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Composition and Sensitivity of Residential Energy Consumption*

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Abstract

Understanding how energy use evolves at different stages of development is essential for reliable prospective analysis and planning. With that aim in mind, this paper examines the composition of residential energy consumption and its sensitivity to income changes, distinguishing fuel types and accounting for complete heterogeneity of the income coefficient. The focus on domestic energy use allows for the examination of fuel transition under the conceptual framework of the energy ladder and energy portfolio hypotheses, showing the increasing need for modern fuels in the household sector. The results indicate a nonlinear relationship between income and domestic energy consumption that can be attributed to two factors. First, along the income distribution, consumption of modern fuels increases, replacing traditional and transitional fuels until modern fuels drive all of the growth in domestic energy demand. Second, at the highest income levels, income elasticity starts to decrease, leading to concavity in energy consumption. That is, the income elasticity of residential energy demand follows an inverse U-shape along the world income distribution. This finding suggests that at high income levels, residential energy consumption shows satiation and net savings effects, potentially implying that energy demand does not grow forever.

JEL codes: Q40; O13

Keywords: residential energy consumption, income per capita, satiation effects, income elasticity of energy demand, machine learning.

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1. Introduction

The extent to which economic progress depends on sufficient energy supply remains an open empirical question. Although a vast literature has studied the association between energy consumption and income, there is still an important gap in understanding how this relationship varies across the income distribution. This issue is particularly relevant for developing countries, as most of the future global demand for energy is expected to arise from such nations (BP 2016; Wolfram, Shelef, and Gertler 2012). Therefore, a better understanding of the composition and the pace of growth in energy demand is needed to improve energy planning and to address the environmental and financial challenges to supplying sufficient energy.

Thus, this paper examines how fuel composition and income elasticity of residential energy consumption evolve in progressive stages of development. To that end, we analyze a data set of more than 100 countries over four decades, paying particular attention to the Latin American and Caribbean (LAC) region. Residential energy refers to all fuels consumed by the household sector—excluding fuels used for private transport—and is also referred to as domestic energy consumption or use. Focusing on this sector allows us to frame the analysis in the conceptual frameworks of two central energy consumption hypotheses: the energy ladder and the energy portfolio. In addition, the consumption of domestic fuels presents suitable statistical properties for regression analysis.

To the best of our knowledge, no previous paper has studied the interrelations between income, income elasticity, and the composition of residential energy consumption at the macro level and for a comparably sized country-year panel data set. In addition, the regression analysis in this study applies a set of estimators that relax strong assumptions usually maintained in the empirical literature, such as coefficient homogeneity and cross-sectional dependence. Coefficient heterogeneity is further investigated with a machine-learning method free of functional form assumptions, thereby allowing for analysis of the distributional characteristics of the income elasticity of residential energy consumption.

The paper is structured as follows. Section 2 describes the conceptual framework. Section 3 presents some relevant stylized facts about domestic energy consumption. Section 4 describes the empirical strategies to estimate income elasticities by energy source: regression analysis and machine-learning. Section 5 discusses the data and statistical properties of the variables. Section 6 summarizes the main results, and Section 7 lays out the conclusions.

2. Conceptual Framework

The transition to modern energy sources has been studied in the context of the household sector under two theoretical frameworks: the energy ladder and the energy portfolio hypothesis (Arseneau 2011; Bacon, Bhattacharya, and Kojima 2010; Kowsari and Zerriffi 2011; Leach 1992). Under both theories, households transition through three stages as their incomes increase. In the first phase, which corresponds to the lowest income level, households rely completely on *traditional fuels* (biomass). In the second stage, in response to income increments, households move to *transitional fuels* such as kerosene, carbon, or charcoal. Finally, at the highest income level, households switch to domestic gas (liquefied petroleum gas and/or natural gas) and electricity. The ladder hypothesis suggests the gradual but complete displacement of basic and transitional fuels by more modern energy sources as the household economic conditions improve. In contrast, the energy portfolio approach argues that multiple fuels are used in an optimal mix, conditional on a set of relevant factors, such as income and cultural influences.

This transition occurs because modern energy sources such as electricity and gas offer greater benefits. Compared with traditional fuels, modern energy sources are cleaner, more convenient, and provide greater efficiency for cooking, lighting, and heating (IEA 2007; Nordhaus 1996; Pachauri and Jiang 2008). In contrast, traditional and transitional fuels have been shown to generate high levels of intra-house pollution, with negative effects on health, especially for women and children. At the same time, traditional fuels tend to be inconvenient, usually requiring a significant amount of time to collect biomass. However, as explained by Hanna and Oliva (2015), at the microeconomic level, the relationship between increases in income and the use of dirty fuels is not obvious, as it depends on the weight that households attach to the health effects of using those fuels. As mentioned by Hanna and Oliva, unless dirty fuels are an inferior good, the substitution effect will not necessarily dominate the wealth effect.

