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Supplemental Material

Widespread Clean Cooking Fuel Scale-Up and under-5 Lower Respiratory Infection Mortality: An Ecological Analysis in Ecuador, 1990–2019

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Figure S3. Cantons that reached 61% clean fuel use in each study period. 61% CF is the threshold found by breakpoint/segmented regression. Cantons below 61% clean fuel use are shown in grey, and the remainder are illustrated in the color palette used in Figure 1. In the period centered at 1988-1992, 15% of cantons were at 61% primary clean fuel use or above; 1999-2003: 69%; 2008-2012: 92%; and 2015-2019: 98%.

Figure S4. Sex-stratified linear and non-linear associations between %CF and under-5 LRI mortality. In the top panel, estimates are shown in white diamonds, the innermost and darkest band is the 66% confidence interval, the second-darkest band is the 80% confidence interval, and the widest and lightest band is the 95% confidence interval. For sex-stratified analyses, sex-specific under-5 canton-period population estimates are used as an offset. We directly count sex-specific canton-period under-5 population in 1990, 2001, and 2010 based on the census. We can estimate overall under-5 population in the 2015-2019 period as discussed above in Table 1. We use the average sex ratio from 1990, 2001, and 2010 to then estimate sex-specific canton-period under-5 population by multiplying the sex ratio with the overall population. Sex-specific splines are restricted to three degrees of freedom.

Figure S5. Period-stratified linear and non-linear associations between %CF and under-5 LRI mortality. In the top panel, estimates are shown in white diamonds, the innermost and darkest band is the 66% confidence interval, the second-darkest band is the 80% confidence interval, and the widest and lightest band is the 95% confidence interval. Period-specific models do not contain canton or period fixed effects. Otherwise, they mirror the preferred specifications.

Figure S6. Region-specific linear and non-linear associations. In the top panel, estimates are shown in white diamonds, the innermost and darkest band is the 66% confidence interval, the second-darkest band is the 80% confidence interval, and the widest and lightest band is the 95% confidence interval. The middle panel shows alternative non-linear associations between canton-level %CF and under-5 LRI mortalities among subsets. The bottom panel shows a histogram of the distribution of canton-period %CF estimates over the full time period, colored by region. Models mirror the preferred specifications.

Figure S7. Estimating the proportion of the decline in under-5 LRI mortalities observed between 1990 and 2019 attributable to increased clean fuel use. Kinks in the plot are associated with period fixed effects (1988-1992 used between 1990 and 1996; 1999-2003 between 1997 and 2006; 2008-2012 between 2007 and 2013; 2015-2019 between 2014 and 2019). Only the 1990 fixed effect was used in the 'Counterfactual' prediction. The counterfactual prediction is associated with 68,972 under-5 LRI mortalities total across the 30-year time period. The "No %CF increase" prediction yields an estimated 37,145 under-5 LRI mortalities and the "True" prediction yields 29,905 under-5 LRI mortalities over the 30-year time period.

Figure S8. Ambient air pollution, clean fuel use, and under-5 LRI mortality. Panel **a** shows raw ambient $PM_{2.5}$ concentrations from van Donkelaar et al. (2021) overlaid with canton-province borders in the years designated. Canton ambient PM2.5 concentrations were estimated by taking the average of the pixels that intersected or fell within each canton in each year of the appropriate period. Then, those five estimates were averaged to produce the canton-period estimates. Panel **b** summarizes the distribution of canton ambient PM2.5 concentrations across periods with violin and box plots (box lines at 25^{th}, 50^{th}, and 75^{th} percentiles and whiskers extend to the maximum and minimum concentrations). World Health Organization interim-1 and guideline shown for annual $PM_{2.5}$ exposure. Panel c shows the association between canton-period %CF and ambient $PM_{2.5}$ concentrations per 10 percentage point increase in %CF in micrograms per cubic meter in an empty model with only canton and period fixed effects and an adjusted model that includes: percent of households in a canton that are rural; percent of households that are not grid electrified; an index of household materials; household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; adult women's literacy; under 18 years of age girls' school attendance rate; and an individual in the household or the respondent speaks an indigenous language. Panel d shows results from models with an outcome of under-5 LRI mortalities per canton-period (1) with an empty model that includes only ambient $PM_{2.5}$ and canton and period fixed effects; (2) with an empty model that includes only %CF and canton and period fixed effects (recall this is only the most recent three periods); (3) an empty model that includes ambient PM2.5, %CF, and canton and period fixed effects; and (4) a fully adjusted model that includes ambient PM2.5, %CF, the full range of potential confounding variables in our preferred specification, and canton and period fixed effects.

Figure S9. Alternative adjusted linear and non-linear associations between clean fuel use and under-5 LRI mortality rate. In the top panel, estimates are shown in white diamonds, the innermost and darkest band is the 66% confidence interval, the second-darkest band is the 80% confidence interval, and the widest and lightest band is the 95% confidence interval. The middle panel shows alternative non-linear associations between canton-level %CF and under-5 LRI mortalities. The bottom panel shows a histogram of the distribution of canton-period %CF estimates over the full time period. See Table S4 for full characterization of covariates included.

Figure S10. Robustness of results to additional degrees of freedom. Figure repeats Figure S7 but with additional degrees of freedom as specified. See Table S4 for full characterization of covariates included.

Figure S11. Specification plots showing main effect estimate for a 10-percentage point increase in %CF in quasi-Poisson GLMs with an offset for under 5 population and fixed effects for canton and period. Specification plots show all potential confounder combinations. Plots are ordered by increasing rate ratio (closer to the null). The empty model (covariates are fixed effects for period and canton only) and preferred specification mortality rate ratios are shown as horizontal lines. The plots show a point estimate and 95% confidence intervals.

Figure S12. Full adjusted non-linear association shown where potential confounders are only included as linear covariates and where potential confounders that display a non-linear association with the outcome are modeled non-linearly using penalized splines with three knots. The top panel shows non-linear associations between canton-level %CF and under-5 LRI mortalities for each specification. The bottom panel shows a histogram of the distribution of canton-period %CF estimates over the full time period.

Figure S13. Linear and non-linear association shown for the preferred outcome specification (quasi-Poisson) and an alternative approach, the negative binomial model. In the top panel, estimates are shown in white diamonds, the innermost and darkest band is the 66% confidence interval, the second-darkest band is the 80% confidence interval, and the widest and lightest band is the 95% confidence interval. The middle panel shows alternative non-linear associations between canton-level %CF and under-5 LRI mortalities by model outcome type. The bottom panel shows a histogram of the distribution of canton-period %CF estimates over the full time period.

Figure S14. Linear and non-linear association shown for the preferred specification (fixed effects for canton) and an alternative specification using random intercepts for canton. In the top panel, estimates are shown in white diamonds, the innermost and darkest band is the 66% confidence interval, the second-darkest band is the 80% confidence interval, and the widest and lightest band is the 95% confidence interval. The middle panel shows alternative non-linear associations between canton-level %CF and under-5 LRI mortalities by model type. The bottom panel shows a histogram of the distribution of canton-period %CF estimates over the full time period.

Figure S15. Robustness of the preferred linear and non-linear specifications and empty models (i.e., only canton and period fixed effects) to the inclusion of a regional fixed effect. Models here mirror the main specification but we additionally include a regional fixed effect for which region each given canton observation is in (Amazon, Andes, or Coast). Associations do not meaningfully differ from models without a regional fixed effect, suggesting that our results are not driven by unmeasured regional level confounding.

Figure S16. Robustness of the full model and Coastal region subset linear and non-linear associations to the exclusion of the Galapagos islands. In the top panel, estimates are shown in white diamonds, the innermost and darkest band is the 66% confidence interval, the second-darkest band is the 80% confidence interval, and the widest and lightest band is the 95% confidence interval. In the lower panel, despite the appearance of only two lines there are four plotted. Models that omit the Galapagos islands are nearly identical to those that include the full study sample.

Figure S17. Robustness of the full model non-linear associations to the exclusion of the cantons containing Quito and Guayaquil. Non-linear empty model (i.e., unadjusted, only including canton and period fixed effects) and preferred specifications mirror the full model but remove all canton-period observations from the cantons containing Quito and Guayaquil.

Figure S18. Province-level linear and non-linear association between percent of households primarily using a clean cooking fuel and under-5 LRI mortality. Models mirror the approach of the main analysis, but aggregate data to the province rather than the canton level.

Figure S19. Scatterplot of province-level primary clean cooking fuel use in each period and Peralta et al. (2019)'s cross-sectional measure of mortality completeness from 2001-2013. Note that there is no variation in the measure of completeness over the four study periods because it is from a single time point.

Correlations between all potential confounding variables and the exposure and outcome, panels A to T

Additional File- Excel Document

1. Supplementary tables

Table S1. Description of data sources

Year	Assigned Study period	Survey	Utilization	Coverage (1990 provinces and cantons)	N (households by default)
1989	1988-1992	Maternal and child health survey (*Encuesta demográfica y de salud maternal e infantil; ENDEMAIN*)	Child health and healthcare	15 provinces 95 cantons	17,001 children
1990	1988-1992	Census	%CF, Covariates, population	22 provinces 173 cantons	2,376,842
1994	1988-1992	Maternal and child health survey (*Encuesta demográfica y de salud maternal e infantil; ENDEMAIN*)	Child health and healthcare	15 provinces 126 cantons	13,582 children
1995	1988-1992	Living conditions survey (*Encuesta de condiciones de vida; ECV)*	Child health and healthcare	19 provinces 52 cantons	5,810
1998	1999-2003	Living conditions survey (*Encuesta de condiciones de vida; ECV)*	Child health and healthcare	19 provinces 52 cantons	5,801
1999	1999-2003	Living conditions survey (*Encuesta de condiciones de vida; ECV)*	Child health and healthcare	15 provinces 47 cantons	5,816
1999	1999-2003	Maternal and child health survey (*Encuesta demográfica y de salud maternal e infantil; ENDEMAIN*)	Child health and healthcare	21 provinces 167 cantons	21,462 children
2001	1999-2003	Census	%CF, Covariates, population	22 provinces 173 cantons	2,885,025
2004	1999-2003	Maternal and child health survey (*Encuesta demográfica y de salud maternal e infantil; ENDEMAIN*)	Child health and healthcare	22 provinces 173 cantons	10,814 children
2006	2008-2012	Living conditions survey (*Encuesta de condiciones de vida; ECV)*	Child health and healthcare	20 provinces 154 cantons	13,581

2010	2008-2012	Census	%CF, Covariates, population	22 provinces 173 cantons	3,815,527
2011	2008-2012	Survey of employment (*Encuesta de empleo, desempleo, y subempleo; ENEMDU)*	%CF, Covariates, population	21 provinces 166 cantons	39,766
2012	2008-2012	National survey of health and nutrition (*Encuesta nacional de salud y nutrición; ENSANUT*)	Child health and healthcare	22 provinces 158 cantons	19,949
2012	2008-2012	Survey of employment (*Encuesta de empleo, desempleo, y subempleo; ENEMDU)*	%CF, Covariates, population	21 provinces 163 cantons	38,376
2014	2008-2012	Living conditions survey (*Encuesta de condiciones de vida; ECV)*	Child health and healthcare	22 provinces 169 cantons	29,000
2015	2015-2019	Survey of employment (*Encuesta de empleo, desempleo, y subempleo; ENEMDU)*	%CF, Covariates, population	22 provinces 171 cantons	76,057
2016	2015-2019	Survey of employment (*Encuesta de empleo, desempleo, y subempleo; ENEMDU)*	%CF, Covariates, population	22 provinces 162 cantons	77,106
2017	2015-2019	Survey of employment (*Encuesta de empleo, desempleo, y subempleo; ENEMDU)*	%CF, Covariates, population	22 provinces 164 cantons	77,163
2018	2015-2019	Survey of employment (*Encuesta de empleo, desempleo, y subempleo; ENEMDU)*	%CF, Covariates, population	22 provinces 173 cantons	136,933
2018	2015-2019	National survey of health and nutrition (*Encuesta nacional de salud y nutrición; ENSANUT*)	Child health and healthcare	22 provinces 164 cantons	43,311
2019	2015-2019	Survey of employment (*Encuesta de empleo, desempleo, y subempleo; ENEMDU)*	%CF, Covariates, population	22 provinces 162 cantons	17,001
Yearly since 1990	All	All mortalities (*Defunciones generales*)	Mortality	All	~ 50,000 to 60,000 deaths

Shading is as follows: Blue are data sources used to construct %CF, covariates, and under-5 population; Orange are data sources used for child health and healthcare (namely, vaccinations and prenatal care); and Green is an overview of mortality data.

Table S2. Comparison of canton-level outcome, exposure, and potential confounding variables by cantons with any observed under-5 LRI mortalities and those without over the full study period.

	Cantons with any observed under-5 LRI mortalities (N=668)	Cantons with no observed under-5 LRI mortalities (N=8)	P-Value
Under-5 lower respiratory infection mortalities			
Mean (SD)	6.25 (21.44)	0.00 (0.00)	
Median (IQR)	1.20 (0.33, 4.00)	0.00 (0.00, 0.00)	
Under-5 lower respiratory infection mortalities, per 100,000 under-5 population			
Mean (SD)	59.57 (112.13)	0.00 (0.00)	
Median (IQR)	26.44 (9.81, 65.56)	0.00 (0.00, 0.00)	
Clean-burning fuel is primary fuel for cooking			< 0.001
Mean (SD)	0.72 (0.25)	0.41 (0.25)	
Median (IQR)	0.81 (0.54, 0.93)	0.38 (0.24, 0.56)	
Under 5 population			0.342
Mean (SD)	9585.38 (25869.62)	881.29 (437.65)	
Median (IQR)	4100.50 (1904.47, 8410.94)	863.31 (615.73, 1019.77)	
Rural			0.010
Mean (SD)	0.63 (0.22)	0.83 (0.05)	
Median (IQR)	0.69 (0.49, 0.81)	0.83 (0.80, 0.88)	
Not grid electrified			0.351
Mean (SD)	0.15 (0.20)	0.22 (0.27)	
Median (IQR)	0.05 (0.00, 0.24)	0.10 (0.00, 0.40)	
Roof material: nicer			< 0.001
Mean (SD)	0.79 (0.24)	0.27 (0.05)	
Median (IQR)	0.93 (0.64, 0.98)	0.26 (0.23, 0.32)	
Wall material: nicest			< 0.001
Mean (SD)	0.58 (0.24)	0.25 (0.11)	
Median (IQR)	0.60 (0.38, 0.79)	0.24 (0.20, 0.29)	
Floor material: nicer			< 0.001
Mean (SD)	0.83 (0.16)	0.49 (0.14)	
Median (IQR)	0.88 (0.76, 0.95)	0.45 (0.42, 0.60)	
Materials index			< 0.001
Mean (SD)	0.04 (1.38)	-3.21 (0.92)	
Median (IQR)	0.33 (-0.78, 1.11)	-3.44 (-3.58, -2.40)	
Household has water from municipal system piped inside			0.105
Mean (SD)	0.41 (0.24)	0.27 (0.18)	
Median (IQR)	0.36 (0.21, 0.56)	0.20 (0.17, 0.33)	
Household has modern toilet with waste removed via municipal system or cesspool or septic tank, or household has latrine			0.114
Mean (SD)	0.72 (0.23)	0.59 (0.31)	
Median (IQR)	0.78 (0.57, 0.92)	0.58 (0.40, 0.86)	
Household has private shower			0.722
Mean (SD)	0.49 (0.24)	0.52 (0.31)	
Median (IQR)	0.46 (0.30, 0.67)	0.48 (0.33, 0.76)	
Household has trash removed via municipal			0.005

	Cantons with any observed under-5 LRI mortalities (N=668)	Cantons with no observed under-5 LRI mortalities (N=8)	P-Value
service			
Mean (SD)	0.50 (0.28)	0.22 (0.15)	
Median (IQR)	0.48 (0.26, 0.74)	0.18 (0.09, 0.36)	
Household hygiene index			0.130
Mean (SD)	-0.01 (1.85)	0.98 (1.90)	
Median (IQR)	0.04 (-1.37, 1.44)	1.34 (-0.56, 2.17)	
Adult women's literacy			0.279
Mean (SD)	0.83 (0.09)	0.87 (0.04)	
Median (IQR)	0.85 (0.79, 0.90)	0.87 (0.83, 0.90)	
Girls under 18 years school attendance			0.712
Mean (SD)	0.83 (0.10)	0.82 (0.12)	
Median (IQR)	0.84 (0.75, 0.92)	0.77 (0.73, 0.92)	
Indigenous language spoken in household			0.170
Mean (SD)	0.08 (0.15)	0.00 (0.00)	
Median (IQR)	0.01 (0.00, 0.06)	0.00 (0.00, 0.00)	
Under-5 tuberculosis vaccine coverage			0.805
Mean (SD)	0.89 (0.12)	0.90 (0.12)	
Median (IQR)	0.93 (0.84, 0.99)	0.95 (0.83, 1.00)	
Under-5 diphtheria, pertussis, tetanus vaccine coverage			0.021
Mean (SD)	0.72 (0.16)	0.85 (0.11)	
Median (IQR)	0.75 (0.65, 0.82)	0.83 (0.79, 0.95)	
Under-5 measles vaccine coverage			0.044
Mean (SD)	0.61 (0.17)	0.73 (0.10)	
Median (IQR)	0.63 (0.50, 0.73)	0.70 (0.67, 0.81)	
Under-5 polio vaccine coverage			0.032
Mean (SD)	0.74 (0.16)	0.86 (0.23)	
Median (IQR)	0.77 (0.67, 0.83)	0.96 (0.82, 1.00)	
Under-5 pneumococcal conjugate vaccine (3 doses) coverage			0.692
Mean (SD)	0.22 (0.27)	0.18 (0.28)	
Median (IQR)	0.00 (0.00, 0.41)	0.06 (0.00, 0.19)	
Vaccine index			0.046
Mean (SD)	0.01 (1.71)	-1.20 (1.55)	
Median (IQR)	-0.41 (-1.09, 0.95)	-1.27 (-2.30, -1.10)	
Average age of mother at delivery			<0.001
Mean (SD)	25.56 (1.13)	27.11 (1.99)	
Median (IQR)	25.47 (24.89, 26.22)	27.79 (26.68, 27.96)	
Antenatal care use			0.745
Mean (SD)	0.86 (0.15)	0.84 (0.21)	
Median (IQR)	0.90 (0.78, 0.98)	0.92 (0.79, 1.00)	
Median antenatal care visits			0.167
Mean (SD)	5.89 (1.56)	5.12 (1.55)	
Median (IQR)	6.00 (5.00, 7.00)	4.98 (4.00, 6.00)	

P-Values from analysis of variance.

Table S3. ICD 9 and 10 codes and causes included in under-5 lower respiratory infection mortalities

ICD 9 (1990 to 1996)	ICD 10 (1997 to 2019)	Cause	% of under-5 mortalities
79		Viral and chlamydial infection in conditions classified elsewhere and of unspecified site	<0.001%
466		Acute bronchitis and bronchiolitis	14.0%
480		Viral pneumonia	0.1%
481		Pneumococcal pneumonia (streptococcus pneumoniae pneumonia)	0.7%
482		Other bacterial pneumonia	0.9%
483		Pneumonia due to other specified organism	<0.001%
484		Pneumonia in infectious diseases classified elsewhere	0%
485		Broncopneumonia, organism unspecified	36.4%
486		Pneumonia, organism unspecified	11.2%
487		Influenzae	5.2%
488		Influenza due to identified Avian influenza virus	None
513		Abscess of lung and mediastinum	<0.0001%
770		Other respiratory conditions of fetus and newborn	31%
	A48	Other bacterial diseases, not elsewhere classified	<0.01%
	B97	Viral agents as the cause of diseases classified elsewhere	0.1%
	J09	Influenza due to certain identified influenza viruses	0.01%
	J10	Influenza due to other identified influenza virus	1.2%
	J11	Influenza due to unidentified influenza virus	0.2%
	J12	Viral pneumonia, not elsewhere classified	0.01%
	J13	Pneumonia due to *Streptococcus pneumoniae*	0.1%
	J14	Pneumonia due to *Hemophilus influenzae*	<0.001%
	J15	Bacterial pneumonia, not elsewhere classified	2.4%
	J16	Pneumonia due to other infectious organisms, not elsewhere classified	<0.01%
	J17	Pneumonia in diseases classified elsewhere	None
	J18	Pneumonia, unspecified organism	67.9%
	J20	Acute bronchitis	12.0%
	J21	Acute bronchiolitis	0.7%
	J22	Unspecified acute lower respiratory infection	0.5%
	J85	Abscess of lung and mediastinum	0.01%
	P23	Congenital pneumonia	14.5%
	U04	Severe acute respiratory syndrome	None

Table S4. Covariates in the final model, and alternative specifications

#	Model	Outcome family	Covariates	Fixed effects
1	**Preferred specification**	quasi-Poission	• percent of households in a canton that are rural; • percent of households that are not grid electrified; • an index of household materials; • household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; • adult women's literacy; • under 18 years of age girls' school attendance rate; • an individual in the household or the respondent speaks an indigenous language; • an index of vaccines administered among children under 5 years; • coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; • percent of women that received formal antenatal care prior to delivery; and • the median number of antenatal care visits if utilized.	• Canton • Period
2	**Without adult female literacy**	quasi-Poission	• percent of households in a canton that are rural; • percent of households that are not grid electrified; • an index of household materials; • household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; • under 18 years of age girls' school attendance rate; • an individual in the household or the respondent speaks an indigenous language; • an index of vaccines administered among children under 5 years; • coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; • percent of women that received formal antenatal care prior to delivery; and • the median number of antenatal care visits if utilized.	• Canton • Period
3	**Replace solid waste removal with piped water**	quasi-Poission	• percent of households in a canton that are rural; • percent of households that are not grid electrified; • an index of household materials; • water is piped directly into the household for use from municipal water system; • adult women's literacy; • under 18 years of age girls' school attendance rate; • an individual in the household or the respondent speaks an indigenous language;	• Canton • Period

			• an index of vaccines administered among children under 5 years; • coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; • percent of women that received formal antenatal care prior to delivery; and • the median number of antenatal care visits if utilized.	
4	**Replace solid waste removal with piped water and without adult female literacy**	quasi-Poission	• percent of households in a canton that are rural; • percent of households that are not grid electrified; • an index of household materials; • water is piped directly into the household for use from municipal water system; • under 18 years of age girls' school attendance rate; • an individual in the household or the respondent speaks an indigenous language; • an index of vaccines administered among children under 5 years; • coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; • percent of women that received formal antenatal care prior to delivery; and • the median number of antenatal care visits if utilized.	• Canton • Period
5	**Add average age of mother at birth**	quasi-Poission	• percent of households in a canton that are rural; • percent of households that are not grid electrified; • an index of household materials; • household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; • adult women's literacy; • under 18 years of age girls' school attendance rate; • an individual in the household or the respondent speaks an indigenous language; • an index of vaccines administered among children under 5 years; • coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; • percent of women that received formal antenatal care prior to delivery; and • the median number of antenatal care visits if utilized; • average age of mother at birth	• Canton • Period
6	**Preferred specification, with non-linear confounding**	quasi-Poission	• percent of households in a canton that are rural modeled as a nonlinear term (penalized spline); • percent of households that are not grid electrified modeled as a nonlinear term (penalized spline); • an index of household materials;	• Canton • Period

			• household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; • adult women's literacy; • under 18 years of age girls' school attendance rate; • an individual in the household or the respondent speaks an indigenous language; • an index of vaccines administered among children under 5 years; • coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; • percent of women that received formal antenatal care prior to delivery; and • the median number of antenatal care visits if utilized.	
7	**Preferred specification, outcome negative binomial**	Negative binomial	• percent of households in a canton that are rural; • percent of households that are not grid electrified; • an index of household materials; • household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; • adult women's literacy; • under 18 years of age girls' school attendance rate; • an individual in the household or the respondent speaks an indigenous language; • an index of vaccines administered among children under 5 years; • coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; • percent of women that received formal antenatal care prior to delivery; and • the median number of antenatal care visits if utilized.	• Canton • Period
8	**Preferred specification, random intercepts for canton**	quasi-Poisson	• percent of households in a canton that are rural; • percent of households that are not grid electrified; • an index of household materials; • household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; • adult women's literacy; • under 18 years of age girls' school attendance rate; • an individual in the household or the respondent speaks an indigenous language; • an index of vaccines administered among children under 5 years; • coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; • percent of women that received formal antenatal care prior to delivery; and	• Canton • Period (random intercepts)

			• the median number of antenatal care visits if utilized.	
9	**Preferred specification, remove Galapagos islands**	quasi-Poisson	• percent of households in a canton that are rural; • percent of households that are not grid electrified; • an index of household materials; • household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; • adult women's literacy; • under 18 years of age girls' school attendance rate; • an individual in the household or the respondent speaks an indigenous language; • an index of vaccines administered among children under 5 years; • coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; • percent of women that received formal antenatal care prior to delivery; and • the median number of antenatal care visits if utilized.	• Canton • Period
10	**Preferred specification, remove the cantons that contain Quito and Guayquil**	quasi-Poisson	• percent of households in a canton that are rural; • percent of households that are not grid electrified; • an index of household materials; • household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; • adult women's literacy; • under 18 years of age girls' school attendance rate; • an individual in the household or the respondent speaks an indigenous language; • an index of vaccines administered among children under 5 years; • coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; • percent of women that received formal antenatal care prior to delivery; and • the median number of antenatal care visits if utilized.	• Canton • Period
11	**Preferred specification, add region fixed effect**	quasi-Poisson	• percent of households in a canton that are rural; • percent of households that are not grid electrified; • an index of household materials; • household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; • adult women's literacy; • under 18 years of age girls' school attendance rate; • an individual in the household or the respondent speaks an indigenous language;	• Canton • Period • Region

			• an index of vaccines administered among children under 5 years; • coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; • percent of women that received formal antenatal care prior to delivery; and • the median number of antenatal care visits if utilized.	
12	**Preferred specification, aggregated to province-level**	quasi-Poisson	• percent of households in a province that are rural; • percent of households that are not grid electrified; • an index of household materials; • household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; • adult women's literacy; • under 18 years of age girls' school attendance rate; • an individual in the household or the respondent speaks an indigenous language; • an index of vaccines administered among children under 5 years; • coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; • percent of women that received formal antenatal care prior to delivery; and • the median number of antenatal care visits if utilized.	• Province • Period

