Carbon pricing and household welfare: evidence from Uganda

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ONLINE APPENDIX

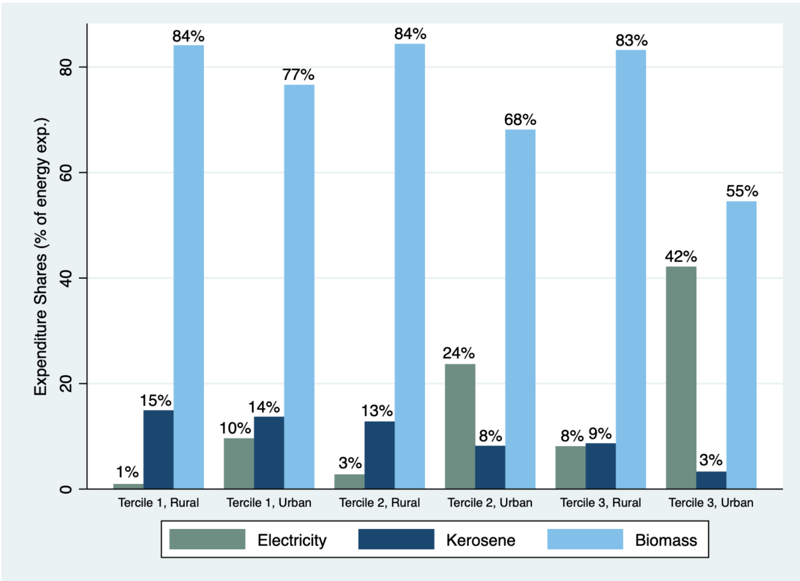
A Data preparation and descriptive statistics

This section presents additional details of the commodity price data, and additional descriptive statistics.

Market prices for food and energy items reported by households in the Uganda National Panel Survey (UNPS, World Bank LSMS), 2015–16, are expressed in various units, including non-standard units with no available metric conversion factors. We first convert the majority of unit codes for which metric conversions are available, into kilograms for food items and charcoal, bundles for firewood, and litres for kerosene. Next, we plot the mean price for each item and unit code, to detect potential outlier unit codes. We omit unit codes with prices in the order of 5–10 times the mean price for a specific item. The remaining unit codes are not converted. Hence, prices are reported in kilograms and litres for the majority of the sample, while the remaining observations contain prices reported in non-standard units such as bundles and heaps of firewood. Therefore, the price variation observed in table 2 partly reflects differences in unit codes of reporting. However, graphical inspection of the range of prices per item, for different unit codes, suggests that only a handful of unit codes reflect outlier values for prices. Further, we subsequently compute and analyse elasticities, which negate differences arising due to measurement units.

We do not employ alternative methods, e.g., estimation of prices by unit codes as outlined in Capéau and Dercon (2006), as estimation of prices for such non-standard fuels and units of measurement as bundles, heaps and bunches of charcoal and firewood, with no available metric conversions, could bias our estimates and introduce potentially non-classical measurement error.

Figure A1: Energy expenditure shares by expenditure tercile and rural/urban areas.

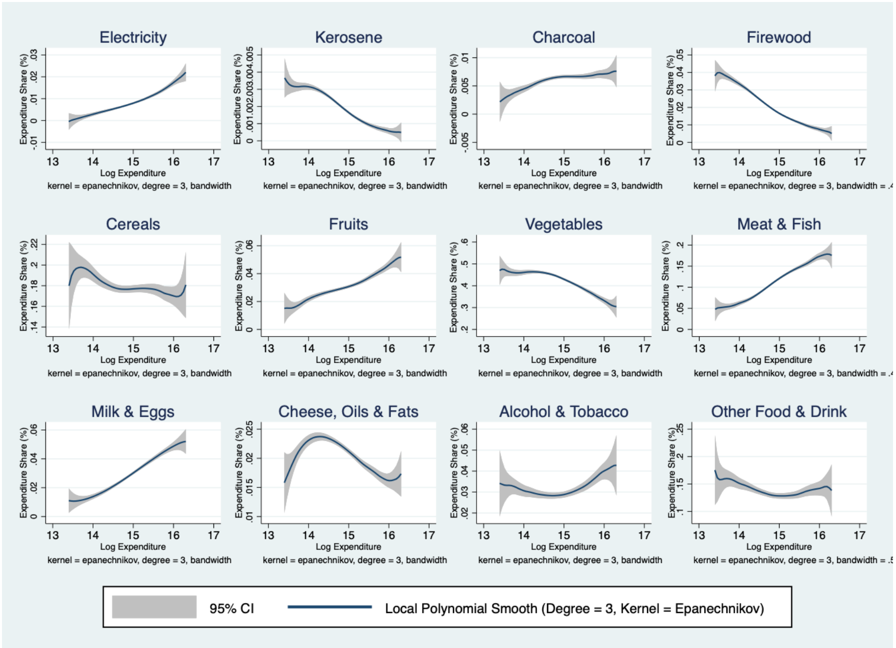


Note: The X-axis represents expenditure terciles, by rural/urban areas, and expenditure shares for each fuel are calculated as a percentage of total energy expenditure (or equivalently the monetary value of biomass). Biomass comprises the total expenditure on or value of charcoal and firewood consumed.

Table A1: Item-wise expenditure shares (%) by expenditure tercile and rural-urban areas

	Tercile 1				Tercile 2				Tercile 3			
	Rural		Urban		Rural		Urban		Rural		Urban	
Item	(1) Mean	(2) Std. Dev.	(3) Mean	(4) Std. Dev.	(5) Mean	(6) Std. Dev.	(7) Mean	(8) Std. Dev.	(9) Mean	(10) Std. Dev.	(11) Mean	(12) Std. Dev.
Electricity	0.09	1.00	0.84	2.79	0.22	1.49	1.76	3.27	0.57	2.15	3.07	4.20
Kerosene	0.32	0.51	0.35	0.60	0.22	0.36	0.17	0.36	0.13	0.46	0.08	0.26
Charcoal	0.26	1.16	1.22	2.12	0.31	1.04	1.63	2.12	0.37	0.99	1.50	1.53
Firewood	3.27	3.41	2.22	3.41	2.38	2.55	0.96	1.92	1.82	2.02	0.60	2.13
Cereals	18.06	18.36	18.14	17.27	17.48	15.95	18.38	15.04	17.34	13.41	17.54	11.97
Fruits	2.65	5.67	2.03	4.47	3.37	5.93	2.51	4.74	4.09	5.94	3.40	5.00
Vegetables	47.04	25.30	38.96	25.32	47.30	21.57	34.23	21.65	43.10	19.02	30.70	17.75
Meat & fish	7.84	10.72	6.63	9.34	11.45	12.57	9.86	11.14	13.80	12.73	13.58	11.76
Milk & eggs	1.71	4.69	1.80	4.83	2.80	5.61	2.84	5.09	3.99	6.05	4.47	5.56
Cheese, oils & fats	2.15	2.90	2.62	3.15	2.08	2.24	2.54	2.68	1.99	2.07	2.21	2.00
Alcohol & tobacco	3.43	7.75	3.29	8.29	2.92	6.80	3.40	7.75	3.15	6.87	3.41	7.28
Other food & drink	13.17	24.25	21.90	30.45	9.46	16.50	21.72	27.73	9.66	14.85	19.45	22.63
N	4,112		998		3,540		1,570		2,736		2,374	

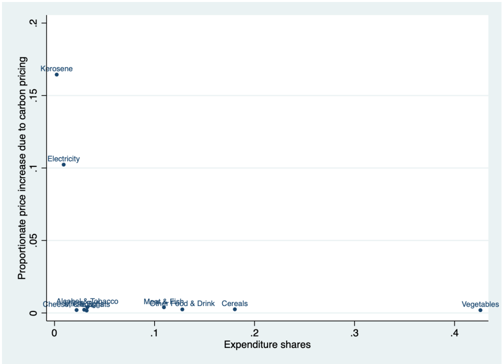
Figure A2: Item-specific Engel curves.



Note: The X-axis represents the household's log of expenditure on food and energy items.