In this context, the portfolio hypothesis seems to be more suitable for reconciling the potential trade-offs that may determine the degree and speed at which the composition of energy consumption changes. Access to modern energy sources, energy prices, household incomes, and cultural factors are all determinants of fuel choice and the intensity of its use (Arseneau 2011; Heltberg 2004; Leach 1992). Further, at the country-aggregate level, such a framework is compatible with some continued consumption of traditional and/or transitional fuels at higher income levels. Even in rich countries, consumption of firewood is still observed due to underlying cultural practices. Alternatively, income inequality within a country may mean that most of the lower quality fuels are consumed by the impoverished.

Several empirical studies of varying size and representativeness have examined fuel switching at the household level, mainly using data sets from developing countries (Davis 1998; Hanna and Oliva 2015; Heltberg 2004; Hiemstra-van der Horst and Hovorka 2008; Hosier and Dowd 1987; Masera, Saatkamp, and Kammen 2000; Pachauri and Jiang 2008; Sathaye and Tyler 1991). These studies have made clear the importance of access to modern fuels and household income in determining take-up and increased use of modern fuels. They also show that solid fuels are far from displaced, particularly in rural areas. To some extent, those results are subject to the short span of the periods analyzed, limiting the potential examination of fuel transition.

With regard to firms, the literature mainly examines interfuel substitution in the industrial sector, distinguishing between electricity, oil products, coal, and gas (Bjørner and Jensen 2002; Steinbuks 2012). Although the findings vary across countries, they suggest low substitution of gas for electricity, and coal for electricity (Stern 2012). The studies are mostly based on cross sections, repeated cross sections, and, to a lesser extent, panel data over relatively short periods, restricting the analysis of the composition and sensitivity of energy consumption and economic development.[1]

This paper is related to the literature studying energy consumption patterns based on aggregate data. This literature includes Fouquet (2014); Judson, Schmalensee, and Stoker (1999); Nguyen-Van (2010); Medlock and Soligo (2001); and Van Benthem and Romani (2009). These

[1] With the exception of Hanna and Oliva (2015), previous papers—at both the firm and the household level—do not address the bi-directionality between income and domestic energy consumption. That is, although income increments may lead to greater use of modern energy, modern energy use may also increase income through less direct channels—productive uses of better energy, human capital accumulation, greater investments, and so forth. Since identifying a causal direction is difficult, a large body of empirical literature tends to address this issue through Granger noncausality tests. This is a basic starting point that is meaningful in the case of the residential sector, where most of the benefits of access to modern fuels are expected to materialize.

studies generally support a reduction in income elasticity and growth in energy demand at higher levels of income or in countries that are ascending the development ladder. In particular, Medlock and Soligo distinguish between economic sectors, finding that in developing and industrialized countries the income elasticity of electricity demand in the residential sector is substantially lower than in other sectors. Fouquet provides an extensive historical analysis of energy consumption by sector in the United Kingdom, finding an inverse U-shape[2] as the economy develops.

However, to the best of our knowledge, no previous studies have concentrated on the residential sector and distinguished by type of fuel at the macro level. The focus on the residential sector is not only coherent from a conceptual standpoint; it is also practical for classifying fuels as traditional, transitional, and modern. That is, consumption of biomass or transitional fuels is more common in the residential sector, and, according to both energy hypotheses, relative variations in the consumption of these fuels are expected as households increase their income. In contrast, attempts at applying such a classification to other sectors (such as industry or transportation) may result in lower variation, as their energy consumption consists mainly of electricity, gas, and liquid fuels.

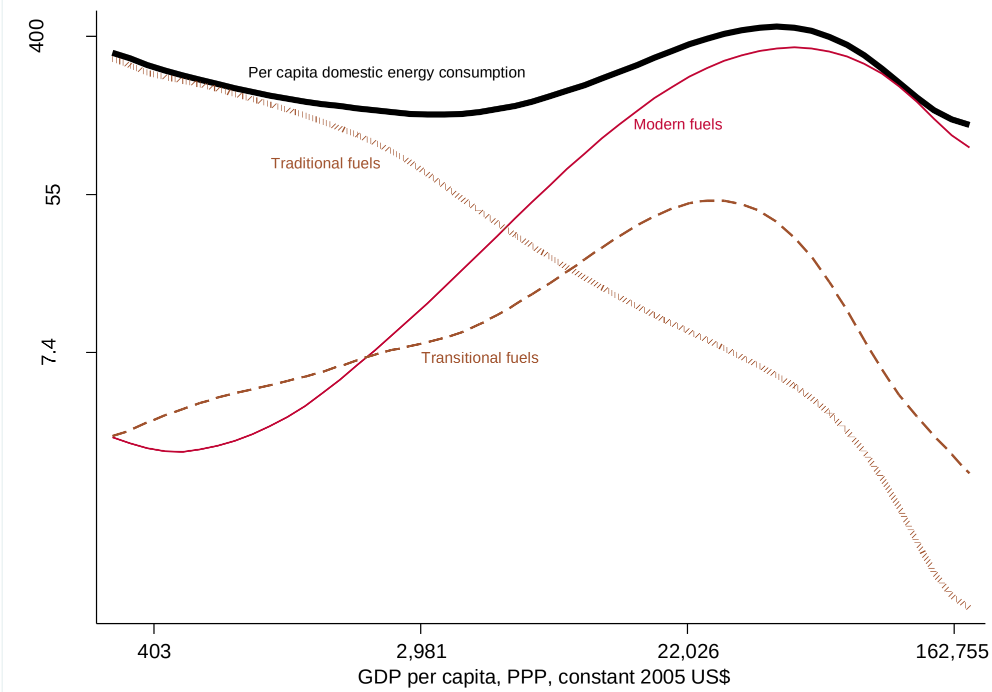
3. Stylized Facts about Domestic Energy Consumption