Table S5. Descriptive statistics of cantonal under-5 lower respiratory infection mortality, clean fuel use, and covariates in the overall sample and by time period

	Overall (N=676 cantons)	1988-1992 (N=169 cantons)	1999-2003 (N=169 cantons)	2008-2012 (N=169 cantons)	2015-2019 (N=169 cantons)
Under-5 lower respiratory infection mortalities [a]					
Mean (SD)	6.18 (21.33)	12.71 (33.15)	5.59 (17.46)	3.79 (15.48)	2.48 (10.41)
Median (IQR)	1.20 (0.25, 4.00)	4.00 (1.00, 10.33)	1.25 (0.25, 3.75)	0.80 (0.21, 2.00)	0.40 (0.00, 1.40)
Total under-5 population [b]					
Mean (SD)	9482 (25733)	8880 (23333)	9398 (25397)	9872 (27273)	9779 (26958)
Median (IQR)	4019 (1834, 8284)	3993 (2240, 7591)	4127 (1917, 7907)	4128 (1720, 8902)	3856 (1713, 9018)
Under-5 lower respiratory infection mortalities, per 100,000 under-5 population					
Mean (SD)	58.95 (111.70)	137.13 (184.86)	50.48 (70.41)	28.88 (33.19)	17.54 (23.59)
Median (IQR)	25.85 (9.03, 64.92)	90.98 (40.12, 147.64)	31.51 (11.59, 58.97)	17.68 (8.46, 36.71)	11.91 (0.00, 23.32)
Clean-burning fuel is primary fuel for cooking [c]					
Mean (SD)	0.71 (0.25)	0.41 (0.18)	0.70 (0.19)	0.83 (0.14)	0.91 (0.10)
Median (IQR)	0.80 (0.53, 0.93)	0.38 (0.26, 0.55)	0.73 (0.54, 0.87)	0.88 (0.75, 0.94)	0.95 (0.87, 0.97)
Rural					
Mean (SD)	0.63 (0.22)	0.68 (0.22)	0.64 (0.22)	0.62 (0.23)	0.59 (0.22)
Median (IQR)	0.70 (0.49, 0.81)	0.74 (0.57, 0.85)	0.70 (0.50, 0.81)	0.68 (0.47, 0.79)	0.65 (0.43, 0.75)
Not grid electrified					
Mean (SD)	0.15 (0.20)	0.39 (0.22)	0.19 (0.15)	0.00 (0.01)	0.03 (0.03)
Median (IQR)	0.05 (0.00, 0.24)	0.40 (0.19, 0.57)	0.14 (0.08, 0.27)	0.00 (0.00, 0.00)	0.02 (0.01, 0.03)
Roof material: nicer [d]					
Mean (SD)	0.79 (0.25)	0.70 (0.31)	0.74 (0.26)	0.83 (0.20)	0.87 (0.17)
Median (IQR)	0.92 (0.62, 0.98)	0.89 (0.42, 0.98)	0.89 (0.56, 0.96)	0.93 (0.71, 0.98)	0.96 (0.79, 0.99)
Wall material: nicest [e]					
Mean (SD)	0.57 (0.25)	0.40 (0.24)	0.54 (0.22)	0.64 (0.21)	0.70 (0.20)
Median (IQR)	0.60 (0.37, 0.79)	0.34 (0.18, 0.60)	0.54 (0.35, 0.75)	0.67 (0.48, 0.82)	0.71 (0.56, 0.87)
Floor material: nicer [f]					
Mean (SD)	0.83 (0.16)	0.74 (0.19)	0.77 (0.16)	0.86 (0.13)	0.93 (0.09)
Median (IQR)	0.88 (0.76, 0.95)	0.80 (0.63, 0.89)	0.81 (0.69, 0.89)	0.90 (0.81, 0.95)	0.96 (0.90, 0.99)
Materials index [g]					
Mean (SD)	0.00 (1.42)	-0.98 (1.52)	-0.37 (1.28)	0.42 (1.11)	0.93 (0.88)
Median (IQR)	0.32 (-0.84, 1.11)	-0.80 (-1.84, 0.11)	-0.17 (-1.20, 0.57)	0.66 (0.03, 1.18)	1.17 (0.50, 1.52)
Household has water from municipal system piped inside					

Mean (SD)	0.41 (0.24)	0.24 (0.15)	0.31 (0.16)	0.39 (0.17)	0.69 (0.21)
Median (IQR)	0.35 (0.21, 0.56)	0.22 (0.13, 0.32)	0.30 (0.19, 0.41)	0.38 (0.26, 0.50)	0.71 (0.54, 0.87)
Household has modern toilet with waste removed via municipal system or cesspool or septic tank, or household has latrine					
Mean (SD)	0.72 (0.23)	0.44 (0.19)	0.69 (0.15)	0.81 (0.13)	0.93 (0.08)
Median (IQR)	0.78 (0.57, 0.92)	0.41 (0.29, 0.59)	0.71 (0.59, 0.80)	0.84 (0.73, 0.91)	0.96 (0.91, 0.98)
Household has private shower					
Mean (SD)	0.49 (0.24)	0.25 (0.14)	0.43 (0.14)	0.48 (0.16)	0.78 (0.13)
Median (IQR)	0.46 (0.30, 0.67)	0.21 (0.14, 0.31)	0.42 (0.33, 0.51)	0.48 (0.37, 0.59)	0.81 (0.71, 0.88)
Household has trash removed via municipal service					
Mean (SD)	0.49 (0.28)	0.25 (0.18)	0.39 (0.22)	0.59 (0.22)	0.74 (0.23)
Median (IQR)	0.48 (0.25, 0.74)	0.22 (0.12, 0.34)	0.34 (0.22, 0.55)	0.58 (0.42, 0.76)	0.80 (0.58, 0.92)
Household hygiene index [g]					
Mean (SD)	-0.00 (1.85)	1.86 (1.19)	0.56 (1.18)	-0.32 (1.14)	-2.10 (1.13)
Median (IQR)	0.06 (-1.36, 1.48)	2.07 (1.27, 2.74)	0.73 (-0.21, 1.35)	-0.34 (-1.15, 0.54)	-2.27 (-3.12, -1.32)
Adult women’s literacy					
Mean (SD)	0.83 (0.09)	0.79 (0.10)	0.85 (0.08)	0.88 (0.06)	0.81 (0.09)
Median (IQR)	0.85 (0.79, 0.90)	0.81 (0.73, 0.86)	0.86 (0.81, 0.90)	0.90 (0.85, 0.92)	0.82 (0.77, 0.87)
Girls under 18 years school attendance					
Mean (SD)	0.83 (0.10)	0.74 (0.06)	0.75 (0.05)	0.89 (0.03)	0.94 (0.04)
Median (IQR)	0.84 (0.75, 0.92)	0.74 (0.70, 0.78)	0.75 (0.71, 0.79)	0.89 (0.87, 0.91)	0.95 (0.93, 0.96)
Indigenous language spoken in household					
Mean (SD)	0.07 (0.15)	0.06 (0.12)	0.08 (0.16)	0.08 (0.15)	0.09 (0.18)
Median (IQR)	0.01 (0.00, 0.06)	0.01 (0.00, 0.05)	0.01 (0.00, 0.06)	0.01 (0.00, 0.06)	0.01 (0.00, 0.07)
Under-5 tuberculosis vaccine coverage					
Mean (SD)	0.89 (0.12)	0.86 (0.17)	0.97 (0.05)	0.92 (0.07)	0.82 (0.11)
Median (IQR)	0.93 (0.84, 0.99)	0.93 (0.77, 1.00)	0.98 (0.95, 1.00)	0.93 (0.89, 0.96)	0.83 (0.75, 0.91)
Under-5 diphtheria, pertussis, tetanus vaccine coverage					
Mean (SD)	0.72 (0.16)	0.68 (0.21)	0.73 (0.15)	0.79 (0.09)	0.69 (0.14)
Median (IQR)	0.75 (0.65, 0.82)	0.73 (0.54, 0.83)	0.75 (0.67, 0.81)	0.80 (0.75, 0.84)	0.68 (0.61, 0.77)
Under-5 measles vaccine coverage					
Mean (SD)	0.61 (0.17)	0.66 (0.20)	0.60 (0.17)	0.67 (0.09)	0.52 (0.14)
Median (IQR)	0.63 (0.50, 0.73)	0.67 (0.52, 0.80)	0.63 (0.50, 0.71)	0.67 (0.63, 0.73)	0.50 (0.44, 0.60)
Under-5 polio vaccine coverage					
Mean (SD)	0.74 (0.16)	0.68 (0.21)	0.78 (0.14)	0.81 (0.09)	0.68 (0.15)
Median (IQR)	0.77 (0.67,	0.73 (0.55,	0.79 (0.73,	0.81 (0.77,	0.68 (0.60,

	0.83)	0.83)	0.85)	0.86)	0.77)
Under-5 pneumococcal conjugate vaccine (3 doses) coverage [h]					
Mean (SD)	0.22 (0.27)	0.00 (0.00)	0.00 (0.00)	0.27 (0.15)	0.60 (0.16)
Median (IQR)	0.00 (0.00, 0.41)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.26 (0.19, 0.33)	0.60 (0.53, 0.69)
Vaccine index [g]					
Mean (SD)	0.00 (1.72)	0.32 (2.35)	-0.39 (1.19)	-0.74 (0.98)	0.82 (1.57)
Median (IQR)	-0.43 (-1.12, 0.94)	-0.43 (-1.39, 1.86)	-0.56 (-1.17, 0.09)	-0.83 (-1.19, -0.40)	0.92 (-0.15, 1.68)
Average age of mothers at delivery					
Mean (SD)	25.58 (1.15)	26.26 (1.04)	25.84 (0.86)	25.07 (0.80)	25.17 (1.37)
Median (IQR)	26.15 (25.50, 26.99)	26.15 (25.50, 26.99)	25.77 (25.16, 26.36)	24.98 (24.48, 25.62)	25.12 (24.38, 25.73)
Pregnant women received formal antenatal care					
Mean (SD)	0.86 (0.15)	0.74 (0.14)	0.82 (0.14)	0.92 (0.15)	0.95 (0.07)
Median (IQR)	0.90 (0.78, 0.98)	0.76 (0.65, 0.84)	0.83 (0.77, 0.92)	0.96 (0.91, 1.00)	0.98 (0.94, 1.00)
Median number of antenatal care visits if any received					
Mean (SD)	5.88 (1.56)	5.07 (1.43)	5.19 (1.36)	6.25 (1.43)	7.01 (1.13)
Median (IQR)	6.00 (5.00, 7.00)	5.00 (4.00, 6.00)	5.00 (4.00, 6.00)	6.50 (5.82, 7.00)	7.00 (7.00, 8.00)
Mean ambient $PM_{2.5}$ (□g/m^3)					
Mean (SD)	16.6 (2.8)	NA	14.8 (2.1)	17.8 (2.7)	17.2 (2.7)
Median (IQR)	16.2 (14.6, 18.6)	NA	14.9 (13.0, 16.6)	17.3 (15.4, 20.4)	16.9 (14.7, 19.5)

[a] Under-5 lower respiratory mortalities represent the yearly average of the years covered in the time period (1990-1992; 1999-2003; 2008-2012; 2015-2019). Therefore, it is possible for a canton-period estimate to not be a whole number.

[b] We estimate under-5 population in the 1990-1992, 1999-2003, and 2008-2012 time periods by counting the number of children under 5 years in the 1990, 2001, and 2010 censuses, respectively. Because there has not been a survey with national coverage since 2010, we rely on age-specific population estimates produced by the Ecuadorian National statistical agency (INEC) that are based on the most recent Census, the national birth and death registries, and data on migration and immigration, among other factors. These can be found freely at https://sni.gob.ec/proyecciones-y-estudios-demograficos. We average the yearly estimates from 2015-2019 to produce the canton-period estimates.

[c] Cooking fuel options included: piped/centralized gas, gas cylinders, electricity, kerosene (locally referred to as kerex), firewood, charcoal, and gasoline. Clean fuel options included piped gas, gas cylinders, and electricity.

[d] Roof material options included: mixed concrete, asbestos-reinforced concrete sheets, zinc corrugated sheets, ceramic shingles, straw, and other. We specified a "nicer" roof material to be anything other than straw.

[e] Wall material options included: mixed concrete / bricks / concrete blocks, mud bricks / mud walls, wooden slats, reinforced bamboo, non-reinforced bamboo, and other. We specified the nicest wall material to be mixed concrete / bricks / concrete blocks.

[f] Floor material options included: tiled floors (broad category that may include other options), ceramic tiles / stone tiles / vinyl flooring, laminate / wood laminate, bricks / concrete, bamboo, and dirt. We specified the "nicer" floor materials to be anything other than bamboo or dirt flooring.

[g] Indices are produced using the first component from principal components analysis. Canton-period indices are produced by subtracting a given canton-period estimate from the overall parameter mean, dividing by the scaling factor, and multiplying by the first principal component. Then, all parameters are summed to produce the index. The household materials index is comprised of roof, wall, and floor materials as specified in d-f; positive values indicate higher quality materials. The household hygiene index is comprised of the household water source, household toilet and solid waste disposal, household trash removal, and household exclusive shower; more negative values indicate more hygienic practices. The vaccine index is comprised of all vaccines other than the pneumococcal conjugate vaccine – 3; more negative values indicate greater overall vaccination coverage.

[h] The pneumococcal conjugate vaccine – 3 did not exist prior to the 2010 time period in Ecuador. Given that there was no similar vaccine, we assign a 0% coverage value to all cantons in the 1990 and 2001 period. We do not have data on which of the multiple pneumococcal conjugate vaccines was administered in the 2010 and 2015-2019 periods in Ecuador.

Table S6. Summarizing results from subset analyses and testing for heterogeneity of effect

Model	MRR from GLM (95% CI)	Cochran's *Q*-test	MRR from 45% to 55% from GAM (95% CI)	MRR from 75% to 85% from GAM (95% CI)
Full, preferred specification	0.87 (0.77-0.98)	NA	0.95 (0.87-1.04)	0.83 (0.74-0.92)
Sex		P=0.90		
Female	0.90 (0.79-1.02)		0.94 (0.83-1.06)	0.81 (0.70-0.93)
Male	0.91 (0.82-1.02)		0.95 (0.85-1.06)	0.82 (0.72-0.93)
Period		P<0.01		
1988-1992	1.03 (0.91-1.17)		0.82 (0.67-1.01)	0.86 (0.65-1.14)
1999-2003	0.83 (0.71-0.96)		0.88 (0.74-1.04)	0.64 (0.54-0.76)
2008-2012	0.74 (0.63-0.87)		0.66 (0.53-0.84)	0.59 (0.50-0.70)
2015-2019	0.65 (0.51-0.83)		0.66 (0.44-0.99)	0.48 (0.38-0.66)
Region [a]		P=0.86		
Amazon	0.88 (0.78-0.99)			
Andes	0.93 (0.80-1.09)			
Coast	0.99 (0.84-1.17)			

[a] We do not estimate mortality rate ratios from 45% to 55% and 75% to 85% from the non-linear association in the region-specific analyses because of our preferred interaction approach, which renders it difficult to generate these statistics. The reader is referred to the Figure S6 for a visual of the associations.

Models adjusted for percent of households in a canton that are rural; percent of households that are not grid electrified; an index of household materials; household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; adult women's literacy; under 18 years of age girls' school attendance rate; an individual in the household or the respondent speaks an indigenous language; an index of vaccines administered among children under 5 years; coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; percent of women that received formal antenatal care prior to delivery; and the median number of antenatal care visits if utilized.

Table S7. Estimated averted under-5 LRI mortalities for preferred specification and alternative potential confounder specifications as based on generalized additive mixed models.

	Model-predicted number of under-5 LRI mortalities based on 1990 %CF and other covariates ($LRI_{\%CF\ Covariates\ 1990}$)	Total estimated declines in under-5 LRI mortality	Estimated under-5 LRI mortalities averted given increased %CF (95% CI)	Percent of under-5 LRI mortalities averted attributable to increased %CF (95% CI) ($LRI\ Decline_{\%CF}$)
Empty model (Only period and canton fixed effects)	69,061	47,763	18,106 (11,130, 25,082)	37.9% (23.3%, 52.5%)
Model 1 (Preferred specification)	68,972	37,145	7,343 (2,555, 12,132)	18.8% (6.5%, 31.1%)
Model 2 (Without adult female literacy)	69,115	39,313	9,061 (3,813, 14,308)	23.0% (9.7%, 36.4%)
Model 3 (Replace solid waste removal with piped water)	69,519	39,593	6,236 (2,400, 10,072)	15.7% (6.1%, 25.4%)
Model 4 (Replace solid waste removal with piped water and without adult female literacy)	69,917	40,010	7,240 (3,070, 11,409)	18.1% (7.7%, 28.5%)
Model 5 (Add average age of mother at birth)	64,450	37,259	7,384 (3,116, 11,652)	23.2% (9.8%, 36.5%)

Table S8. Estimated thresholds and mortality rate ratios for preferred specification and alternative potential confounder specifications in segmented generalized linear model regressions.

	Estimated threshold (95% CI)	Mortality rate ratio below threshold	Mortality rate ratio above threshold
Model 1 (Preferred specification)	61.35% (52.45%, 70.25%)	0.99 (0.88, 1.10)	0.81 (0.72, 0.92)
Model 2 (Without adult female literacy)	61.75% (53.89%, 69.61%)	0.98 (0.88, 1.09)	0.79 (0.71, 0.88)
Model 3 (Replace solid waste removal with piped water)	61.76% (52.80%, 70.71%)	1.01 (0.91, 1.11)	0.84 (0.75, 0.93)
Model 4 (Replace solid waste removal with piped water and without adult female literacy)	61.82% (53.59%, 70.01 %)	1.00 (0.91, 1.10)	0.82 (0.74, 0.90)
Model 5 (Add average age of mother at birth)	61.82% (53.36%, 69.99 %)	1.00 (0.91, 1.10)	0.82 (0.74, 0.91)

Table S9. Summary of estimated linear associations across all alternative potential confounder combinations.

	Estimated mortality rate ratio (MRR) per 10 percentage point increase in %CF
Empty model (95% CI)	0.79 (0.75 to 0.83)
Preferred specification (95% CI)	0.90 (0.82 to 0.99)
Across all alternative potential confounder combinations	
Mean MRR (SD)	0.898 (0.041)
Median MRR (IQR)	0.899 (0.870 to 0.922)
10th percentile to 90th percentile of estimated MRRs	0.844 to 0.947
Additional summary information	
MRR below 1.00	98.7% of models
P<0.05	70.3% of models

Preferred specification adjusted for percent of households in a canton that are rural; percent of households that are not grid electrified; an index of household materials; household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; adult women's literacy; under 18 years of age girls' school attendance rate; an individual in the household or the respondent speaks an indigenous language; an index of vaccines administered among children under 5 years; coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; percent of women that received formal antenatal care prior to delivery; and the median number of antenatal care visits if utilized.

2. Supplementary figures

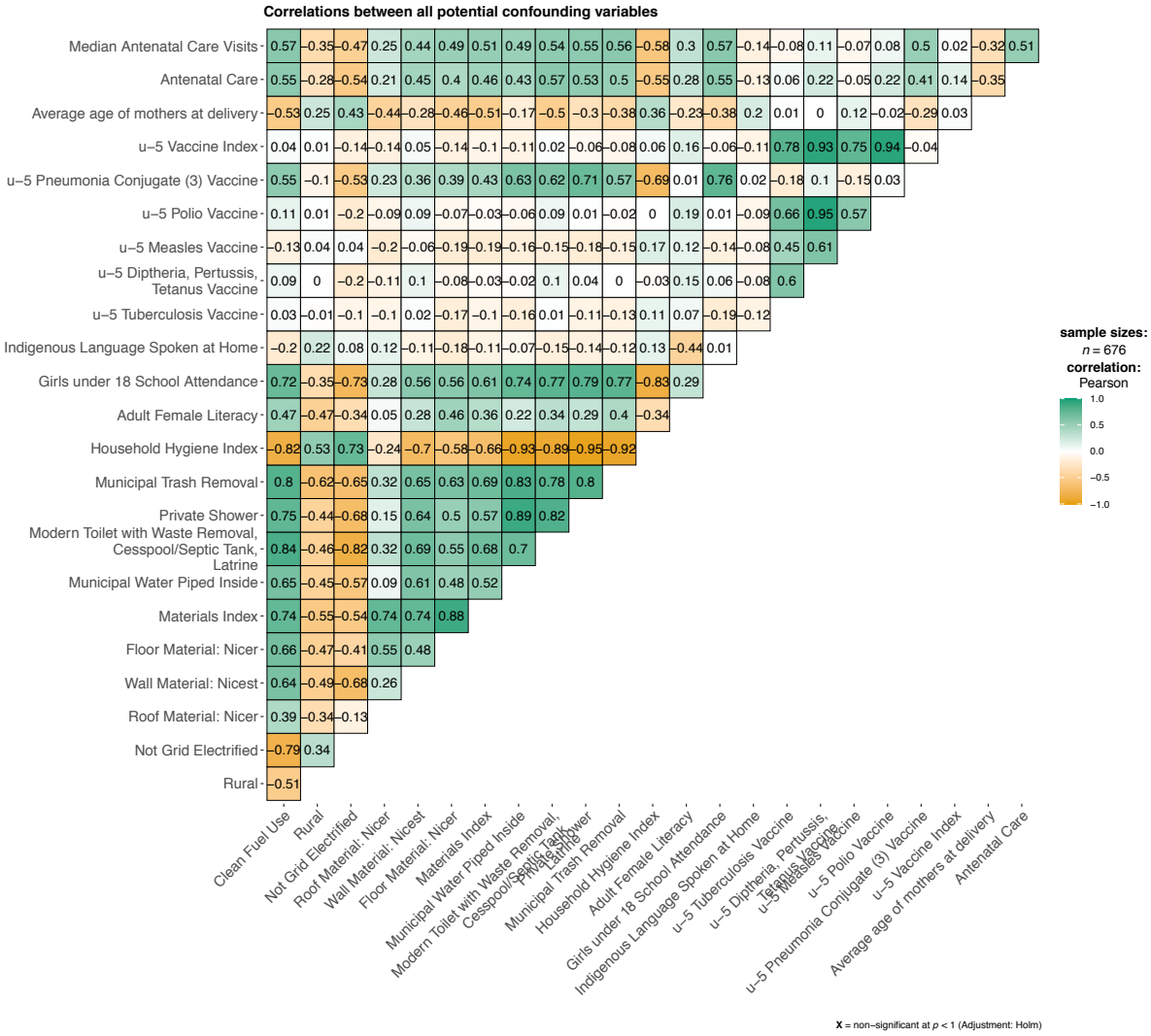


Figure S1. Correlations among all potential confounding variables. Values are Pearson's correlation coefficients.

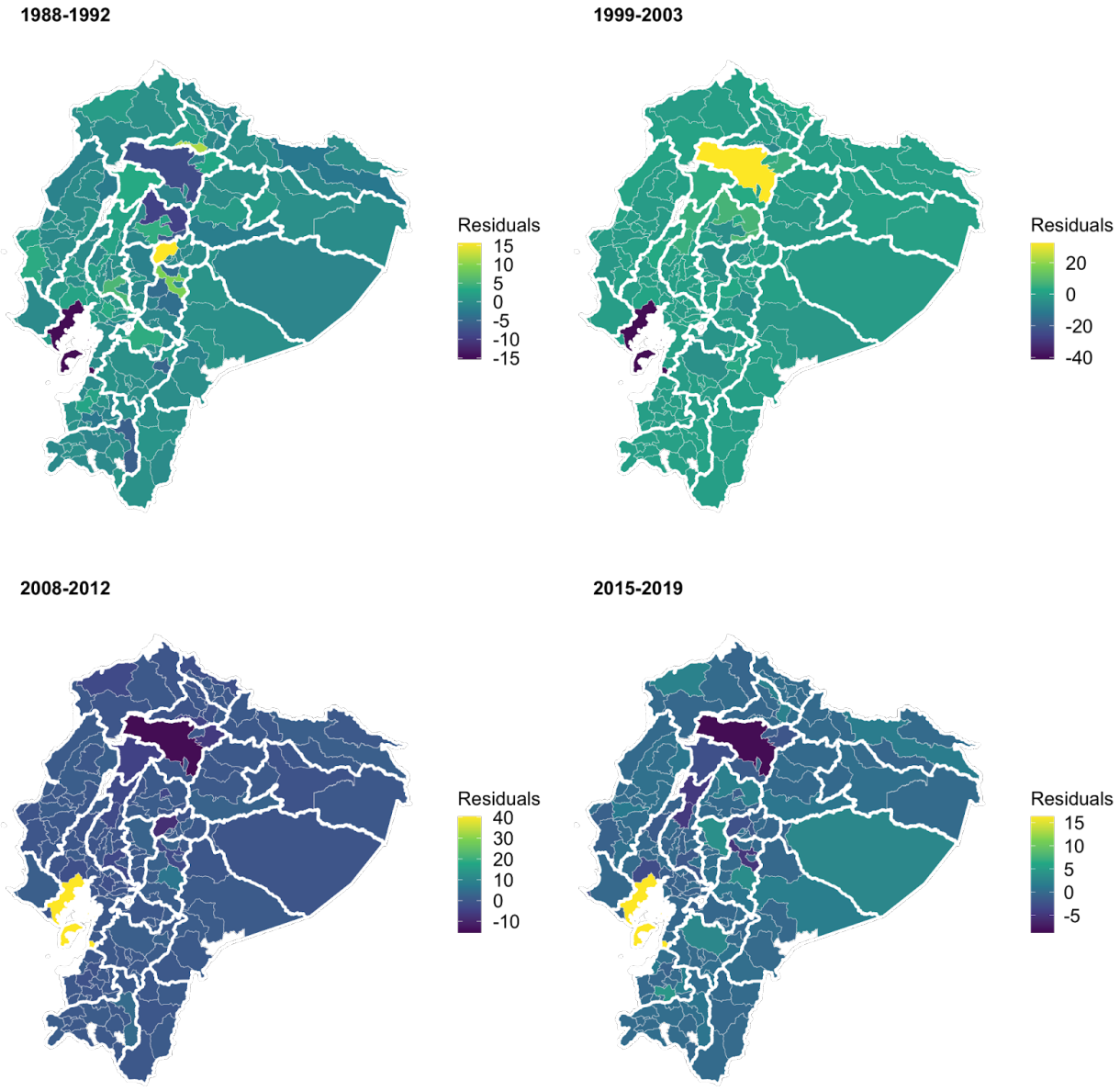


Figure S2. Map of canton-level residuals from the preferred model by study period.

