Land Economics 95(3), August 2019
"Fire, Tractors, and Health in the Amazon: A Cost-Benefit Analysis of Fire Policy,"
by Thiago Morello, Simone Martino, Alejandro F. Duarte, and Liana Anderson

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1 Epidemiological evidence: detailed review of literature

Table A1 Literature review on epidemiological impact of fires and biomass burning on respiratory health

Summary	Source	Outcome	Symptoms	Method	Age groups	Country	Reference
Prevalence of cough symptoms was higher among the sample group cooking with wood, compared to the groups cooking with charcoal or other fuels. Other respiratory symptoms such as chest pain and wheezing did not differed in prevalence between groups.	Wood biomass burning for cooking	Respiratory symptoms	Dry cough, cough with phlegm	Primary data from a survey is used to test for significant of correlations with respiratory symptoms and type of cooking fuel used	Women > 14 years (in charge of cooking)	Mozambique (suburbs of Maputo)	Ellegard, A. Cooking fuel smoke and respiratory symptoms among women in low-income areas of Maputo. Environ. Health Perspect 1996; 104:980-5.
Haze-related air pollution caused by mega forest fires in Indonesia, 1997, caused increased respiratory symptoms, exacerbaction of asthma and decreased lung function. The outcomes were observed mainly in children and elderly. The increase in acute respiratory infection was especially high.	Mega forest fire	Acute respiratory infection, brochial asthma, pneumonia	Cough, eye irritation, dysponea and phlegm, wheezing (only for individuals with prior history of respiratory problems)	Outpatient and hospital admissions data, as well as data from multiple surveys, is summarized with descriptive statistics	All ages	Indonesia	Dawud Y. Smoke Episodes and Assessment of Health impacts Related to Haze from Forest Fires: Indonesian Experience. In: HEALTH GUIDELINES FOR VEGETATION FIRE EVENTS, Lima, Peru, 1998. Geneva, WHO, 1999; 313-33. (Background papers).
Both atmospheric concentration of pollutants and reported cases of respiratory illnesses increased during smoke from mega-wildfires of 1997 in Indonesia. Survey with population from affected regions revealed increase in respiratory symptoms and illnesses	Mega forest fire	Pneumonia, asthma, bronchitis, laryngitis, bronchiectasis	Eye irritation, cough, sneezing, headach, fatigue, running nose, phlegm, breathlessness, chest discomfort, fever, etc	Primary data on symptoms, diseases and pollution, analyzed with descriptive statistics	All ages	Indonesia	Kunii O. Basic facts-determining downwind exposures and their associated health effects in practice: a case study in the 1997 forest fires in Indonesia. In: HEALTH GUIDELINES FOR VEGETATION FIRE EVENTS, Lima, Peru, 1998, Geneva, WHO, 1999; 295-312. (Background papers).
Haze-related air pollution caused by mega forest fires in Thailand, 1997, multiple respiratory illnesses have their prevalence increased. Out-patient visits and hospital admissions, related with respiratory diseases, peaked in the haze period.	Mega forest fire	Pneumonia, upper respiratory tract infection, bronchitis, COPD, asthma, conjunctivitis and eczema	Not informed	Outpatient visits and hospital admissions are correlated with with air pollution with time-series analysis	All ages	Thailand	Phonboon K, Paisarn-Uchapong O, Kanatharana P, Agsorn S. Smoke episodes emissions characterization and assessment of health risks related downwind air qualitycase study, Thailand. In: HEALTH GUIDELINES FOR VEGETATION FIRE EVENTS, Lima, Peru, 6-9. 1998. Geneva, WHO, 1999; 334-58. (Background papers).
Mega forest fie in California, 1987, increased the number of emergency room visits, particularly by persons with asthma, COPD, sinusitis, upper respiratory infections and laryngitis.	Mega forest fire	Asthma, COPD, sinusitis, upper respiratory infections and laryngitis.	Not informed	Data on emergency room visits before and after mega-fire was compared and statistical difference detected.	All ages	USA	Duclos P, Sanderson LM, Lipsett M. The 1987 Forest Fire Disaster in California: assessment of emergency room visits. Arch. Environ. Health 1990; 45: 53-8.
Burning of agricultural residual by farmers increased the level of air pollution in Winninpeg in 1992. A total of 42% of interviewers reported symptoms such as cough, wheezing, chest tightness and shortness of breath, created or exacerbated by the episode.	Agricultural residue burning	Respiratory symptoms	Cough, wheezing, chest tightness and shortness of breath	Primary data from a survey with part of a sample from an epidemiological study is analyzed with descriptive statistics	35-64 years, with mild to moderate airways obstruction and high level of airways hyperreactivity	Canada	Long W, Tate RB, Neuman M, Manfreda J, Becker AB, Anthonisen, NR. Respiratory symptoms in a susceptible population due to burning of agricultural residue. Chest 1998; 113:351-7.
Forest firefighters presented respiratory symptoms after fire season, however only change of pulmonary function was statistically relevant.	Wildfires	Respiratory symptoms and pulmonary function	Cough, phlegm, sore throath, chest tightness, chest pain and wheezing.	Primary data from a survey with firefighters is analyzed with descriptive and correlation statistics	Firefighters	USA	Betchley G, Koening JQ, Van Belle G, Checkoway H, Reinhardt T. Pulmonary function and respiratory symptoms in forest firefighters. Am. J. Ind. Med 1997; 31:503-9
Forest firefighters presented statistically significant increase in respiratory symptoms after fire season.	Wildfires	Decrease in pulmonary function	Eye irritation, nose irritation and wheezing	Primary data on pulmonary function and respiratory symptoms are compared across fire seasons with mean difference tests	Firefighters	USA	Rothman N, Ford DP, Baser ME, Hansen JÁ, OToole T, Tockman MS, Strickland PT. Pulmonary function and respiratory symptoms in firefighters. J. Occup. Med 1991; 33:1163-7.
Hospital admissions related with asthma increased significantly in the season of sugarcane burning	Sugar cane burning	Asthma	Not informed	Daily records of asthma hospital admissions and secondary data on air pollution were connected via time-series statistical modelling (dose-response)	All ages	Brazil	Arbex, M. A., Martins, L. C., de Oliveira, R. C., Pereira, L. A. A., Arbex, F. F., Cançado, J. E. D., ... & Braga, A. L. F. (2007). Air pollution from biomass burning and asthma hospital admissions in a sugar cane plantation area in Brazil. Journal of Epidemiology & Community Health, 61(5), 395-400.
Emergency room visits due to pneumonia increased significantly with air pollution in the season of sugarcane burning	Sugar cane burning	Pneumonia	Not informed	Primary data on emergency room visits and secondary data on air pollution were connected via time-series statistical modelling (dose-response)	All ages	Brazil	Arbex, M. A., Pereira, L. A. A., Carvalho-Oliveira, R., do Nascimento Saldiva, P. H., & Braga, A. L. F. (2014). The effect of air pollution on pneumonia-related emergency department visits in a region of extensive sugar cane plantations: a 30-month time-series study. J Epidemiol Community Health, 68(7), 669-674.
Hospital admissions of children and elderly due to respiratory illnesses increased during surgarcane burning season.	Sugar cane burning	Hospital admissions due to respiratory illnesses	Not informed	Primary data on pollution is correlated with data on hospital admissions with statistical modelling (dose-response)	< 13 years and > 64 years	Brazil	Cançado, J. E., Saldiva, P. H., Pereira, L. A., Lara, L. B., Artaxo, P., Martinelli, L. A., ... & Braga, A. L. (2006). The impact of sugar cane–burning emissions on the respiratory system of children and the elderly. Environmental health perspectives, 114(5), 725.
Workers of sugarcane farms were shown to have their nasal mucociliary clearance impaired and to present abnormal mucus properties	Sugar cane burning	Impairement of nasal mucociliary clearance and abnormal mucus properties.	Not informed	A survey with sugarcane workers, in which material from workers' airways was collected, comprehended two periods, after sugar cane burning season and a control period. Mean-difference tests are applied.	Sugarcane workers	Brazil	Goto, D. M., Lança, M., Obuti, C. A., Barbosa, C. M. G., Saldiva, P. H. N., Zanetta, D. M. T., ... & Nakagawa, N. K. (2011). Effects of biomass burning on nasal mucociliary clearance and mucus properties after sugarcane harvesting. Environmental research, 111(5), 664-669.
Prevalence of respiratory symptoms increased with number of days with fire smoke, and ashmatics were clearly highly impacted.	Wildfires	Asthma and bronchitis	Wheezing, sore throat, eye irritation, sneezing, stuffy (blocked) nose, dry cough, cough with phlegm ("wet cough")	A symptom survey with children from California Children's Health Study is connected with pollution data (PM10). Prevalence of symptoms is correlated with degree of exposure to air pollution.	6-7 and 17-18 years	USA	Bennion, J., McConnell, R., Gilliland, F. D., Berhane, K., Lurmann, F., Winer, A., ... & Aiguader, C. D. (2006). Health Effects of the 2003 Southern California Wildfire on Children. *Am J Respir Crit Care Med* , *174* , 12211228Lenihan.
Emergency department visits due to dysphagia were positively correlated with O3 level	Generic air pollution	Dysphagia (difficulty in swallowing) and chest pain	Dysphagia	Data from emergency room visits in Utah is correlated with air pollution (O3)	2 to 90 years	USA	Maestas, M. M., Perry, K. D., Smith, K., Firszt, R., Joy, L., & Peterson, K. (2017). EMERGENCY DEPARTMENT VISITS AND HOSPITALIZATIONS AMONG PATIENTS WITH EOSINOPHILIC ESOPHAGITIS AND ACUTE EXPOSURES TO AMBIENT AIR POLLUTION. *AIR POLLUTION AND GASTROINTESTINAL DISEASES IN UTAH* , 45.
Wildfires increased prevalence, among children, of sore throat and eye irritation, with the impact being more notorious among individuals with asthma and rhinitis.	Wildfires	Sore throat, eye irritation	Sore throat, eye irritation	Primary data on children respiratory symptoms and diseases from a wildfire and a control period is used to test the effect of wildfire on health.	Children (age not informed)	Spain	Vicedo-Cabrera, A. M., Esplugues, A., Iñiguez, C., Estarlich, M., & Ballester, F. (2016). Health effects of the 2012 Valencia (Spain) wildfires on children in a cohort study. Environmental geochemistry and health, 38(3), 703-712.
Women exposed to carbon monoxide from ovens fueled with wood, crop residue and dung had higher prevance of shortness of breath, diziness, headache. Both indoor and outdoor burning were considered.	Agricultural residue burning	Shortness of breath, diziness, headache	Shortness of breath, diziness, headache	Survey data is analyzed with descriptive statistics	Women 22-55 years	India	Joon, V., Kumar, K., Bhattacharya, M., & Chandra, A. (2014). Non-invasive measurement of carbon monoxide in rural Indian woman exposed to different cooking fuel smoke. Aerosol and Air Quality Research, 14(6), 1789-1797.

Table A1 Literature review on epidemiological impact of fires and biomass burning on respiratory health (cont.)