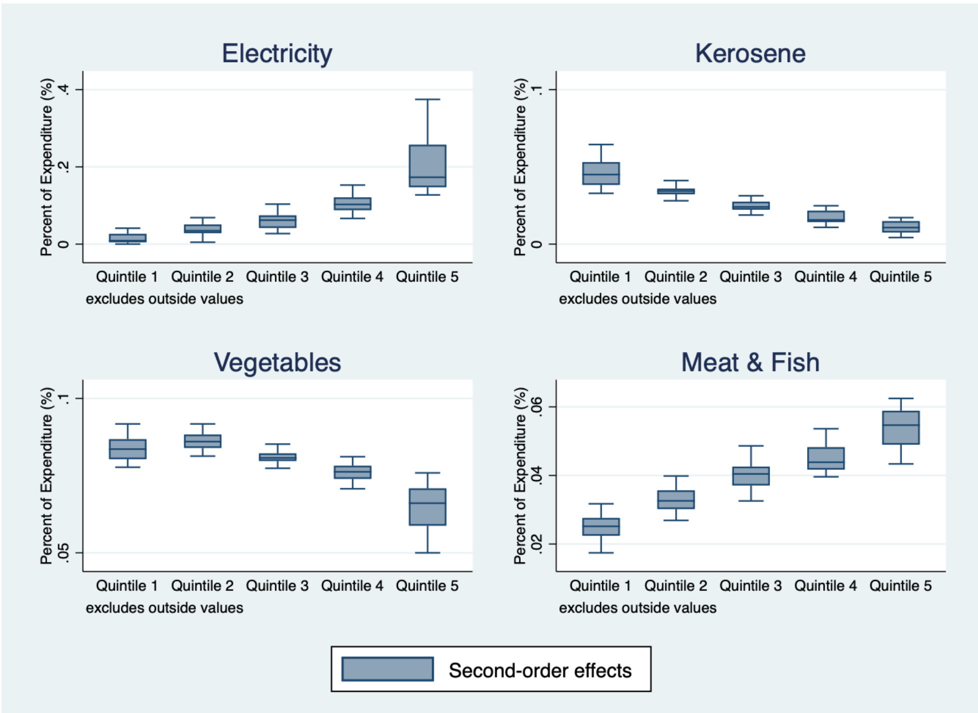
While the Engel curves are nonlinear for several items, the EASI model specification we employ is parsimonious and linearly approximates Engel curves for model tractability. Hence, the demand system approximates elasticities for a majority of households which exhibit linear Engel curves. While price elasticities of demand are likely unbiased, the income elasticities of demand depend on the shapes of the Engel curves. For convex-shaped Engel curves, demand responses to income are likely underestimated, as demand rises more sharply at higher income levels than estimated in a linear system. For concave-shaped Engel curves, demand responses to income are potentially overestimated as demand does not rise very sharply at higher income levels. The income elasticities of demand are most pertinent for biomass (charcoal and fuelwood) in our analysis, as it is important to understand whether solid fuels are "normal" or "inferior" goods among Ugandan households. Since Engel curves for these fuels are approximately linear, concerns of bias in income effects are largely negated.

Figure A3: Scatterplot of item-wise price increases and expenditure shares.



Note: The markers in the scatterplot correspond to the 12 items modelled in the demand system.

Figure A4: Welfare losses of carbon pricing for energy & select food items by expenditure quintile.



Note: We calculate the average welfare loss for each item, at each percentile, and plot the variation in the average losses within expenditure quintiles. Expenditure percentiles are calculated based on households' total real expenditure, while the welfare loss is measured as a percentage of the household's expenditure on food and energy. The boxes represent the interquartile range (25th percentile to 75th percentile) and the horizontal line in each box represents the median value. The upper and lower whiskers capture the upper (lower) adjacent values, which are the largest (smallest) observations equal to the value at the third (first) quartile plus (minus) 1.5 times the interquartile range, while all remaining observations, i.e., those above (below) the upper (lower) adjacent values, are excluded from the plot.

B Derivation: proportionate change in quantity demanded

Consider a Marshallian demand function f_i for commodity i, as a function of the J-vector of prices q, and total household expenditure x:

$$f_i = f_i(q_1, q_2, ..., q_i, ..., q_J; x).$$

The differential of f_i is expressed as:

$$df_i = \frac{\partial f_i}{\partial q_1} dq_1 + ... + \frac{\partial f_i}{\partial q_J} dq_J + \frac{\partial f_i}{\partial x} dx.$$

Now we consider changes in all commodities' prices, holding total expenditure x constant (hence $dx = 0$), and compute the proportionate change in quantity demanded for good i:

$$\frac{df_i}{f_i} = \frac{\partial f_i}{q_1} \frac{q_1}{f_i} \frac{dq_1}{q_1} + ... + \frac{\partial f_i}{\partial q_J} \frac{q_J}{f_i} \frac{dq_J}{q_J}.$$

For small price changes around the initial demand vector, this can be approximated in elasticity form, as follows:

$$\begin{aligned} \frac{\Delta f_i}{f_i} &\approx e^u_{f_i,q_1} \frac{\Delta q_1}{q_1} + ... + e^u_{f_i,q_J} \frac{\Delta q_J}{q_J} \\ &\approx \sum_{j=1}^{J} e^u_{f_i,q_j} \frac{\Delta q_j}{q_j}. \end{aligned}$$

C Regression coefficients and estimates

This section presents the (i) expenditure elasticities of demand, computed from the Tobit model regressions, (ii) the coefficients from the Tobit model regressions and the compensated price elasticities of demand for the rural and urban sub-samples, estimated from the Tobit models.

Table A2: Expenditure elasticities of demand (full sample)

Item	Elasticity of demand w.r.t. real expenditure
Electricity	1.064
	(0.003)
Kerosene	0.825
	(0.009)
Charcoal	1.093
	(0.005)
Firewood	0.693
	(0.012)
Cereals	0.970
	(0.010)
Fruits	1.228
	(0.009)
Vegetables	0.790
	(0.006)
Meat & fish	1.346
	(0.009)
Milk & eggs	1.281
	(0.008)
Cheese, oils & fats	1.076
	(0.010)
Alcohol & tobacco	1.139
	(0.008)
Other food & drink	1.143
	(0.016)

Note: Robust standard errors in parentheses.
N = 15,324.

The income elasticity of demand for a good reflects whether it is a necessity, an inferior good or a luxury good for households. The estimated expenditure elasticities of demand are used to compute the uncompensated price elasticities of demand.

Impacts on patterns of food consumption in response to carbon pricing suggest that individuals attempt to purchase foods that provide a cheaper source of calorie intake, as evidenced by the price per calorie computed for each food group (table A3).

Table A3: Price (UgX) per calorie, by broad food category

Item (Unit)	Mean price (per kg)	Mean price (per kcal)
Cereals (Kg)	1,865.19	0.63
Fruits (Kg)	954.12	1.27
Vegetables (Kg)	1,287.6	0.97
Meat & fish (Kg)	5,911.7	2.61
Milk & eggs (Kg)	1,161.59	0.8
Cheese, oils & fats (Kg)	2,142.63	0.26
Other food & drink (Kg/L)	1,589.82	0.56

Note: Prices are in Ugandan shillings (UgX) per kilogram/litre (kg/L) or per kilocalorie (kcal).

Table A4: Compensated price elasticities of demand (full sample)