For a first glance at how domestic energy consumption has evolved, Figure 1 plots its relationship with per capita income, taking into consideration variability across countries and over time. The figure provides a global historical view of patterns in domestic energy consumption along the entire income distribution, showing energy consumption (the bold line) tends to follow a nonlinear path. Consumption tends to be high at lower income levels, where the use of traditional fuels is prevalent. Moving to the right of the income distribution, pronounced substitution of traditional fuels with transitional and modern fuels is observed. This substitution pattern between modern and conventional energy sources determines the nonlinear shape of total

[2] In the study mentioned, the inverse U-shape refers to increasing per capita energy use up to the upper-middle-income level, after which it starts to reduce gradually.

domestic energy use, depicted as a compressed S-curve. Annex A shows similar trends for LAC countries.

Figure 1. Consumption of Domestic Fuels along the World Income Distribution

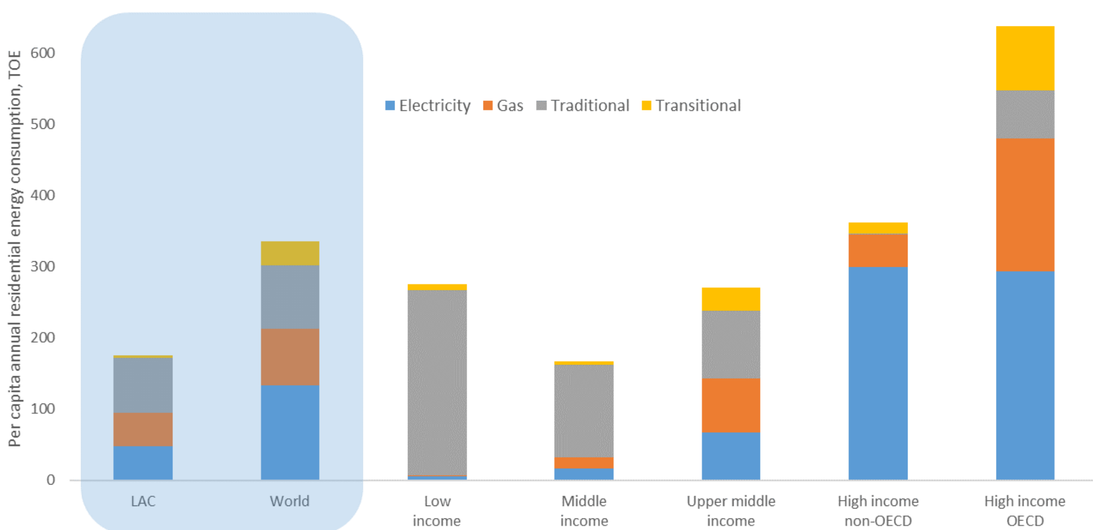


Source: Authors' calculations based on data from the International Energy Agency.
Note: The axes are in log scale. Values are for 104 countries over 1971 to 2013. The curves are fitted with a polynomial of degree 2. Modern fuels = electricity and gas; transitional fuels = kerosene, paraffin, and so forth; and traditional fuels = biomass. GDP = gross domestic product; Ktoe = kilotons of oil equivalent; PPP = purchasing power parity.

Figure 1 supports the existence of a transition in the composition of residential energy consumption to the right of the income distribution. Per capita use of traditional fuels decreases as income increases, while the use of transitional fuels tends to increase to a certain level and then decline at higher income levels. At the same time, consumption of modern fuels grows nonlinearly until it accounts for most of the per capita energy consumption at the highest income levels. That is, as countries become wealthier, growth in overall per capita energy use tends to be explained mainly by higher consumption of modern fuels. These patterns are congruent with previous studies, such as those of Meier, Jamasb, and Orea (2013), and Rodriguez-Oreggia and Yepez-Garcia (2014), suggesting the presence of inflection points in the relationship between household energy consumption and income.