Summary	Source	Outcome	Symptoms	Method	Age groups	Country	Reference
From all households sampled, 88% smelled smoke from wildfires and 14% reported headache as a symptom (the first most recurrent symptom, cough, was reported by 25%)	Wildfires	Headache, cough, shortness of breath	Headache, cough, shortness of breath	Primary data from a "wildfire experience survey" is analyzed with descriptive statistics (together with estimates of economic costs of wildfire impacts on health)	All, households were interviewed	USA	Benjamin A. Jones, Jennifer A. Thacher, Janie M. Chermak & Robert P. Berrens (2016) Wildfire smoke health costs: a methods case study for a Southwestern US 'mega-fire ', Journal of Environmental Economics and Policy, 5:2, 181-199, DOI: 10.1080/21606544.2015.1070765
Rate of asthma, headache and coronary artery disease (CAD) were significantly related with PM 10 levels in the year the wildfire occurred.	Wildfires	asthma and headache	asthma and headache	With outpatient and pollution data, correlations are tested in dose-response fashion	All ages	USA	Tze-San Lee , Kenneth Falter , Pamela Meyer , Joshua Mott & Charon Gwynn (2009) Risk factors associated with clinic visits during the 1999 forest fires near the Hoopa Valley Indian Reservation, California, USA, International Journal of Environmental Health Research, 19:5, 315-327, DOI: 10.1080/09603120802712750
Hospital admissions by children and elderly due to respiratorty illnesses increased significantly in the fire season of 2005, year with one of the largest rates of wildfires in the Amazon	Agricultural fires	Hospital admissions due to respiratory illnesses	Not informed	Secondary data on hospital admissions linked with air pollution data (PM10) via statistical modelling (dose-response)	Children < 5 years, elderly > 64 years	Brazil (Amazon)	Ignotti, E., Hacon, S. D. S., Silva, A. M. C., Junger, W. L., & Castro, H. (2007). Effects of biomass burning in Amazon: method to select municipalities using health indicators. Revista Brasileira de Epidemiologia, 10(4), 453-464.
Mortality of elderly due to circulatory diseases was significantly correlated with air pollution, both variables considered for 2005, an year of drought, of high rate of wildfires in Amazon and in which pollution reached record levels in the fire season	Agricultural fires	Hospital admissions due to circulatory diseases	Not informed	Secondary data on hospital admissions linked with air pollution data (PM2.5) via statistical correlations	Elderly > 65 years	Brazil (Amazon)	Nunes, K. V. R., Ignotti, E., & Hacon, S. D. S. (2013). Circulatory disease mortality rates in the elderly and exposure to PM2. 5 generated by biomass burning in the Brazilian Amazon in 2005. Cadernos de saude publica, 29(3), 589-598.
Hospital admissions due to respiratory illnesses were positively correlated with pollution in Rio Branco, a Brazilian Amazon town in which pollution levels increased in September 2005 due to agricultural fires and wildfires. Increase in illnesses was particularly high for children < 10 years and pollution was positively correlated also with emergency room visits for asthma. Only the peak of dry season was considered (1-30 September, 2005).	Agricultural fires	Hospital admissions due to respiratory illnesses, asthma	Cough. Fever, dyspnoea, chest pain, wheezing, sore throat, expectoration, rhinorrea	Secondary data on hospital admissions linked with air pollution data (PM2.5) via statistical correlation	All ages	Brazil (Amazon)	Mascarenhas, M. D. M., Vieira, L. C., Lanzieri, T. M., Leal, A. P. P. R., Duarte, A. F., & Hatch, D. L. (2008). Anthropogenic air pollution and respiratory disease-related emergency room visits in Rio Branco, Brazil-September, 2005. Jornal Brasileiro de Pneumologia, 34(1), 42-46.
On field measurements of peak expiratory flow of children from 6-15 years evidenced decline in days with high concentrations of particulate matter in the air. The survey was pursued in Alta Floresta, Brazilian Amazon, during the fire season (August-December). The impact was higher whether exposure occurred between 0 to 5h30 AM, as burnings were conducted overnight.	Agricultural fires	Pulmonary function	Cough, runny nose, headache, watery eyes	Primmary data on peak respiratory flow connected with pollution data (PM 2.5) via statistical modelling (dose-response)	Children from 6-15 years	Brazil (Amazon)	Jacobson, L. D. S. V., de Souza Hacon, S., de Castro, H. A., Ignotti, E., Artaxo, P., & de Leon, A. C. M. P. (2012). Association between fine particulate matter and the peak expiratory flow of schoolchildren in the Brazilian subequatorial Amazon: a panel study. Environmental research, 117, 27-35.
As the previous study, peak expiratory flow, a measure of pulmonary function, was evidenced to decline in days with higher concentrations of particulate matter in the air. Both variables were obtained for the fire season of 2008 and for Tangará da Serra, Brazilian Amazon. Among children from 6 to 8 years, correlations were higher.	Agricultural fires	Pulmonary function	Not informed	Primmary data on peak respiratory flow connected with pollution data (PM 2.5 and PM 10) via statistical modelling (dose-response). Multiple specifications of the time-series models were tested and results were robust for most of them.	Children from 6-15 years	Brazil (Amazon)	Jacobson, L. D. S. V., de Souza Hacon, S., de Castro, H. A., Ignotti, E., Artaxo, P., Saldiva, P. H. N., & de Leon, A. C. M. P. (2014). Acute effects of particulate matter and black carbon from seasonal fires on peak expiratory flow of schoolchildren in the Brazilian Amazon. PloS one, 9(8), e104177.
Survey of toxicological exposure of children to air pollutants evidenced increased exposure and intake of pollutants during the fire season in Rio Branco, Amazon.	Agricultural fires	Intake of pollutants/ toxicological risk	Not informed	Primary data on local (at a school) concentration of pollutants (O3 and PM2.5) were obtained, together with coefficients from literature and daily times children were outdoor (in the school) to estimate pollutant intake.	Children from 6-14 years	Brazil (Amazon)	Silva, P. R. D. S., Ignotti, E., Oliveira, B. F. A. D., Junger, W. L., Morais, F., Artaxo, P., & Hacon, S. (2016). High risk of respiratory diseases in children in the fire period in Western Amazon. Revista de saude publica, 50.
Pre-natal and neonatal health of children were negatively impacted by exposure to smoke from sugarcane burning	Sugar cane burning	Birth weigth, gestational length and in utero survival	Not informed	Hotpot data (point fire detections) were connected with secondary data from hospitals on infant health via econometric modelling. Effect of fire in smoke also proved relevant as well as the effect of wind on health outcomes.	Newborn children	Brazil	Rangel, M. A., & Vogl, T. (2016). Agricultural Fires and Infant Health (No. w22955). National Bureau of Economic Research.
Hospital admissions due to respiratory illnesses were positively correlated with extent of sugarcane plantations, the latter being burned for harvest.	Sugar cane burning	Hospital admissions due to respiratory illnesses	Not informed	Secondary data on the extent of sugarcane plantations and hospital admissions, at municipal level, were connected via spatial econometric modelling	All ages	Brazil	Chagas, A. L., Azzoni, C. R., & Almeida, A. N. (2016). A spatial difference-in-differences analysis of the impact of sugarcane production on respiratory diseases. Regional Science and Urban Economics, 59, 24-36.
Similar to previous paper, from secondary data it was found positive correlation of hospital admissions and extent of sugarcane plantations	Sugar cane burning	Hospital admissions due to respiratory illnesses	Not informed	Similar to the previous paper, except for the fact that it was compared two periods, before and after a law decomissioning sugarcane burning and	All ages	Brazil	Nicolella, A. C., & Belluzzo, W. (2015). The effect of reducing the pre-harvest burning of sugar cane on respiratory health in Brazil. Environment and Development Economics, 20(1), 127-140.
Reduction of deforestation fires would prevent 400-1,700 deaths in South America.	Agricultural fires	Mortality	Not informed	Dose-response functions from epidemiological literature and correlation between fires and smoke (aerosol optical depth) are used to estimate avoided mortality due to reduction on deforestation fires.	Adults > 30 years	Brazil (Amazon)	Reddington, C. L., Butt, E. W., Ridley, D. A., Artaxo, P., Morgan, W. T., Coe, H., & Spracklen, D. V. (2015). Air quality and human health improvements from reductions in deforestation-related fire in Brazil. Nature Geoscience, 8(10), 768-771.
Hospital admissions of children < 5 years due to respiratory illnesses increased in the droughts of 2005 and 2010, episodes that registered record levels of aerosol due to agricultural fires	Agricultural fires	Hospital admissions	Not informed	Secondary data on hospital admissions, rainfall, deforestation and fires were connected with a spatial Poisson statistical model	Children < 5 years	Brazil (Amazon)	Smith, L. T., Aragao, L. E., Sabel, C. E., & Nakaya, T. (2014). Drought impacts on children's respiratory health in the Brazilian Amazon. Scientific reports, 4.
Hospital admissions of children due to respiratory illnesses increased with air pollution in the city of Rio Branco, which is part of Amazons' arc of deforestation, which is known for concentrating large proportion of Amazon fires.	Agricultural fires	Hospital admissions of children	Not informed	Data on hospital admissions and air pollution (PM 2.5) are connected with statistical modelling (dose-response)	Children < 10 years	Brazil (Amazon)	Do Carmo, C. N., Alves, M. B., & de Souza Hacon, S. (2013). Impact of biomass burning and weather conditions on children's health in a city of Western Amazon region. Air Quality, Atmosphere & Health, 6(2), 517-525.
Hospital admissions due to respiratory illnesses were positively impacted by fires within 300 miles. Only the area impacted by wildfire smoke is considered	Wildfires	Hospital admissions	Not informed	A dose response function relating pollutants and hospital admissions is estimated from secondary data	All ages	USA	Moeltner, K., Kim, M. K., Zhu, E., & Yang, W. (2013). Wildfire smoke and health impacts: A closer look at fire attributes and their marginal effects. Journal of Environmental Economics and Management, 66(3), 476-496.

2 Aggregate benefit and aggregate cost: detailed formulas

Efficiency is measured in the paper as welfare surplus which is equivalent to aggregate net benefit. This section presents the formulas used to calculate aggregate costs and benefits and provides an overview of the following section that detail the estimation of population sizes. The aggregate net benefit of a p-th policy implemented in the s-th sector of the study region is B(s) – C(s,p), with B(.) being aggregate benefit and C(.) the aggregate cost. The estimate for the government's cost of supplying subsidized tractors is also detailed here for being relevant to assessment of financial performance of policies (what is referred in the main text as "subsidy cost"). These three values are defined and broken down into components in subsections that follow.