	E	K	C	Fw	Ce	Fr	V	Me	Mi	Ch	Al	O
Electricity	-1.006	0.001	-0.008	0.021	0.022	0.008	0.008	-0.014	0.013	-0.003	0.005	0.015
	(0.024)	(0.005)	(0.008)	(0.006)	(0.009)	(0.003)	(0.005)	(0.005)	(0.005)	(0.003)	(0.005)	(0.012)
Kerosene	-0.586	-1.114	-0.035	-0.001	-0.083	0.045	-0.048	0.032	-0.066	0.012	0.132	-0.222
	(0.093)	(0.015)	(0.024)	(0.024)	(0.025)	(0.013)	(0.017)	(0.015)	(0.023)	(0.008)	(0.022)	(0.045)
Charcoal	-0.076	0.005	-1.288	0.099	0.04	0.016	0.072	-0.039	-0.002	-0.009	0	-0.013
	(0.059)	(0.013)	(0.025)	(0.016)	(0.019)	(0.007)	(0.013)	(0.013)	(0.012)	(0.006)	(0.011)	(0.026)
Firewood	0.474	0.089	0.252	-1.17	-0.159	-0.063	-0.067	0.05	-0.095	0.031	0.024	-0.006
	(0.108)	(0.029)	(0.041)	(0.03)	(0.024)	(0.012)	(0.023)	(0.018)	(0.022)	(0.011)	(0.015)	(0.044)
Cereals	-0.079	0.137	-0.065	-0.167	-1.275	0.142	0.236	0.066	-0.039	-0.024	-0.329	0.695
	(0.109)	(0.028)	(0.027)	(0.031)	(0.027)	(0.014)	(0.023)	(0.018)	(0.019)	(0.011)	(0.021)	(0.045)
Fruits	-0.185	-0.069	-0.025	-0.006	0.049	-1.292	0.009	0.141	-0.018	0.014	0.173	0.194
	(0.11)	(0.027)	(0.027)	(0.031)	(0.029)	(0.013)	(0.026)	(0.02)	(0.022)	(0.011)	(0.023)	(0.046)
Vegetables	-0.148	-0.036	0.033	0.081	0.077	-0.052	-1.038	-0.025	0.05	-0.006	0.137	-0.118
	(0.073)	(0.018)	(0.015)	(0.019)	(0.018)	(0.008)	(0.015)	(0.011)	(0.013)	(0.006)	(0.013)	(0.031)
Meat & fish	-0.531	-0.068	-0.086	-0.108	0.195	-0.002	-0.145	-1.079	0.074	-0.057	-0.048	-0.253
	(0.108)	(0.027)	(0.031)	(0.03)	(0.028)	(0.013)	(0.021)	(0.015)	(0.022)	(0.01)	(0.018)	(0.045)
Milk & eggs	-0.434	0.03	-0.089	-0.095	0.081	0.058	0.12	0.094	-1.56	0.025	-0.089	0.302
	(0.096)	(0.023)	(0.024)	(0.026)	(0.026)	(0.013)	(0.021)	(0.016)	(0.02)	(0.009)	(0.017)	(0.042)
Cheese, oils & fats	-0.527	0.062	-0.099	0.094	-0.062	0.063	-0.136	-0.007	-0.055	-1.135	0.076	0.147
	(0.114)	(0.027)	(0.028)	(0.031)	(0.032)	(0.014)	(0.024)	(0.019)	(0.023)	(0.01)	(0.021)	(0.055)
Alcohol & tobacco	-0.442	0.035	0.005	-0.018	-0.029	0.009	0.007	0.022	0.023	0.031	-1.188	0.157
	(0.095)	(0.034)	(0.025)	(0.025)	(0.023)	(0.013)	(0.019)	(0.016)	(0.019)	(0.009)	(0.013)	(0.037)
Other food & drink	0.837	-0.037	0.095	0.1	0.058	0.01	-0.07	-0.027	0.02	0.044	0.145	-1.518
	(0.175)	(0.037)	(0.039)	(0.034)	(0.034)	(0.017)	(0.03)	(0.018)	(0.032)	(0.011)	(0.026)	(0.073)

Note: The items are: Electricity (E), Kerosene (K), Charcoal (C), Firewood (Fw), Cereals (Ce), Fruits (Fr), Vegetables (V), Meat & fish (Me), Milk & eggs (Mi), Cheese, oils & fats (Ch), Alcohol & tobacco (Al) and Other food and drink (O). Robust standard errors in parentheses. The source Tobit regressions include dummy variables for region, rural-urban area and household size. N = 15,324.

Table A5: Tobit model regression coefficients

Coeff.	w1	Coeff.	w2	Coeff.	w3	Coeff.	w4	Coeff.	w5	Coeff.	w6
$b_{1,y}$	0.004	$b_{2,y}$	-0.001	$b_{3,y}$	0.002	$b_{4,y}$	-0.011	$b_{5,y}$	-0.006	$b_{6,y}$	0.015
	(0.000)		(0.000)		(0.000)		(0.000)		(0.002)		(0.001)
$a_{1,1}$	0.000	$a_{2,1}$	-0.004	$a_{3,1}$	-0.002	$a_{4,1}$	0.017	$a_{5,1}$	-0.016	$a_{6,1}$	-0.012
	(0.000)		(0.001)		(0.002)		(0.004)		(0.023)		(0.007)
$a_{1,2}$	0.000	$a_{2,2}$	-0.001	$a_{3,2}$	0.000	$a_{4,2}$	0.003	$a_{5,2}$	0.029	$a_{6,2}$	-0.004
	(0.000)		(0.000)		(0.001)		(0.001)		(0.006)		(0.002)
$a_{1,3}$	0.000	$a_{2,3}$	-0.000	$a_{3,3}$	-0.007	$a_{4,3}$	0.009	$a_{5,3}$	-0.012	$a_{6,3}$	-0.001
	(0.000)		(0.000)		(0.001)		(0.001)		(0.006)		(0.002)
$a_{1,4}$	0.001	$a_{2,4}$	0.000	$a_{3,4}$	0.003	$a_{4,4}$	-0.006	$a_{5,4}$	-0.035	$a_{6,4}$	-0.000
	(0.000)		(0.000)		(0.000)		(0.001)		(0.006)		(0.002)
$a_{1,5}$	0.001	$a_{2,5}$	-0.001	$a_{3,5}$	0.001	$a_{4,5}$	-0.005	$a_{5,5}$	-0.058	$a_{6,5}$	0.003
	(0.000)		(0.000)		(0.000)		(0.000)		(0.006)		(0.002)
$a_{1,6}$	0.000	$a_{2,6}$	0.000	$a_{3,6}$	0.000	$a_{4,6}$	-0.002	$a_{5,6}$	0.030	$a_{6,6}$	-0.010
	(0.000)		(0.000)		(0.000)		(0.000)		(0.003)		(0.001)
$a_{1,7}$	0.000	$a_{2,7}$	-0.000	$a_{3,7}$	0.002	$a_{4,7}$	-0.002	$a_{5,7}$	0.050	$a_{6,7}$	0.001
	(0.000)		(0.000)		(0.000)		(0.001)		(0.005)		(0.002)
$a_{1,8}$	-0.001	$a_{2,8}$	0.000	$a_{3,8}$	-0.001	$a_{4,8}$	0.002	$a_{5,8}$	0.014	$a_{6,8}$	0.009
	(0.000)		(0.000)		(0.000)		(0.001)		(0.004)		(0.001)
$a_{1,9}$	0.001	$a_{2,9}$	-0.000	$a_{3,9}$	-0.000	$a_{4,9}$	-0.003	$a_{5,9}$	-0.008	$a_{6,9}$	-0.001
	(0.000)		(0.000)		(0.000)		(0.001)		(0.004)		(0.001)
$a_{1,10}$	0.000	$a_{2,10}$	0.000	$a_{3,10}$	-0.000	$a_{4,10}$	0.001	$a_{5,10}$	-0.003	$a_{6,10}$	0.001
	(0.000)		(0.000)		(0.000)		(0.000)		(0.002)		(0.001)
$a_{1,11}$	0.000	$a_{2,11}$	0.001	$a_{3,11}$	0.000	$a_{4,11}$	0.001	$a_{5,11}$	-0.069	$a_{6,11}$	0.012
	(0.000)		(0.000)		(0.000)		(0.0001)		(0.004)		(0.002)
$a_{1,12}$	0.001	$a_{2,12}$	-0.001	$a_{3,12}$	-0.000	$a_{4,12}$	-0.000	$a_{5,12}$	0.147	$a_{6,12}$	0.013
	(0.000)		(0.000)		(0.001)		(0.002)		(0.010)		(0.003)
F-st.	68.17	F-st.	47.82	F-st.	155.07	F-st.	146.53	F-st.	83.81	F-st.	66.50
P.-R^2	1.31	P.-R^2	-0.07	P.-R^2	-1.12	P.-R^2	-0.15	P.-R^2	-0.55	P.-R^2	-0.59

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Table A5. Tobit model regression coefficients (contd.)