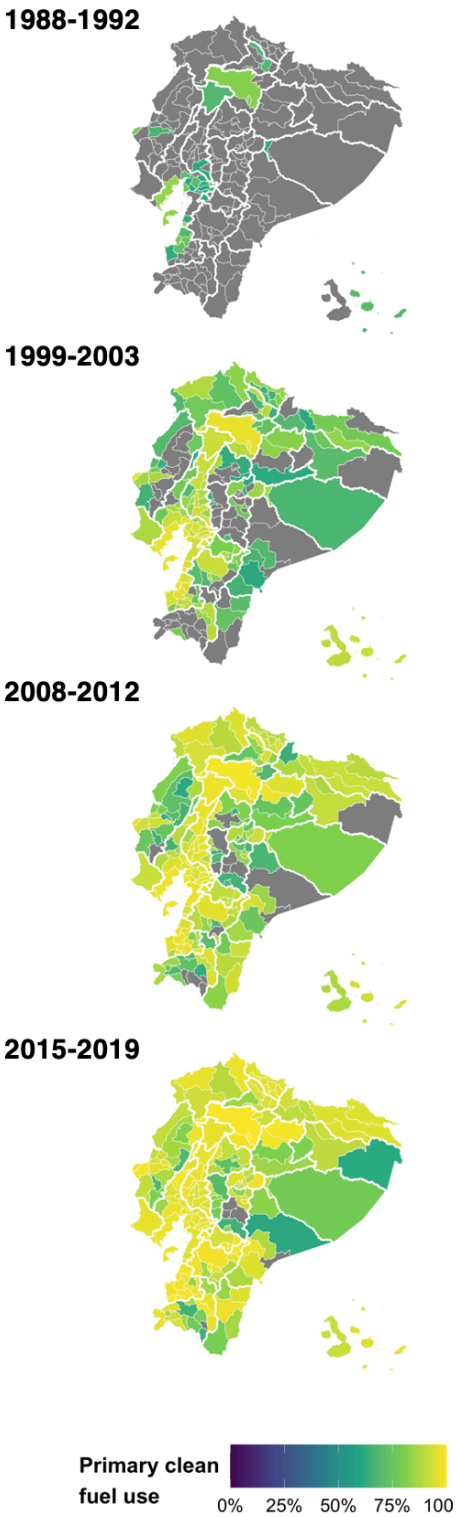


Figure S3. Cantons that reached 61% clean fuel use in each study period. 61% CF is the threshold found by breakpoint/segmented regression. Cantons below 61% clean fuel use are shown in grey, and the remainder are illustrated in the color palette used in Figure 1. In the period centered at 1988-1992, 15% of cantons were at 61% primary clean fuel use or above; 1999-2003: 69%; 2008-2012: 92%; and 2015-2019: 98%.

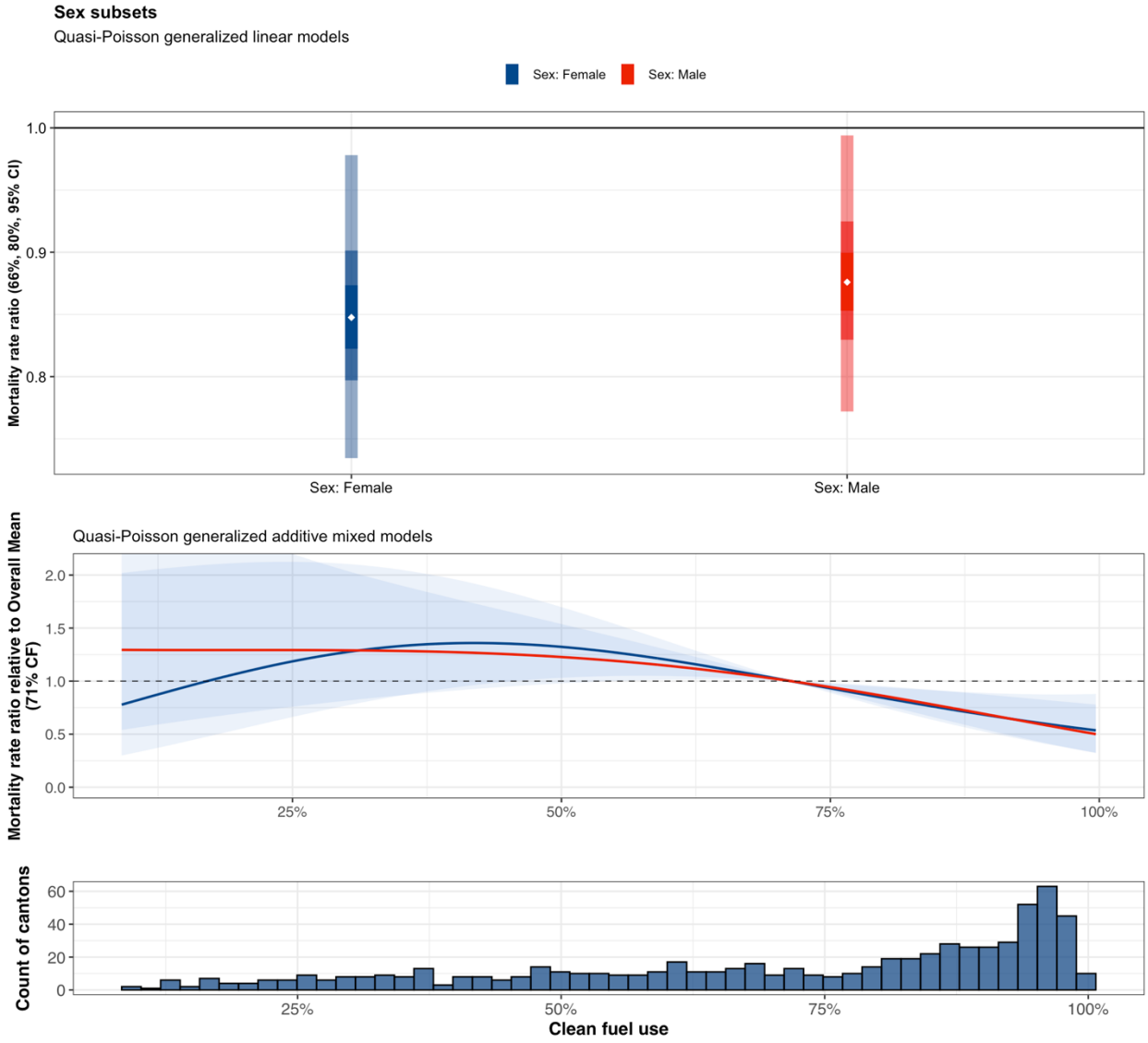


Figure S4. Sex-stratified linear and non-linear associations between %CF and under-5 LRI mortality. In the top panel, estimates are shown in white diamonds, the innermost and darkest band is the 66% confidence interval, the second-darkest band is the 80% confidence interval, and the widest and lightest band is the 95% confidence interval. For sex-stratified analyses, sex-specific under-5 canton-period population estimates are used as an offset. We directly count sex-specific canton-period under-5 population in 1990, 2001, and 2010 based on the census. We can estimate overall under-5 population in the 2015-2019 period as discussed above in Table 1. We use the average sex ratio from 1990, 2001, and 2010 to then estimate sex-specific canton-period under-5 population by multiplying the sex ratio with the overall population. Sex-specific splines are restricted to three degrees of freedom.

Preferred specification adjusted for percent of households in a canton that are rural; percent of households that are not grid electrified; an index of household materials; household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; adult women's literacy; under 18 years of age girls' school attendance rate; an individual in the household or the respondent speaks an indigenous language; an index of vaccines administered among children under 5 years; coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; percent of women that received formal antenatal care prior to delivery; and the median number of antenatal care visits if utilized.

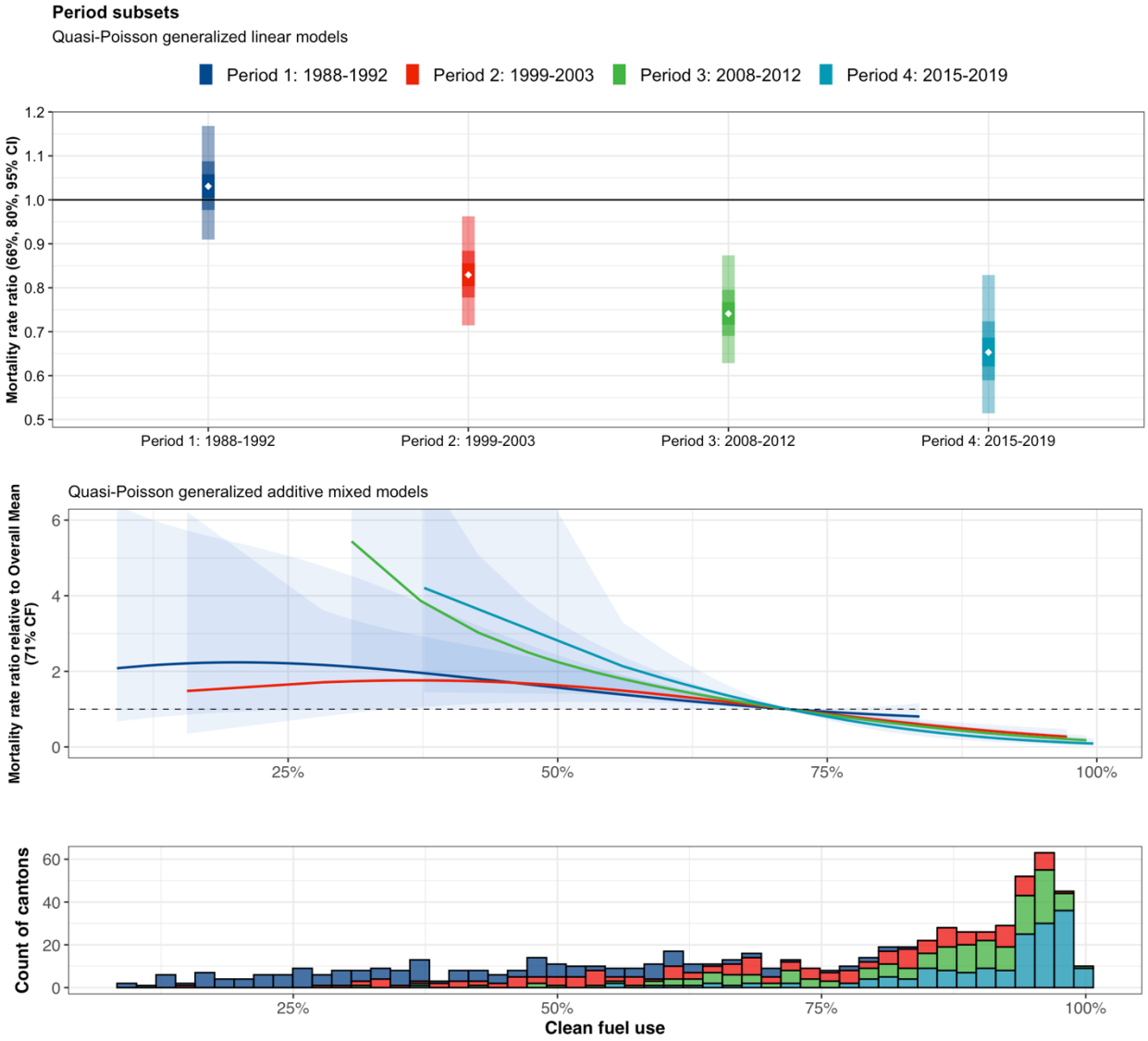


Figure S5. Period-stratified linear and non-linear associations between %CF and under-5 LRI mortality. In the top panel, estimates are shown in white diamonds, the innermost and darkest band is the 66% confidence interval, the second-darkest band is the 80% confidence interval, and the widest and lightest band is the 95% confidence interval. Period-specific models do not contain canton or period fixed effects. Otherwise, they mirror the preferred specifications.

Preferred specification adjusted for percent of households in a canton that are rural; percent of households that are not grid electrified; an index of household materials; household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; adult women's literacy; under 18 years of age girls' school attendance rate; an individual in the household or the respondent speaks an indigenous language; an index of vaccines administered among children under 5 years; coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; percent of women that received formal antenatal care prior to delivery; and the median number of antenatal care visits if utilized.

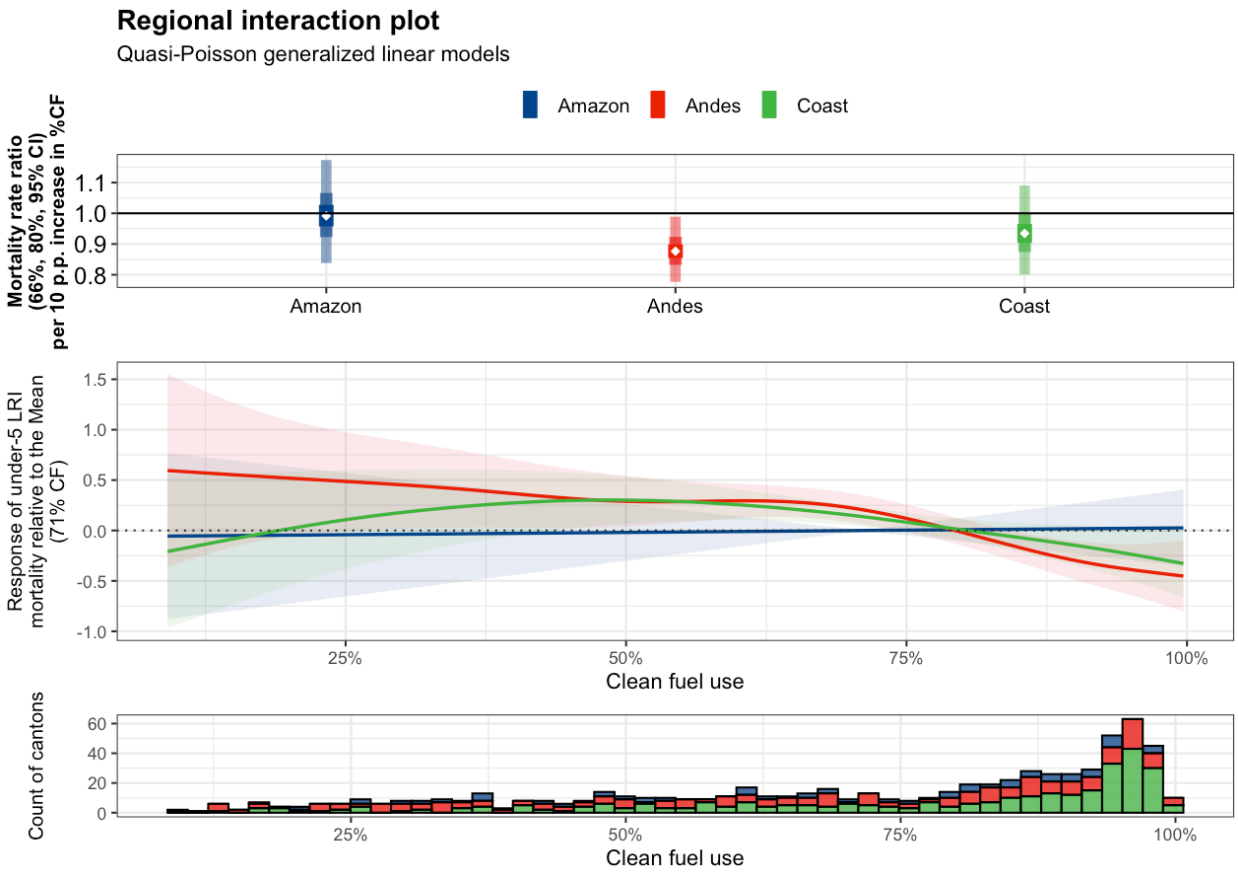


Figure S6. Region-specific linear and non-linear associations. In the top panel, estimates are shown in white diamonds, the innermost and darkest band is the 66% confidence interval, the second-darkest band is the 80% confidence interval, and the widest and lightest band is the 95% confidence interval. The middle panel shows alternative non-linear associations between canton-level %CF and under-5 LRI mortalities among subsets. The bottom panel shows a histogram of the distribution of canton-period %CF estimates over the full time period, colored by region. Models mirror the preferred specifications.

Preferred specification adjusted for percent of households in a canton that are rural; percent of households that are not grid electrified; an index of household materials; household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; adult women's literacy; under 18 years of age girls' school attendance rate; an individual in the household or the respondent speaks an indigenous language; an index of vaccines administered among children under 5 years; coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; percent of women that received formal antenatal care prior to delivery; and the median number of antenatal care visits if utilized.

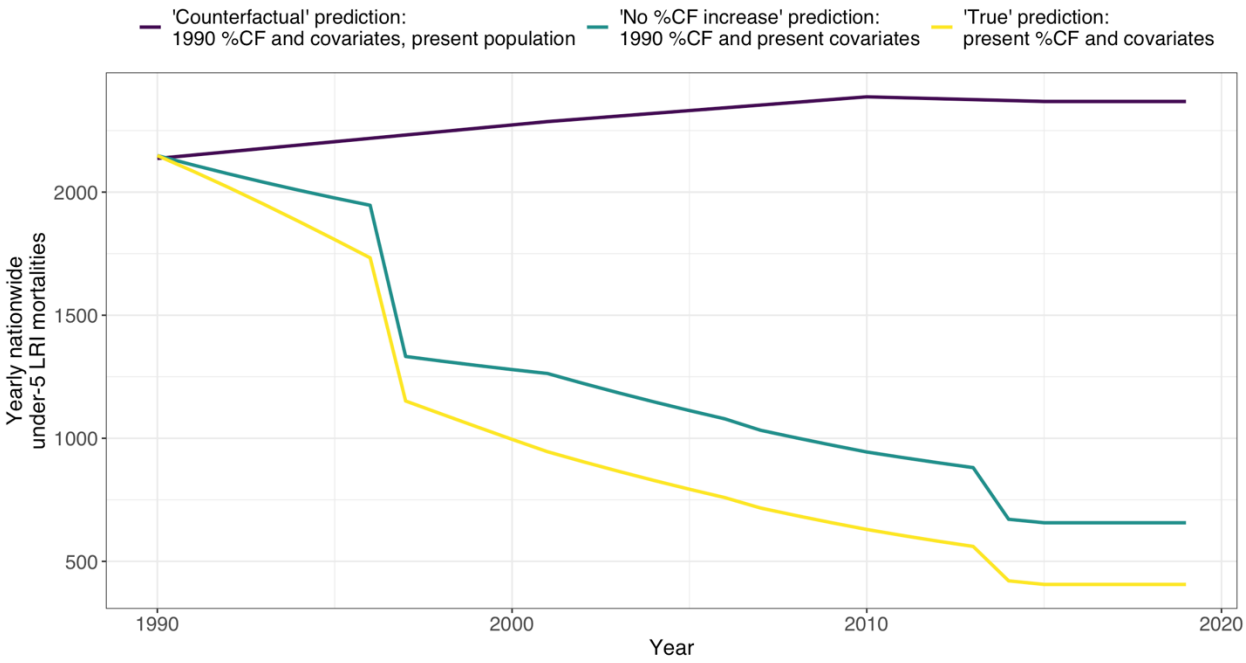


Figure S7. Estimating the proportion of the decline in under-5 LRI mortalities observed between 1990 and 2019 attributable to increased clean fuel use. Kinks in the plot are associated with period fixed effects (1988-1992 used between 1990 and 1996; 1999-2003 between 1997 and 2006; 2008-2012 between 2007 and 2013; 2015-2019 between 2014 and 2019). Only the 1990 fixed effect was used in the 'Counterfactual' prediction. The counterfactual prediction is associated with 68,972 under-5 LRI mortalities total across the 30-year time period. The "No %CF increase" prediction yields an estimated 37,145 under-5 LRI mortalities and the "True" prediction yields 29,905 under-5 LRI mortalities over the 30-year time period.

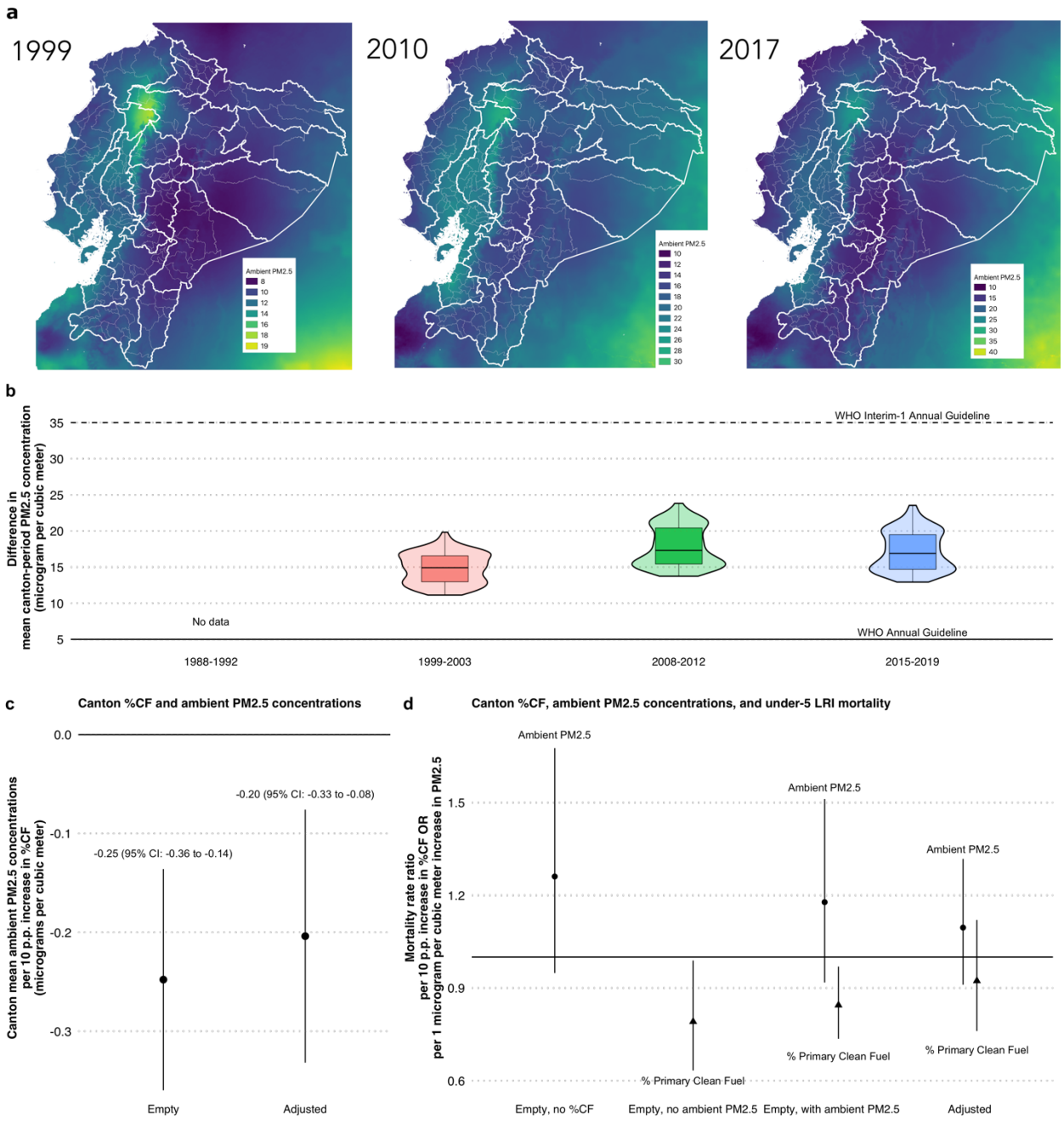


Figure S8. Ambient air pollution, clean fuel use, and under-5 LRI mortality. Panel **a** shows raw ambient $PM_{2.5}$ concentrations from van Donkelaar et al. (2021) overlaid with canton-province borders in the years designated. Canton ambient $PM_{2.5}$ concentrations were estimated by taking the average of the pixels that intersected or fell within each canton in each year of the appropriate period. Then, those five estimates were averaged to produce the canton-period estimates. Panel **b** summarizes the distribution of canton ambient $PM_{2.5}$ concentrations across periods with violin and box plots (box lines at 25th, 50th, and 75th percentiles and whiskers extend to the maximum and minimum concentrations). World Health Organization interim-1 and guideline shown for annual $PM_{2.5}$ exposure. Panel **c** shows the association between canton-period %CF and ambient $PM_{2.5}$ concentrations per 10 percentage point increase in %CF in micrograms per cubic meter in an empty model with only canton and period fixed effects and an adjusted model that includes: percent of households in a canton that are rural; percent of households that are

not grid electrified; an index of household materials; household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; adult women's literacy; under 18 years of age girls' school attendance rate; and an individual in the household or the respondent speaks an indigenous language. Panel **d** shows results from models with an outcome of under-5 LRI mortalities per canton-period (1) with an empty model that includes only ambient $PM_{2.5}$ and canton and period fixed effects; (2) with an empty model that includes only %CF and canton and period fixed effects (recall this is only the most recent three periods); (3) an empty model that includes ambient $PM_{2.5}$, %CF, and canton and period fixed effects; and (4) a fully adjusted model that includes ambient $PM_{2.5}$, %CF, the full range of potential confounding variables in our preferred specification, and canton and period fixed effects.