2.1 Aggregate benefit

Benefit (B(s)) = Avoided welfare loss from acute respiratory illnesses caused by fires in the s-th sector of the study region =

$$\Delta HS(p,s)\, C_a(s) C_b\, m(WTP) * 128 * 4/4 = \widehat{\Omega}_B(p,s)\, m(WTP) \quad (1, \text{benefit})$$

With:

$\Delta HS(p,s)$ ≡ annual reduction in point fire detections associated with bringing to the limit instituted by the p-th policy the areas annually burned in smallholdings of the s-th sector [fires-year/year-farm] {details on section 3.1.4}

$C_a(s)$ ≡ marginal effect of fires located in the s-th sector of the study region on the monthly aerosol optical depth (AOD) level of the average urban neighbourhood of Rio Branco's urban perimeter [AOD-average neighborhood-month/fires-month] {details on sections 3.1.2 and 3.2.1}

C_b ≡ marginal effect of monthly urban AOD level on the count of urban respiratory illnesses, urban neighborhood level [illnesses-average-neighborhood-month/AOD-average-neighborhood-month] {details on sections 3.1.3 and 3.2.2}

m(WTP) ≡ mean for the welfare loss caused by an illness case, as measured by urban dwellers' willingness to pay [R$/ illness] {details on sections 3.1 and 4.1 of the main text}

128 ≡ number of urban neighborhoods which allows for capturing the effect of fire reduction in the whole set of neighboords of Rio Branco's urban perimeter (as Ca(s) * Cb returns the effect in the average neighborhood).

4/4 ≡ dimension correction for converting fire point detections from month to annual basis. The denominator corrects ΔHS my multiplying it to 1 year / 4 months and the numerator corrects $C_a(s)$ by multiplying by 4 months / year (this correction is neutral, it was only introduced here to attest rigor with measurement units.[1])

$\widehat{\Omega}_B(p,s)$ ≡ estimate for better-off population size; it is also referred as "total avoidable physical impact".

2.2 Aggregate cost

Cost (C(p,s)) = Welfare loss by smallholdings located in the s-th sector due to compliance with the p-th policy =

$$\widehat{\Omega}_C(p,s)\ m(WTA(p)) \quad (2, \text{cost})$$

With:

$\widehat{\Omega}_C(p,s)$ ≡ number of smallholdings with burned area above policy limit in s-th sector, as attested by average annual burned area (2014-2016) based in satellite and GIS data [count of smallholdings-year] {details on section 3.1.4}

m(WTA(p)) = mean for the welfare loss by smallholders from policy compliance [R$ / smallholding-year], as measured by smallholders' WTA {details on sections 3.2 and 4.2 of the main text}

2.3 Aggregate subsidy cost

By subsidy cost it is understood the accounting cost of executing a particular policy only in what regards to providing increased tractor hours. It was calculated based in formula below.

$$\text{Subsidy cost } (M(p,s)) \equiv \widehat{\Omega}_C(p,s)\ W\ \delta(p) \quad (3, \text{subsidy cost})$$

With W ≡ vector with tractor hour costs for each of the two tractors (harrowing and bulldozer) [R$/tractor-hour-smallholding] and $\delta(p)$ ≡ vector with increases in hours of the two tractors to be delivered by policy.

The accounting cost of mechanization was estimated as the product of the tractor rental price required by private providers of tractors (R$250/hour for bulldozer and R$150/hour for harrowing tractor) and a multiplier that incorporates indirect costs faced in public provision of tractors. The multiplier is equal to (direct public cost + indirect public cost) / direct public cost, with both direct and indirect total cost by each

[1] Ca(s) was obtained from 12-month year time-series data and HS is the total HS of the 4-month fire season. However, it is understood that the correlation captured by time series is owned mostly to the 4 months of fire season, and a multiplication by 3 of Ca would overestimate the annual average across months for such effect (such would be the case if a dimension correction of 12/4 was used). This is why only 4 months are considered for dimension conversions. To avoid overestimation of benefit is in accordance with the conservativeness CBA principle.

tractor type having been calculated from detailed costs estimates based on information obtained with technicians from Rio Branco municipal mechanization program (Safra, 2017).

3 Estimates of population sizes

3.1 Method

3.1.1 First stage: fire and smoke

Due to the complex influence of multiple climate and topographic factors, the effect of fires in the smoke captured by AOD data is hard to identify based only in the spatial relationship of AOD and fires. Remote sensing studies focus in the temporal relationship between these two variables (Mishra et al., 2015, Bevan et al., 2009, Koren et al., 2007). What yields results based mainly in the common seasonal pattern fires and AOD monthly time series reveal. The analysis pursued combined the time-series approach of mentioned studies with a simple spatial explicit framework detailed in the next paragraph.

The SR was subdivided into "sectors", based in a grid with 10 km x 10 km cells (Figure A1). The grid was refined to contain only the cells whose extent was fully inside the SR. The polygon comprising the urban town of Rio Branco (herein "urban perimeter"), or, more precisely, its centroid, was taken as the reference for delimiting sectors and will be herein referred as "geographical centre" (it is located 2.04 km away from the municipal capital). The grid cells were grouped in nine sectors that differed in (i) the distance from cell centroid to the geographical centre, which was discretized in four classes, (i.a) zero to 10 km, (i.b) 10 to 50 km, (i.c) 50 to 100 km, (i.d) more than 100km and; (ii) the angle formed by the straight line linking cell centroid and the geographical centre, which was discretized in four classes according with the trigonometric circle: (ii.a) 0 to 90 degrees (first quadrant/1stQuad or "northeast" in the main text), (ii.b) 90 to 180 degrees (second quadrant/2ndQuad/northwest), (ii.c) 180 to 270 degrees (third quadrant/3rdQuad/southwest), (ii.d) 270 to 360 degrees (fourth quadrant/4thQuad/southeast).

For each sector of the SR, fire and wind speed time-series were compiled covering all months from January 2010 to December 2016. More precisely, those series capture the total number of fire detections for each month and the sector average for the monthly dominant wind direction angle. AOD time-series was compiled only for the urban perimeter which corresponds to 40% of the urban area sector. Median AOD was computed for each month for the 1km cells of the original data and then averaged, at each month, for all cells that intercepted the urban perimeter, with the averages weighted by the share of cell within the targeted region. It must be reminded that time-series analysis links rural fire detections and rural wind direction with urban air pollution.

The econometric techniques that can provide unbiased assessment of correlation between time series depends on whether the series are stationary or not. This is why the first step in time series analysis is testing for the stationarity with unit root tests (Enders, 2014). All time-series were subjected to Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. The null hypotheses of these tests are that one unit root is present and the alternative hypotheses are of zero unit roots, i.e., stationarity (Enders, 2014).

The ADF test was pursued with a conservative approach to determine the number of time series lags in the base model (following recommendations by Enders, 2014, p.217). Starting with twelve, number of lags was reduced only if the Q Portmanteau test pointed to no significant autocorrelation in residuals for all 12 lags of an ARIMA model that had only the autoregressive component (AR). This procedure was repeated until the condition was violated (at least one lag significant at 10%) or number of lags decayed to one. Whether all the two time series capturing fire point detections and wind a given sector, and the urban AOD series proves stationary, the partial correlations among them can be unbiasedly estimated with ordinary least squares (OLS) regressions (Enders, 2014, p.198, and Wooldridge 2003, p.362). Whether at least one time series proves non-stationary, cointegration analysis is needed (Enders, 2014, Greene, 2003).

Wind direction is included in the model in order to control for the effect it has in the spatial diffusion of smoke generated by fires. Mishra et al. (2015) found the correlation of fire point detections and AOD in Amazon's deforestation arc to increase in a specific direction, west, when the spatial reference for AOD measurement (a 1^o x 1^o pixel) was shifted. The authors attributed this effect to the "westward advection of the smoke plumes by steady winds over the basin in the dry [burning] season" and provided further attestation based on 11-year average wind vectors. Bevan et al. (2006) also observed the smoke diffusion pattern in Amazon to be related with vectors of wind direction. With wind blowing dominantly in western direction in the peak month for fires, September, authors sustain that smoke from fires at east are "transported across the region". Smoke form sources at the north may be transported across the region in March, authors observe, a month in which the southwestern direction prevails (these patterns are notorious in figure 5 of Bevan et al., 2006). The dominance of west/southwest wind directions, reported in the articles mentioned, was captured by the satellite wind data taken as basis in this paper. In all sectors of the study region, southwest was the dominant wind direction, considering all months from January 2010 to December 2016 (Table A2; southwest is, in exact terms, an angle of 225^o, based in a tolerance of 30^o (195^o to 255^o) all sectors had a southwestern average wind direction). It is also observable that the westward vector is more influential out of the burning season (first row of Table A2, Figure A1) and the southward is more influential within the burning season.

Table A2 Wind direction, average for wind speed angle in trigonometric degrees, sectors of SR, January 2010 to December 2016

Sector / Wind direction	**Jan-Jul + Dec**	**Aug-Nov**
10to50km_1stquad	211.2452	232.4906
10to50km_2ndquad	221.2654	244.572
10to50km_3rdquad	225.6518	251.0208
10to50km_4thquad	220.9678	241.7796
50to100km_1stquad	208.0236	233.0458
50to100km_2ndquad	221.7639	245.4297
50to100km_3rdquad	236.3253	250.4001
50to100km_4thquad	220.6412	241.2685
Urban area	223.5211	254.7209

Source: MERRA, 2017

Wind direction, per se, i.e., measured as an angle, cannot be included in the econometric model for a matter of lack of clear interpretation of the associated coefficient, as it is hard to see what "larger" or "smaller" angles mean. That's why previous studies measuring the effect of fires in smoke classify angles in order to give them a rather straightforward interpretation in terms of geographical directions (Rangel and Volg, 2016, Deryugina et al., 2016, Chagas and Azzoni, 2016). However, the main interest in including wind direction in the econometric model is to know such factor alters the relationship of fires detected in particular locations, most of them rural, and smoke measured in the urban perimeter. This means the sources and the "sink" of smoke are clearly specified and, thus, the relevant wind direction that which prevails across the path from smokes' source to sink. To tackle this specific need, wind direction is included in the model as a dummy variable indicating whether wind direction in the source blew towards the urban area, in a given month.

The "centripetal" wind was obtained from two sources of information, (i) the "distance angle (α_d)", i.e., the angle formed by the straight line linking sector (source) centroid and the urban perimeter (sink) centroid and (ii) the "wind angle (α_w)" capturing dominant wind direction in the whole sector/month. The latter was calculated from the eastward and northward components of wind speed at 10m height from the ground, whose source was Modern-Era Retrospective Analysis for Research and Applications (MERRA) data retrieved from NASA Giovanni website (MERRA, 2017). Wind direction angle was calculated based in the conventions proposed in Deryugina et al. (2016). Even with coarse resolution (0.5^o x 0.625^o ~ 50km x 65km), the data had non-ignorable variation across the sectors (wind angle had a standard deviation/mean ratio of 0.18 across sectors, considering the average value of the ratio across all months). For all month/sectors that had distance and wind angles in diametrically opposite trigonometric quadrants (eg, wind angle in 1st quadrant and distance angle in 3rd quadrant), wind could considered to be blowing towards the urban area (it was "centripetal). Such criterion could not, however, identify a reasonably centripetal wind direction for some combinations of distance and wind angles (eg, wind angle = 0 and distance angle = 225). A further refinement was applied by introducing a tolerance threshold for distance-wind angle difference. A 90^0 tolerance threshold would constrain angle differences to the [135º; 225º] interval. For a narrower 30^0 tolerance, the threshold was of [165º; 195º]. Two versions of the centripetal wind dummy were thus obtained, as follows.

$$d_{wind_{30}} = \begin{cases} 1, if \alpha_d \in 1Q \wedge \alpha_w \in 3Q \wedge |\alpha_d - \alpha_w| \in [165^o; 195^o] \\ 1, if \alpha_d \in 2Q \wedge \alpha_w \in 4Q \wedge |\alpha_d - \alpha_w| \in [165^o; 195^o] \\ 1, if \alpha_d \in 3Q \wedge \alpha_w \in 1Q \wedge |\alpha_d - \alpha_w| \in [165^o; 195^o] \\ 1, if \alpha_d \in 4Q \wedge \alpha_w \in 2Q \wedge |\alpha_d - \alpha_w| \in [165^o; 195^o] \\ 0, otherwise \end{cases}$$

And analogously for the 90º tolerance interval. The two thresholds were considered in estimations, with each battery of regressions incorporated one of the two corresponding versions of the centripetal dummies.