Coeff.	w7	Coeff.	w8	Coeff.	w9	Coeff.	w10	Coeff.	w11	Coeff.	w12
$b_{7,y}$	-0.093	$b_{8,y}$	0.057	$b_{9,y}$	0.021	$b_{10,y}$	0.002	$b_{11,y}$	0.014	$b_{12,y}$	0.020
	(0.003)		(0.002)		(0.001)		(0.000)		(0.0031)		(0.002)
$a_{7,1}$	-0.064	$a_{8,1}$	-0.087	$a_{9,1}$	-0.032	$a_{10,1}$	-0.016	$a_{11,1}$	-0.044	$a_{12,1}$	0.118
	(0.033)		(0.018)		(0.007)		(0.004)		(0.010)		(0.025)
$a_{7,2}$	-0.016	$a_{8,2}$	-0.011	$a_{9,2}$	0.002	$a_{10,2}$	0.002	$a_{11,2}$	0.004	$a_{12,2}$	-0.005
	(0.008)		(0.004)		(0.002)		(0.001)		(0.003)		(0.005)
$a_{7,3}$	0.015	$a_{8,3}$	-0.014	$a_{9,3}$	-0.006	$a_{10,3}$	-0.003	$a_{11,3}$	0.001	$a_{12,3}$	0.013
	(0.007)		(0.005)		(0.002)		(0.001)		(0.003)		(0.005)
$a_{7,4}$	0.036	$a_{8,4}$	-0.017	$a_{9,4}$	-0.007	$a_{10,4}$	0.003	$a_{11,4}$	-0.001	$a_{12,4}$	0.014
	(0.008)		(0.005)		(0.002)		(0.001)		(0.002)		(0.005)
$a_{7,5}$	0.034	$a_{8,5}$	0.032	$a_{9,5}$	0.006	$a_{10,5}$	-0.001	$a_{11,5}$	-0.002	$a_{12,5}$	0.008
	(0.008)		(0.005)		(0.002)		(0.001)		(0.002)		(0.005)
$a_{7,6}$	-0.023	$a_{8,6}$	-0.001	$a_{9,6}$	0.004	$a_{10,6}$	0.002	$a_{11,6}$	0.001	$a_{12,6}$	0.001
	(0.004)		(0.002)		(0.001)		(0.000)		(0.001)		(0.002)
$a_{7,7}$	-0.015	$a_{8,7}$	-0.022	$a_{9,7}$	0.009	$a_{10,7}$	-0.004	$a_{11,7}$	0.001	$a_{12,7}$	-0.010
	(0.006)		(0.003)		(0.002)		(0.001)		(0.002)		(0.004)
$a_{7,8}$	-0.011	$a_{8,8}$	-0.012	$a_{9,8}$	0.007	$a_{10,8}$	-0.000	$a_{11,8}$	0.002	$a_{12,8}$	-0.004
	(0.005)		(0.002)		(0.002)		(0.001)		(0.002)		(0.002)
$a_{7,9}$	0.022	$a_{8,9}$	0.012	$a_{9,9}$	-0.041	$a_{10,9}$	-0.001	$a_{11,9}$	0.002	$a_{12,9}$	0.003
	(0.006)		(0.004)		(0.002)		(0.001)		(0.002)		(0.005)
$a_{7,10}$	-0.002	$a_{8,10}$	-0.009	$a_{9,10}$	0.002	$a_{10,10}$	-0.004	$a_{11,10}$	0.003	$a_{12,10}$	0.006
	(0.003)		(0.002)		(0.001)		(0.000)		(0.001)		(0.002)
$a_{7,11}$	0.061	$a_{8,11}$	-0.007	$a_{9,11}$	-0.006	$a_{10,11}$	0.002	$a_{11,11}$	-0.018	$a_{12,11}$	0.020
	(0.006)		(0.003)		(0.001)		(0.001)		(0.001)		(0.004)
$a_{7,12}$	-0.052	$a_{8,12}$	-0.041	$a_{9,12}$	0.022	$a_{10,12}$	0.005	$a_{11,12}$	0.016	$a_{12,12}$	-0.073
	(0.014)		(0.007)		(0.003)		(0.002)		(0.004)		(0.010)
F-st.	274.87	F-st.	124.18	F-st.	116.81	F-st.	88.86	F-st.	66.60	F-st.	131.90
P.-R^2	1.93	P.-R^2	1.24	P.-R^2	2.11	P.-R^2	-0.05	P.-R^2	0.19	P.-R^2	-2.73

Note: This regression is based on equation (8) and includes the following control variables: region, rural/urban and household size. Constant term suppressed. Robust standard errors in parentheses. N = 15,324.

Table A6: Compensated price elasticities of demand (rural sample)

	E	K	C	Fw	Ce	Fr	V	Me	Mi	Ch	Al	O
Electricity	-1.026	-0.001	-0.008	0.024	0.007	0.008	-0.002	-0.006	0.018	-0.006	0.011	0.017
	(0.019)	(0.002)	(0.006)	(0.005)	(0.005)	(0.003)	(0.004)	(0.003)	(0.004)	(0.002)	(0.004)	(0.008)
Kerosene	-0.435	-1.16	0.08	-0.003	-0.102	0.062	-0.073	0.051	-0.067	0.004	0.152	-0.277
	(0.118)	(0.019)	(0.033)	(0.033)	(0.03)	(0.018)	(0.021)	(0.017)	(0.03)	(0.01)	(0.029)	(0.059)
Charcoal	-0.102	-0.004	-1.17	0.114	0.001	0.01	-0.03	-0.04	0.005	-0.036	0.011	0.075
	(0.051)	(0.009)	(0.021)	(0.014)	(0.012)	(0.007)	(0.01)	(0.008)	(0.01)	(0.004)	(0.009)	(0.018)
Firewood	0.927	0.146	0.346	-1.305	-0.17	-0.053	-0.048	0.057	-0.059	0.083	0.057	-0.158
	(0.138)	(0.039)	(0.062)	(0.037)	(0.029)	(0.016)	(0.028)	(0.022)	(0.027)	(0.013)	(0.018)	(0.057)
Cereals	-0.088	0.213	-0.042	-0.206	-1.289	0.135	0.221	0.058	-0.067	-0.053	-0.33	0.811
	(0.135)	(0.034)	(0.034)	(0.037)	(0.03)	(0.019)	(0.028)	(0.019)	(0.023)	(0.012)	(0.023)	(0.052)
Fruits	-0.187	-0.127	-0.024	0.058	0.025	-1.519	-0.102	0.145	-0.081	0.012	0.101	0.276
	(0.128)	(0.03)	(0.032)	(0.038)	(0.03)	(0.018)	(0.031)	(0.021)	(0.025)	(0.012)	(0.024)	(0.05)
Vegetables	-0.04	-0.064	0.059	0.087	0.062	-0.044	-1.137	-0.039	0.059	-0.016	0.17	-0.157
	(0.084)	(0.021)	(0.017)	(0.022)	(0.019)	(0.011)	(0.016)	(0.011)	(0.015)	(0.007)	(0.014)	(0.033)
Meat & fish	-0.662	-0.069	-0.122	-0.05	0.142	0.038	-0.224	-1.197	0.071	-0.057	-0.059	-0.174
	(0.129)	(0.031)	(0.039)	(0.037)	(0.028)	(0.016)	(0.024)	(0.016)	(0.025)	(0.011)	(0.019)	(0.05)
Milk & eggs	-0.405	0.055	-0.096	-0.073	0.088	0.086	0.118	0.063	-1.823	0.015	-0.09	0.557
	(0.102)	(0.022)	(0.026)	(0.029)	(0.027)	(0.015)	(0.023)	(0.013)	(0.024)	(0.009)	(0.016)	(0.042)
Cheese, oils & fats	-0.465	0.096	-0.086	0.175	-0.131	0.059	-0.276	-0.024	-0.159	-1.216	0.085	0.311
	(0.136)	(0.03)	(0.034)	(0.039)	(0.034)	(0.018)	(0.028)	(0.019)	(0.026)	(0.012)	(0.023)	(0.06)
Alcohol & tobacco	-0.262	0.024	-0.01	0.006	-0.058	-0.048	0.006	0.049	0.027	0.026	-1.355	0.211
	(0.107)	(0.04)	(0.028)	(0.03)	(0.023)	(0.015)	(0.021)	(0.018)	(0.02)	(0.01)	(0.015)	(0.04)
Other food & drink	0.487	-0.049	0.05	0.109	0.178	0.086	0.302	0.099	0.248	0.138	0.195	-1.916
	(0.237)	(0.058)	(0.055)	(0.052)	(0.045)	(0.026)	(0.043)	(0.021)	(0.042)	(0.016)	(0.035)	(0.098)

Note: The items are: Electricity (E), Kerosene (K), Charcoal (C), Firewood (Fw), Cereals (Ce), Fruits (Fr), Vegetables (V), Meat & fish (Me), Milk & eggs (Mi), Cheese, oils & fats (Ch), Alcohol & tobacco (Al) and Other food and drink (O). Robust standard errors in parentheses. The source Tobit regressions include dummy variables for region, rural-urban area and household size. $N = 10{,}353$.