While Figure 1 indicates that most traditional and transitional fuels are consumed toward the left of the world income distribution, some consumption is still observed in high-income countries, a practice that may be attributed to cultural factors, or to consumption by low-income households within relatively rich countries.[3] To complement this view, Figure 2 shows the composition of annual per capita residential energy use, averaged over 2009–13, by income classification. In low-income countries, traditional and transitional fuels represent 90 percent of per capita residential energy consumption, a share that tends to decrease with rising incomes. However, in high-income countries there is still substantial consumption of traditional fuels, mainly firewood. In the case of LAC countries, use of non-modern fuels is also considerable, representing around 45 percent of per capita domestic energy use.

Figure 2. Composition of Per Capita Energy Consumption by Country Income Classification, Average for 2009–13



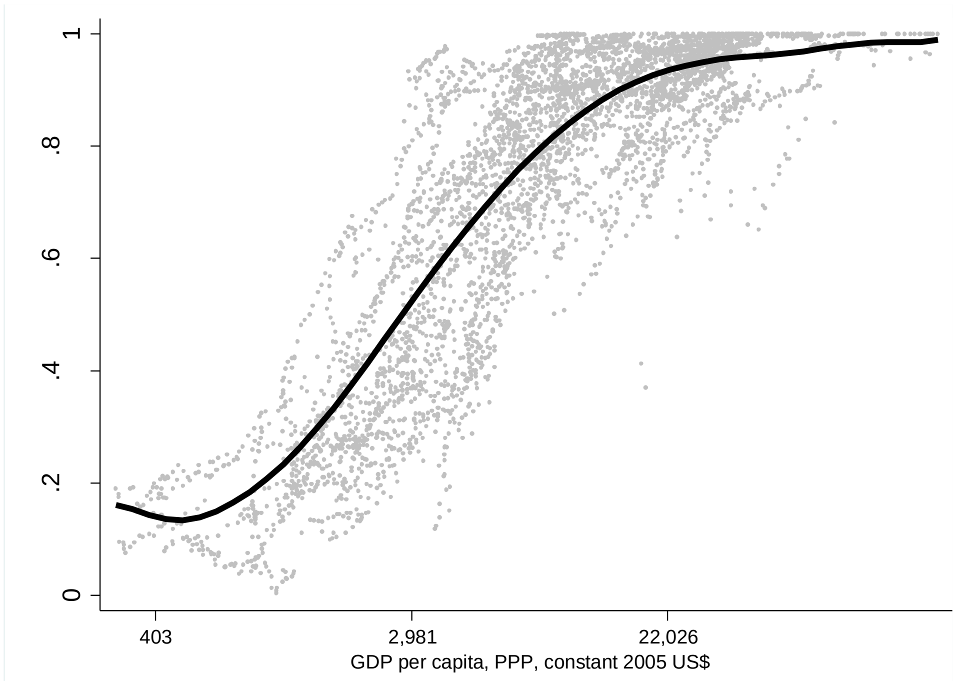
Sources: Authors' calculations based on data from the International Energy Agency and World Development Indicators.
Note: Countries are classified by income according to the World Bank income classifications. LAC = Latin America and the Caribbean; OECD = Organisation for Economic Co-operation and Development; TOE = tons of oil equivalent.

The resulting change in composition can be seen directly in Figure 3, where the share of modern fuels in domestic consumption follows a sigmoid shape, reinforcing the fact that modern fuels tend to displace other energy sources at the highest income levels. The switch toward modern fuels accelerates as countries transition from low-income to medium- and high-income

[3] For example, in Chile and Uruguay there is still a high share of biomass in residential energy consumption.

levels, and then the pace of substitution decreases at the highest income levels ($\gtrsim$ US\$20,000). Such lower pace may be related to the last-mile problem, in which the difficulty of reaching isolated rural areas is an obstacle to achieving complete access to modern fuels. In fact, Figure 3 shows a similar s-shaped curve observed in the rate of rural access to electricity along the income distribution (Jimenez 2016).