The coefficients estimated were used to obtain the marginal effect of fire in AOD based in the derivation below.

Marginal effect = $\{E[AOD_{it}|fire=s_0+\Delta,d\_wind=d_0] - E[AOD_{it}|fire=s_0,d\_wind=d_0]\}/\Delta$ =

$\{[\beta_0 + \beta_1.(s_0+\Delta) + \beta_2.d_0 + \beta_3.(s_0+\Delta).d_0] - [\beta_0 + \beta_1.s_0 + \beta_2.d_0 + \beta_3.s_0d_0]\}/\Delta$ =

$\{[\beta_1.\Delta + \beta_3.\Delta.d_0]\}/\Delta \rightarrow$ marginal effect = $\beta_1 + \beta_3.d_0$. Taking d_0 as the time-series average for wind dummy, and replacing parameter for its estimates, the estimated marginal effect is $\widehat{\beta_1} + \widehat{\beta_3}\,\overline{d_{wind}}$.

The averaged wind dummy is equal to the share of months with centripetal wind in each sector, what seems more reasonable to consider rather than extreme 0/1 values as this yields average effect of fires and wind in AOD, rather than the effect in particular years or months.

3.1.2 Second stage: smoke and health

The main goal was to obtain an estimate for the effect of a marginal change in AOD level on the illness count, what was done by employing the "margins" routine of STATA® after estimations. For this, the average marginal effect on the predicted number of events (i.e., the number of illnesses) was estimated based on the assumption of zero unobserved heterogeneity (a = 0; see Cameron and Trivedi 2009, chap.8 and section 18.6).

3.1.3 Smallholdings above policy burning limits and reduction in fire point detections

<u>Worse-off population: count of smallholdings</u>

By spatially joining the property map with burn scar maps, the average property-level total burned area from 2014-2015 was calculated. A total of 37% smallholdings were above the 0.5 ha burning limit and 49% were above the zero limit.

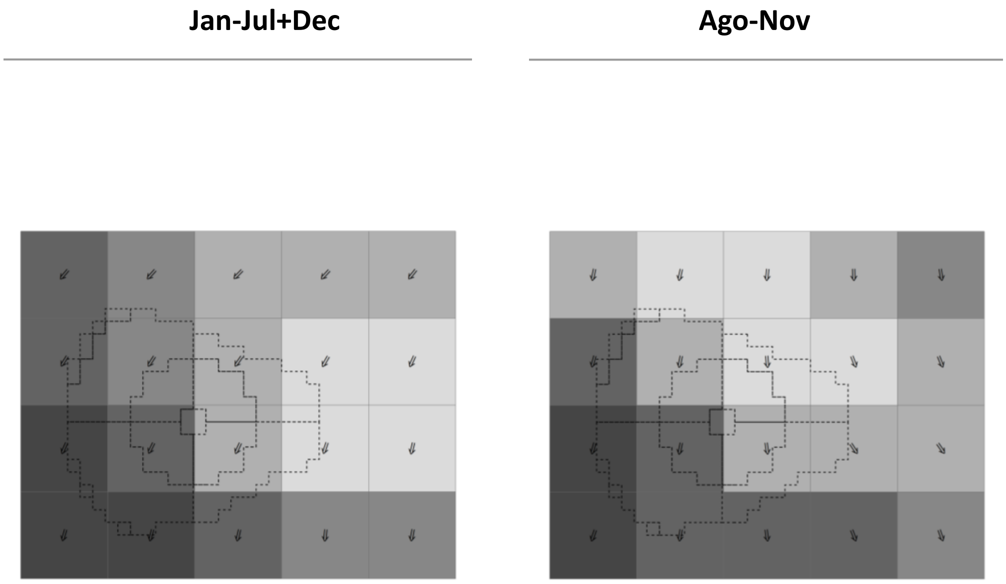
The smallholdings were assigned to the SR sector that embraced the largest proportion of their area. The minimum value for the largest proportion of area within a sector was of 42. The sector-level numbers of smallholdings above policy limits, which is the population size targeted here, were calculated based in the burned areas of smallholdings assigned to each sector.

<u>Better-off population: estimated number of fire point detections avoided</u>

The econometric model used to generate the status quo and amendment scenarios was based on a dataset for the years of 2014 to 2016, containing 16,595 SR smallholdings.

Seven econometric models were estimated belonging to three groups, negative binomial (population-averaged, fixed effects and random effects), Poisson (idem) and pooled-sample OLS. All models had significant and positive coefficient for burned area and were also globally significant (Table A3). Poisson population averaged was the model that returned the smallest absolute variations, comparing status quo and policy scenarios (half and zero), in predicted hotstpot counts across all models, what is most coherent with the principle of conservativeness in CBA (the smaller the absolute variation, the smaller the benefit). The sectoral absolute variations from the Poisson population averaged model were thus selected as basis for benefit aggregation.

Figure A1 Wind direction and speed in the RS and around, 10m height from the ground



Source: Modern-Era Retrospective Analysis for Research and Applications, MERRA (M2TMNXSLV v5.12.4), eastward and northward wind speed components. Retrieved from Giovanni website, NASA.

Table A3 Fire point detections vs burned area models

	negbin PA	negbin FE	negbin RE	Poisson PA	Poisson FE	Poisson RE	OLS (pooled)
burned area	0.0463475***	0.0245190***	0.0393967***	0.0284507***	0.0242789***	0.0360783***	0.0462996***
	[0.0017858]	[0.0015497]	[0.0017322]	[0.0019219]	[0.0020139]	[0.0014998]	[0.0018359]
dummy 2014	-0.7721022***	-0.8029657***	-0.7767184***	-0.8007564***	-0.8129613***	-0.7888244***	-0.3022663***
	[0.0223683]	[0.0203870]	[0.0200018]	[0.0226212]	[0.0225922]	[0.0199028]	[0.0104133]
dummy 2015	0.0232593	0.0068407	0.0247214+	0.0246727	0.0121162	0.0235303	0.0220214+
	[0.0193683]	[0.0166198]	[0.0145201]	[0.0220302]	[0.0183833]	[0.0188025]	[0.0128973]
Constant	-0.6201517***	0.5026726***	0.5376044***	-0.5564771***		-0.5997349***	0.5260748***
	[0.0150233]	[0.0429717]	[0.0385575]	[0.0188520]		[0.0167788]	[0.0090982]
ln_r							
_cons			1.5424721***				
			[0.0205019]				
ln_s							
_cons			0.1767635***				
			[0.0295382]				
lnalpha							
_cons						0.3834902***	
						[0.0173095]	
N	49785	26376	49785	49785	26376	49785	49785
N_clust	16595	8792	16595	16595	8792	16595	
r2							0.0810128
F							748.8314586
chi2	2224.129587	3451.208309	2513.012119	2497.18671	2164.046517	4134.449748	
p	0	0	0	0	0	0	0
ll		-16644.71714	-44302.68737	5	-17487.48656	-45035.27374	-72482.30953

3.2 Results

3.2.1 First stage

At least visually the three time series appeared correlated due to relevant number of matching peaks in all sectors (Figure A2). This correlation is of course expected based in previous studies (Mishra et al., 2015, Koren et al., 2007, Bevan et al., 2009), however the goal of econometric analysis was not to bring further confirmation but to estimate the intensity with which the correlation manifests in particular locations of the study region.

Based on the "conservative" ADF test, 2 of 28 time series, both corresponding to point fire detections, did not rejected the hypothesis of one unit root (urban pollution was stationary in all tests performed). Such time series, however, rejected the hypothesis of one unit root based in the PP test and also in a less conservative

ADF test with only one lag[2]. Therefore, it was understood that all time-series were stationary, what makes sense as graphic inspection reveals none of them had a clear trend, not even for short fractions of the time horizon (most of series oscillate around a fixed average or are "pulse" series; see Figure A2). The main implication of the unit root test is that coefficient estimates based on ordinary least-square regressions are unbiased (Enders, chap.4).

Fires had significant and positive coefficients in all sectors and tolerance levels except for four of the eighteen combinations (urban sector and 30^0 tolerance, 10to50km-4Quad sector and 90^o tolerance, 50to100km-2Quad sector and 90^o tolerance and 50to100km-3Quad both tolerance levels as wind dummy was zero for all periods; Tables A5 and B2). It is important to note that the lack of significance in urban area sector with 30^o tolerance in the wind dummy was accompanied by a highly significant and positive interaction term, suggesting that, fires in this sector, which contains the urban perimeter, only have impact if wind is blowing towards the its own centre, what makes sense.

The interaction between fires and centripetal wind dummy was either non-significant or negative in most of the models it could be included (11 of 14 models) and positive in only two models, both of them with 30^o tolerance (Tables A5 and B2). It was expected a positive significant interaction is most models, as it is intuitive that in months with a larger number of fires and with wind blowing towards the urban area, smoke tends to achieve higher levels in such place.

This failure of the time-series models to capture the joint influence of wind and fires seems to be grounded in scarcity of evidence. Taking the case of the 10to50km at first quadrant, which had a negative significant interaction term, we see that for only 2 of the 84 months it was positive (August and November 2016). Therefore, the simultaneous coincidence of fire and centripetal wind "treatments" has almost not occurred in the sector, what made measurement of treatment effect highly imprecise. It is enlightening what imprecision meant for this particular sector. The negative sign resulted from a comparison of only two months, ironically both of them with fires and AOD above the 90th percentile, September 2010 and August 2016. In the former, which was the dataset's AOD outlier, wind was not "centripetal" and in the latter it was, what made the interaction term zero and huge, respectively. Summing up, the scarce variation of the fires vs wind dummy interaction was insufficient to basis the identification of the variable's effect in all the models – interaction was zero in at least 89% of the months for models with 90^o tolerance, and in at least 97% of months with 30^o tolerance. If it was significant in some models this was mainly due to a few observations and outliers. Of course, the reason for this may be the restrictive definition of the dummy.

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[2] This is the correct thing to do based in the following excerpt from Enders (2014): "Including too many lags [in the base-model of ADF test] reduces the power of the test to reject the null of a unit root since the increased number of lags necessitates the estimation of additional parameters and a loss of degrees of freedom."