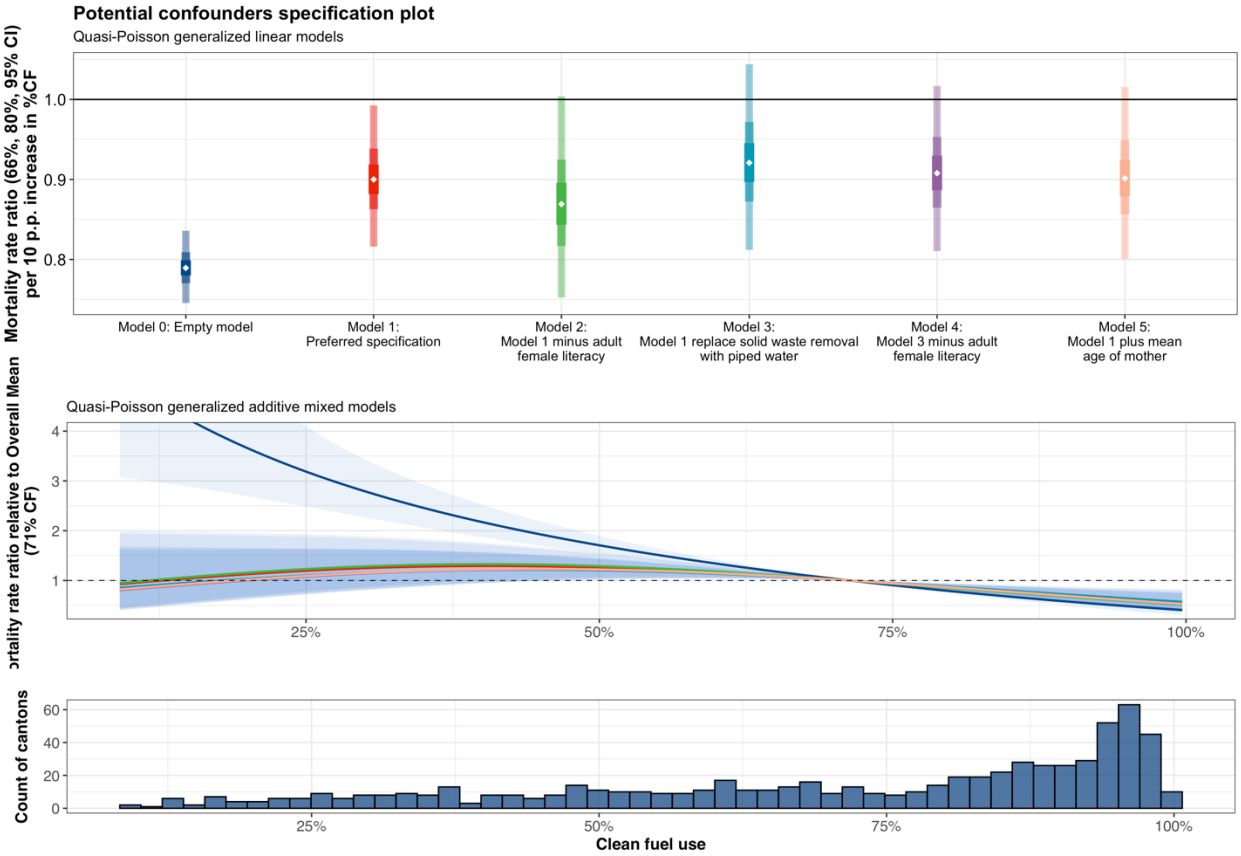


Figure S9. Alternative adjusted linear and non-linear associations between clean fuel use and under-5 LRI mortality rate. In the top panel, estimates are shown in white diamonds, the innermost and darkest band is the 66% confidence interval, the second-darkest band is the 80% confidence interval, and the widest and lightest band is the 95% confidence interval. The middle panel shows alternative non-linear associations between canton-level %CF and under-5 LRI mortalities. The bottom panel shows a histogram of the distribution of canton-period %CF estimates over the full time period. See Table S4 for full characterization of covariates included.

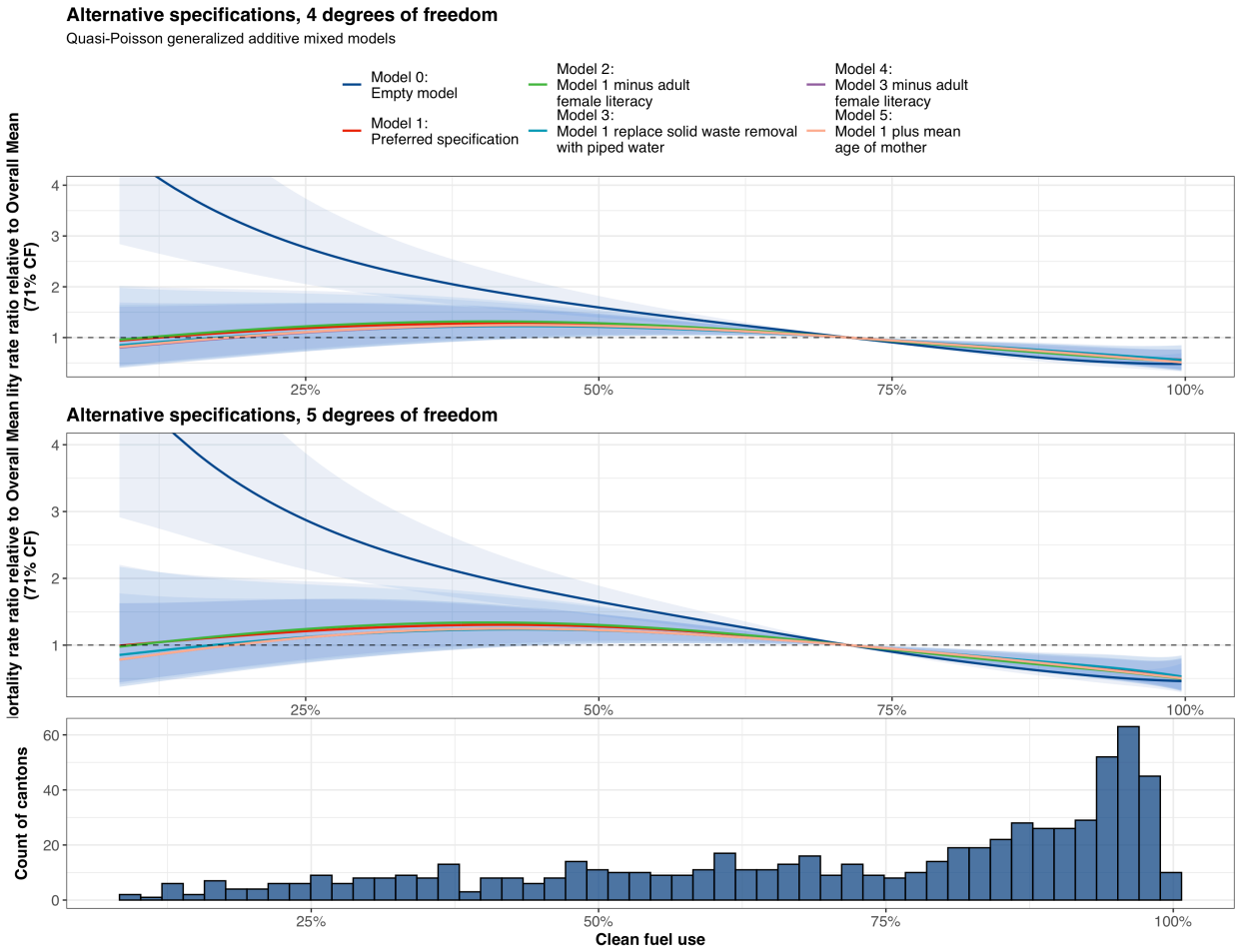


Figure S10. Robustness of results to additional degrees of freedom. Figure repeats Figure S7 but with additional degrees of freedom as specified. See Table S4 for full characterization of covariates included.

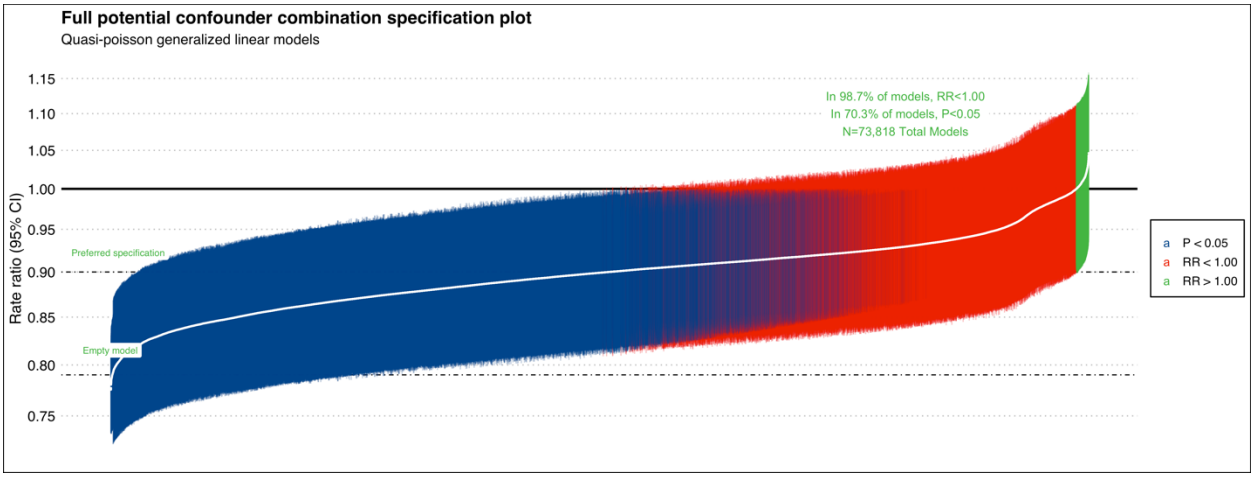


Figure S11. Specification plots showing main effect estimate for a 10-percentage point increase in %CF in quasi-Poisson GLMs with an offset for under 5 population and fixed effects for canton and period.
Specification plots show all potential confounder combinations. Plots are ordered by increasing rate ratio (closer to the null). The empty model (covariates are fixed effects for period and canton only) and preferred specification mortality rate ratios are shown as horizontal lines. The plots show a point estimate and 95% confidence intervals.

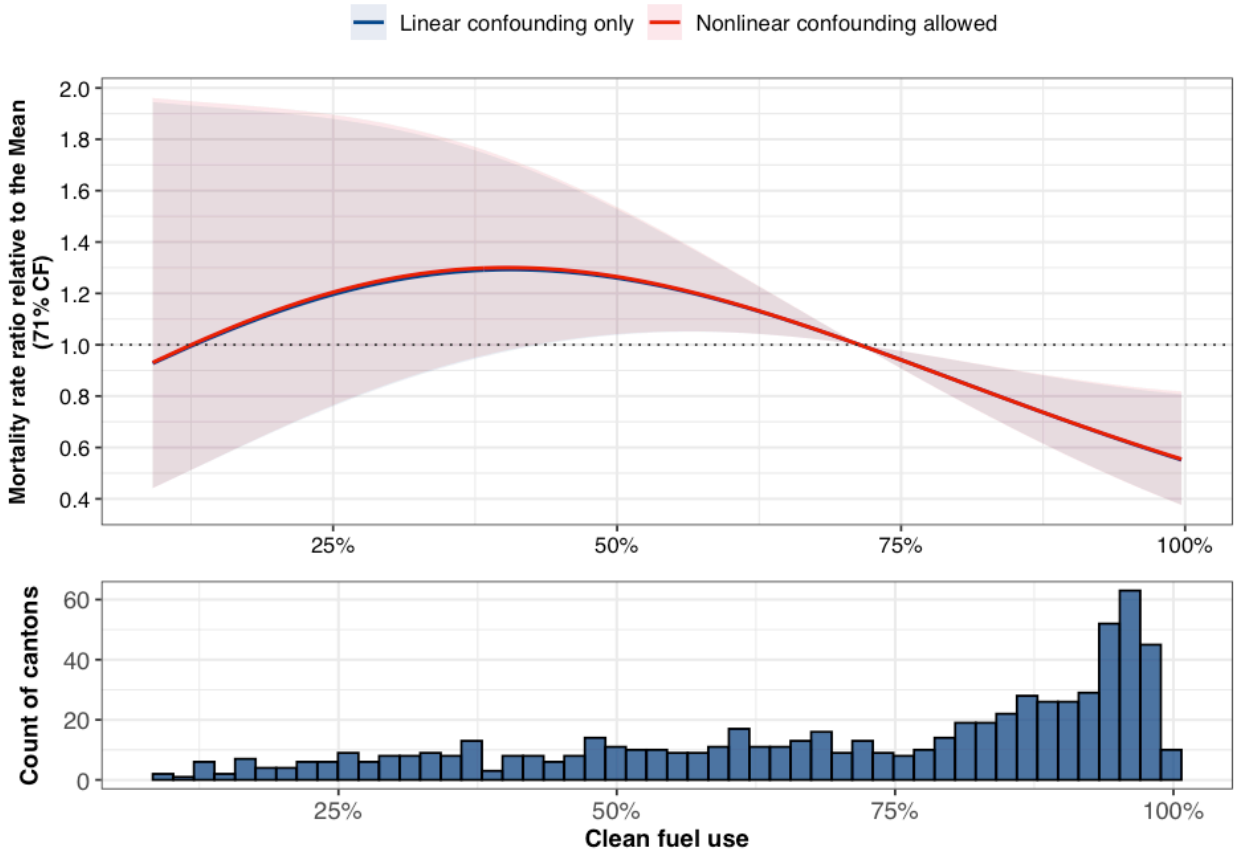


Figure S12. Full adjusted non-linear association shown where potential confounders are only included as linear covariates and where potential confounders that display a non-linear association with the outcome are modeled non-linearly using penalized splines with three knots. The top panel shows non-linear associations between canton-level %CF and under-5 LRI mortalities for each specification. The bottom panel shows a histogram of the distribution of canton-period %CF estimates over the full time period.

Preferred specification adjusted for percent of households in a canton that are rural; percent of households that are not grid electrified; an index of household materials; household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; adult women's literacy; under 18 years of age girls' school attendance rate; an individual in the household or the respondent speaks an indigenous language; an index of vaccines administered among children under 5 years; coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; percent of women that received formal antenatal care prior to delivery; and the median number of antenatal care visits if utilized.

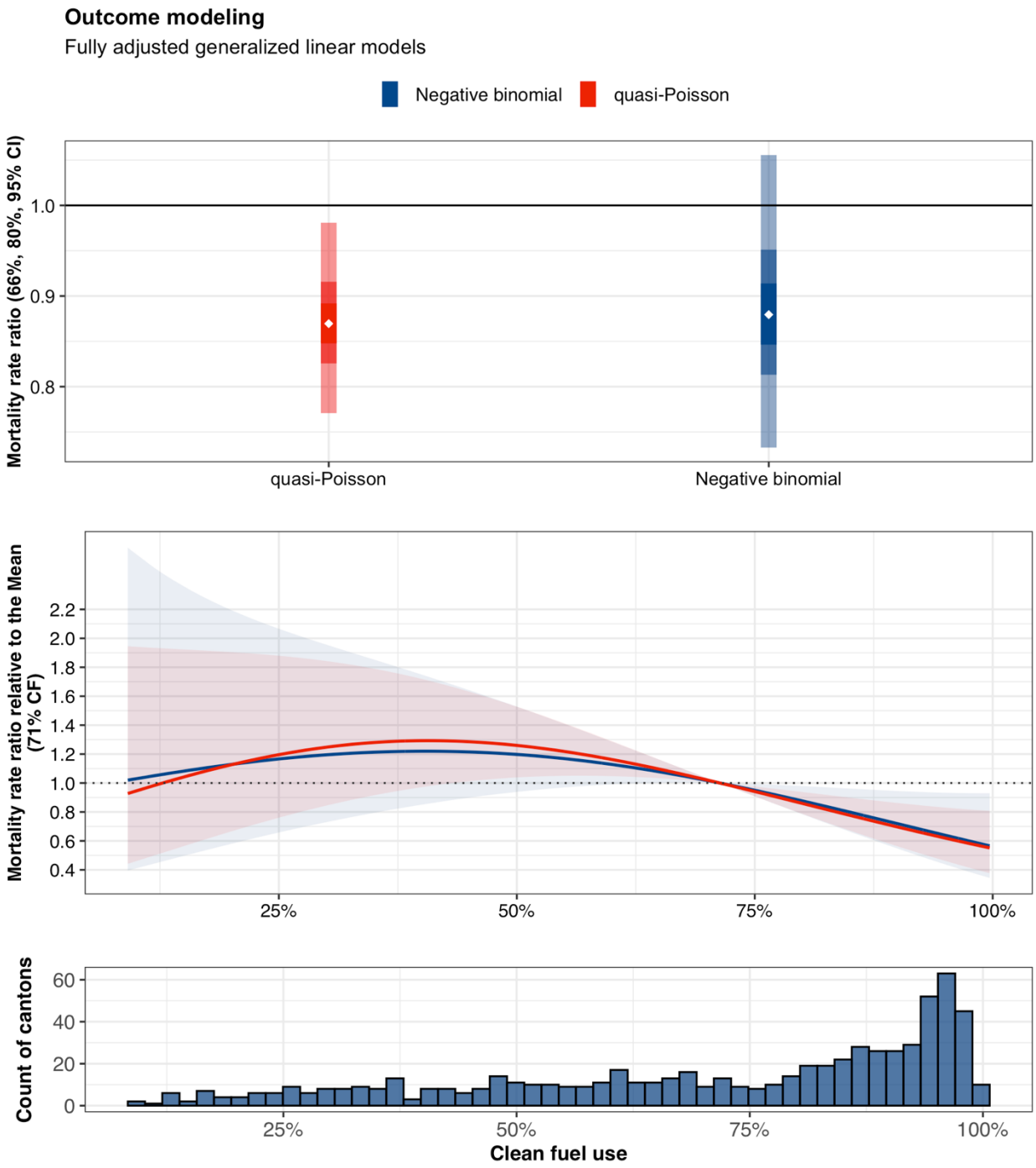


Figure S13. Linear and non-linear association shown for the preferred outcome specification (quasi-Poisson) and an alternative approach, the negative binomial model. In the top panel, estimates are shown in white diamonds, the innermost and darkest band is the 66% confidence interval, the second-darkest band is the 80% confidence interval, and the widest and lightest band is the 95% confidence interval. The middle panel shows alternative non-linear associations between canton-level %CF and under-5 LRI mortalities by model outcome type. The bottom panel shows a histogram of the distribution of canton-period %CF estimates over the full time period.

Preferred specification adjusted for percent of households in a canton that are rural; percent of households that are not grid electrified; an index of household materials; household has a modern toilet connected to the municipal

sewers or a septic tank, a cesspool, or a latrine; adult women's literacy; under 18 years of age girls' school attendance rate; an individual in the household or the respondent speaks an indigenous language; an index of vaccines administered among children under 5 years; coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; percent of women that received formal antenatal care prior to delivery; and the median number of antenatal care visits if utilized.

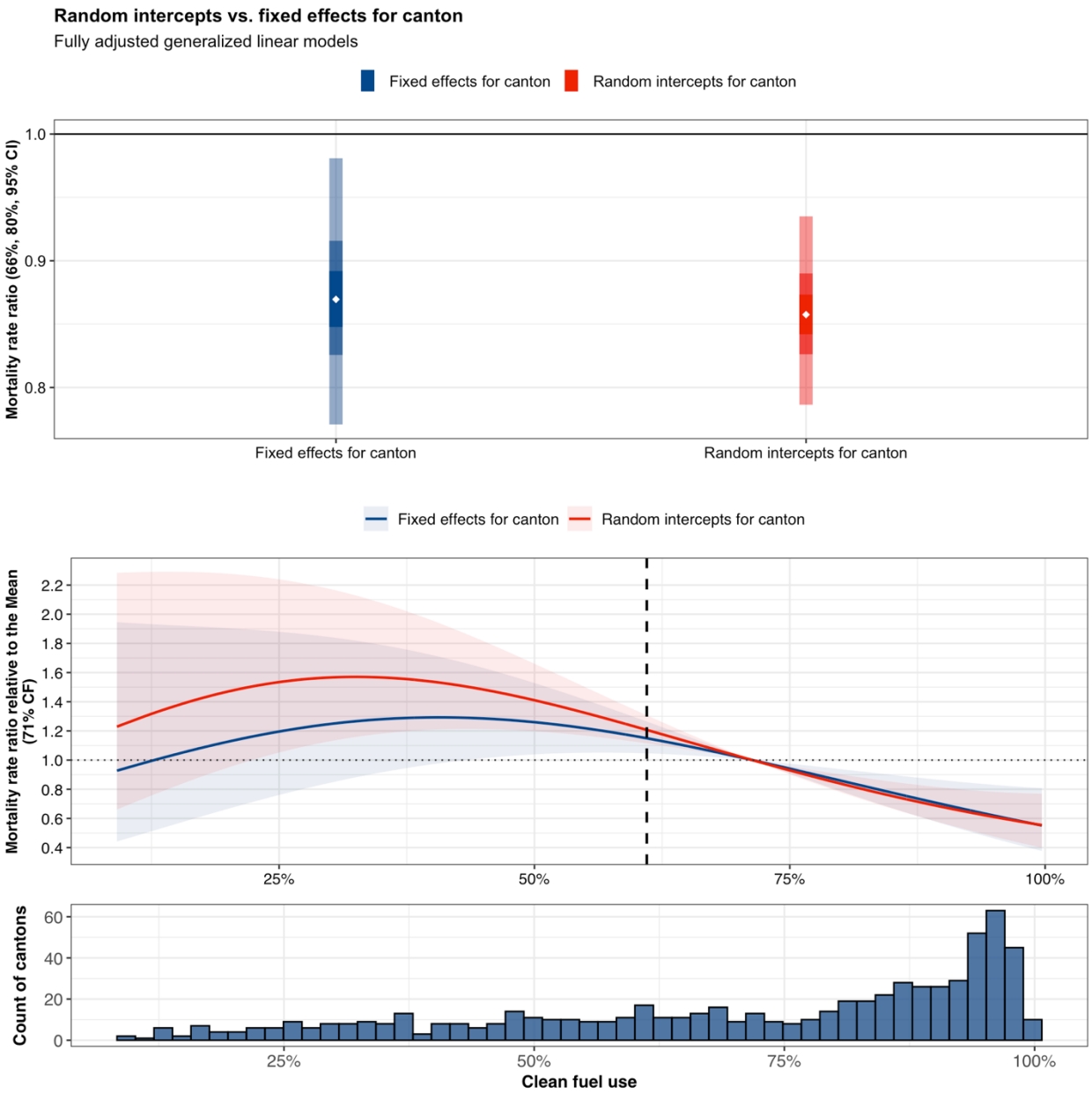


Figure S14. Linear and non-linear association shown for the preferred specification (fixed effects for canton) and an alternative specification using random intercepts for canton. In the top panel, estimates are shown in white diamonds, the innermost and darkest band is the 66% confidence interval, the second-darkest band is the 80% confidence interval, and the widest and lightest band is the 95% confidence interval. The middle panel shows alternative non-linear associations between canton-level %CF and under-5 LRI mortalities by model type. The bottom panel shows a histogram of the distribution of canton-period %CF estimates over the full time period.

Preferred specification adjusted for percent of households in a canton that are rural; percent of households that are not grid electrified; an index of household materials; household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; adult women's literacy; under 18 years of age girls' school attendance rate; an individual in the household or the respondent speaks an indigenous language; an index of vaccines administered among children under 5 years; coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; percent of women that received formal antenatal care prior to delivery; and the median number of antenatal care visits if utilized.

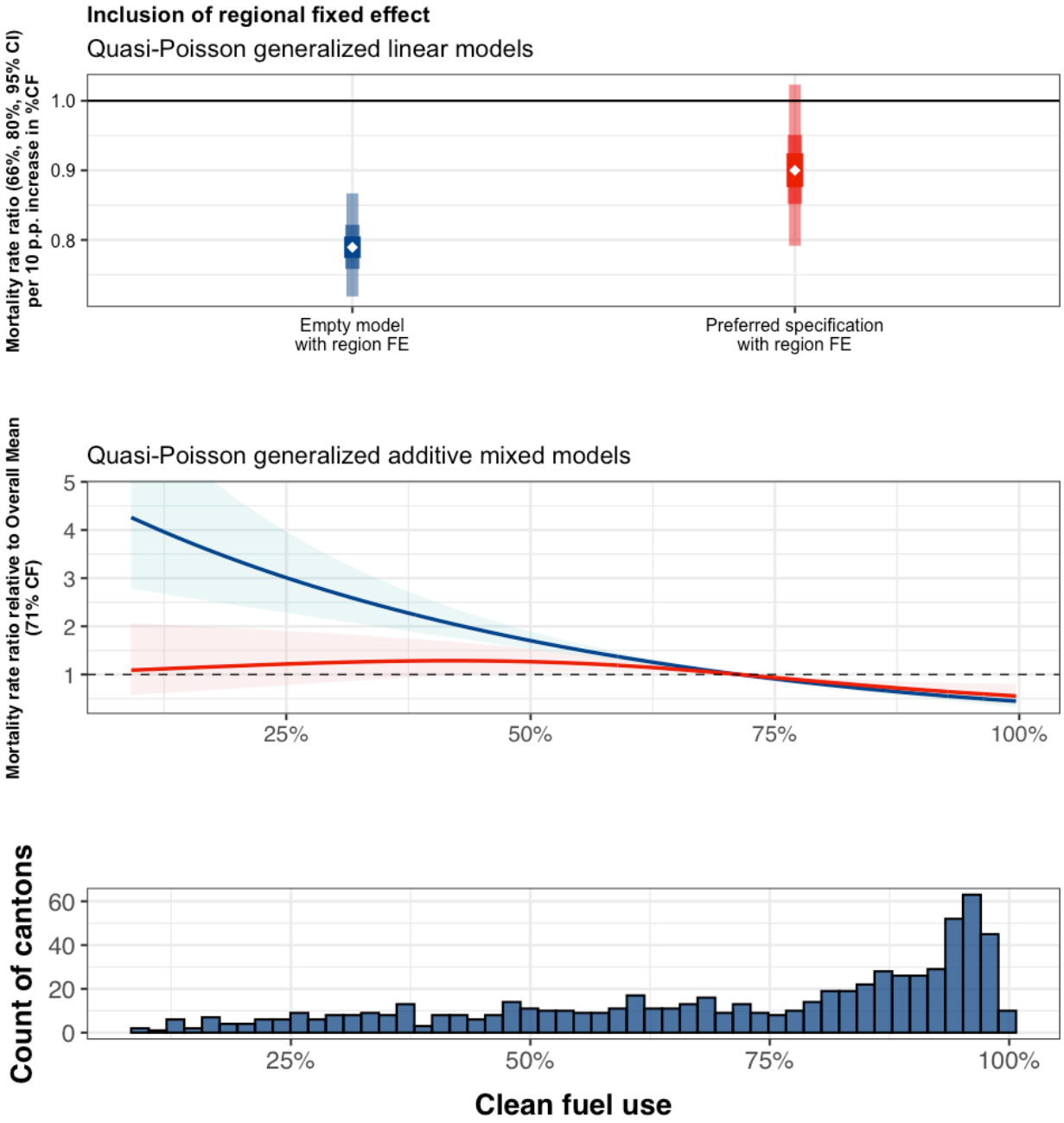


Figure S15. Robustness of the preferred linear and non-linear specifications and empty models (i.e., only canton and period fixed effects) to the inclusion of a regional fixed effect. Models here mirror the main specification but we additionally include a regional fixed effect for which region each given canton observation is in (Amazon, Andes, or Coast). Associations do not meaningfully differ from models without a regional fixed effect, suggesting that our results are not driven by unmeasured regional level confounding.