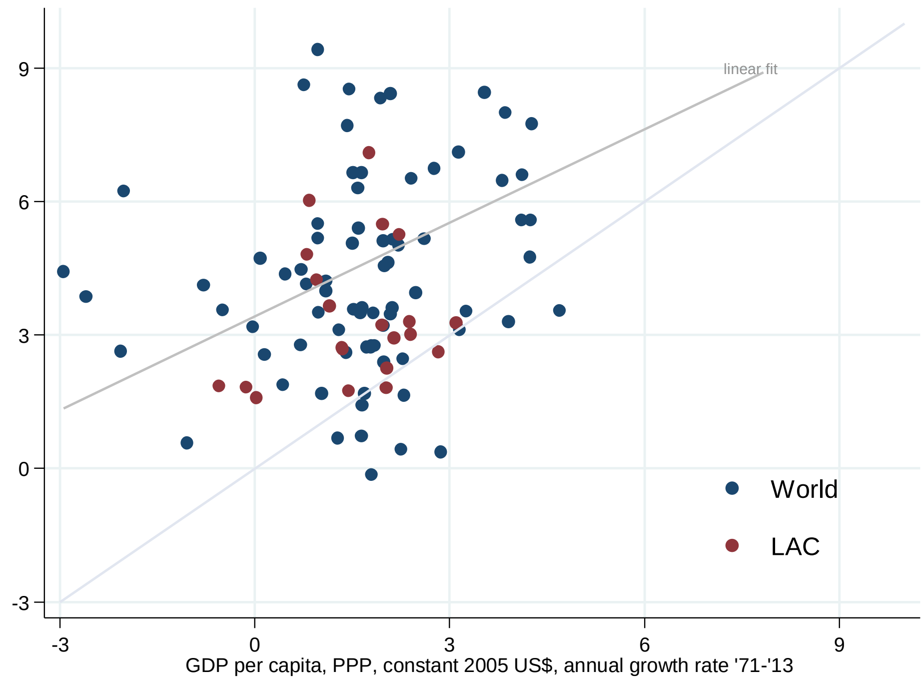
Figure 3. Share of Modern Fuels along the World Income Distribution



Source: Authors' calculations.
Note: The axes are in log scale. Values are for 104 countries between 1971 and 2013. Modern fuels include electricity and gas. The curve is fitted with a polynomial of degree 2. GDP = gross domestic product; PPP = purchasing power parity.

It is important to emphasize the substantial degree of heterogeneity between countries with regard to the rate at which consumption of modern energy has grown in the period under review. Figure 4 plots the average annual growth rate of both income per capita and per capita consumption of modern energy, showing a strong positive association between these variables. The figure also indicates that residential modern energy consumption has grown at a faster rate than income, although with significant heterogeneity between countries, suggesting that the estimation of income elasticities needs to take into account country-specific characteristics.

Figure 4. Modern Energy Consumption versus Income Growth



Source: Authors' calculations.
Note: Values are for 104 countries from 1971 to 2013, including 22 countries in LAC. GDP = gross domestic product; LAC = Latin America and the Caribbean; PPP = purchasing power parity.

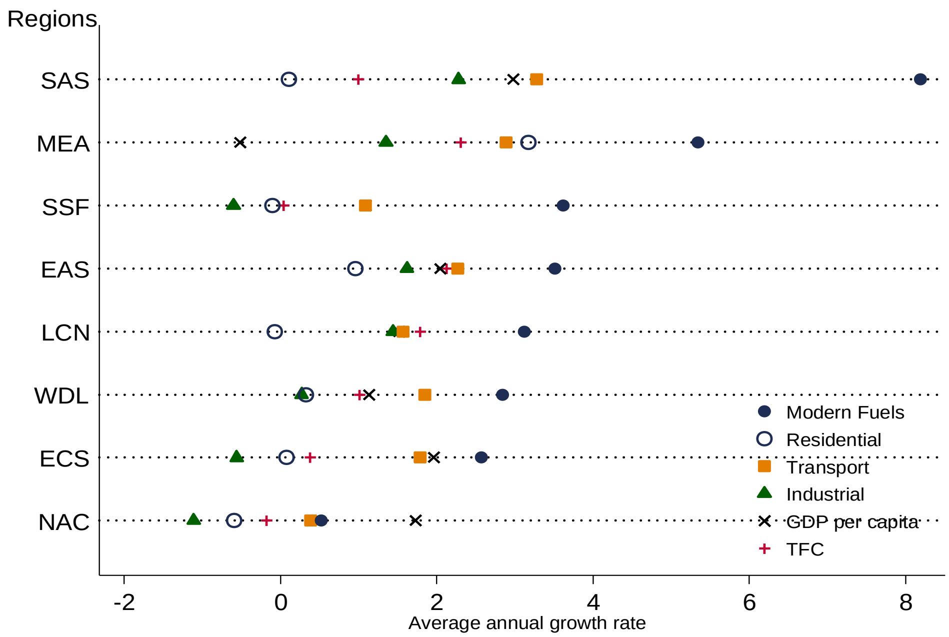
In a broader context, with regard to modern fuels, residential energy consumption has not only grown at a higher rate than income but also at a higher rate than energy consumption by other sectors. Figure 5 illustrates that while per capita energy consumption in the residential sector has grown at relatively low rates in most regions, the modern fuel component has grown at a markedly higher rate than in other sectors, such as transportation and industry, which together constitute 55 percent of aggregate final energy consumption.[4] This pattern occurs in all regions (with the exception of North America) and is especially marked in Sub-Saharan Africa, and the Middle East and North Africa.