Table A7: Compensated price elasticities of demand (urban sample)

	E	K	C	Fw	Ce	Fr	V	Me	Mi	Ch	Al	O
Electricity	-1.211	0.03	0.009	0.082	0.154	0.074	0.062	0.007	0.027	0.064	-0.065	-0.016
	(0.154)	(0.056)	(0.043)	(0.038)	(0.075)	(0.023)	(0.039)	(0.055)	(0.034)	(0.02)	(0.042)	(0.087)
Kerosene	-0.532	-1.059	-0.103	0.031	-0.166	0.006	0.038	-0.072	0	0.027	-0.008	-0.412
	(0.133)	(0.02)	(0.036)	(0.034)	(0.059)	(0.017)	(0.034)	(0.042)	(0.034)	(0.015)	(0.044)	(0.077)
Charcoal	-0.249	0.027	-1.67	0.158	0.28	0.069	0.404	0.339	-0.016	0.154	-0.303	-0.677
	(0.184)	(0.058)	(0.054)	(0.057)	(0.088)	(0.026)	(0.054)	(0.059)	(0.037)	(0.027)	(0.05)	(0.106)
Firewood	0.125	0.041	0.18	-1.018	-0.135	-0.054	0.05	-0.028	-0.108	-0.076	-0.096	-0.027
	(0.144)	(0.024)	(0.046)	(0.033)	(0.059)	(0.014)	(0.036)	(0.047)	(0.039)	(0.02)	(0.046)	(0.065)
Cereals	0.147	-0.061	-0.212	-0.1	-0.94	0.154	0.314	0.207	0.016	0.049	-0.286	0.085
	(0.179)	(0.045)	(0.043)	(0.061)	(0.097)	(0.024)	(0.048)	(0.058)	(0.034)	(0.021)	(0.05)	(0.102)
Fruits	-0.624	0.088	0.08	-0.16	0.217	-0.875	0.038	0.258	0.048	-0.009	-0.017	0.113
	(0.192)	(0.067)	(0.053)	(0.052)	(0.088)	(0.027)	(0.05)	(0.061)	(0.041)	(0.022)	(0.055)	(0.105)
Vegetables	-0.106	0.011	-0.001	0.089	0.157	-0.085	-0.722	0.09	0.07	-0.003	-0.499	-0.274
	(0.139)	(0.043)	(0.033)	(0.04)	(0.06)	(0.016)	(0.039)	(0.039)	(0.028)	(0.015)	(0.043)	(0.078)
Meat & fish	-0.965	-0.066	-0.14	-0.045	0.386	-0.001	-0.061	0.145	0.116	-0.106	-0.352	-0.431
	(0.182)	(0.066)	(0.055)	(0.047)	(0.083)	(0.022)	(0.049)	(0.058)	(0.039)	(0.022)	(0.053)	(0.095)
Milk & eggs	-0.689	0.091	-0.117	-0.06	0.087	-0.047	0.143	0.327	-0.597	-0.001	-0.104	-0.183
	(0.183)	(0.057)	(0.053)	(0.055)	(0.085)	(0.024)	(0.051)	(0.059)	(0.043)	(0.022)	(0.051)	(0.107)
Cheese, oils & fats	-0.79	-0.061	-0.273	0.166	0.296	0.027	0.19	0.29	0.135	-0.899	-0.222	-0.476
	(0.196)	(0.052)	(0.052)	(0.06)	(0.078)	(0.026)	(0.05)	(0.065)	(0.042)	(0.024)	(0.061)	(0.121)
Alcohol & tobacco	-0.605	0.02	0.006	0.008	-0.211	-0.001	-0.165	-0.212	-0.065	-0.037	0.188	-0.061
	(0.149)	(0.038)	(0.042)	(0.044)	(0.071)	(0.02)	(0.041)	(0.047)	(0.032)	(0.017)	(0.052)	(0.068)
Other food & drink	1.03	0.034	0.256	-0.057	-0.365	-0.013	-0.554	-0.804	-0.262	-0.006	0.578	-0.469
	(0.256)	(0.052)	(0.059)	(0.047)	(0.106)	(0.028)	(0.062)	(0.07)	(0.054)	(0.023)	(0.08)	(0.132)

Note: The items are: Electricity (E), Kerosene (K), Charcoal (C), Firewood (Fw), Cereals (Ce), Fruits (Fr), Vegetables (V), Meat & fish (Me), Milk & eggs (Mi), Cheese, oils & fats (Ch), Alcohol & tobacco (Al) and Other food and drink (O). Robust standard errors in parentheses. The source Tobit regressions include dummy variables for region, rural-urban area and household size. N = 4,979.

Table A8: Matching of UNHS consumption items with GTAP sectors

UNHS item code	UNHS item	GTAP sector	GTAP code
101	Matooke (bunch)	v_f	4
102	Matooke (cluster)	v_f	4
103	Matooke (heap)	v_f	4
107	Cassava (fresh)	v_f	4
109	Irish potatoes	v_f	4
114	Bread (wheat)	ofd	25
116	Sorghum	ofd	25
117	Beef	cmt	19
119	Goat meat	cmt	19
120	Other meat (e.g., duck, rabbit)	omt	20
125	Fresh milk	mil	22
126	Infant formula foods	ofd	25
128	Ghee	mil	22
129	Margarine	vol	21
130	Passion fruits	v_f	4
132	Mangoes	v_f	4
133	Oranges/Tangerines	v_f	4
134	Other fruits	v_f	4
135	Onions	v_f	4
136	Tomatoes	v_f	4
138	Dodo/Nakati/Gyobyo/Malakwang	v_f	4
139	Other vegetables	v_f	4
140	Bean (fresh)	v_f	4
141	Beans (dry)	ofd	25
142	Ground nuts (in shell)	v_f	4
143	Ground nuts (shelled)	v_f	4
144	Ground nuts (pounded)	v_f	4

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Table A8 – Matching of UNHS consumption items with GTAP sectors (contd.)

UNHS item code	UNHS item	GTAP sector	GTAP code
145	Peas (fresh)	v_f	4
147	Sugar	sgr	24
150	Salt	ocr	8
151	Soda	b_t	26
152	Beer	b_t	26
153	Other alcoholic drinks	b_t	26
154	Other drinks	b_t	26
155	Cigarettes	b_t	26
156	Other tobacco	b_t	26
157	Food in restaurants	ofd	25
158	Soda in restaurants	b_t	26
159	Beer in restaurants	b_t	26
160	Other juice packed in restaurant	b_t	26
161	Other foods in restaurants	ofd	25
162	Peas (dry)	ofd	25
163	Ground nuts (paste)	ofd	25
164	Green pepper	v_f	4
165	Pumpkins	v_f	4
166	Avocado	v_f	4
167	Carrots	v_f	4
168	Eggplants	v_f	4
169	Watermelon	v_f	4
170	Pineapple	v_f	4
171	Pawpaw	v_f	4
172	Wheat (flour)	wht	2
173	Chapati	ofd	25
174	Apples	v_f	4

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Table A8 – Matching of UNHS consumption items with GTAP sectors (contd.)

UNHS item code	UNHS item	GTAP sector	GTAP code
175	Water	b_t	26
306	Electricity	ely	46
308	Paraffin or kerosene	p_c	32
309	Charcoal	NA	0
310	Firewood	NA	0
1051	Sweet potatoes white/yellow (fres	v_f	4
1052	Sweet potatoes-orange fleshed (f	v_f	4
1061	Sweet potatoes white/yellow (dry)	v_f	4
1062	Sweet potatoes-orange (dry)	v_f	4
1063	Sweet potatoes white/yellow (flo	v_f	4
1081	Cassava (dry)	v_f	4
1082	Cassava (flour)	v_f	4
1083	Pancakes (Kabalagala)	v_f	4
1101	Rice (white)	pdr	1
1102	Rice (brown)	pdr	1
1111	Maize yellow (grains)	gro	3
1112	Maize white (grains)	gro	3
1121	Maize white (cobs)	gro	3
1122	Maize yellow (cobs)	gro	3
1131	Maize white (flour)	ofd	25
1132	Maize yellow (flour)	ofd	25
1151	Millet flour	ofd	25
1171	Beef liver	cmt	19
1172	Beef offals	cmt	19
1191	Goat liver	cmt	19
1192	Goat offals	cmt	19
1193	Roasted goat meat	cmt	19

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Table A8 – Matching of UNHS consumption items with GTAP sectors (contd.)