Besides models' imprecisions regarding the joint effect of fire and wind, they were successful in capturing the individual effects, as in most of models, the two variables were significant and explained a significant part of AOD timely variation (Tables A5 and B2). The only exception were the models for the sector 50to100km-3quad which, in fact, makes a lot of sense based in the fact that wind blew in more than half of periods in a non-"centripetal" way in the two thirds of the sectors (Figure A1, Table A4).

Only the stricter 30º degree tolerance will be considered in the discussion about marginal effect of fires (this is also the only set of results shown in the main text). First because it was associated with shorter intervals for direction-wind angle difference being less prone to error in regards whether wind was truly centripetal, second because the econometric performance of models based in the 30º tolerance had better econometric performance (higher share of models with significant fires or interaction term) and third because it yielded marginal effects whose spatial pattern made more sense.

Table A6 shows marginal effects for sectors. Two main patterns are clear. All quadrants had larger marginal effects the smaller the distance to the urban area, what makes sense as the effect of fire on pollution, controlling for wind direction, should decay with source-sink distance, ceteris paribus (Cameron, 2006, Mishra et al., 2015, Chagas et al., 2016). Third quadrant sectors had the lowest marginal effects within distance classes of 10to50km and 50to100km, what is reasonable as in these, wind blows in the opposite direction to the urban area (see Figure A1).

At first glance it seems counter-intuitive that pollution in urban perimeter was less sensitive to fires detected in the sector that embraces it, compared to those detected in sectors more than 10km away. This is maybe caused by the higher imprecision of the wind dummy for the urban area, as it was calculated based in two points that are only 200m from each other. The imprecision was attested by the larger difference between estimates for the two tolerance levels, something only observed for the urban area sector. Nevertheless, this could not had meaningful impact in cost-benefit analysis due to the low number of fires of urban area (Table A4).

Figure A2 Visual assessment of correlation in the three times series, fire point detections (continuous line with dots), AOD (strong continuous line), centripetal wind dummy with 30º tolerance (dashed line)

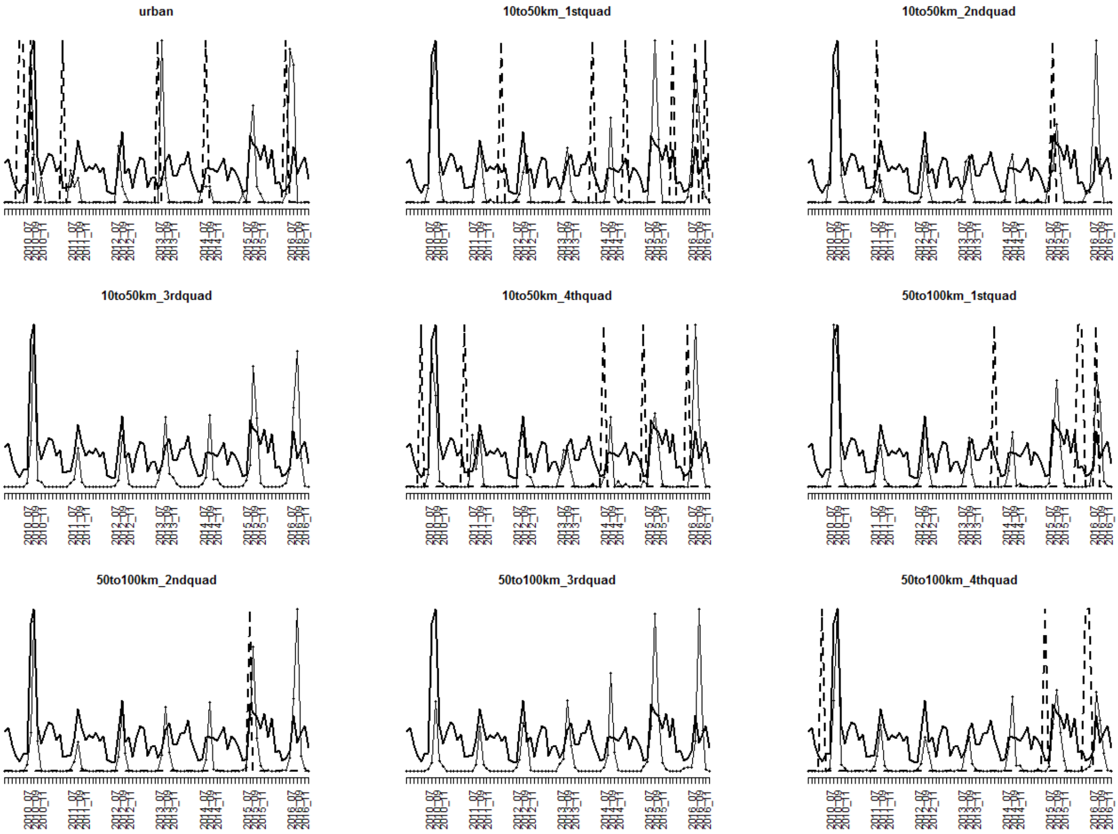


Table A4 Variables definition and summary (mean;sd;minimum;maximum)*

Definition	**Description**	AOD level of urban perimeter (daily medians, spatially averaged)	Fire (mean, SD, min, max)	Centripetal wind dummy, 90o tolerance	Centripetal wind dummy, 30o tolerance
	Short name	AOD	fire	d_wind_90	d_wind_30
	Unit	dimentionless	count	binary	binary
Summary	urban perimeter	166.56;114.89;40.74;780.19	NA	NA	NA
	urban area	NA	1.64;4.23;0;20	0.19;0.4;0;1	0.08;0.28;0;1
	10to50k-1stQ	NA	5.74;12.78;0;59	0.44;0.5;0;1	0.07;0.26;0;1
	10to50k-2ndQ	NA	4.94;11.27;0;60	0.3;0.46;0;1	0.02;0.15;0;1
	10to50k-3rdQ	NA	10.01;23.42;0;125	0.01;0.11;0;1	0;0;0;0
	10to50k-4thQ	NA	4.56;9.57;0;53	0.2;0.4;0;1	0.06;0.24;0;1
	50to100k-1stQ	NA	19.17;44.99;0;236	0.24;0.43;0;1	0.05;0.21;0;1
	50to100k-2ndQ	NA	23.44;58.4;0;307	0.24;0.43;0;1	0.01;0.11;0;1
	50to100k-3rdQ	NA	14.9;35.76;0;195	0;0;0;0	0;0;0;0
	50to100k-4thQ	NA	11.18;25.8;0;165	0.14;0.35;0;1	0.05;0.21;0;1

*Note: number of observations was 84 for all variables (12 months x 7 years).

Table A5 Estimation results, centripetal wind dummy with 90º tolerance

Covariate	Fire	Fire * d_wind_90	global p-value
urban area	13.51765 (0.031)	0	<0.01%
10to50k-1stQ	6.963084 (0.005)	-3.885035	<0.01%
10to50k-2ndQ	4.947613 (0.047)	0	<0.01%
10to50k-3rdQ	2.755728 (0.012)	0	<0.01%
10to50k-4thQ	0 (0.053)	0	<0.01%
50to100k-1stQ	2.133544 (0)	-1.442474	<0.01%
50to100k-2ndQ	0 (0.062)	0	0.0004
50to100k-3rdQ	0 (0.068)	0	0.0675
50to100k-4thQ	3.184406 (0)	-1.69566	<0.01%

Table A6 Average marginal effects

Sector	Marginal effect
10to50km_1stquad	6.151044571
10to50km_2ndquad	6.636051714
10to50km_3rdquad	2.767259
10to50km_4thquad	6.432715738
50to100km_1stquad	1.980418429
50to100km_2ndquad	1.039057
50to100km_3rdquad	0
50to100km_4thquad	3.157113333
Urban area	2.817595

3.2.2 Second stage

Table A7 below presents the definition and statistical summary of variables in the econometric model. Detailed results are found in Table B2.

Table A7 Definition and summary of variables, 2nd stage econometric analysis*

Description	Short name	Unit	TV?	Obs	Mean	Std. Dev.	Min	Max
Respiratory illnesses count : total	_total	count	y	1388	36.50865	51.48988	0	389
Respiratory illnesses count : age group 0 to 4 years	age:00to04	count	y	1388	11.40058	16.73271	0	131
Respiratory illnesses count : age group 5 to 17 years	age:05to17	count	y	1388	14.50432	20.82604	0	164
Respiratory illnesses count : age group 18 to 65 years	age:18to65	count	y	1388	8.668588	13.11415	0	99
Respiratory illnesses count : age group above 65 years	age:above65	count	y	1388	1.935159	3.025744	0	19
Respiratory illnesses count : cold	ill:cold	count	y	1388	2.740634	5.414248	0	40

Respiratory illnesses count : pneumonia	ill:other	count	y	1388	30.28242	43.04691	0	346
Respiratory illnesses count : other illnesses	ill:pneumonia	count	y	1388	3.485591	5.310321	0	38
Aerosol optical depth (AOD)	aod	dimensionless	y	1388	192.5358	69.88332	13.70258	380.5156
Street density (proxy for vehicle pollution)	street	m of street / m2	n	1388	0.0114596	0.0058642	0	0.0244052
Health unit density	units	count / km2	n	1388	0.4914592	0.2438173	0.0368672	1.040154
Population density	pd	count/m2	n	1388	0.387517	0.2558814	0.001469	1.111912
Population aged up to 4 years	pop_b4	share of population (%)	n	1388	0.0226347	0.0059145	0.0093929	0.0362316
Population aged 5 to 17 years	pop_5_17	idem	n	1388	0.119131	0.0237316	0.0688953	0.1851293
Population aged 18 to 65 years	pop_18_65	idem	n	1388	0.774682	0.0249861	0.6945018	0.8380111
Population aged more than 65 years	pop_a65	idem	n	1388	0.0968072	0.0354873	0.0462523	0.2260311
Monthly household income	hhinc	$10^3\text{R\$}$ of 2016	n	1388	3.829981	2.180647	1.321481	11.53536
Night light intensity	nlight	Six-bit digital number	n	1388	60.05301	6.351488	21.30665	63
Neighborhood area	area	km2	n	1388	1.185297	2.039585	0.0371715	11.7219
Year 2014	d_2014	binary	y	1388	0.3688761	0.4826742	0	1
Year 2015	d_2015	binary	y	1388	0.3544669	0.4785239	0	1
Month September	d_sept	binary	y	1388	0.2766571	0.4475067	0	1
Month October	d_oct	binary	y	1388	0.2672911	0.442705	0	1
Month November	d_nov	binary	y	1388	0.1793948	0.3838209	0	1

*TV ≡ time-variant

4 Urban dwellers' health survey: sampling and questionnaire

4.1 Sampling procedure

A procedure mixing conglomerate, quota and random sampling was adopted for selecting respondents. Five steps were followed.