Preferred specification adjusted for percent of households in a canton that are rural; percent of households that are not grid electrified; an index of household materials; household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; adult women's literacy; under 18 years of age girls' school attendance rate; an individual in the household or the respondent speaks an indigenous language; an index of vaccines administered among children under 5 years; coverage of the pneumococcal conjugate vaccine (three doses)

among children under 5 years; percent of women that received formal antenatal care prior to delivery; and the median number of antenatal care visits if utilized.

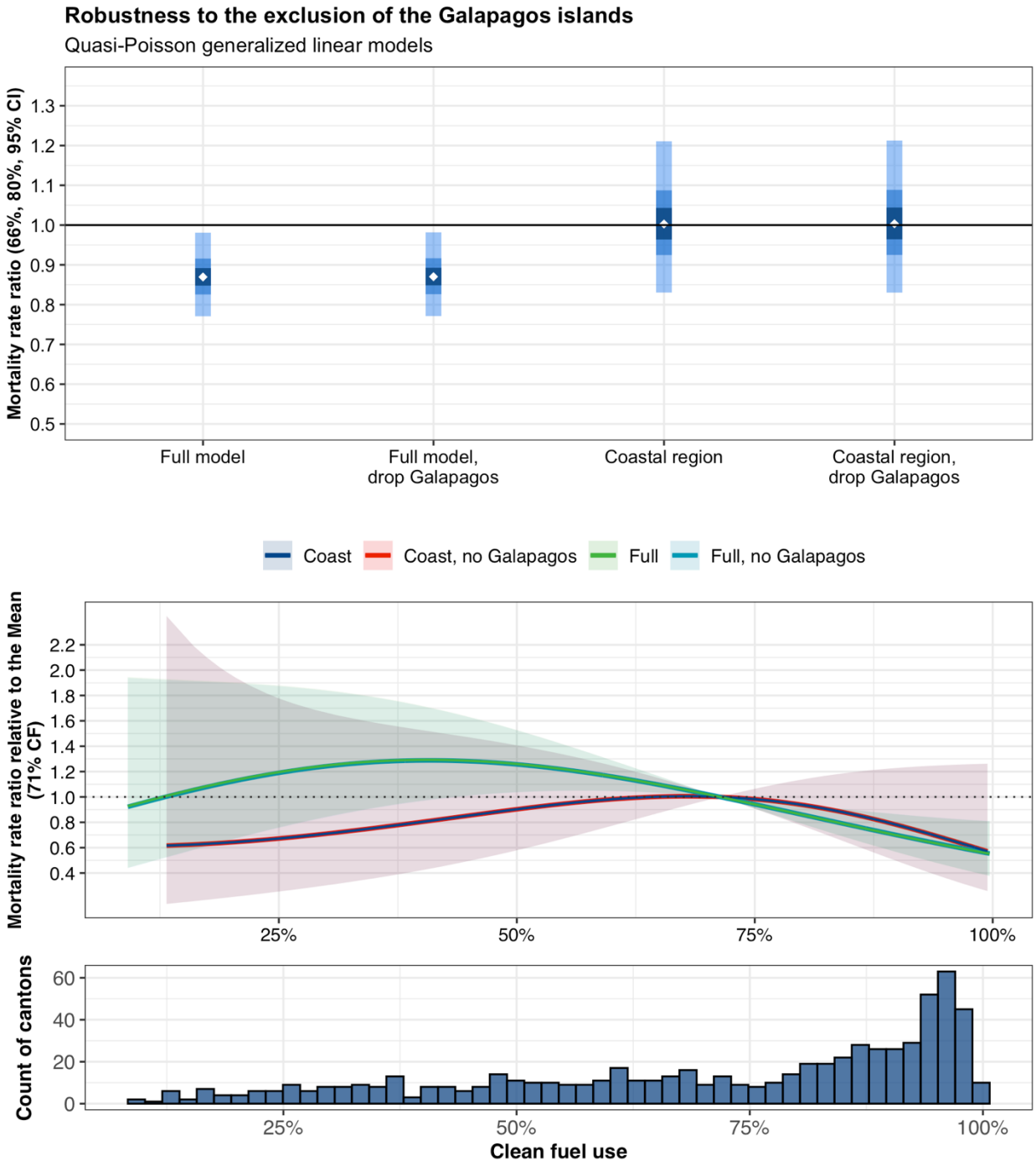


Figure S16. Robustness of the full model and Coastal region subset linear and non-linear associations to the exclusion of the Galapagos islands. In the top panel, estimates are shown in white diamonds, the innermost and darkest band is the 66% confidence interval, the second-darkest band is the 80% confidence interval, and the widest and lightest band is the 95% confidence interval. In the lower panel, despite the appearance of only two lines there are four plotted. Models that omit the Galapagos islands are nearly identical to those that include the full study sample.

Preferred specification adjusted for percent of households in a canton that are rural; percent of households that are not grid electrified; an index of household materials; household has a modern toilet connected to the municipal

sewers or a septic tank, a cesspool, or a latrine; adult women's literacy; under 18 years of age girls' school attendance rate; an individual in the household or the respondent speaks an indigenous language; an index of vaccines administered among children under 5 years; coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; percent of women that received formal antenatal care prior to delivery; and the median number of antenatal care visits if utilized.

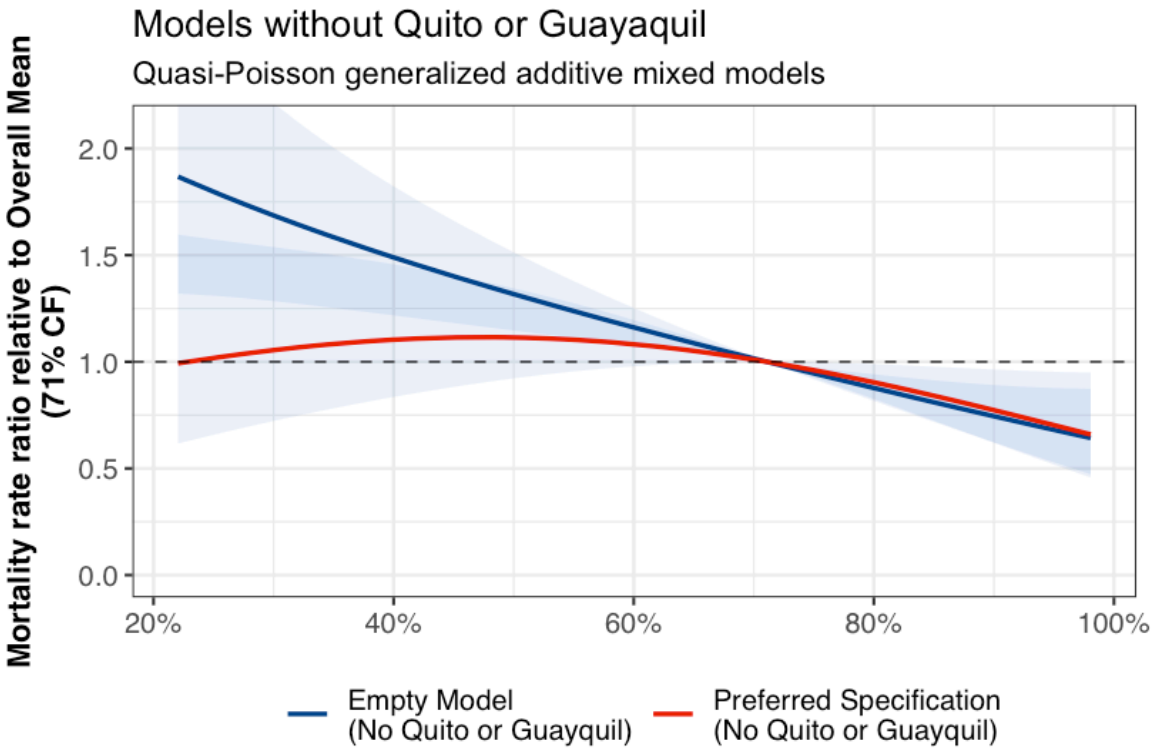


Figure S17. Robustness of the full model non-linear associations to the exclusion of the cantons containing Quito and Guayaquil. Non-linear empty model (i.e., unadjusted, only including canton and period fixed effects) and preferred specifications mirror the full model but remove all canton-period observations from the cantons containing Quito and Guayaquil.

Preferred specification adjusted for percent of households in a canton that are rural; percent of households that are not grid electrified; an index of household materials; household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; adult women's literacy; under 18 years of age girls' school attendance rate; an individual in the household or the respondent speaks an indigenous language; an index of vaccines administered among children under 5 years; coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; percent of women that received formal antenatal care prior to delivery; and the median number of antenatal care visits if utilized.

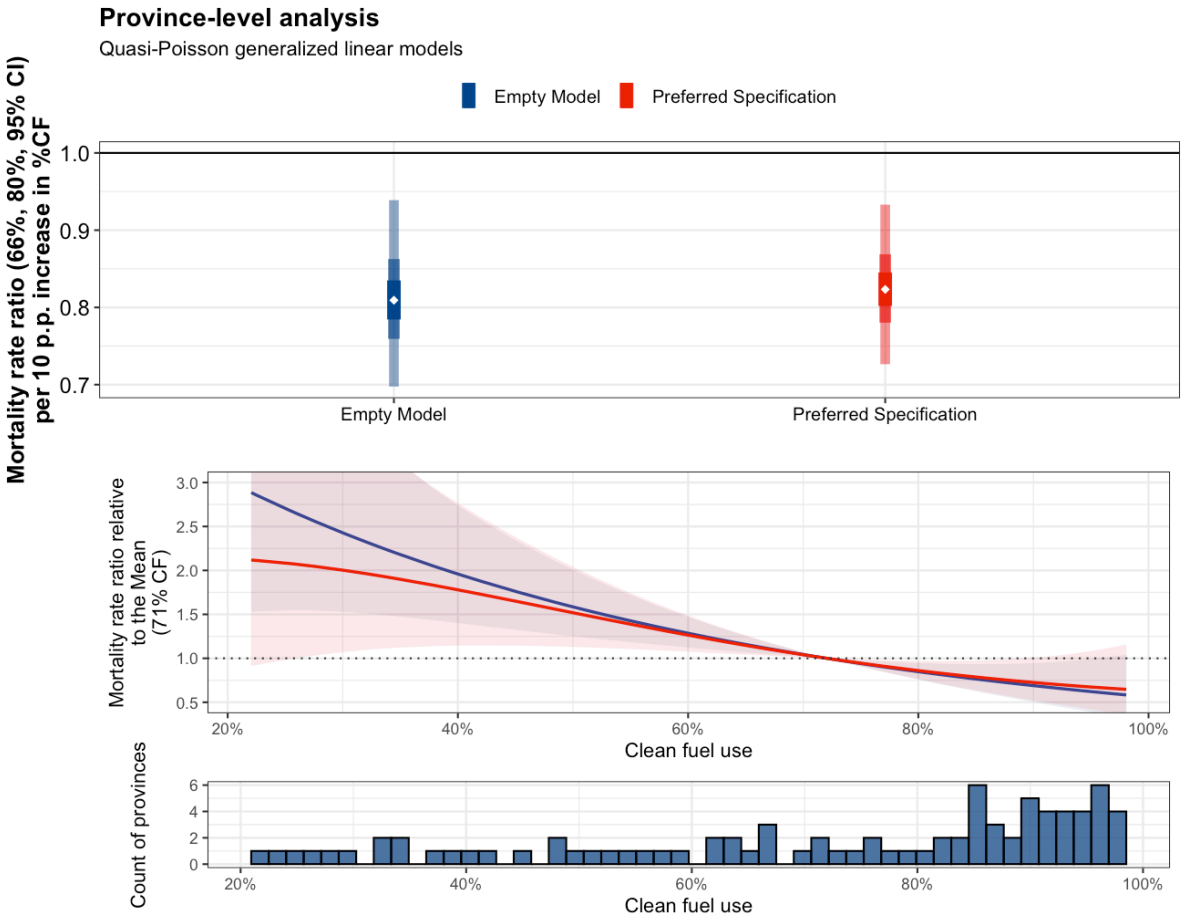


Figure S18. Province-level linear and non-linear association between percent of households primarily using a clean cooking fuel and under-5 LRI mortality. Models mirror the approach of the main analysis, but aggregate data to the province rather than the canton level.

Preferred specification adjusted for percent of households in a canton that are rural; percent of households that are not grid electrified; an index of household materials; household has a modern toilet connected to the municipal sewers or a septic tank, a cesspool, or a latrine; adult women's literacy; under 18 years of age girls' school attendance rate; an individual in the household or the respondent speaks an indigenous language; an index of vaccines administered among children under 5 years; coverage of the pneumococcal conjugate vaccine (three doses) among children under 5 years; percent of women that received formal antenatal care prior to delivery; and the median number of antenatal care visits if utilized.

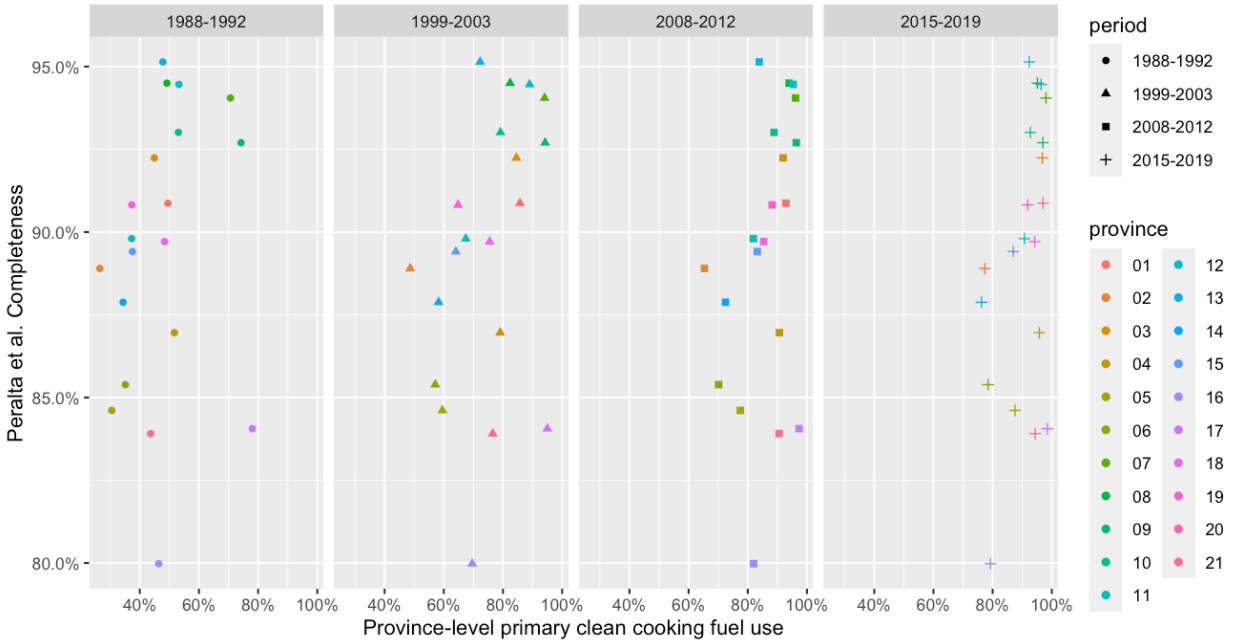


Figure S19. Scatterplot of province-level primary clean cooking fuel use in each period and Peralta et al. (2019)'s cross-sectional measure of mortality completeness from 2001-2013. Note that there is no variation in the measure of completeness over the four study periods because it is from a single time point.

We regressed Peralta et al. (2019)'s cross-sectional measure of mortality completeness from 2001-2013 on province-level %CF in each study period, with fixed effects for province and period, with standard errors clustered at the province level and found no association between the two. Results from the analysis are presented below:

Observations: 80
Fixed-effects: province: 20, period: 4
Standard-errors: Clustered (province)

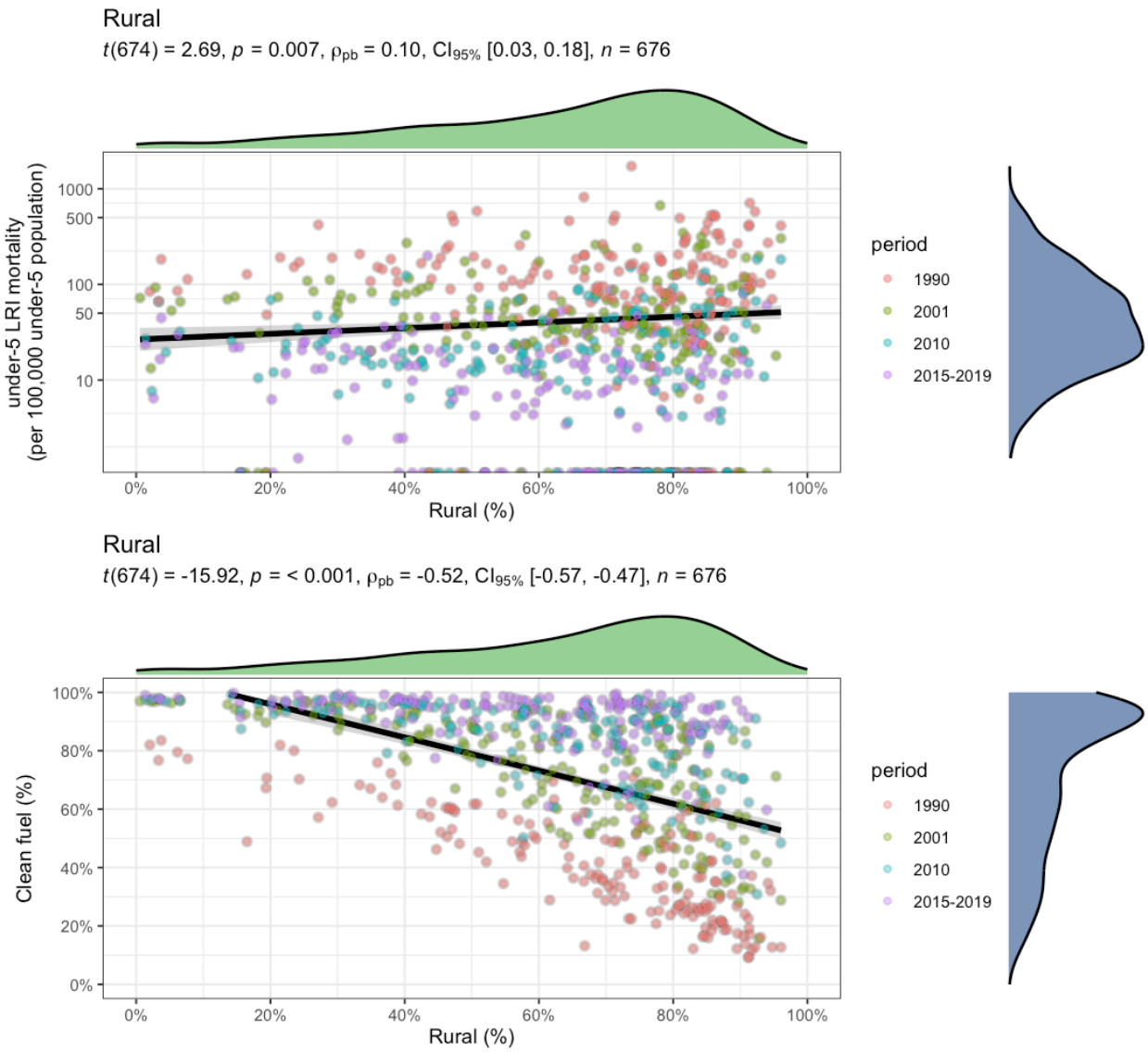
	Estimate	Std. Error	t value	Pr(>|t|)
cf	1.28e-28	8e-29	1.6023	0.12558

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
RMSE: 9.533e-15 Adj. R2: 1 Within R2: 0

3. Correlations between all potential confounding variables and the exposure and outcome, panels A to T.

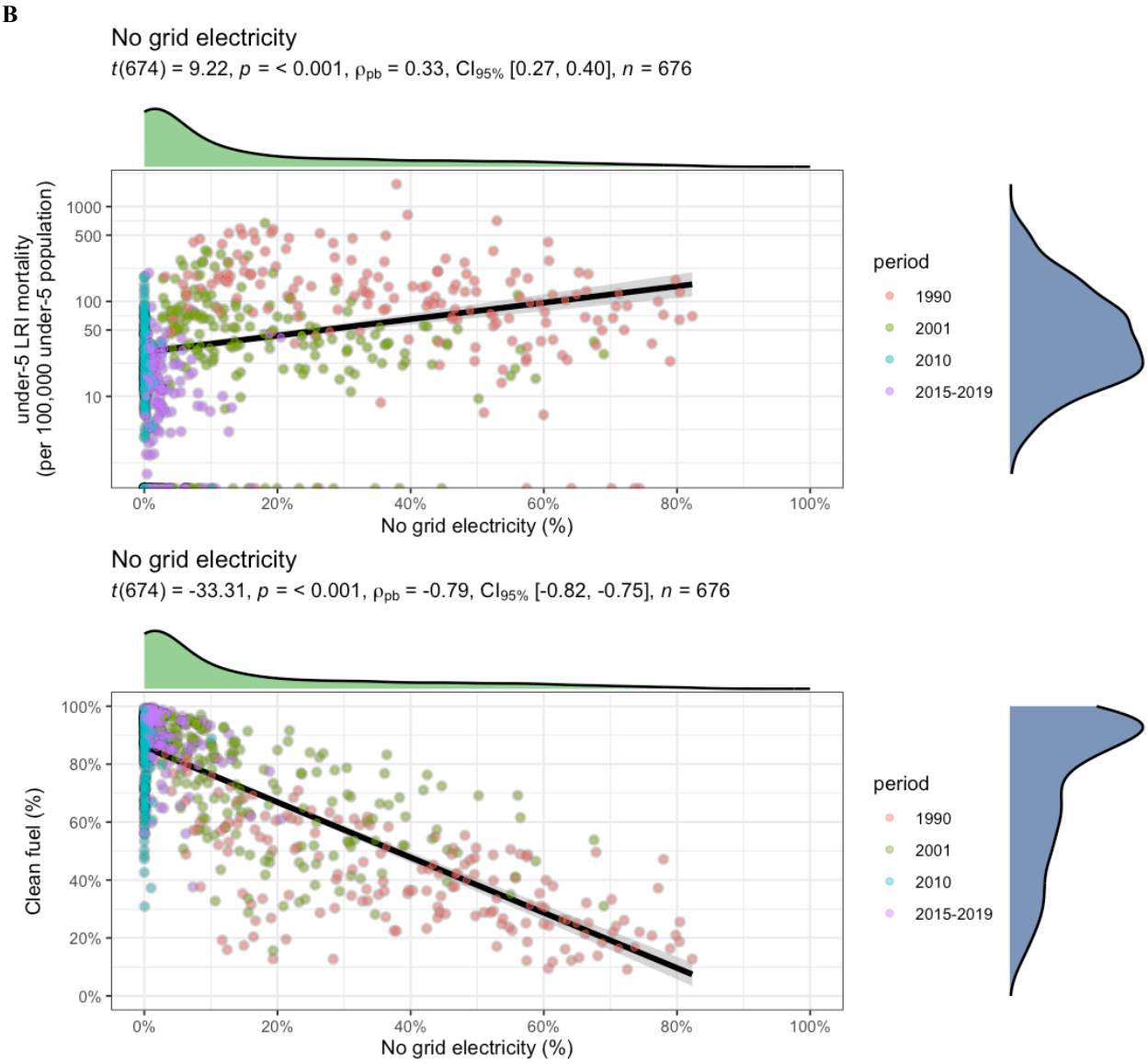
Regression models that include canton and period fixed effects are included below each panel. Under-5 LRI mortality modeled in generalized linear models using count data (quasi-Poisson) with an offset for under-5 population. Clean fuel data modeled as a continuous variable in linear models.