UNHS item code	UNHS item	GTAP sector	GTAP code
1201	Roasted other meat	*omt*	20
1211	Chicken off-layer	*oap*	10
1212	Chicken broiler	*oap*	10
1213	Chicken kroiler	*oap*	10
1214	Chicken local	*oap*	10
1215	Roasted chicken	*oap*	10
1221	Fresh tilapia fish	*ofd*	25
1222	Fresh Nile perch	*ofd*	25
1231	Dry/ Smoked tilapia fish	*ofd*	25
1232	Dry/Smoked Nile perch	*ofd*	25
1234	Dried Nkejje	*ofd*	25
1235	Other fresh fish	*ofd*	25
1236	Other dry/smoked fish	*ofd*	25
1237	Silver fish (Mukene)	*ofd*	25
1241	Eggs (yellow yolk)	*oap*	10
1242	Eggs (white yolk)	*oap*	10
1243	Other eggs (duck, turkey etc)	*oap*	10
1251	Milk powdered	*mil*	22
1252	Fermented milk (Bongo)	*mil*	22
1253	Ice-cream	*mil*	22
1254	Yoghurt	*mil*	22
1271	Cooking oil refined	*vol*	21
1272	Cooking oil unrefined	*vol*	21
1281	Cheese	*mil*	22
1291	Butter	*mil*	22
1311	Sweet bananas-Ndiizi	v_f	4
1312	Sweet bananas-Bogoya	v_f	4

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Table A8 – Matching of UNHS consumption items with GTAP sectors (contd.)

UNHS item code	UNHS item	GTAP sector	GTAP code
1313	Plantain (gonja/kivuvu)	v_f	4
1351	Garlic	v_f	4
1352	Ginger fresh	v_f	4
1353	Ginger powder	ocr	8
1371	Cabbage – red leaf	v_f	4
1372	Cabbage – green leaf	v_f	4
1391	Other spices	ocr	8
1461	Simsim	osd	5
1462	Simsim paste	osd	5
1471	Honey	oap	10
1472	Jam/Marmalade	ofd	25
1481	Coffee	b_t	26
1482	Coffee other	ocr	8
1491	Tea leaves	ocr	8
1492	Tea bags	b_t	26
1493	Green tea	b_t	26
1601	Other juice fresh	b_t	26
1602	Other juice packed	b_t	26
1603	Other juice fresh in restaurants	b_t	26
1651	Pumpkin leaves	v_f	4
1652	Mushrooms	v_f	4
1653	Cucumber	v_f	4
1654	Okra	v_f	4
1721	Macaroni/Spaghetti	ofd	25
1731	Biscuits	ofd	25
1732	Cakes	ofd	25
1733	Doughnuts	ofd	25

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Table A8 – Matching of UNHS consumption items with GTAP sectors (contd.)

UNHS item code	UNHS item	GTAP sector	GTAP code
1734	Cornflakes	ofd	25
1735	Samosas	ofd	25
1741	Jackfruit (ffene)	v_f	4
1761	Soya beans (fresh)	v_f	4
1762	Soya beans (dry)	ofd	25

D Robustness checks

We first conduct a robustness check to simulate the effects of carbon pricing, accounting for indirect emissions from the transportation of biomass and consequent price increases for solid fuels, charcoal and firewood. Next, we conduct two robustness checks for the demand system, employing an alternative methodology, and accounting for the potential pass-through of transport prices to commodity prices, and hence employing an instrumental variable approach.

D.1 Carbon pricing with indirect taxes on biomass

To account for the indirect emissions generated from biomass consumption, primarily due to transportation of charcoal and firewood to different markets, we match charcoal and firewood consumption from the Uganda National Household Survey (UNHS) to the forestry sector of GTAP, to obtain the indirect CO2 emissions intensity of biomass.[1] We apply a carbon price of USD40/ton, which raises prices of charcoal and firewood by nearly 1 per cent (table A9). We find analogous results, with the aggregate demand

[1]In this exercise, we map biomass consumption from the household survey to the forestry sector in GTAP, to obtain approximate effects of a carbon price on transportation on price increases for biomass. However, the forestry sector in GTAP does not distinguish the carbon intensities of charcoal vis-á-vis firewood, while evidence suggests charcoal value chains are more strongly linked to transportation networks than firewood (MEMD, 2015).

for electricity and kerosene declining by 11 and 20 per cent respectively, and firewood consumption rising by 10 per cent due to the carbon price.

Table A9: Price and demand changes due to carbon pricing (USD40/tCO2)

Category	(1) Price increase (%)	(2) Demand change (%)
Electricity	10.2	-11.18
Kerosene	16.4	-19.85
Charcoal	0.58	-1.83
Firewood	0.58	10.00
Cereals	0.25	68.99
Fruits	0.17	-15.60
Vegetables	0.19	-53.30
Meat & fish	0.39	-47.08
Milk & eggs	0.22	-1.97
Cheese, oils & fats	0.20	0.65
Alcohol & tobacco	0.40	-0.73
Other food & drink	0.25	7.48

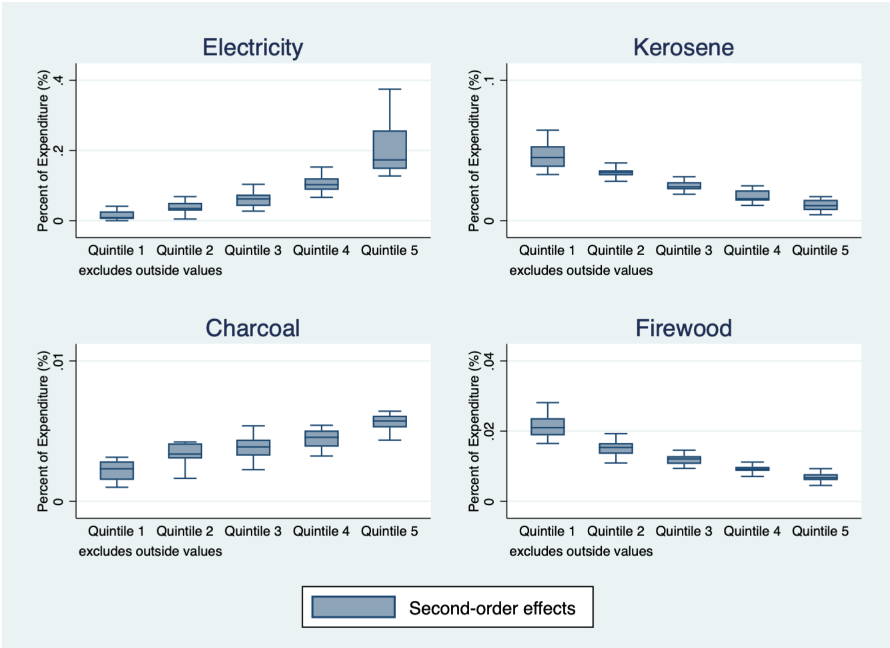
Note: Demand changes (%) are based on the uncompensated price elasticities of demand estimated for the full sample (table 3).

Welfare losses generated by a carbon price are slightly higher when biomass is also taxed, with second-order effects in the range of 0.2 to 12.4 per cent of household expenditure on food and fuel. Welfare losses due to charcoal are progressive across the expenditure distribution, while those due to firewood are regressive (figure A5).

We additionally compute the potential increase in deforested area due to higher firewood consumption from carbon pricing. Firewood consumption increases by 10 per cent due to a carbon price of USD40/tCO2, which is equivalent to 630 MT of firewood, relative to baseline consumption in Uganda. We draw on two estimates from the literature on the above-ground biomass yield per sq km in different types of Ugandan forests. The first estimate is a national average of 48.4 MT of firewood per 1,000 sq km in Uganda (Sridharan *et al.*, 2020). This suggests additional forest clearing of 13,013 sq km in Uganda, while the current area of forest land in Uganda is 23,460.84 sq km, which suggests significant deforestation of over half of Uganda's remaining forest reserves due to households' demand for fuelwood.

The second estimate is obtained from Jagger and Kittner (2017) based on a field study

Figure A5: Distribution of welfare losses due to a carbon price of USD40/ton.



Note: We calculate the average welfare loss for each item, at each percentile, and plot the variation in the average losses within expenditure quintiles. Expenditure percentiles are calculated based on households' total real expenditure, while the welfare loss is measured as a percentage of the household's expenditure on food and energy. The boxes represent the interquartile range (25th percentile to 75th percentile) and the horizontal line in each box represents the median value. The upper and lower whiskers capture the upper (lower) adjacent values, which are the largest (smallest) observations equal to the value at the third (first) quartile plus (minus) 1.5 times the interquartile range, while all remaining observations, i.e., those above (below) the upper (lower) adjacent values, are excluded from the plot.

conducted in Western Uganda in 2010. We weight the different biomass yields from the different types of forest with the share of each type in the total forest cover, obtained from the State of Uganda's Forestry report, 2015 (Ministry of Water and Environment, 2015), for the corresponding year, 2010, and find an average yield of 1,338.37 MT of biomass per sq km, which is substantially higher than the estimate from Sridharan *et al.* (2020). Based on this estimate from Jagger and Kittner (2017), we find additional forest clearing of less than 1 sq km, in Western Uganda. However, while this study examined a number of field sites, it may not represent the entire Western region of Uganda. In addition, estimates from 2010 may not apply to the present day, when significantly more deforestation has occurred in Uganda. Lastly, it is extremely challenging to reconcile such diverse estimates from the literature, to analyse the potential change in forest cover from additional fuelwood demand for the entire country.