1. [Conglomerate random sampling] Random pre-selection of a set of 10 neighborhoods of Rio Branco urban perimeter, based in representativeness and variability criteria (see below);
2. [Conglomerate resampling] Re-selection of neighborhoods in function of practical issues preventing survey execution in the pre-selected neighborhoods (such as unavailability of community health agents or impossibility to obtain their support);
3. Selection of three community health agents (CHA) in each neighborhood;
4. [Quota sampling] Quota list generation with CHAs classifying population under their monitoring responsibility into 8 groups of age and sex;
5. [Random sampling] Random selection of potential interviewees within listed groups.

The age quotas were defined, first of all, in accordance with previous studies of impacts of fires on health in the Amazon. Specifically, in the articles by Ignotti et al. (2007 and 2010), Carmo et al. (2010) and Nunes et al. (2013), it is stated that the age groups most sensitive to respiratory diseases are children up to four years old and elderly over 65 years old. In order to stratify the middle age range, 5 to 65 years, it was considered that, in most of cases, only adults have control of their own budget and, therefore, have discretion to fully decide their willingness to pay. As adulthood begins legally at the age of 18 in Brazil, two additional age groups were considered, 5 to 17 years (children or adolescents) and 18 to 65 years (adults). Accounting for two sex groups, male and female, it resulted a total of eight quota groups.

The sizes of quotas were defined in basis of (i) groups' participation in the population, according with the latest Census of 2010 and (ii) the number of interviews per CHA that proved practically feasible during the pilot, 18. Adjustments were applied, as the most susceptible groups, children and elderly, had low population shares (Table A8).

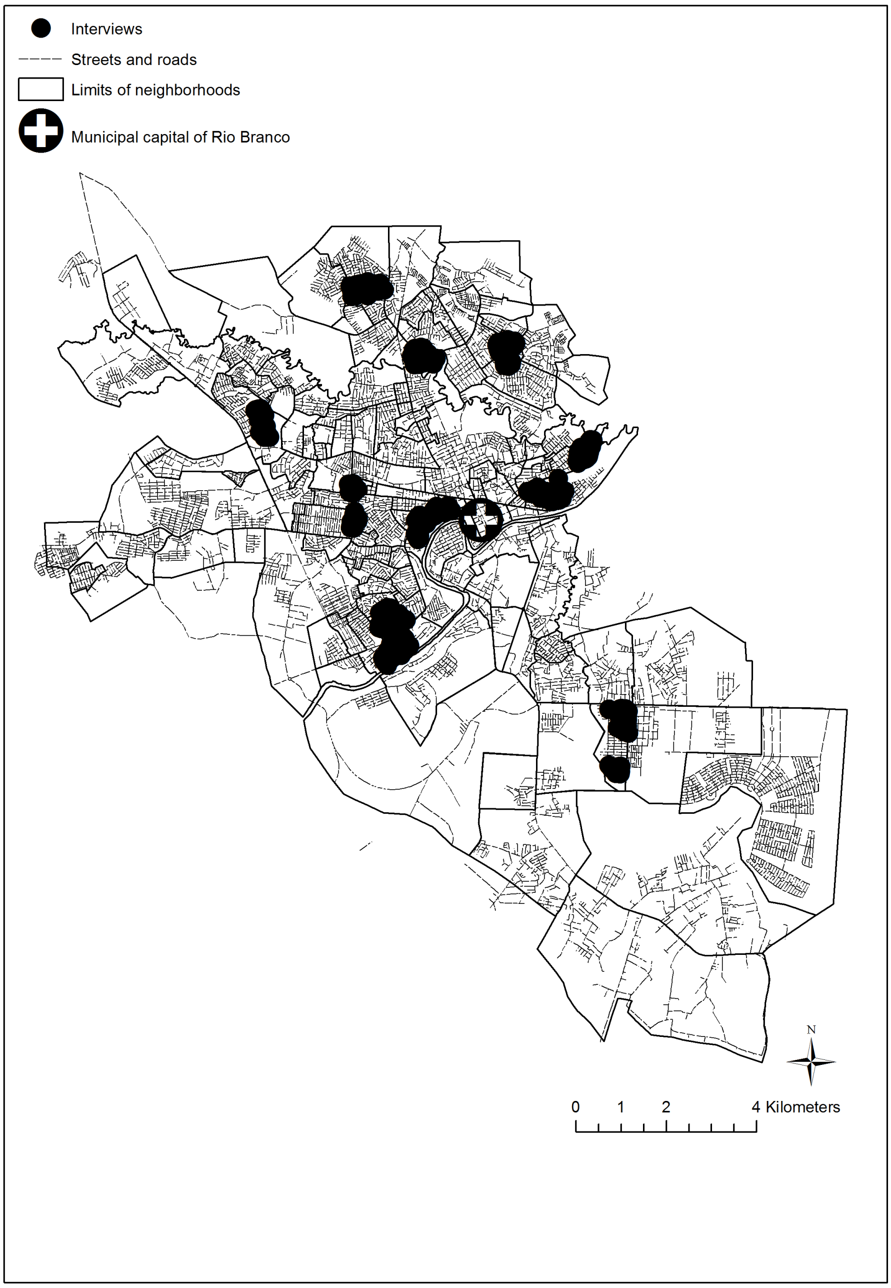
Table A8 Definition of age vs sex quotas for health survey

Sex	**Age (years)**	**Population shares**	**Exact quotas for a set of 18 interviews**	**Final (adjusted) quotas**	**Differences**
Male	0 to 4	1.13%	0	1	1
Male	5 to 17	6.11%	1	3	2
Male	18 to 65	37.37%	7	4	-3
Male	Above 65	4.22%	1	1	0
Female	0 to 4	1.14%	0	1	1
Female	5 to 17	5.90%	1	3	2
Female	18 to 65	40.56%	7	4	-3
Female	Above 65	4.99%	1	1	0

Note: each CHA was responsible for 18 interviews.

Urban dwellers were visited and interviewed in their homes. Interviews are generally believed to bias results by favouring "yea saying", but such bias seems to be less serious, for the case of the region of study, than that imposed by remote surveys (internet, telephone or mail). First because access to internet in a way that allows form filling is restricted to the wealthier residents of Rio Branco, which are minority of the population. Considering the population of whole Acre state in 2015 (which was 46% concentrated in Rio Branco), 44% accessed the internet (national average: 57.5%) and only 23% accessed the internet with a PC (IBGE, 2017a). Secondly, illiteracy rate is high, of 15% of Acre population, twice the national average, and functional illiteracy is also above the national average (IBGE, 2017b).

Figure A3 GPS points of respondents' houses in Rio Branco urban perimeter



4.2 Sampling results

Age distribution matched pre-defined quotas which were designed to differ from the population by having higher rates of children, teenagers and elderlies (section 4.1 and Table A9). This is desirable as these groups, besides representing small fractions of population, are more susceptible to acquire respiratory illnesses whether exposed to air pollution (Ignotti et al., 2007 and 2010, and Carmo et al., 2010, Ortiz et al., 2011). Income was only 10% lower in the sample without inflation correction (Table A9). In addition, the correlations between income and five household assets proxying wealth were all significant and followed a rank of magnitude that exactly matched that of the national household survey of 2015.

Table A9 Basic characteristics of sample compared to Rio Branco population

	Population[b]	Sample	Municipal illness data	Adults	Children[c]	Full sample[c]
Age: 0 to 4	2.3%	11.1%	34%	0.0%	24.9%	11.3%
Age: 5 to 17	12.1%	33.3%	24%	0.0%	75.1%	34.1%
Age: 18 to 65	77.7%	44.4%	36%	80.4%	0.0%	43.9%
Age: > 65	9.3%	11.1%	6%	19.6%	0.0%	10.7%
Gender: female	48.7%	50.0%	DA	48.9%	50.2%	49.5%
Average income [a]	2,770.68	DA	DA	2,411.37	2,336.34	2,377.29

a Household income comes from the 2015 household survey (IBGE, 2016) and comprises all classes of income considered in the sample plus interest on savings. Only urban areas of Acre were accounted for in the average. Inflation correction converted income of the first two columns from Reais of 2015 to Reais of 31 December 2016 based on the national consumer price index (IPEADATA,2017).

b Only urban census tracts of Rio Branco were considered. Census data is from 2010 (IBGE, 2013).

c It is considered the age and gender of the targeted respondent, i.e., of children and not of parents

4.3 Questionnaire

A pilot study involving 146 respondents was conducted in October-November 2016. The full-fledged survey covered 542 respondents in 11 neighborhoods of Rio Branco during March-July 2017.

A questionnaire, divided into four sections, guided the interviews of the full-fledged survey. The first section defined the reference illness by focussing on respondents' most recent illness episode. It asked which of 21 pre-defined symptoms were faced, the year and month the episode started and its duration. A 3 point Likert scale (Brooks et al. 1996, p.69, Soeteman et al., 2016 and Jagielski et al., 2014), measured the pain and discomfort caused by symptoms. In the only question mentioning fires, respondents were confronted with four 5-point Likert scales of certainty about the likelihood that four potential factors could have caused the reference illness, only two of them being fires. It was also asked whether respondents visited a doctor to take care of the respiratory illnesses they reported and the diagnosis received.

WTP was elicited in the second section in double bounded dichotomous choice (Hanemann et al., 1991) and open-ended formats. Before WTP questions, one page of text was read to respondents with information on (i) the two scenarios of the CV experiment, (ii) the payment vehicle, (iii) a reminder on inconveniences the vaccine could avoid, (iv) a reminder to consider actual budget constraint. The first scenario was the certain recurrence of the reference respiratory illness exactly 31 days after the interview. The second scenario was the purchase of the vaccine and the full avoidance of recurrence. A payment term of 31 days was offered because in the pilot survey it was observed that many respondents had cashflow or ATM/bank access issues.

It was informed that the vaccine, once taken, would provide immunization during only 31 days, what was fully coherent with the first scenario – please note the vaccine would always avoid illness recurrence, no matter the exact point in the 31 days term it was purchased. The main reason for the short duration of vaccine was preventing WTP to capture more than one respiratory illness, what would bias CBA.

The elicitation format was a double-bounded dichotomous choice as in Hanemann et al. (1991) and Ara and Tekesin (2016). A total of eight prices were offered, {10,20,50,100,200,300,500,600}. In the first bid, the two extreme prices (10 and 600) were ignored and one of the remaining prices was randomly drawn. The price vector was obtained from statistics of the WTPs declared in the pilot survey, in which the random cards elicitation procedure proposed by Smith (2006) and Brandt et al. (2012) was applied.

Protest responses were identified with answers to two open-ended debriefing questions, one after the DBDC question, the other after the open-ended (OE) WTP question. Responses were classified into eight classes, as follows.

1. *Prices offered are above my willingness to pay (absent from OE debriefing);*
2. *I don't believe the vaccine is effective [reaction to payment vehicle];*
3. *I (my son/daughter) dislike vaccination [reaction to payment vehicle];*
4. *Avoiding respiratory illness (for me/my son/daughter) is not important to me;*
5. *I have no money to buy the vaccine;*
6. *I rather use my money alternatively;*
7. *I believe the government should supply the vaccine for free [reaction to the hypothetical scenarios];*
8. *The vaccine would cause* negative side-effects (to me/my son/daughter) [reaction to payment vehicle].