A



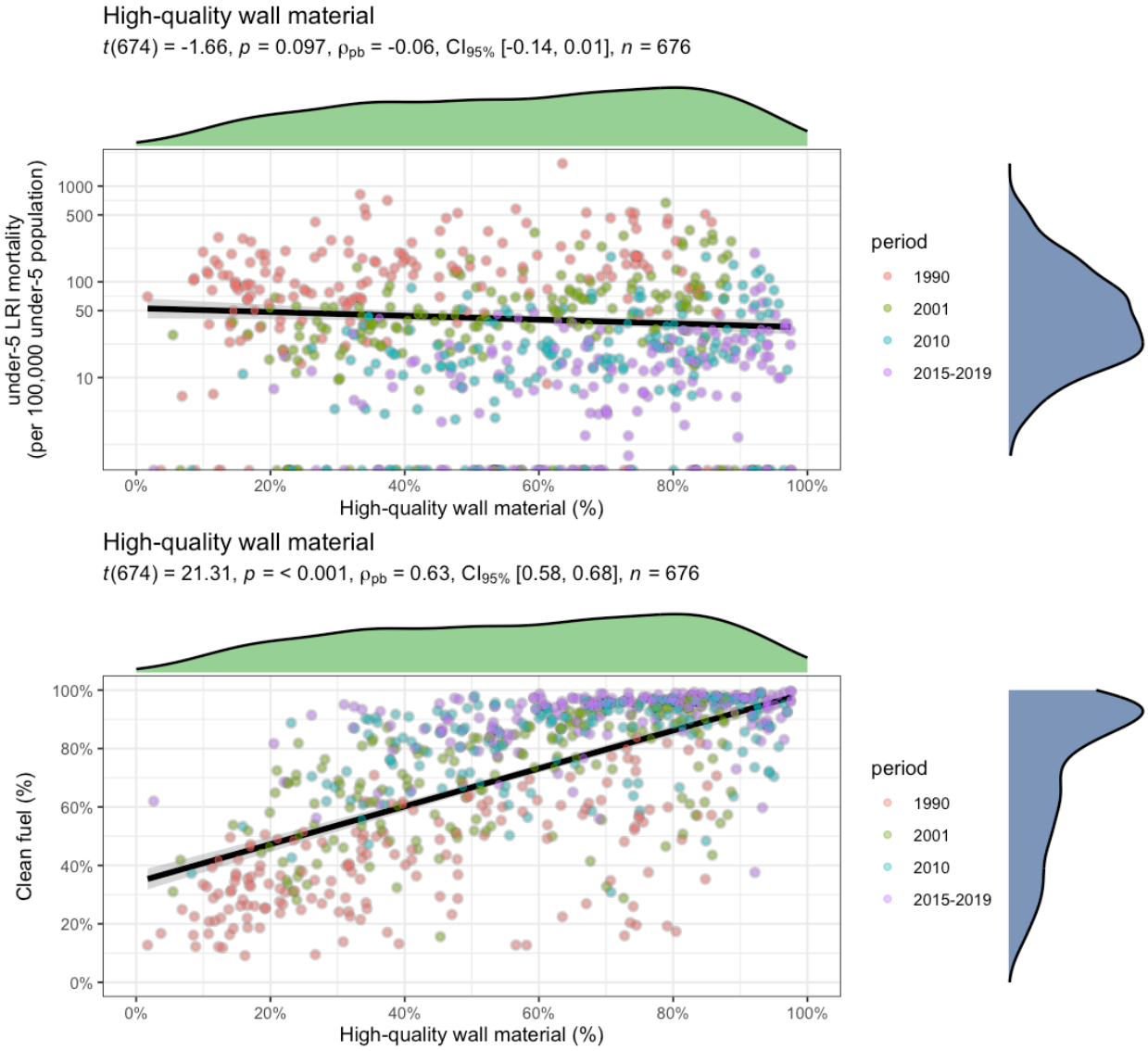
Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	1.08	0.32	0.0008
Clean fuel use	-0.18	0.08	0.02

B



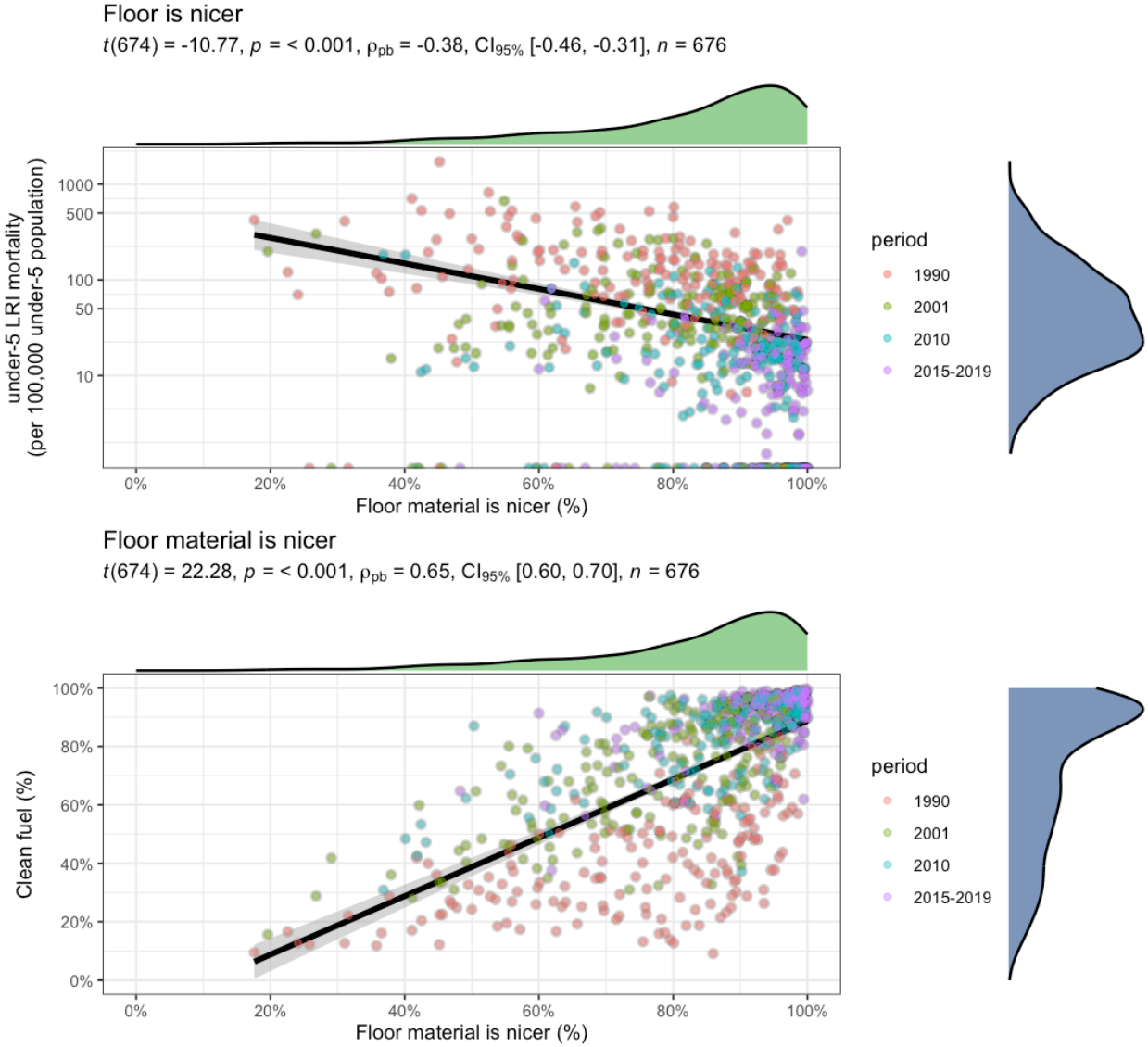
Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	1.21	0.188	2.79e-10
Clean fuel use	-0.318	0.0309	1.14e-22

C



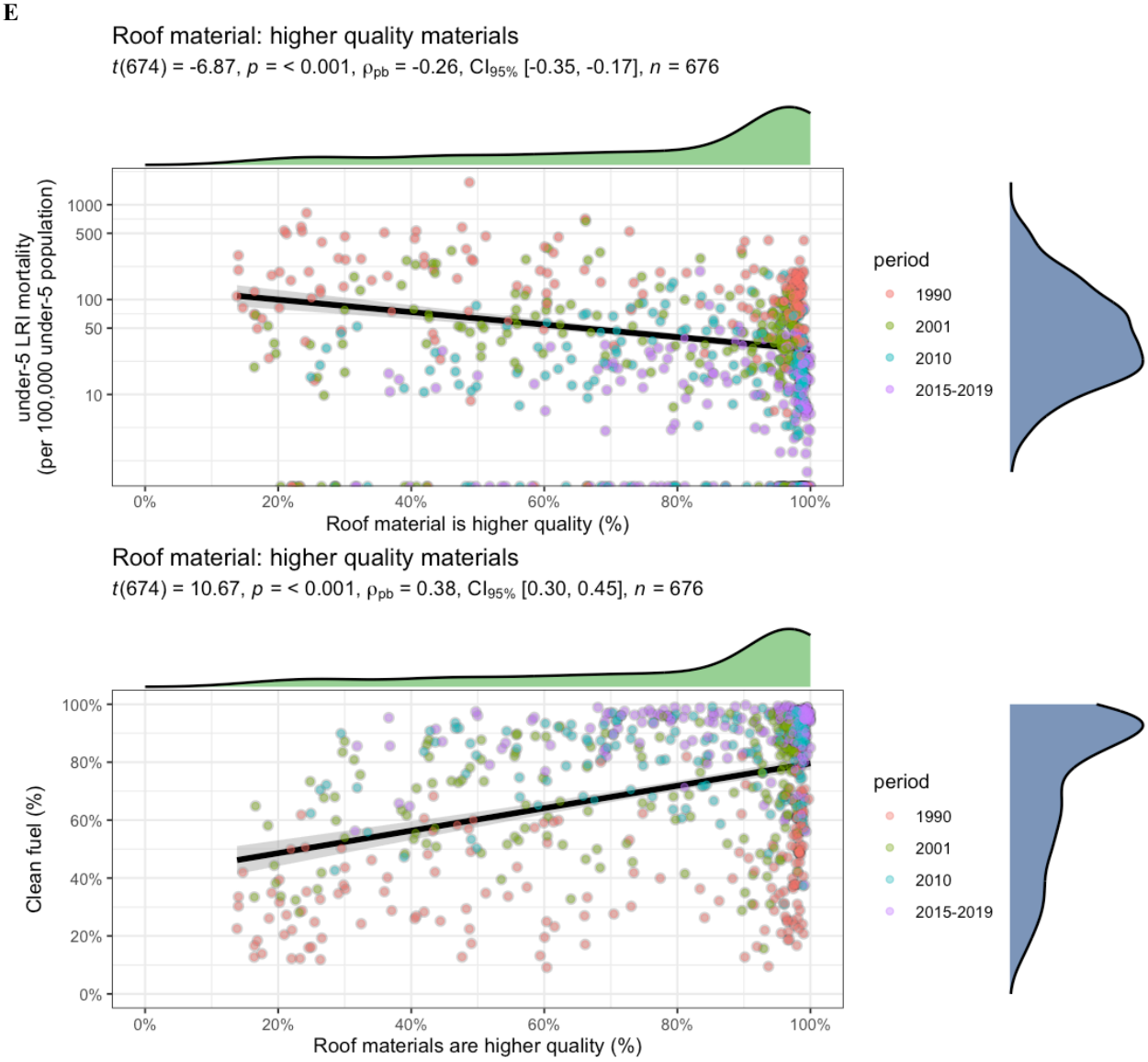
Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	-2.45	0.285	1.11e-16
Clean fuel use	0.363	0.0503	1.97e-12

D



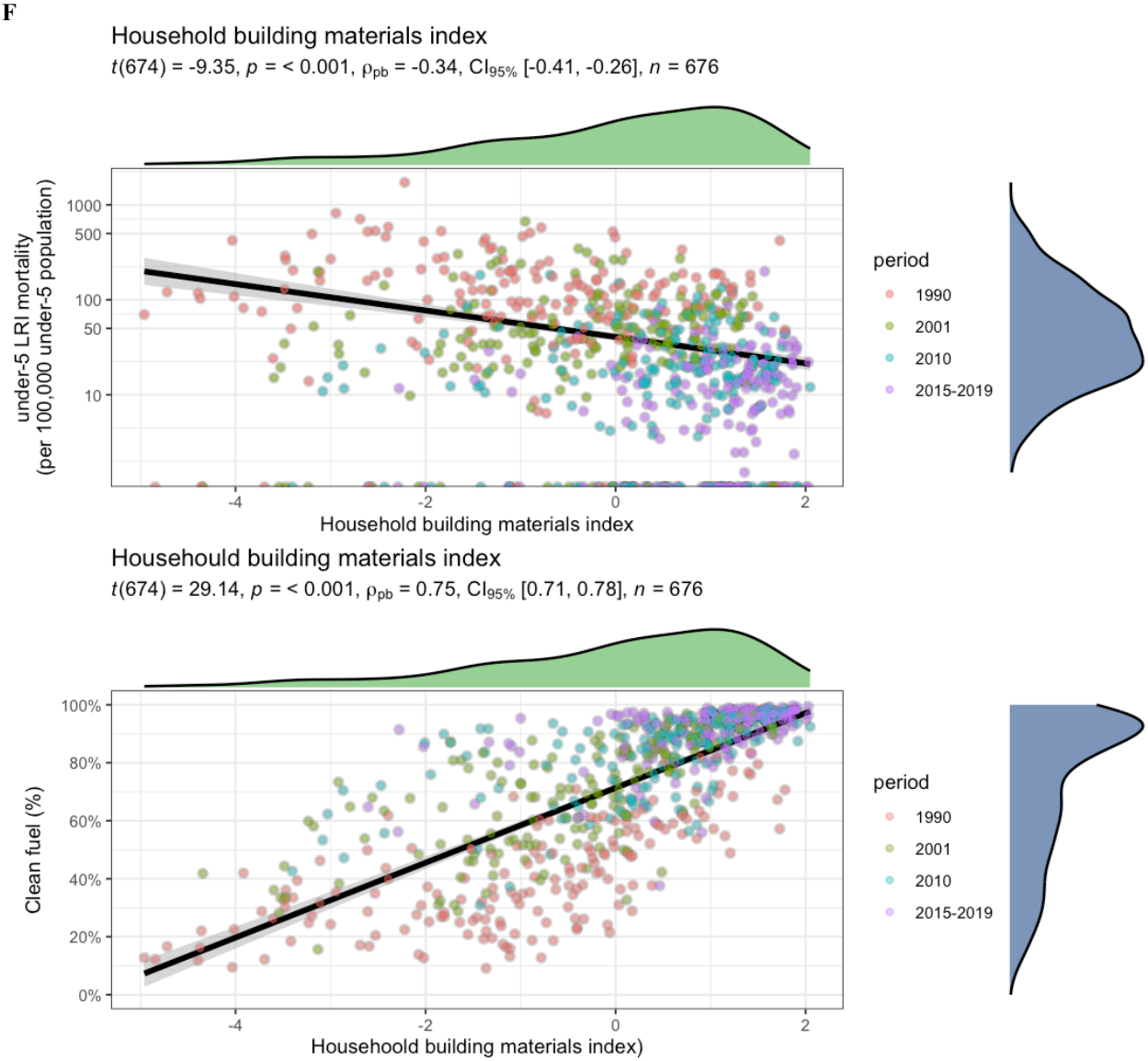
Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	-2.76	0.278	2.12e-21
Clean fuel use	0.517	0.0505	1.71e-22

E



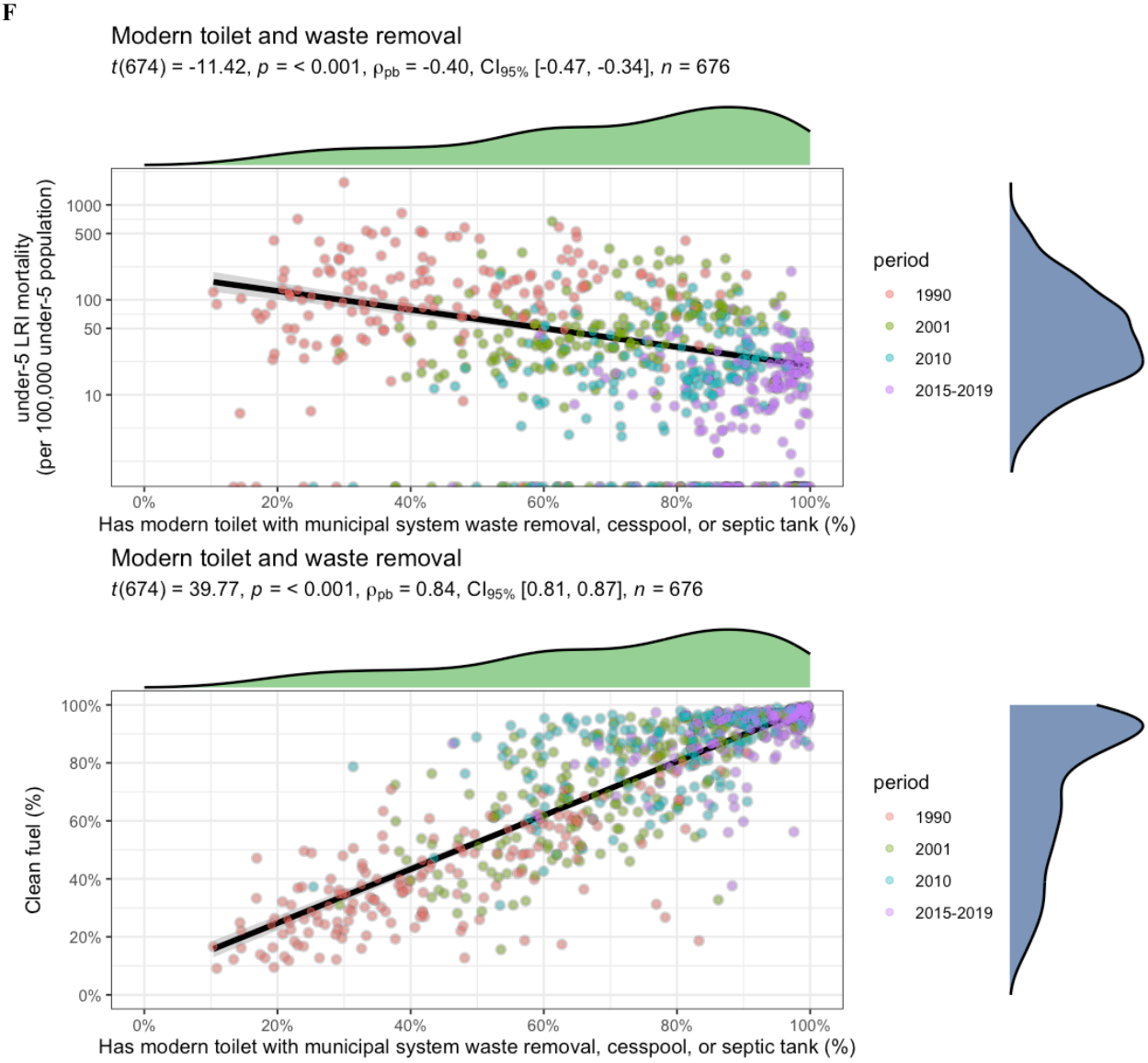
Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	-1.87	0.224	5.83e-16
Clean fuel use	0.282	0.0407	1.24e-11

F



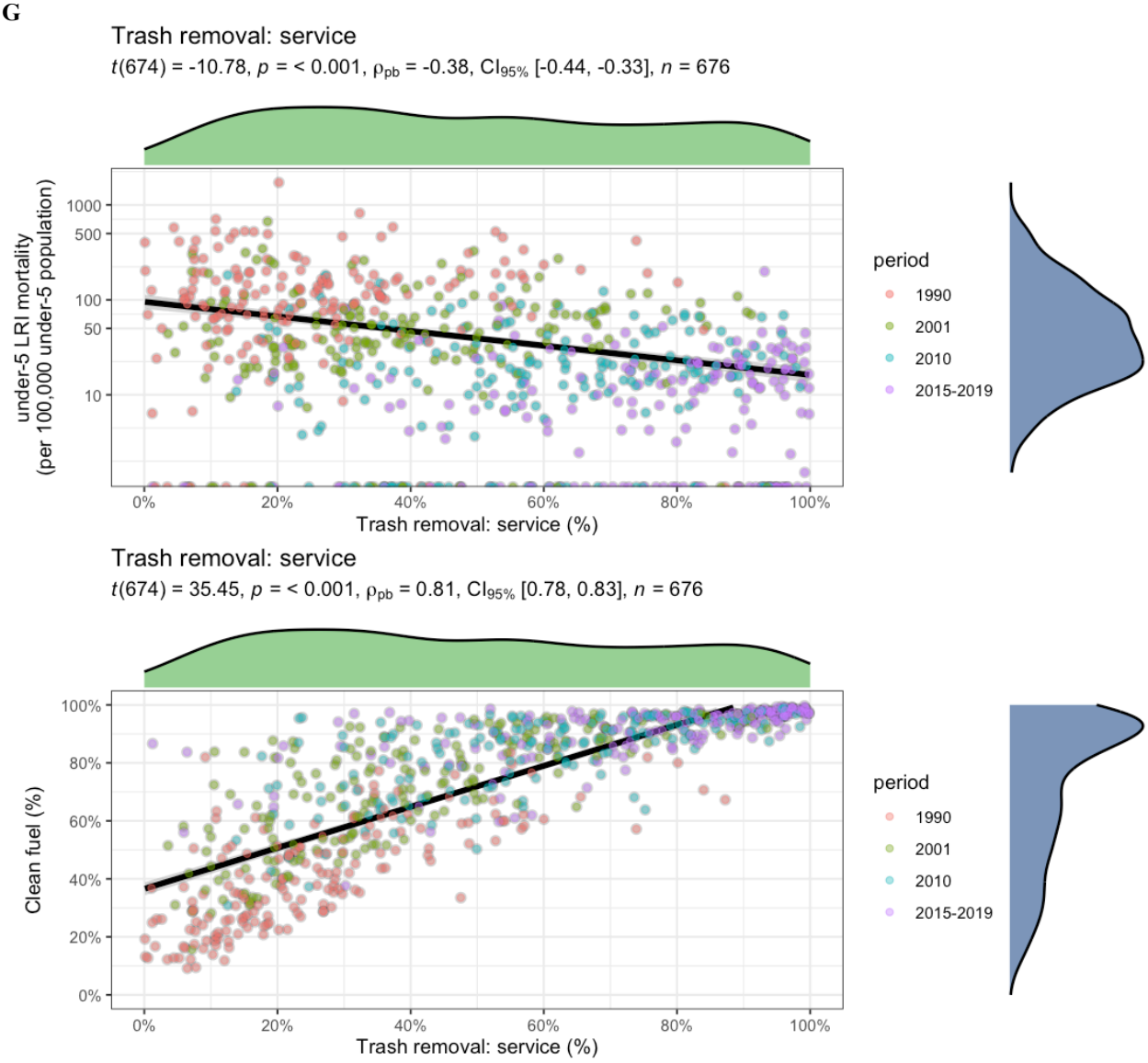
Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	-0.357	0.0339	1.41e-23
Clean fuel use	0.0830	0.00690	1.88e-29

F



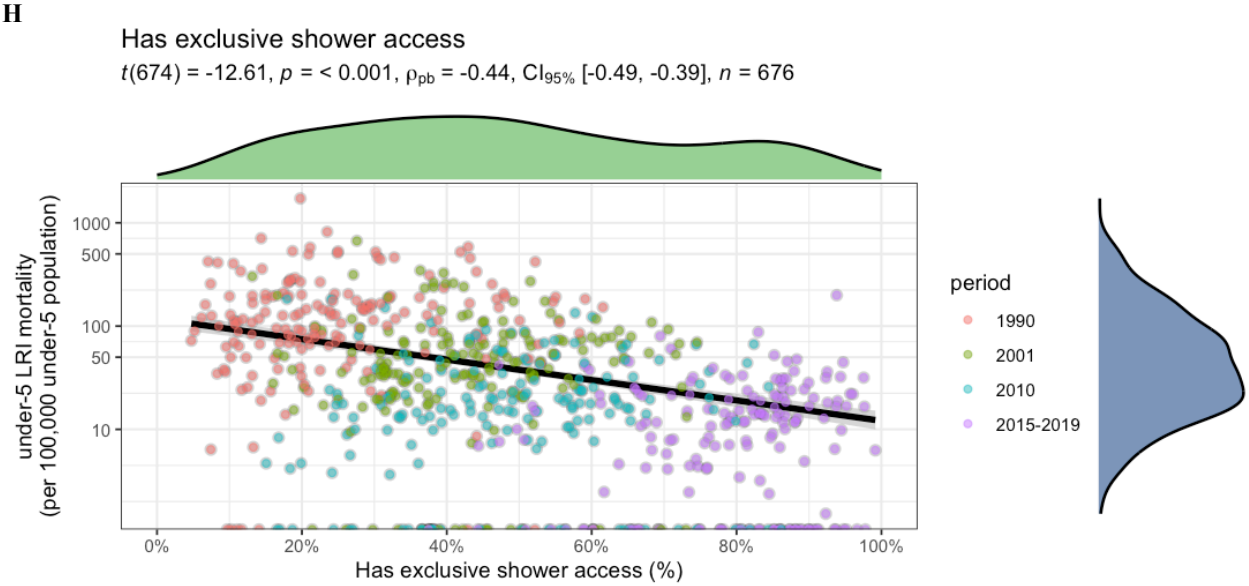
Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	-1.61	0.192	3.98e-16
Clean fuel use	0.450	0.0362	3.61e-31

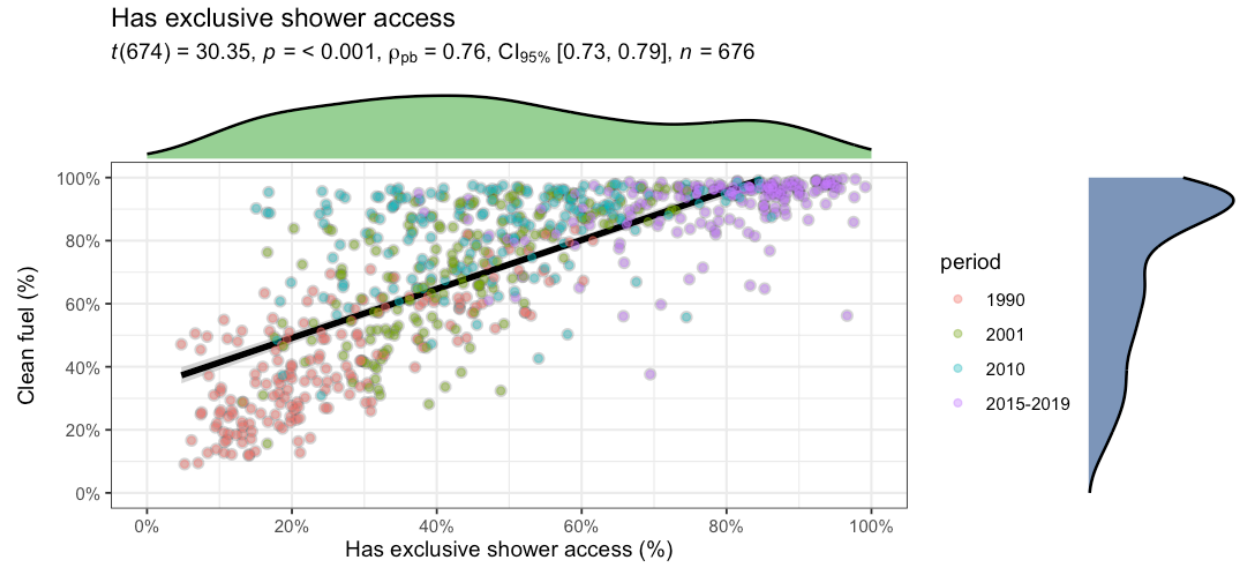
G



Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	-0.572	0.205	0.00555
Clean fuel use	0.175	0.0324	0.000000109