We additionally explore estimates for the biomass yield in forests in other East African countries, to understand the range of magnitudes estimated for the East African region, a key biodiversity hotspot. Kinyanjui *et al.* (2014) estimate the density of woody biomass stocks in the Mau Forest Ecosystem of Kenya, one the most densely forested regions, and find an average density of 23.6 MT of biomass per 1,000 sq km. Similarly, Gizachew *et al.* (2016) estimate the density of biomass in the Miombo woodlands in Tanzania based on samples of 500 plots, and find a mean density of 8.1 MT of biomass per 1,000 sq km. Therefore, the estimates from Sridharan *et al.* (2020) for Uganda are slightly higher than those for neighbouring countries, while estimates from Jagger and Kittner (2017) are outliers in the considered range of estimates. Given the large variation in estimates, we interpret the implications of fuelwood usage for forest clearing and related emissions from land use change, with caution. These are open research questions to be considered carefully in future work.

D.2 Robustness checks – estimation of elasticities

D.2.1 Alternative econometric estimation of the EASI demand system

The main estimation of the EASI demand model applies the Tobit Type I estimator to each of the 12 commodity equations modelled in the demand system, while controlling for regional heterogeneity and economies of scale in the household. While we observe negative compensated own-price elasticities of demand (table A4), the equation-by-equation Tobit models do not allow us to impose certain parameter restrictions required for the estimates to be consistent with consumer theory.

Following Lewbel and Pendakur's (2009) EASI demand system (equations (1)–(7)), these restrictions include Walras' law, homogeneity of the cost function of degree one in prices and symmetry of the Slutsky matrix: $1'_J b_0 = 1$, $1'_J b_1 = 0$, $1'_J A = 0$, and $a_{jk} = a_{kj}$, $\forall j \neq k$. Imposing these parameter restrictions requires joint estimation of the system of commodity share equations. We build on advancements made by Meyerhoefer *et al.* (2005), Jakubson (1988) and Chamberlain (1980, 1984) in efficient estimation of censored models for nonlinear equation systems.

We utilise the Generalized Method of Moments (GMM) to jointly estimate this system of 12 correlated equations in an efficient manner (Hansen, 1982; Wooldridge, 2010), while incorporating the censored regression model (Tobit Type I) into the moment equations. The derivation of the expected value continues from section 2.2, with the Tobit model equations reproduced below.

The latent budget share equation for good j and household i, based on equation (2), is

$$w_{ij}^{*} = b_{0j} + b_{1j}\tilde{y}_i + \sum_{k=1}^{J} a_{jk}p_{kd} + \tilde{\epsilon}_{ij}, \tag{1}$$

where $\tilde{\epsilon}_{ij} \sim N(0, \sigma_{\epsilon}^{2})$, with the corresponding Tobit Type I model

$$w_{ij} = max(0, w_{ij}^{*}),$$

where w_{ij} is the observed budget share, $\tilde{y}_i$ is the natural logarithm of household real expenditure (nominal expenditure x, deflated by the consumer price index), p_{kd} are *log* prices for commodity k and district d and $\tilde{\epsilon}_{ij}$ is a normally distributed error term.

In compact form, let w denote the vector of observed budget shares (w_{ij}), X the vector of covariates ($\tilde{y}, p_{kd}$), β the vector of coefficients (b_{0j}, b_{1j}, a_{jk}), and let $X\beta$ be the expected value of the latent budget share.

Assuming weak exogeneity between the covariates and the error terms, i.e. $E(\tilde{\epsilon}_{ij}|X_i) = 0$, we apply the pooled Tobit estimator, which maximizes the partial likelihood for each equation. Given potential correlation between error terms across equations, we estimate the equation system efficiently via GMM, using all covariates as instruments. As each of the covariates is plausibly exogenous, the number of instruments equals the number of regressors, and the model is exactly identified. We define each moment condition as follows:

$$E[g(w, X, \beta)] = E[w_{ij} - E(w_{ij}|X)] = 0.$$

The expected value of the observed budget share given covariates X is obtained from the

Tobit model as

$$E(w_{ij}|X) = \Phi(\frac{X\beta}{\sigma_\epsilon})X\beta + \sigma_\epsilon \phi(\frac{X\beta}{\sigma_\epsilon}),$$

where $\Phi(.)$ is the standard normal cumulative distribution function and $\phi(.)$ is the corresponding probability density function (Wooldridge, 2010, p. 672).

Identification of the coefficient vector β thus requires a preliminary estimator for σ_ϵ. We estimate each commodity equation distinctly using pooled Tobit and obtain an estimator $\bar{\sigma}_\epsilon$. From the Law of Large Numbers, the Continuous Mapping Theorem and the Slutsky Theorem, $\bar{\sigma}_\epsilon$ consistently (albeit not efficiently) estimates σ_ϵ. We then implement two-step GMM, taking advantage of cross-equation correlations in the error terms, and impose cross-equation parameter restrictions from consumer theory, to obtain a consistent and efficient estimator for the coefficient vector β, to solve the minimization problem

$$min_{b \in \Theta} \bar{g}(w, X, b)' W \bar{g}(w, X, b),$$

where $\bar{g}$ are the sample analogues of the population moment conditions and W is the weight matrix.

While the regression coefficients obtained from the Tobit model (equation (8), table A5) are the unrestricted estimates, those obtained from the combined Tobit-GMM model provide the restricted estimates. The resulting compensated price elasticities of demand are displayed in table A10. An important caveat with this estimation method is that the model loses precision with the additional of control variables, such that a parsimonious specification yields the most efficient results. Therefore, we are unable to include potentially important control variables such as region and rural/urban dummies.

Table A10: Compensated price elasticities of demand (full sample) – Restricted estimates (robustness check I)

	E	K	C	Fw	Ce	Fr	V	Me	Mi	Ch	Al	O
Electricity	-3.054	0.004	-0.246	0.309	-0.323	0.082	0.644	1.036	0.026	0.146	0.206	0.171
	(0.1587)	(0.0101)	(0.0352)	(0.0306)	(0.0774)	(0.0390)	(0.0715)	(0.0942)	(0.0554)	(0.0203)	(0.0781)	(0.1526)
Kerosene	0.051	-1.381	0.242	-0.278	0.180	0.077	-0.076	0.138	-0.031	-0.113	0.599	-0.407
	(0.1295)	(0.0528)	(0.0628)	(0.0736)	(0.0631)	(0.0349)	(0.0484)	(0.0583)	(0.0532)	(0.0245)	(0.0518)	(0.1037)
Charcoal	-0.787	0.060	-2.097	0.181	-0.194	0.239	1.408	-0.155	0.375	0.098	0.479	-0.607
	(0.1128)	(0.0157)	(0.0920)	(0.0368)	(0.0674)	(0.0375)	(0.0634)	(0.0575)	(0.0565)	(0.0234)	(0.0482)	(0.1108)
Firewood	0.686	-0.048	0.125	-1.324	-0.276	-0.075	-0.133	-0.042	-0.217	0.057	0.068	0.179
	(0.0677)	(0.0127)	(0.0255)	(0.0483)	(0.0408)	(0.0194)	(0.0374)	(0.0278)	(0.0302)	(0.0146)	(0.0247)	(0.0647)
Cereals	-0.115	0.005	-0.022	-0.045	-1.406	0.050	0.349	0.059	0.003	-0.070	-0.307	0.500
	(0.0277)	(0.0018)	(0.0075)	(0.0066)	(0.0300)	(0.0130)	(0.0225)	(0.0183)	(0.0146)	(0.0049)	(0.0196)	(0.0333)
Fruits	0.098	0.007	0.089	-0.040	0.167	-1.547	-0.323	0.099	0.125	0.026	0.152	0.147
	(0.0467)	(0.0033)	(0.0140)	(0.0105)	(0.0434)	(0.0305)	(0.0370)	(0.0300)	(0.0312)	(0.0090)	(0.0360)	(0.0633)
Vegetables	0.106	-0.001	0.072	-0.010	0.160	-0.044	-1.174	-0.092	0.032	-0.009	0.014	-0.054
	(0.0117)	(0.0006)	(0.0033)	(0.0028)	(0.0103)	(0.0051)	(0.0133)	(0.0079)	(0.0064)	(0.0018)	(0.0090)	(0.0149)
Meat & fish	0.475	0.005	-0.022	-0.009	0.076	0.038	-0.257	-1.145	0.087	-0.022	0.040	-0.266
	(0.0432)	(0.0021)	(0.0082)	(0.0058)	(0.0234)	(0.0115)	(0.0220)	(0.0217)	(0.0170)	(0.0045)	(0.0201)	(0.0437)
Milk & eggs	0.028	-0.003	0.128	-0.107	0.008	0.114	0.215	0.208	-2.007	0.055	-0.014	0.374
	(0.0605)	(0.0045)	(0.0193)	(0.0149)	(0.0447)	(0.0284)	(0.0427)	(0.0405)	(0.0585)	(0.0123)	(0.0406)	(0.0786)
Cheese, oils & fats	0.365	-0.022	0.077	0.065	-0.493	0.055	-0.145	-0.122	0.127	-1.139	0.141	0.090
	(0.0510)	(0.0048)	(0.0184)	(0.0166)	(0.0345)	(0.0189)	(0.0282)	(0.0245)	(0.0283)	(0.0131)	(0.0270)	(0.0578)
Alcohol & tobacco	0.169	0.038	0.123	0.025	-0.707	0.105	0.072	0.071	-0.010	0.046	-1.762	0.828
	(0.0643)	(0.0033)	(0.0124)	(0.0092)	(0.0452)	(0.0248)	(0.0453)	(0.0361)	(0.0306)	(0.0089)	(0.0483)	(0.0780)
Other food & drink	0.093	-0.017	-0.103	0.044	0.760	0.067	-0.180	-0.316	0.186	0.019	0.547	-2.100
	(0.0830)	(0.0044)	(0.0188)	(0.0159)	(0.0506)	(0.0287)	(0.0493)	(0.0518)	(0.0392)	(0.0125)	(0.0516)	(0.1300)