Classes 2, 3, 7 and 8 were considered as genuine protest responses for representing negative reactions to the payment vehicle (vaccine) or to the scenarios offered (in 7, the respondent rejects the notion of having to pay for vaccination).

Observations were also classified as protests whether responses to debriefing questions reacted to payment vehicle or violated the scenarios offered in ways that differed from the eight cases above. Whether at least one of the two debriefing questions (referring to bids or OE) had a protest-classified response, the respondent was discarded from the database.

The third section of the questionnaire gathered information about socioeconomic control variables, including household income and wealth proxies (Filmer and Pritchett, 2001), education, smoking and private health insurance, serious lung diseases (Alberini et al., 1997) and distance to the closest health unit.

5 Smallholder survey: sampling and questionnaire

5.1 Sampling procedure

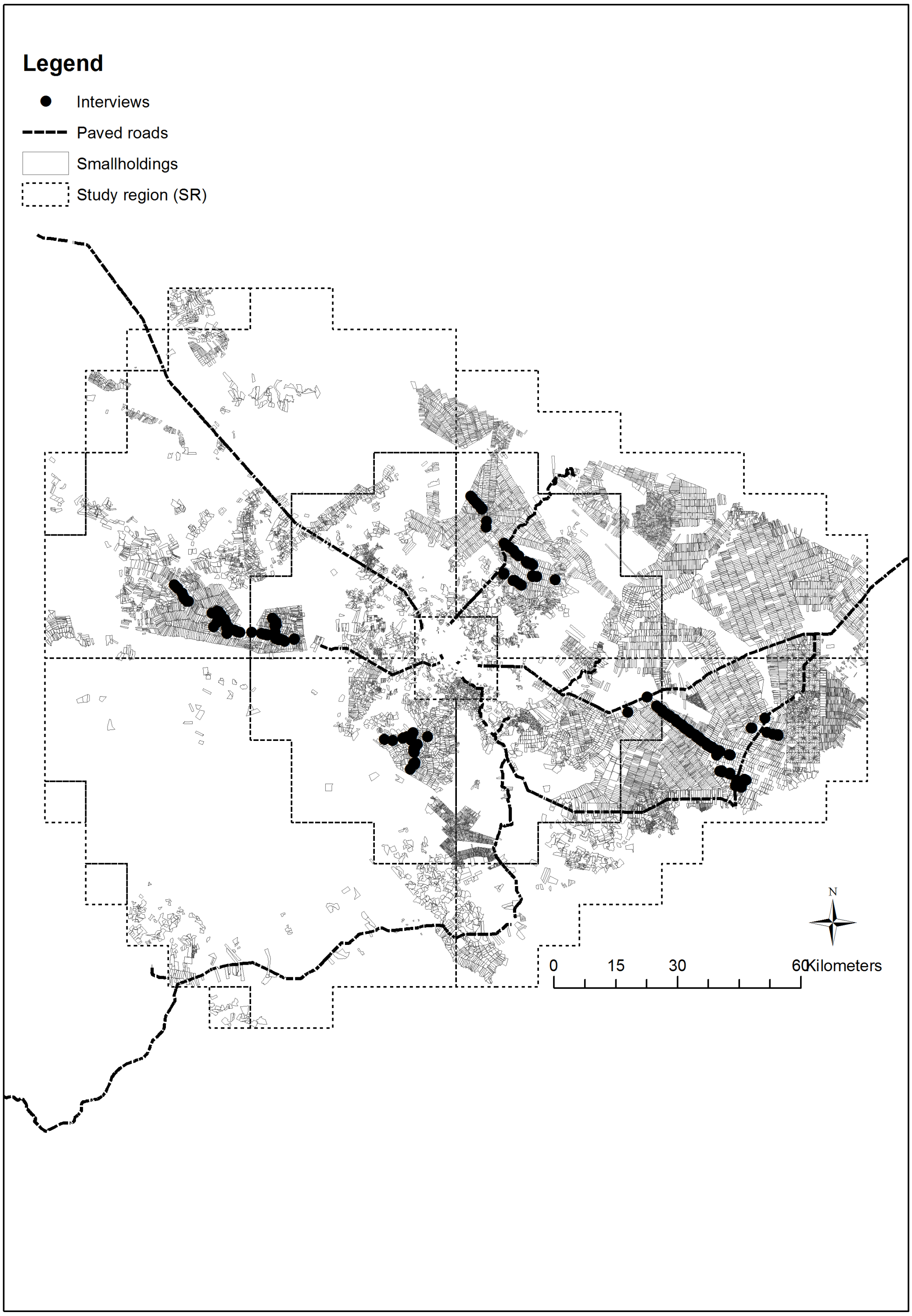
Sampling included two stages. The first consisted in identification of "top spots" of the study region (SR), being them understood as clusters of 1km x 1km grid cells that had, in 2016, high probabilities of occurrence of smallholder fires, according with satellite data on fires and official data on land properties. The "top spots" were identified and taken as the target spatial units for data collection. In the second stage, the number of interviews at each "top spot" was defined and in the third stage smallholders were selected on field. Sampling was defined together with the research unit that co-conducted the field surveys, which belonged to economics department of the Federal University of Acre and had 20 years of experience in smallholder surveys in the SR (hereafter "research unit").

As part of first stage, six "top spots", i.e., clusters of smallholders and fires, were identified. A total of six locations seemed manageable in logistic terms, given the budget and agenda constraints.

In the second stage, total sample size was divided across the 6 top spots located in 4 clusters (Figure A4). A sample size of 222 was fixed based in three principles: (i) sample size should be around 200, a reasonable size considering recent literature (see Kuhnfuss et al., 2015, Christensen et al., 2014, Schulz et al., 2014) and feasible with the budget available, (ii) a security margin of 10% should be added to accommodate elimination of observations (due to protest/collection failures) and (iii) the sample size should be multiple of 3, the number of choice set blocks in second pilot wave. Division of total sample size, or, more precisely, the number of respondents sampled in each top spot, was defined based in (i) sample sizes of surveys previously conducted in the top spots by the research unit, which were originally calculated to achieve representativeness of top spot's main typologies of smallholders, (ii) top spot's smallholder fire probability.

To select interviewees at each top spot, a pragmatic convenience sampling approach was followed. It consisted in three principles (i) maximize daily productivity (number of interviews/day) and (ii) avoid poorly accessible places with high risk of miring the vehicle transporting the team. As a result of the principles' implementation, most of the interviewees were located near the roads of best quality of each top spot, which were paved. This does not mean, of course, that all interviewees had direct access to paved roads. In fact, 69 of the 222 respondents (31%) lived in the proximity of unpaved roads. It has to be stressed that smallholders close to paved roads are also more accessible by subsidized tractors due to the high cost of transporting the machines along unpaved roads, and therefore, are among those that would be reached first by the policy that were the object of the interviews.

Figure A4 Smallholdings where interviews occurred


Legend
Interviews
Paved roads
Smallholdings
Study region (SR)
N
0
15
30
60
Kilometers

5.2 Sampling results

The sample was representative of population in terms of smallholding area (p-value of Mann-Whitney of 6.76% > 5% and Table A10), a "catch-all" variable that is correlated with multiple characteristics of smallholders, including income and farming system (Perz et al, 2003, Guedes et al., 2014, Siegmund-Schultze et al., 2007). Sampling overestimated the population burned area ratio (p-value of Mann-Whitney rank sum test < 0.01%), as envisaged (Section 5), as the policies here evaluated are targeted to fire users and not to all smallholders. The characteristics of respondents mentioned in the main text are found in Table A11 together with more information. Table A12 show responses for scenarios credibility debriefing.

Table A10 Percent of smallholdings in farm area intervals, population (SR) and sample*

Smallholding area (hectares)	Population	Sample	Difference
(0,20]	27.80%	23.42%	4.38%
(20,40]	19.70%	16.67%	3.03%
(40,60]	20.76%	21.62%	-0.86%
(60,80]	19.22%	22.52%	-3.30%
(80,100]	7.02%	13.06%	-6.04%
(100,120]	1.95%	0.45%	1.50%
(120,140]	0.72%	0.90%	-0.18%
(140,160]	0.58%	0.00%	0.58%
(160,400]	2.24%	1.35%	0.89%
Mean+	DA	DA	2.31%
Maximum+	DA	DA	6.04%

* "Population" refers to smallholdings (i) registered in the property mapping for environmental and land policy (CAR) of Brazilian federal government, (ii) with maximum area not above the legal maximum smallholding (family farm) area, of 400 ha (4 x the maximum size of land modules for fiscal purposes, 100 hectares), (iii) located in the 9 municipalities that intercepted the SR (municipalities' areas out of SR were also considered). Sample smallholding areas refer to the areas of all properties reported without summing them for respondents that declared ownership of more than one property + mean and maximum were calculated from the absolute value of differences to avoid cancelling.

Table A11 Respondents' profile (sample vs population (2010 Census))

	Population (rural only)	Population (rural and urban)	Sample
Age	37.32	37.49	49.44
Gender (female rate)	0.55	0.49	0.31
Literacy rate	0.69	0.79	0.82
Farming goal: self-supply	DA	DA	0.14
Farming goal: crop only	DA	DA	0.12
Farming goal: cattle only	DA	DA	0.11
Farming goal: crop & cattle	DA	DA	0.22
Self-declared fire users	DA	DA	0.13
Protest	DA	DA	0
SQ rate	DA	DA	0.10

Note: DA ≡ does not apply.

Table A12 After choice-experiment debriefing questions on government credibility, share of respondents in the cells

	What is the likelihood that government effectively fines a burning-limit transgression?	What is the likelihood that government delivers the expanded support on mechanization?
High likelihood	68%	14%
Moderate likelihood	21%	28%
Low likelihood	11%	59%
Total	100%	100%

5.3 Questionnaire

Two waves of pilot surveys were conducted involving 58 respondents. The full-fledged survey took place in May 2017 covering three municipalities of Acre state within the SR and six agrarian land settlements of federal government. A total of 222 smallholders were interviewed (for sampling see Section 5).