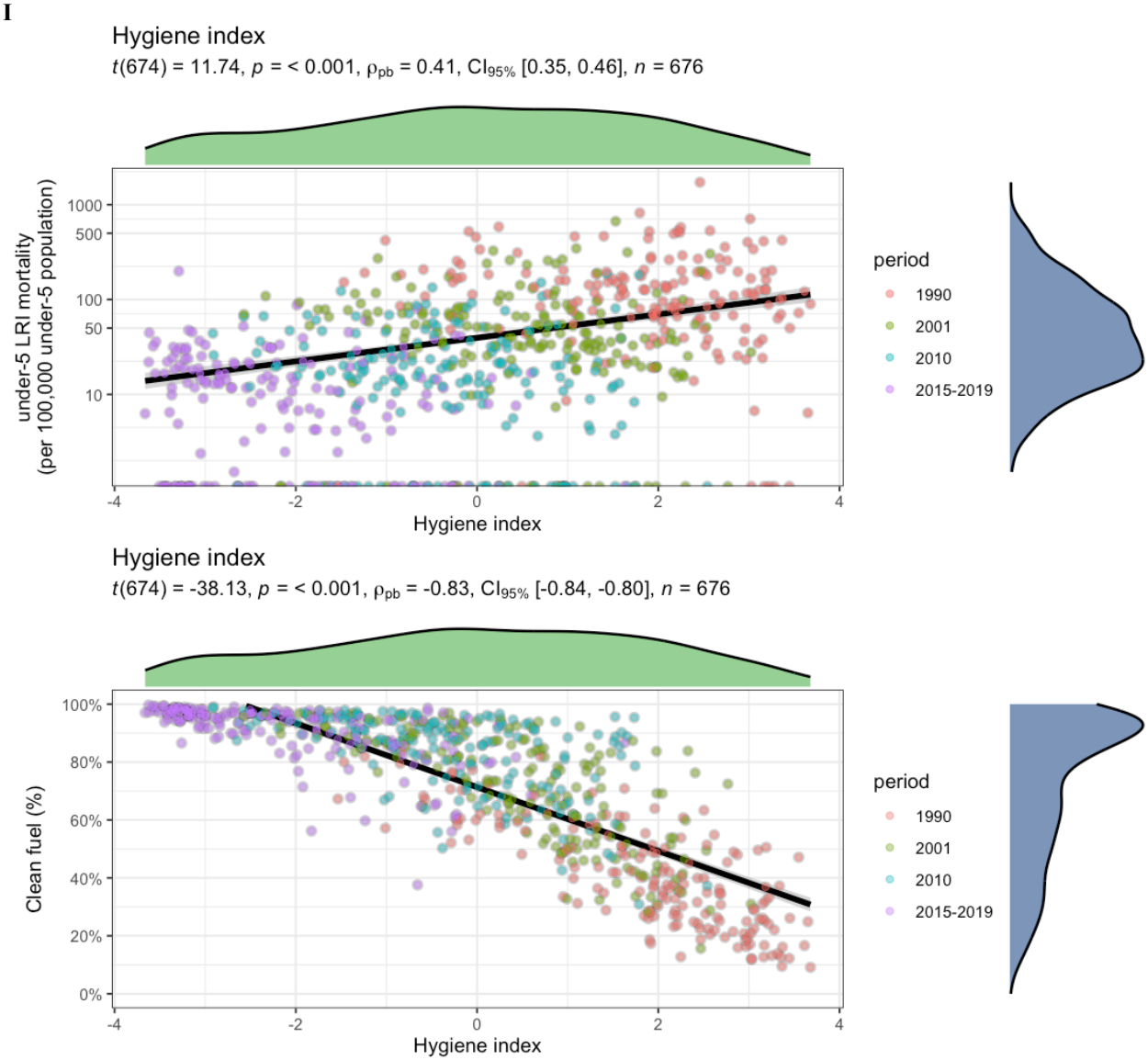
H





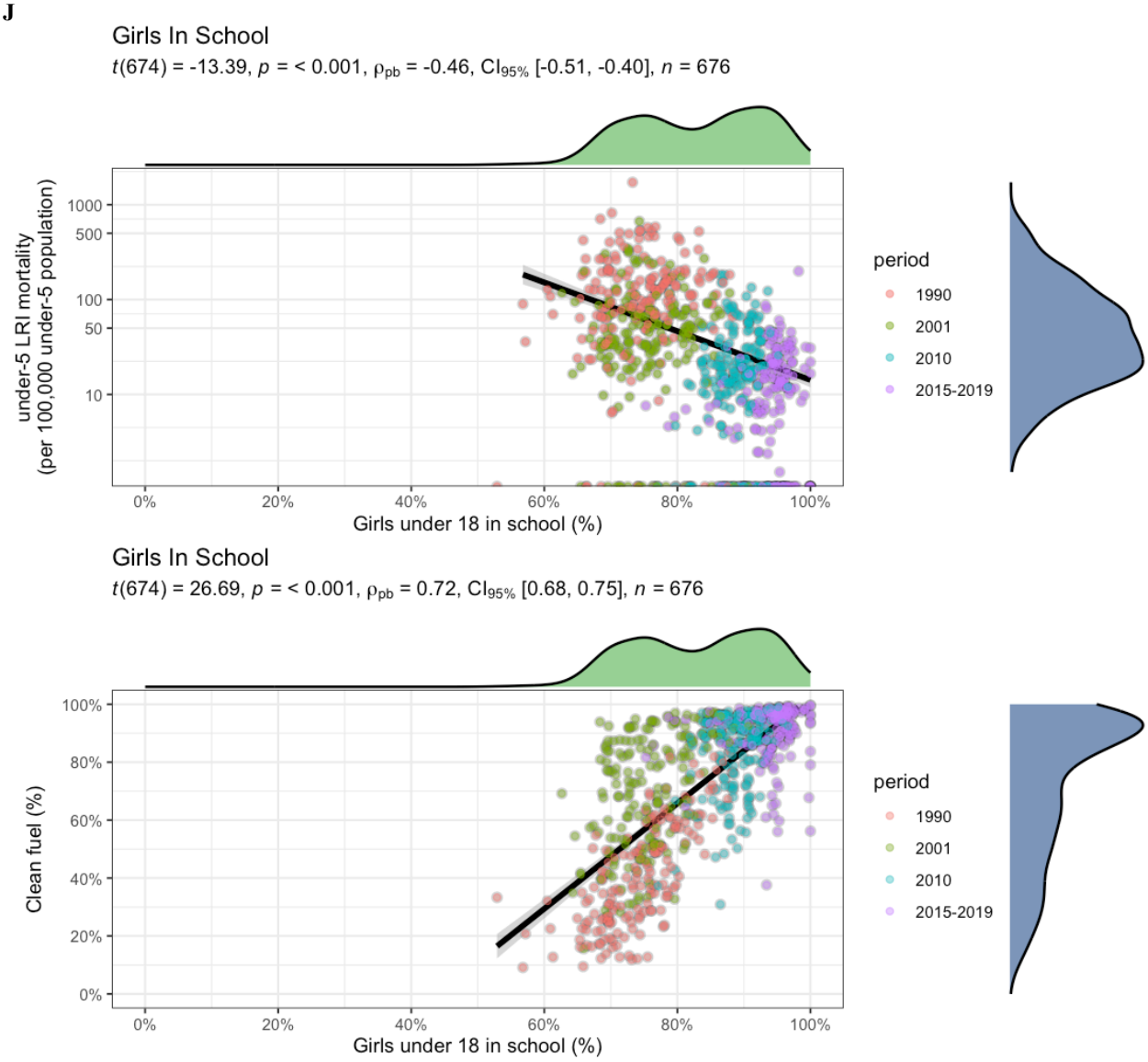
Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	-2.24	0.333	5.23e-11
Clean fuel use	0.375	0.0454	1.20e-15

I



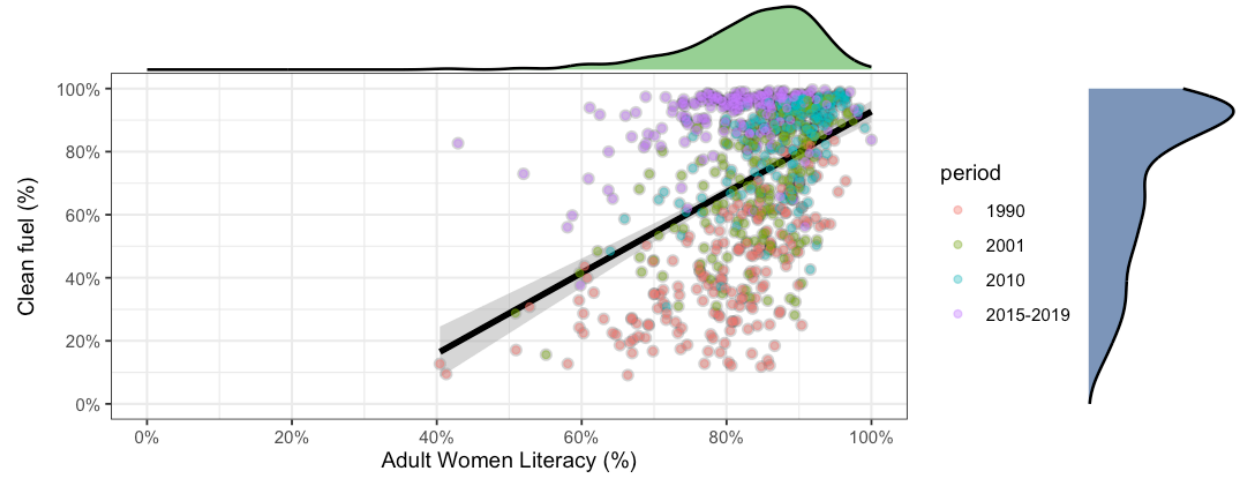
Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	0.313	0.0476	1.30e-10
Clean fuel use	-0.0680	0.00648	2.10e-23

J



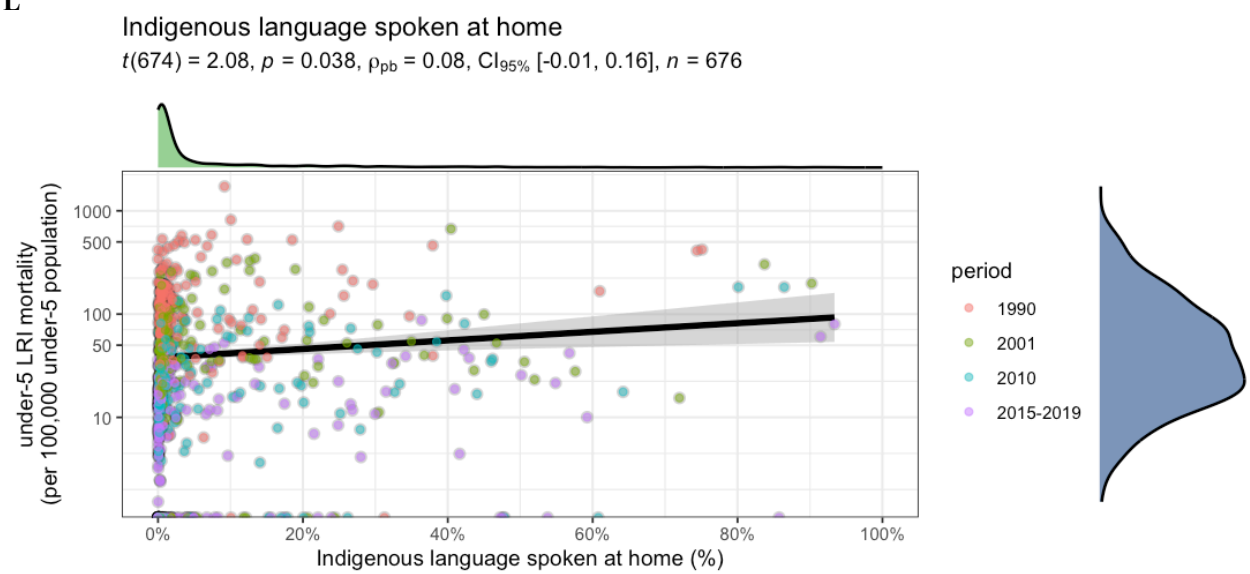
Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	-4.49	0.554	4.32e-15
Clean fuel use	0.912	0.0928	5.40e-21

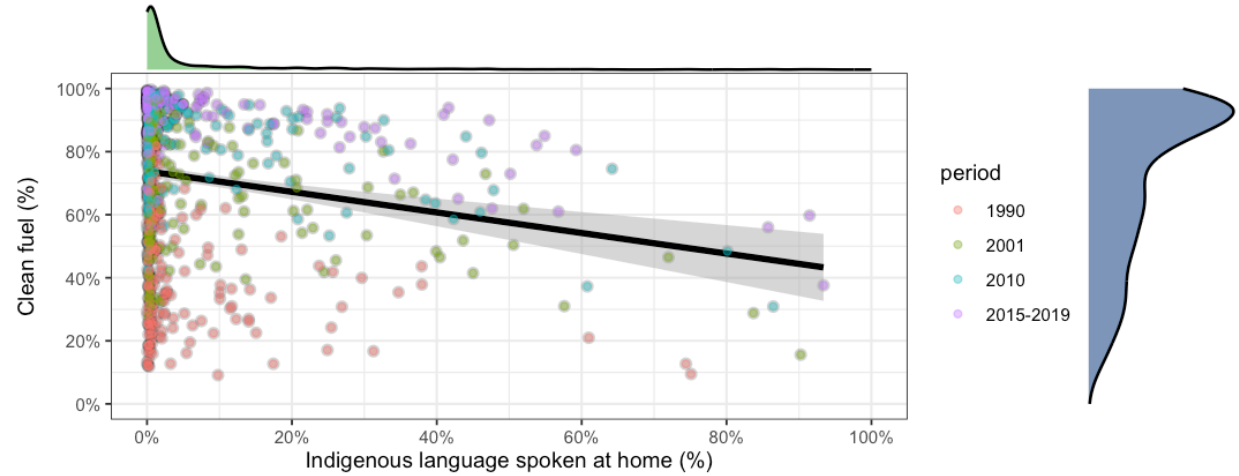
K



Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	-2.96	0.521	0.0000000217
Clean fuel use	0.653	0.105	0.00000000116

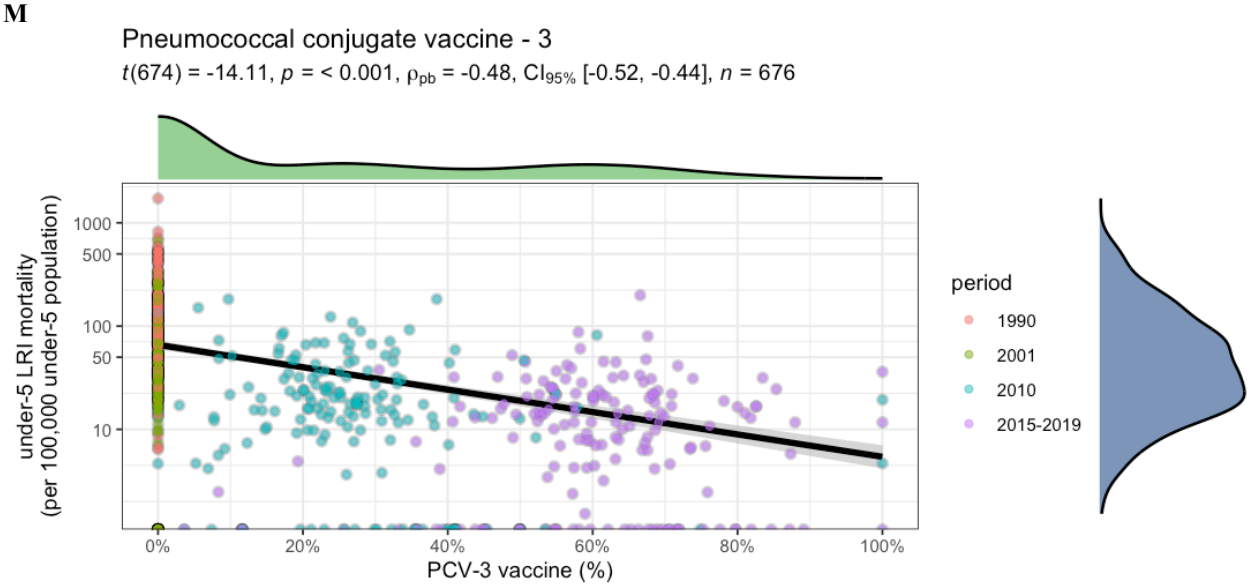
L

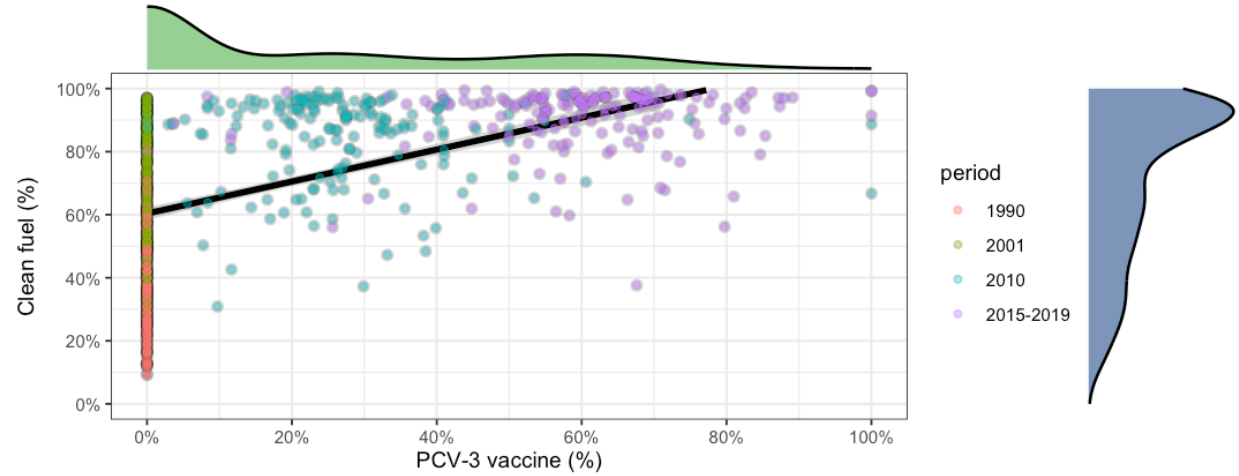




Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	-1.65	0.476	0.000591
Clean fuel use	-0.210	0.0778	0.00718

M

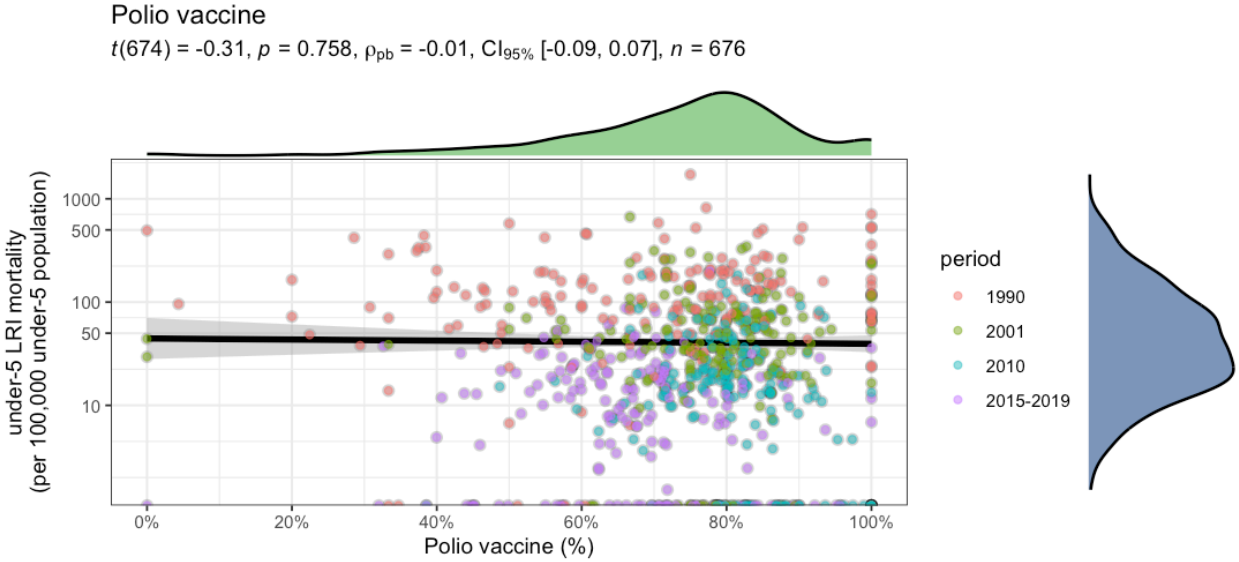


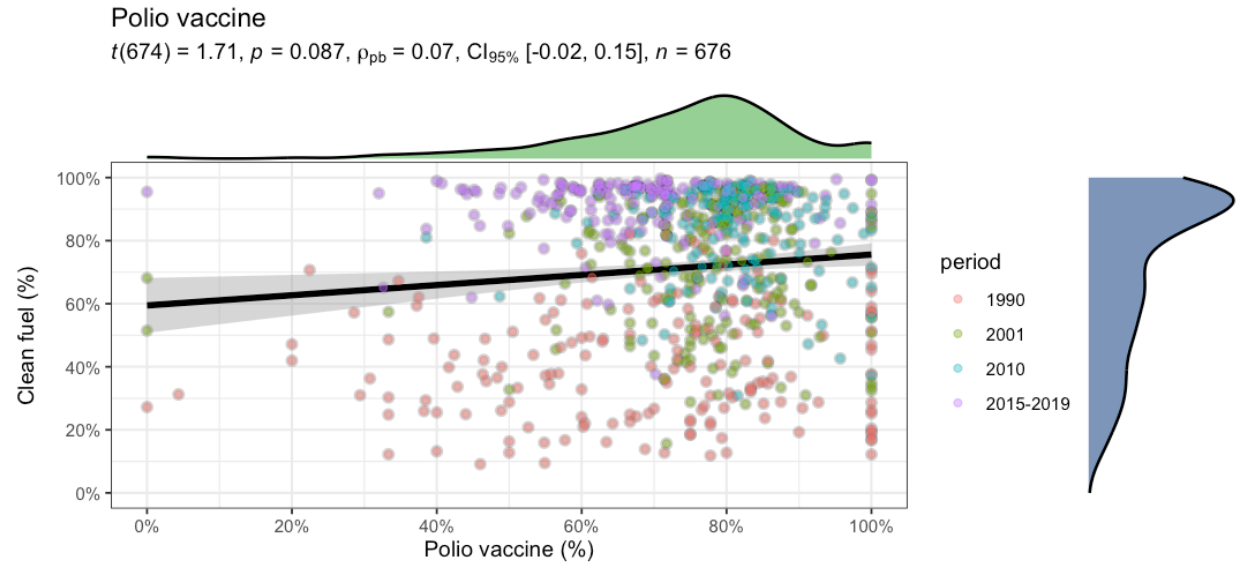


Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	-0.175	0.362	0.630
Clean fuel use	0.0276	0.0345	0.423

In the 1988-1992 and 1999-2003 periods, there was no PCV-3 vaccine and therefore estimates are zero. In the regressions, these periods were omitted.