Note: The items are: Electricity (E), Kerosene (K), Charcoal (C), Firewood (Fw), Cereals (Ce), Fruits (Fr), Vegetables (V), Meat & fish (Me), Milk & eggs (Mi), Cheese, oils & fats (Ch), Alcohol & tobacco (Al) and Other food and drink (O). Robust standard errors in parentheses. N = 13,582.

D.2.2 Instrumental variables for commodity prices

We use instrumental variables to correct for potential endogeneity of commodity prices, specifically the simultaneity of transport and commodity prices. Transportation is a key component in the supply chain for food items and energy sources. We therefore construct instrumental variables to mitigate the influence of transportation costs in final commodity prices, to avoid the bad control problem (Angrist and Pischke, 2008).

We first conduct regressions of the pass-through of transport prices to commodity prices for all energy[2] and food items, using a district-level panel dataset of commodity prices constructed from the World Bank's LSMS database for Uganda (UNPS, for the period 2009–2020). We draw on monthly international diesel prices to proxy for local transportation costs. We find a positive and statistically significant pass-through of diesel prices to all commodity prices (results are available on request). We then construct instruments for food and energy prices as follows:

$$lnp_{iv,id\tau} = lnp_{id\tau} - \beta_i lnd_t,$$

where β_i is the coefficient from the price pass-through regression for commodity i, and lnd_t is the international price of diesel (converted to Ugandan shillings) in month t. The 12 constructed commodity prices $lnp_{iv,id\tau}$ (corresponding to good i, district d and time period τ) and the price of diesel, lnd_t are used as instruments for the original prices, $lnp_{id\tau}$. We additionally introduce sub-region dummy variables as instruments to capture geographical heterogeneity in demand responses. The estimated compensated price elasticities of demand are presented in table A11. While the broad patterns of substitution are similar to estimates from the main Tobit regressions, the model does not meet the criterion for over-identification as Hansen's J-statistic is large, and we reject the null hypothesis of all instruments being valid.

[2] Electricity tariff schedules set by the Electricity Regulatory Authority in Uganda are also influenced by international fuel prices and the nominal exchange rate.

Table A11: Compensated price elasticities of demand (full sample) – Instrumental variables (robustness check II)

	E	K	C	Fw	Ce	Fr	V	Me	Mi	Ch	Al	O
Electricity	-4.537	-0.138	-0.630	0.772	-1.172	0.452	1.367	3.263	0.241	0.549	0.846	-2.013
	(0.398)	(0.033)	(0.083)	(0.126)	(0.193)	(0.095)	(0.162)	(0.244)	(0.13)	(0.059)	(0.193)	(0.398)
Kerosene	-1.410	-1.911	0.294	1.859	1.202	-0.097	-0.164	0.364	-0.564	-0.225	2.059	-2.406
	(0.338)	(0.145)	(0.141)	(0.203)	(0.185)	(0.08)	(0.125)	(0.183)	(0.143)	(0.064)	(0.167)	(0.303)
Charcoal	-1.970	0.090	-3.399	1.067	-0.629	0.365	4.214	-1.073	0.431	0.489	0.613	-1.197
	(0.26)	(0.043)	(0.201)	(0.098)	(0.163)	(0.086)	(0.166)	(0.099)	(0.127)	(0.059)	(0.092)	(0.252)
Firewood	0.762	0.180	0.337	-1.356	-0.790	-0.098	0.336	0.009	-0.406	0.050	0.066	-0.09
	(0.124)	(0.02)	(0.031)	(0.067)	(0.06)	(0.028)	(0.058)	(0.041)	(0.04)	(0.021)	(0.131)	(0.259)
Cereals	-0.129	0.013	-0.022	-0.088	-1.480	0.099	0.382	0.031	-0.003	-0.059	-0.352	0.610
	(0.021)	(0.002)	(0.006)	(0.007)	(0.033)	(0.012)	(0.024)	(0.019)	(0.012)	(0.005)	(0.017)	(0.03)
Fruits	0.298	-0.006	0.077	-0.065	0.589	-1.936	-0.674	0.106	0.263	0.117	0.176	0.056
	(0.062)	(0.005)	(0.018)	(0.019)	(0.074)	(0.048)	(0.059)	(0.046)	(0.044)	(0.017)	(0.062)	(0.115)
Vegetables	0.063	-0.001	0.062	0.016	0.159	-0.047	-1.163	-0.096	0.014	-0.025	0.059	-0.041
	(0.007)	(0.001)	(0.002)	(0.003)	(0.01)	(0.004)	(0.013)	(0.007)	(0.005)	(0.002)	(0.007)	(0.012)
Meat & fish	0.586	0.006	-0.062	0.002	0.050	0.029	-0.375	-1.163	0.125	-0.058	0.045	-0.185
	(0.044)	(0.003)	(0.006)	(0.008)	(0.03)	(0.013)	(0.029)	(0.028)	(0.019)	(0.006)	(0.022)	(0.045)
Milk & eggs	0.171	-0.039	0.098	-0.293	-0.019	0.284	0.211	0.493	-2.782	0.177	0.002	0.697
	(0.092)	(0.01)	(0.029)	(0.029)	(0.08)	(0.047)	(0.071)	(0.074)	(0.095)	(0.025)	(0.066)	(0.129)
Cheese, oils & fats	0.512	-0.021	0.146	0.047	-0.500	0.165	-0.509	-0.300	0.232	-1.103	0.074	0.255
	(0.055)	(0.006)	(0.018)	(0.02)	(0.044)	(0.023)	(0.035)	(0.03)	(0.033)	(0.017)	(0.03)	(0.067)
Alcohol & tobacco	0.555	0.132	0.128	0.044	-2.095	0.176	0.845	0.163	0.002	0.052	-2.345	1.343
	(0.127)	(0.011)	(0.019)	(0.087)	(0.103)	(0.061)	(0.104)	(0.081)	(0.06)	(0.021)	(0.093)	(0.169)
Other food & drink	-0.293	-0.034	-0.056	-0.013	0.805	0.012	-0.130	-0.150	0.143	0.040	0.298	-1.622
	(0.058)	(0.004)	(0.012)	(0.038)	(0.04)	(0.025)	(0.038)	(0.037)	(0.026)	(0.01)	(0.038)	(0.109)

Note: The items are: Electricity (E), Kerosene (K), Charcoal (C), Firewood (Fw), Cereals (Ce), Fruits (Fr), Vegetables (V), Meat & fish (Me), Milk & eggs (Mi), Cheese, oils & fats (Ch), Alcohol & tobacco (Al) and Other food and drink (O). Robust standard errors in parentheses. The Hansen J chi-sq. statistic for over-identification is 5,693.11 (p = 0.0000). N = 13,582.

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