0.351***
	(0.084)	(0.267)	(0.083)	(0.208)	(0.108)	(0.068)
N	90.000	73.000	101.000	49.000	43.000	107.000
chi2	1111.809***	2410.764***	208.871***	44.461***	113.439***	82.885***

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01