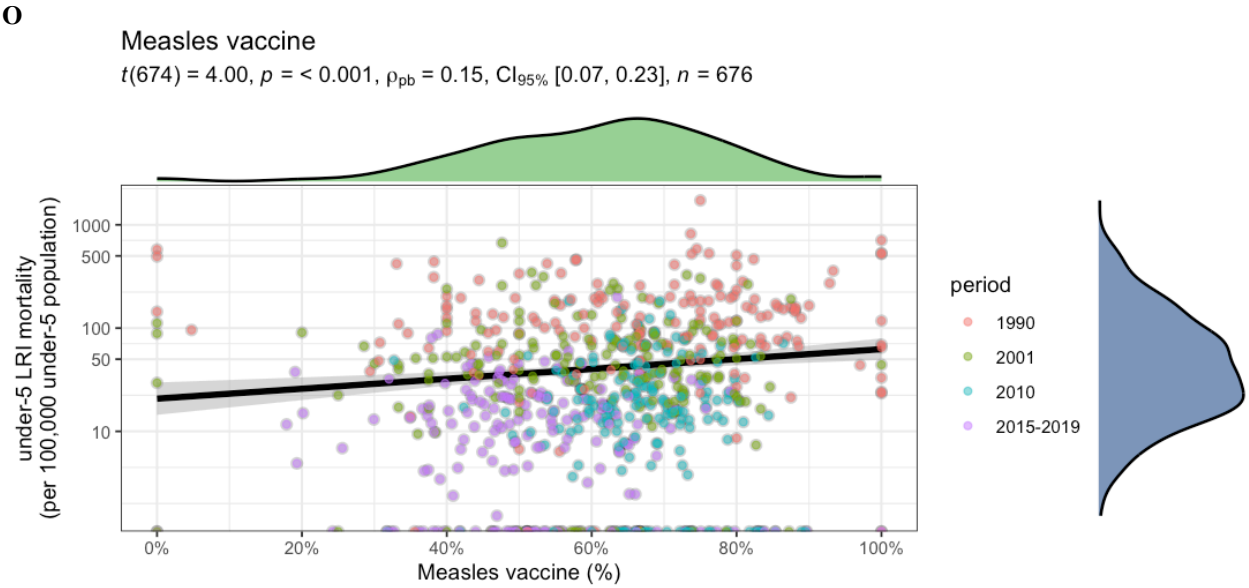
N

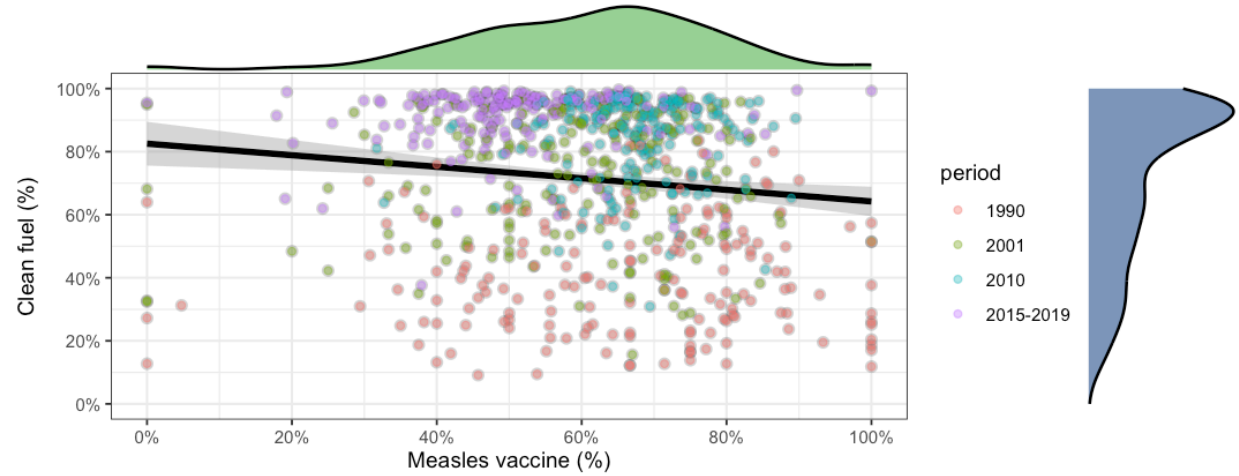




Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	0.241	0.173	0.165
Clean fuel use	0.0464	0.0267	0.0826

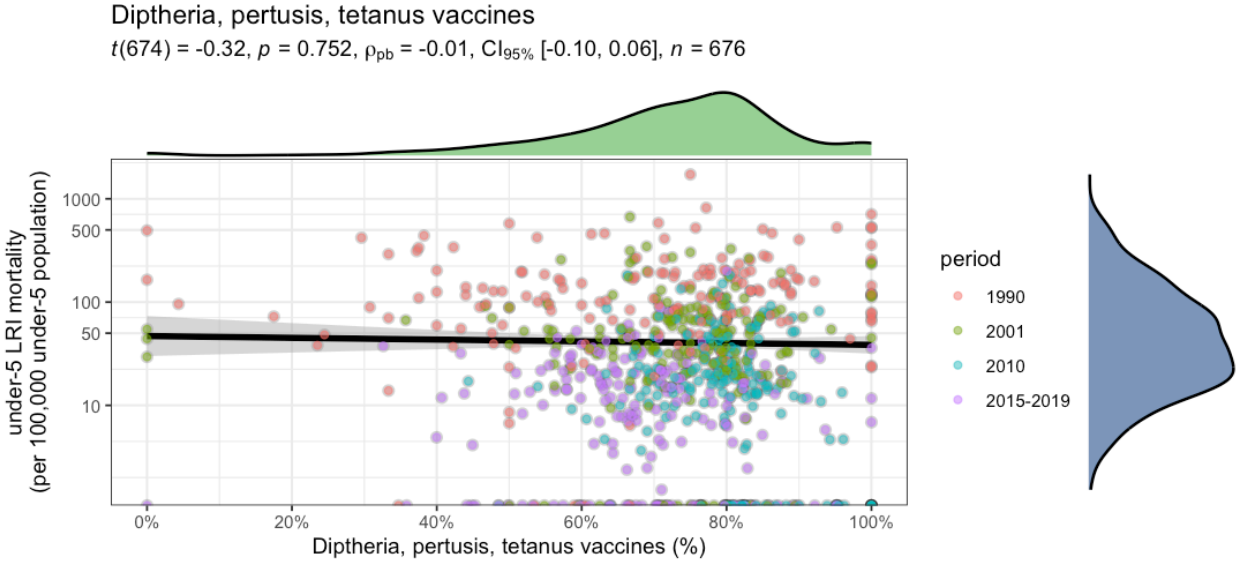
O

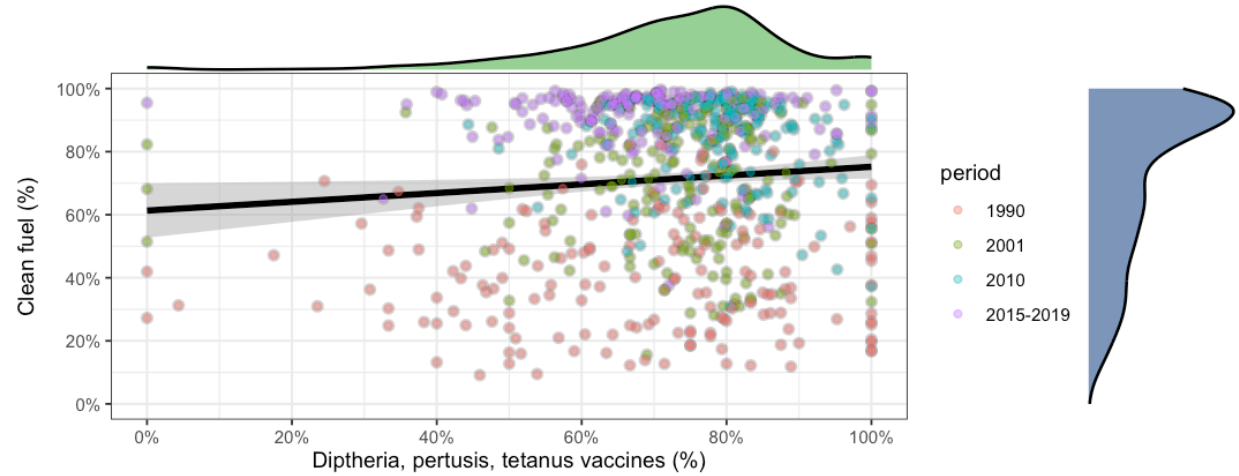




Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	0.0623	0.163	0.702
Clean fuel use	0.0255	0.0247	0.303

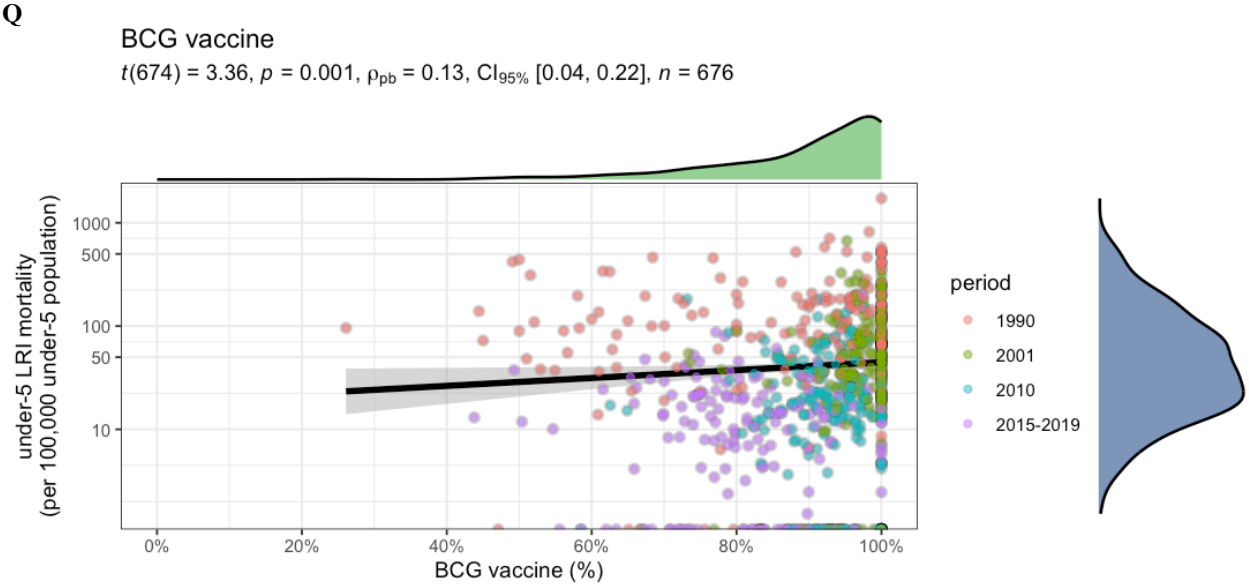
P

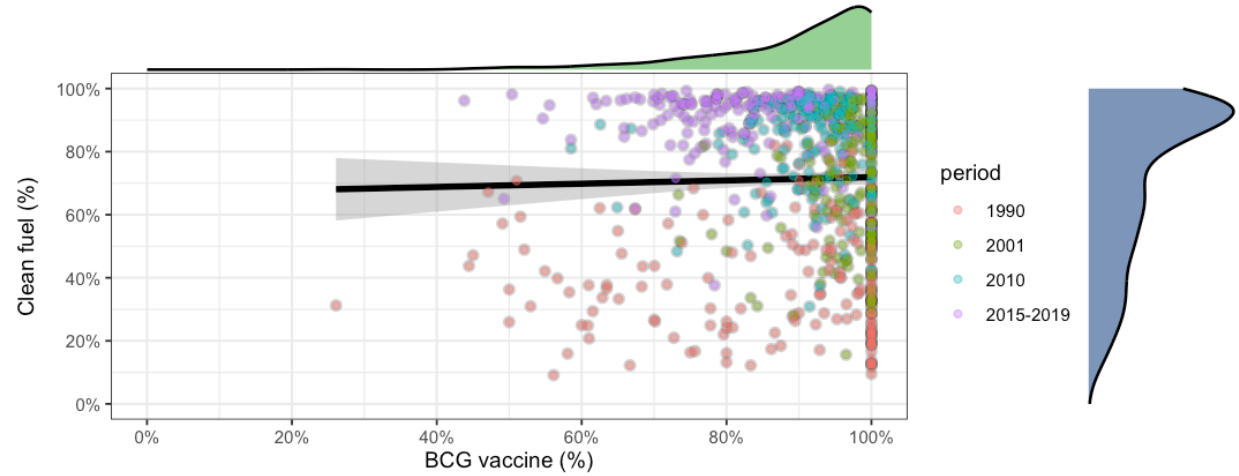




Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	0.151	0.162	0.350
Clean fuel use	0.0316	0.0258	0.222

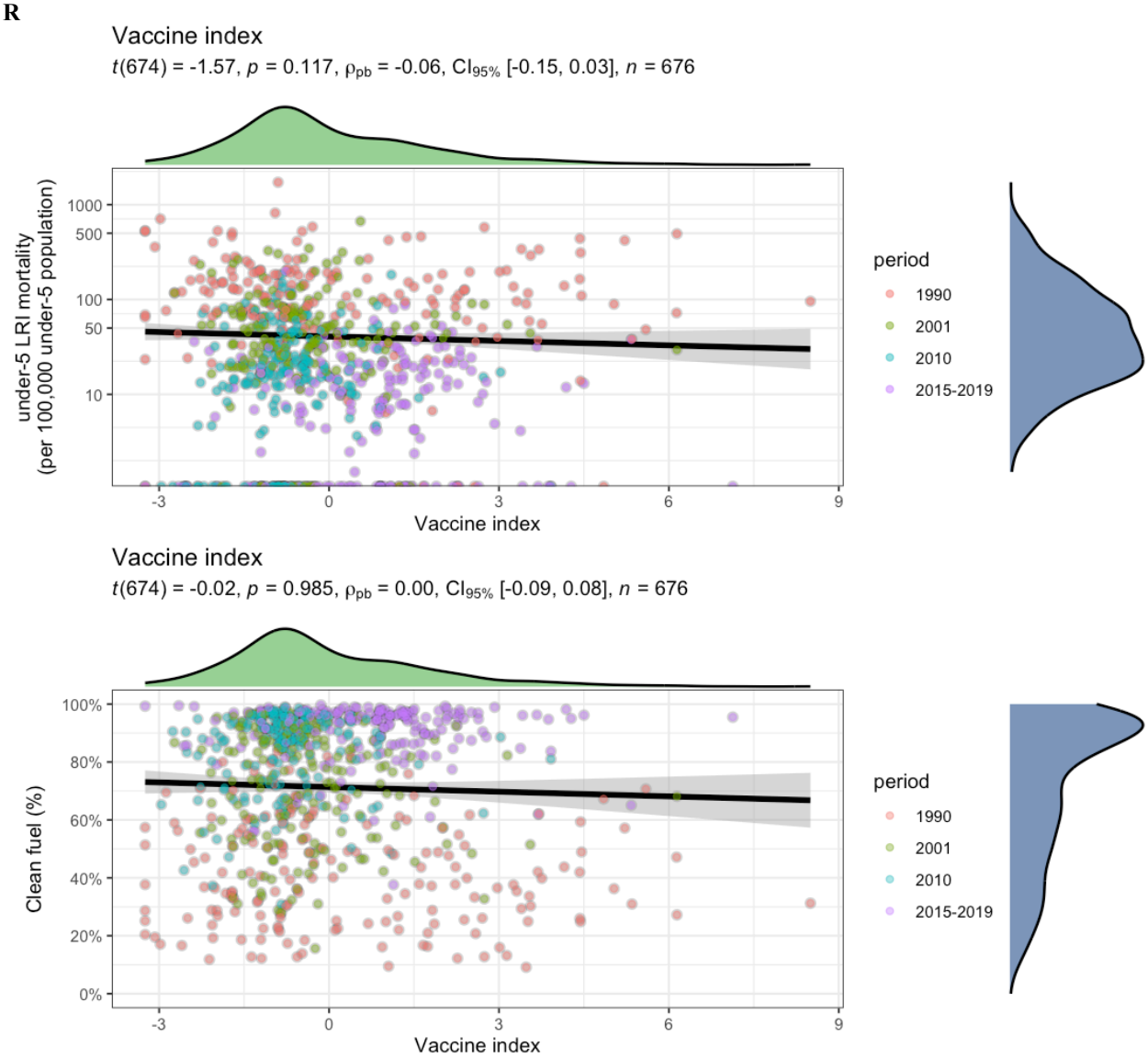
Q





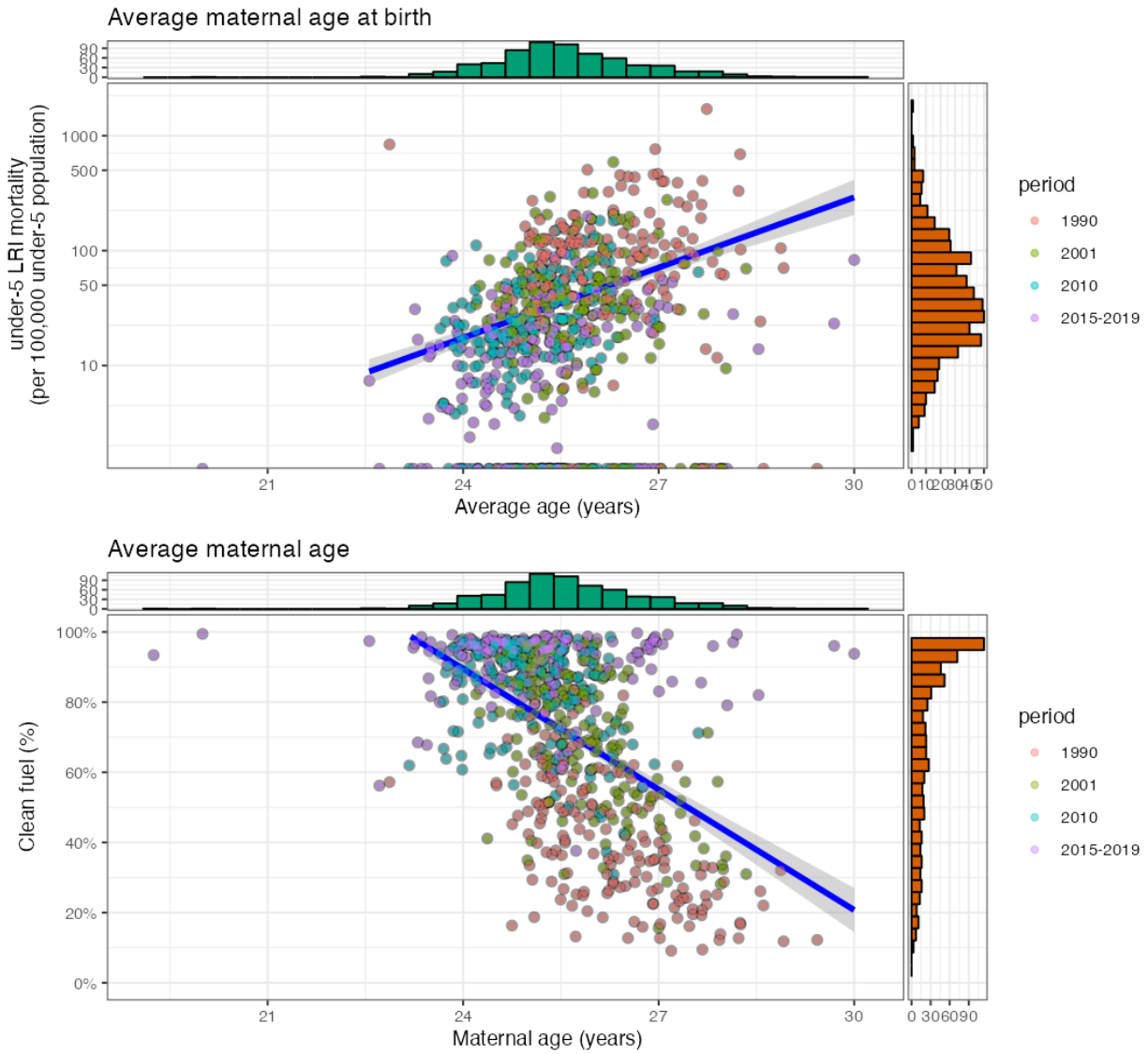
Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	-0.108	0.227	0.635
Clean fuel use	0.0389	0.0358	0.277

R



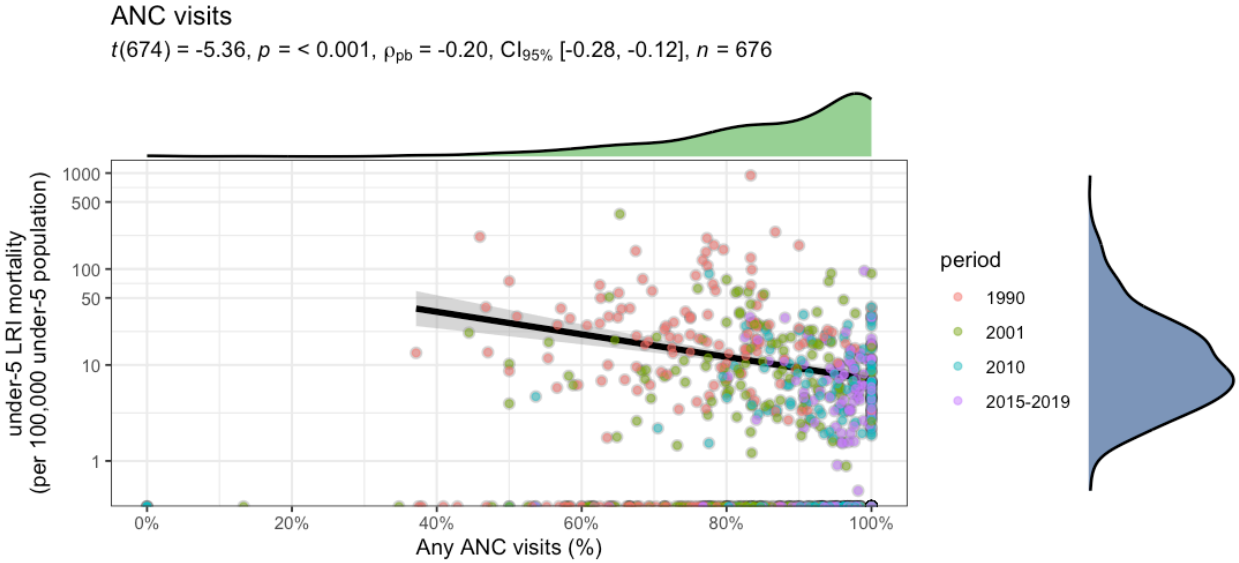
Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	-0.0108	0.0155	0.486
Clean fuel use	-0.00375	0.00249	0.133

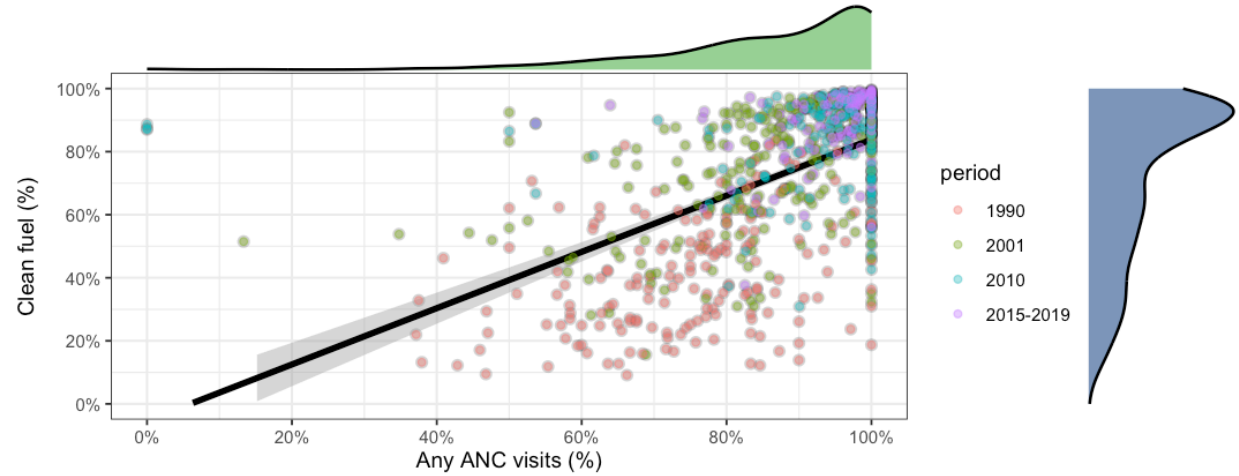
S



Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	0.308	0.0423	1.37e-12
Clean fuel use	-0.0319	0.00464	1.85e-11

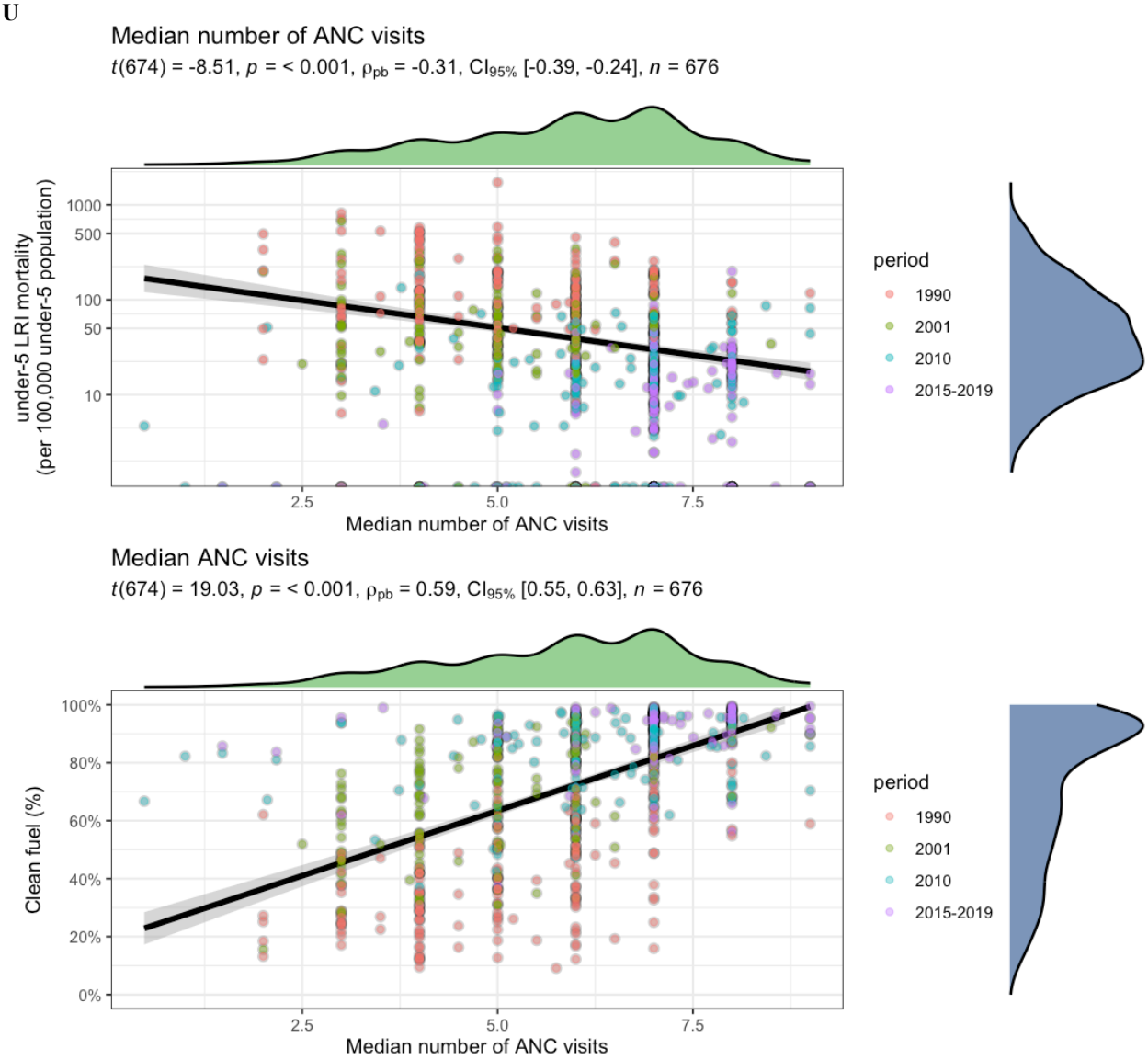
T





Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	-0.882	0.256	0.000623
Clean fuel use	0.0493	0.0311	0.113

U



Outcome	Estimate	Standard Error	P-Value
Under-5 LRI mortality	-0.0823	0.0196	0.0000311
Clean fuel use	0.0117	0.00313	0.000216