The stylized facts described in this section emphasize the relevance of distinguishing between energy sources when studying the relationship between energy consumption and income. Economic progress seems to drive the growing demand for modern fuels, but not

[4] As of 2013, transport and industry accounted for 25 and 30 percent, respectively, of total final consumption in our sample.

traditional or transitional fuels. Therefore, in the case of the residential sector, focusing on aggregate energy consumption may lead to biased interpretations because of the shift in composition and its nonlinear pattern along the income distribution.

Figure 5. Average Annual Growth Rate by Fuel, Sector, and Region



Source: Authors' calculations.
Note: Values are average annual growth from 1971 to 2013. Modern fuels = electricity and gas; transitional fuels = kerosene, paraffin, and so forth; and traditional fuels = biomass. Regions follow the World Bank classification: SAS = South Asia, MEA = Middle East and North Africa; SSF = Sub-Saharan Africa; EAS = East Asia and Pacific; LCN = Latin America and the Caribbean; WDL = world; ECS = Europe and Central Asia; and NAC = North America. GDP = gross domestic product; TFC = total final consumption of all sectors. GDP per capita is in constant 2005 PPP prices.

4. Empirical Approach

The composition and sensitivity of domestic energy consumption are examined using a parametric approach and a machine-learning approach. In the parametric setting, the general specification takes the following form:

$$y_{it} = \alpha x_{it} + W'\beta + \varepsilon_{it} \quad (1)$$

$$y_{it} = \theta y_{it-1} + \alpha x_{it} + W'\beta + \varepsilon_{it} \quad (2)$$

where y_{it} represents a dependent variable for country i in year t. The dependent variables are (separately) consumption of traditional, transitional, and modern fuels, and the share of modern fuels, all measured in per capita terms. The last variable aims to capture the composition of domestic energy consumption, which is defined as $s = m/E$, the ratio of modern fuels (m) in total residential energy consumption (E), and therefore is defined within the range $[0,1]$. The main independent variable is per capita income (x_{it}), and α is the vector of parameters of interest.

The set of covariates W_{it} includes international petroleum prices, the share of power produced from hydro, net exports of fossil fuels, country-specific dummies and/or country-specific trends. A drawback of our specification is that we do not have information on end-user energy prices (electricity and gas) for the entire sample. Since our main interest is estimating α, we expect that the set of controls captures differences in energy prices; for example, oil prices may be relevant in countries without a significant share of renewables, or that are net importers of fossil fuels. To some degree, our control variables also capture heterogeneity between countries.

We apply the following estimators: (i) the fixed effect (FE) estimator, which is the standard baseline and allows cross-country time-invariant heterogeneity, but assumes coefficient homogeneity and cross-sectional independence; (ii) the Pesaran and Smith (1995) mean group (MG) estimator, which takes into account time-variant unobservables for each country and coefficient heterogeneity, while still assuming cross-sectional independence; and, (iii) the Pesaran (2006) Common Correlated Effects (CCE) estimator, which further allows cross-sectional dependence (CSD), requiring only covariates with cross-sectional variation. The CCE model, therefore, does not include international oil prices.[5] Although a less restricted

[5] In our case, CSD refers to the existence of variable and/or residual correlation across countries caused by common shocks or spillover effects, such as oil price shocks, global financial crises, or contagious economic recession. CSD also can arise from unobserved components that become a part of the error term. The presence of a common shock leads to high standard errors, while the unobserved components may lead to inconsistent estimators if they are correlated with the regressors of interest. To capture the CSD, the CCE estimator augments equations (1) and (2) with the cross-sectional averages of the dependent variable and the regressors; therefore, any variable with no cross-sectional variation would be perfectly collinear to such an augmentation.

specification and estimator would be preferable, it is also interesting to evaluate the differences between the estimates taking into account some source of heterogeneity.[6]

The energy consumption, income, and price variables are expressed in logarithmic scale, so the estimates from equation (1) can be interpreted as short-run elasticities. However, a distinction in our framework is the long-run effect of income changes on energy consumption and its composition. The long-run relationship is captured by including the lagged dependent variable as a regressor in equation (2), and then calculating the long-run elasticity as the corresponding derivative, which in a linear setting is $\varepsilon_{E,x} = \alpha_1/(1-\theta)$, where θ is the coefficient of the lagged variable.

These regressions return average elasticities, which are informative by type of fuel, but not for the suspected changing association between income and energy consumption along the income distribution. To address this issue, the regressions are also performed by income group, which allows for the evaluation of the change in income elasticities across groups at different development stages at the cost of reducing the sample per estimation and not accounting for changes in the sample composition.

To further examine the change in consumption of modern fuels, we replace the linear income regressor with an income polynomial, with its degree chosen based on cross-validation procedures. In a linear setting, α is expected to be positive, while a polynomial can capture potential nonlinearities, approximating the shape of the responsiveness to income changes. In a nonlinear setting, the sign and significance of α are less clear but may have significant implications for how energy consumption patterns change along the income distribution.