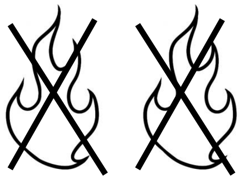
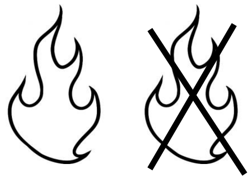
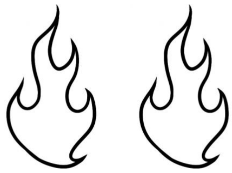
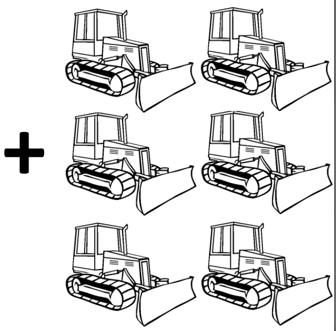
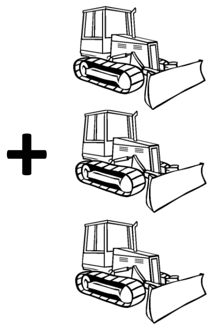
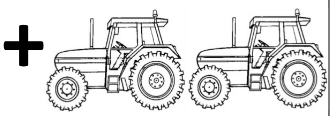
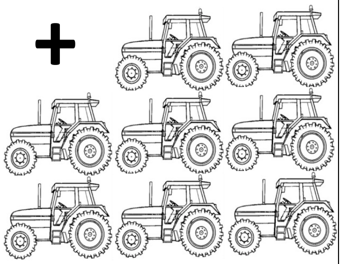
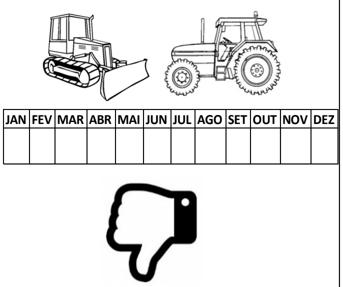
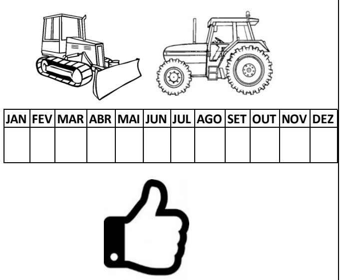
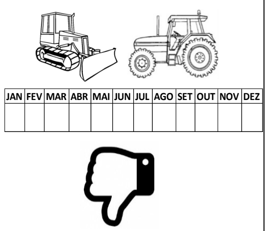
The questionnaire that guided interviews of the full-fledged survey had three sections. The first assessed directly and indirectly whether respondents used fire. The second section presented the choice experiment, first describing the policy scenarios, then describing the choice procedure, the attributes and their levels (see Figure A5 below for an example of a choice set). Before choice sets were shown, respondents were recommended to take the exercise realistic and not to choose options that could threaten their farming, especially in regards to food security, or that they could not comply with, as fines would be effectively applied. Two debriefing questions were asked to measure credibility of policy scenarios. The third section was about respondent characteristics. Protests were detected with the below debriefing question, adapted from Kuhfuss et al. (2016). It was asked after each choice set if SQ option was chosen.

If you just choose the option "current situation (no change)", could you tell me why you have chosen it?

1. *The payment is too low*
2. *The increase in tractor hours and the reduction in tractor delay are insufficient*
3. *The burned area allowed for alternatives A and B is too small (A and B = non SQ)*
4. *I don´t believe the government will deliver the increased support*
5. *I don´t think it is correct to reduce the burned area limit, no matter the increase in tractor support or the payment offered*
6. *Other:* ____

Only alternatives 4 and 5 were deemed as protests. Disbelief in government (4) violated the assumption that increased support would be delivered. Resistance to reduce burned area (5) meant non-willingness to exchange fire for tractors. None of the cases in which the open-ended alternative (6) was filled characterized a protest.

Figure A5 Example of a choice card

	Alternative A	**Alternative B**	**Current situation (no change)**
(1) Allowed annual burning limit [hectare/smallholding/year]	**Zero** 	**1/2 hectare/farm/year** 	**1 hectare/farm/year** 
(2) Increase in bulldozer hours [tractor-hours/year]	**Increase of 6 hours per year** 	**Increase of 3 hours per year** 	**No increase**
(3) Increase in harrowing tractor hours [tractor-hours/year]	**Increase of 2 hours per year** 	**Increase of 8 hours per year** 	**No increase**
(4) Reduction in tractor arrival delay	**No reduction in delay** 	**Reduction of delay to zero** 	**No reduction in delay** 
(5) Compensation payment to be **received** during **5 years** [R$/smallholding/year]	**R$ 1000/farm/year**	**R$ 500/farm/year**	**Zero**

Choose the option you prefer →	☐	☐	☐

6 Epidemiological validity of survey for valuing fire-caused illnesses

The urban health survey is the basis for assigning a monetary value to the impact of fires on health. Next paragraphs provide arguments, based in epidemiological evidence, to show that such endeavour was consistently pursued. Before advancing, it must be clarified that what follows is not an attempt to make the point that the reference illnesses reported on sample were, indeed, caused by fire. What was clearly not the case, as, in the basis of (i) respondents' assessment on the cause of reference illness and (ii) whether the illness occurred in the fire season, it was found that fire was, with satisfactory certainty, the cause of only 6.75% of reference illnesses.

Nevertheless, the point here is that, even if most of illnesses valued were not caused by fire, the economic values assigned to them by respondents were still coherent as a basis to value respiratory illnesses caused by fire. Such goal is pursued by showing that the objects of valuation for most of respondents, i.e., the reference illnesses (Table A13), are negligibly different from the respiratory illnesses commonly caused by fires. It may be also helpful to remember that the goal of the survey was to estimate the value that the average resident of Rio Branco urban perimeter would pay to avoid a respiratory illness, irrespective of the cause behind the illness.

The first potential issue to be discussed is the fact that most of respiratory illnesses in sample did not occurred in the fire season and, therefore, could hardly be caused by fires. However, this is not an issue as, comparing fire season (August to November) and non-fire season months with out-patient visits data from 2014 and 2016, it is observed that the top eight classes of respiratory illnesses from 2014 and 2016, were exactly the same within and without the dry season, having nearly the same joint share of cases reported, of 90.4% out of the fire season and of 91.6% in the fire season. This means the epidemiological profile of fire season and non-fire season months is mostly similar, in what regards to illnesses[3].

In addition to the epidemiological equivalence of fire and non-fire seasons, Table A14 presents sources of primary epidemiological evidence connecting most of the symptoms reported by respondents with fires or biomass burning. For eight of the twenty one symptoms it was not possible to find a corroborating paper. However, three of these cases had low recurrence in sample (≤ 20%), one of them, difficulty in swallowing, is either caused by or highly correlated with sore throat[4], a symptom backed by three articles. The four remaining symptoms, body pains, aching muscles, sensation of weakness and malaise, are not of prime

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[3] The top eight respiratory illnesses, from 2014-2016, follow, with in fire season - out fire season rates in parenthesis. Upper respiratory tract infections (36.59%-37.13%), Tonsillitis (18.09%-18.66%), Pneumonia (10.33%-10.16%), Asthma (5.98%-5.61%), Influenza (5.86%-5.38%), Bronchitis (5.4%-6.29%), Pharyngitis (5%-5.51%), Acute respiratory infections (3.09%-2.80%).

[4] According with Boureau et al., 1999, difficulty in swallowing is a sensory quality of sore throat pain.

interest for being not necessarily respiratory (i.e., are commonly observed in non-respiratory illnesses). In summary, all respiratory symptoms reported by respondents were mentioned in the epidemiological literature as potential consequences of exposure to fire pollution.

Table A13 Diagnosis received by respondents that went to a doctor during the reference respiratory illness reported

Diagnostics	**N**	**%**
Tonsillitis	4	2%
Asthma	5	3%
Bronchitis	9	5%
Throat (Irritation or inflammation)	12	7%
Influenza	98	53%
Acute respiratory infection	4	2%
Upper respiratory tract infection	4	2%
Pneumonia	16	9%
Generic virus (probably influenza)	8	4%
Other	14	8%
Without diagnostic	10	5%
Total	184	100%
Have not visited a doctor	304	

Table A14 Epidemiological evidence of relationship between fires or biomass burning and symptoms reported in the sample

Symptom	Rate in sample	Articles
Runny nose	76%	Kunii et al., 1998 [Indonesia mega-fire of 1997], Jacobson et al., 2012 [Amazon fires' effects on children]
Stuffy nose	83%	Künzli et al., 2006 [wildfire effects on children]
Sneeze	79%	Kunii et al., 1998 [Indonesia mega-fire of 1997], Betchley et al., 1997 [wildfire effects in firefighters], Künzli et al., 2006 [wildfire effects on children/
Dry cough	59%	Ellegard, 1996 (indoor biomass burning), Kunii et al., 1998 [generic cough; Indonesia mega-fire of 1997], Künzli et al., 2006 [wildfire effects on children]
Cough with phlegm	55%	Ellegard, 1996 (indoor biomass burning), Kunii et al., 1998 [generic cough and phlegm, separately enquired; Indonesia mega-fire of 1997], Betchley et al., 1997 [only phlegm; wildfire effects in firefighters], Künzli et al., 2006 [wildfire effects on children]
Fever	53%	Kunii et al., 1998 [Indonesia mega-fire of 1997], Mascarenhas et al., 2008 [wildfires and agricultural fires in Rio Branco, Amazon]
Difficulty in swallowing (dysphagia)	49%	[this symptom was originally supposed to be related with sore throat]
Eye irritation	42%	Dawud, 1998 [Indonesia mega-fire of 1997], Kunii et al., 1998 [Indonesia mega-fire of 1997], Rothman et al., 1991 [firefighters], Künzli et al., 2006 [wildfire effects on children], Vicedo-Cabrera et al., 2006 [wildfire effects on children/
Sore throat	69%	Betchley et al., 1997 [wildfire effects in firefighters], Künzli et al., 2006 [wildfire effects on children], Vicedo-Cabrera et al., 2006 [wildfire effects on children/
Headache	67%	Joon et al., 2014 [crop residual burning for cooking], Jones et al., 2016 [wildfire], Lee et al., 2009 [wildifre], Jacobson et al., 2012 [Amazon fires' effects on children]
Body pains	49%	No article relating the symptom with fires or biomass burning found
Aching muscles	36%	No article relating the symptom with fires or biomass burning found
Chest pain	35%	Long et al., 1998 [chest tightness; outdoor burning of agricultural residue (straw and stubble), Betchley et al., 1997 [wildfire effects in firefighters]
Earache (Otitis)	20%	No article relating the symptom with fires or biomass burning found
Rash	5%	No article relating the symptom with fires or biomass burning found
Shortness of breath (dysponea)	49%	Dawud, 1998 [Indonesia mega-fire of 1997], Kunii et al., 1998 [Indonesia mega-fire of 1997], Long et al., 1998 [Outdoor burning of agricultural residuae (straw and stubble), Joon et al., 2014 [crop residual burning for cooking]
Wheezing	37%	Dawud, 1998 [Indonesia mega-fire of 1997], Long et al., 1998 [Outdoor burning of agricultural residue (straw and stubble), Betchley et al., 1997 [wildfire effects in firefighters], Rothman et al., 1991 [firefighters], Künzli et al., 2006 [wildfire effects on children/
Dizzy or faint sensation	28%	Joon et al., 2014 [crop residual burning for cooking]
Sensation of weakness	53%	No article relating the symptom with fires or biomass burning found
Malaise	73%	No article relating the symptom with fires or biomass burning found
Ear inflammation	7%	No article relating the symptom with fires or biomass burning found

Notes: Only empirical studies providing original evidence were considered (studies with second-hand evidence were ignored). Not all studies found were reported, but only a maximum of four studies per symptom. Regarding effects in firefighters, the statement from Arbex et al. (2004) should be considered, especially due to the expert knowledge of the fist author (Brazilian pneumologist with multiple articles on surgarcane burning effects on health). He states that since firefighters are more healthy than average population it is "reasonable to suppose that similar effects could be observed in the general population on similar or smaller [degrees of] exposure[.]".

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