The next step is to completely relax the functional form in order to allow the income elasticity to change along the world income distribution. This problem is quite complicated in semiparametric or nonparametric settings, where the returned coefficients are difficult to recover and interpret. A recent suitable approach to this problem is the application of a machine-learning method, the Kernel Regularized Least Squares (KRLS) estimator proposed by Hainmueller and

[6] In addition, an advantage of the MG and CCE estimators is that they allow for the recovery of country-specific coefficients, so the heterogeneity of the slope coefficients (α_i) can be examined.

Hazlett (2014), under which the distribution of α can be estimated without relying on linearity or additivity assumptions. The KRLS estimator solves the following problem:

$$\omega^* = argmin(y - K\omega)^T(y - K\omega) + \lambda\omega^T K\omega\ ,\ \omega\epsilon\mathbb{R}^D \quad (3)$$

where

ω^* = test point coefficients or weights, containing α and β.

y = outcome variable.

K = matrix of kernel functions (z_j, z_i), where z represents the vector of covariates, previously defined as x and W.

The kernel function $k(.)$ measures the similarity between observations for each z_i. A greater similarity translates to a greater influence of z_i over the outcome. Therefore, $K\omega$ represents a space of functions that aim to approximate the outcome point to point, such that similar observations would tend to have similar outcomes. This problem is solved computationally, obtaining an estimated surface response. Because it does not impose any functional parametric form, the search for the best fit of the KRLS does not assume constant marginal effects.[7] This is particularly important in our context, as the returned distribution of coefficients will contain long-run information without requiring any transformation. Further, in obtaining pointwise estimates, the KRLS allows for investigation of how the coefficient of interest is distributed and how it behaves along the income distribution. In particular, the estimated vector α contains the pointwise income elasticities by country at each point of the income distribution.

An important aspect of the empirical analysis is determining whether the estimates have a causal interpretation or represent conditional correlations. It is expected that the inclusion of the covariates and fixed effects helps to clean the relationship between energy and income of omitted potential confounding effects. However, potential econometric problems are not being addressed, such as income endogeneity or measurement error. Therefore, since there is a conceptual and empirical basis to argue for bi-directionality between income and consumption of modern energy sources, we attach no causal interpretation to the estimates.

[7] This part closely follows Hainmueller and Hazlett (2014).

5. Data

This study uses a panel of 104 countries, over 1971 to 2013, including 22 LAC countries. All the variables are measured at the aggregate country level on a yearly basis. Countries with fewer than 43 observations per variable were dropped in order to obtain a balanced panel. Given the objective of this paper, it is important to gather the largest sample of countries over the longest period possible, to provide a comprehensive analysis of the relationship between the elasticity and composition of energy consumption and income per capita.

Along with the conceptual framework, we distinguish between the following types of energy sources: traditional, including biomass; transitional, including paraffin, kerosene, charcoal, carbon, and other liquid fuels; and modern fuels, including electricity and gas. These energy sources are the main dependent variables, and they are measured as final energy consumption (quantities). For comparison purposes we also gathered data on total energy consumption of the transportation and industry sectors, and for the whole economy.

The main independent variable is per capita gross domestic product at purchasing power parity in constant 2005 U.S. dollars. The other covariates are the share of hydroelectricity, net fossil fuel exports, and international oil prices in constant 2005 U.S. dollars. The main sources of information are the International Energy Agency, BP annual statistics, and World Development Indicators.

Examination of residential consumption of modern fuels indicates that they are integrated of order 1. The residuals of a base linear specification of equation (1) present nonconstant variance and cross-sectional dependence (see Annex B). The last characteristic supports the use of the CCE estimator. Two types of cointegration tests are applied: those proposed by Pedroni (1999) and those proposed by Westerlund (2007). Both types of tests are estimated with no intercept and no deterministic trends, and the optimal lags are determined using the Akaike information criterion. Table 1 shows that both groups of tests return similar results for electricity, gas, and modern fuels, for LAC and all countries, suggesting a stable long-run relationship between income and modern residential energy sources. However, the results are less conclusive for the case of total final consumption (TFC) by the residential sector, particularly in the case of the Westerlund tests.[8]

One consideration is that the period analyzed may include structural breaks that occur at different points. These structural breaks may include changes in energy policies not taken into account by the independent variables, thus leading to biased estimates if they are correlated with income per capita. To reduce this potential source of bias, the years in which structural breaks occurred are estimated and included as covariates in additional regressions (Annex D). However, as structural breaks are difficult to identify, and may confound underlying nonlinear relationships between variables, the results should be interpreted carefully.[9]

Table 1. Cointegration Tests for Domestic Fuels

			LAC				WDL			
			Elect.	Gas	E&G	TFC	Elect.	Gas	E&G	TFC
Westerlund (2007)	Z-value	Ga	1.84	-0.44	1.62	2.71	2.61	0.11	2.24	5.59
		Gt	-3.53	-4.22	-3.57	0.32	-8.35	-11.93	-11.03	-0.67
		Pa	-0.61	-3.34	-2.16	-0.09	-5.04	-3.10	-5.24	-6.86
		Pt	-3.82	-7.02	-6.70	-1.29	-15.77	-6.77	-14.24	-17.12
	P-value	Ga	0.97	0.33	0.95	1.00	1.00	0.55	0.99	1.00
		Gt	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.25
		Pa	0.27	0.00	0.02	0.47	0.00	0.00	0.00	0.00
		Pt	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
	Robust P-value	Ga	0.79	0.10	0.66	0.96	0.41	0.09	0.35	0.99
		Gt	0.04	0.01	0.02	0.58	0.00	0.00	0.00	0.40
		Pa	0.35	0.03	0.07	0.55	0.02	0.17	0.07	0.28
		Pt	0.03	0.00	0.00	0.32	0.00	0.01	0.00	0.17
Pedroni (1999)	Panel test	adf	-2.44	-3.35	-2.89	-1.98	-2.18	-5.33	-3.20	-2.71
		rho	-1.69	-2.77	-2.18	-1.69	-0.60	-2.85	-0.65	-1.62
		t	-3.15	-4.28	-3.32	-2.38	-3.32	-5.98	-4.16	-4.09
		v	0.11	0.71	0.65	1.11	0.87	1.22	0.28	2.15
	Group test	adf	-2.60	-3.97	-2.72	-1.82	-2.64	-5.31	-4.58	-2.66
		rho	-1.05	-1.60	-0.98	-0.42	1.36	-0.57	0.97	0.09
		t	-3.46	-4.02	-3.03	-1.86	-2.55	-5.51	-4.34	-3.49

Source: Authors' calculations.
Note: a = semiparametric test; adf = Augmented Dickey–Fuller test; G = group mean test; LAC = Latin America and the Caribbean; P = panel test; t = parametric test; WDL = world. The *p*-value is for a one-sided test based on a normal distribution; the robust *p*-value is for a one-sided test based on a bootstrapped distribution (500 bootstrap replications). No intercept and no deterministic trend.

[8] The tests were also performed for transport, industry, and aggregate energy consumption, with less evidence of cointegration. However, these results are exploratory requiring more detailed analysis.
[9] Improvements to the cointegration tests include accounting for structural breaks and nonlinear relationships between energy consumption and income.

6. Results

The panel regressions are summarized in Table 2 showing significant differences by estimation method. With the exception of residential TFC, the FE estimator tends to return stronger associations with income per capita for both samples of countries (world and LAC). In contrast, accounting for country-specific trends (MG) and cross-sectional dependence (CCE) systematically reduces the estimated elasticities. In the case of residential TFC, we interpret the non–statistically significant elasticities as a result of the nonlinear pattern originating from the change in fuel composition.

The share of modern fuels is strongly associated with income, particularly in the long run. A common pattern between estimators is that modern fuels are more sensitive to income than total residential energy consumption, which is expected since traditional and transitional fuels have negative or zero elasticities. As expected, long-run elasticities tend to be greater than short-run elasticities for modern fuels, suggesting an adaptive response by households. On average, a 1 percent increase in income translates into a 0.33 percent increase in modern fuel consumption in the short run, and a 0.44 percent increase in the long run (under the CEE model in the world sample).

The income elasticities for transitional fuels present a wider range of variation across estimators from -0.84 (FE) to 0.45 (MG), while the preferred model gives 0.28 (CEE), statistically significant in all cases (world sample). Notice that the short- and long-run elasticities are not markedly different, and in LAC, the long-run elasticities are even lower. In the case of traditional fuels, income elasticities tend to be negative but not statistically significant.

These estimates are aligned with both energy consumption hypotheses, suggesting a greater substitution effect for traditional fuels, and a positive wealth effect over transitional and modern fuels. This supports the intuition that modern domestic fuels exhibit characteristics of normal goods, whereas traditional fuels exhibit characteristics of inferior goods, implying that households attach a substantial positive value to the health benefits of using modern fuels.

For the case of modern fuels, Annex D presents the panel regressions including dummy variables to capture structural breaks in each country. In the MG and particularly in the FE model, the short-run income elasticities tend to be lower than the estimations in Table 2.

However, in the case of the CCE model, the estimations tend to be quite similar. The introduction of structural breaks also leads to different estimates in the case of the dynamic regressions for the FE and MG models (although without systematic bias direction), while the CEE model continues to return similar elasticities.

To provide a comparative view of the income elasticity of energy consumption between economic sectors, Annex E summarizes the estimations for residential, industrial, transportation, and total final energy consumption (all sectors). The estimated income elasticities are higher for industry and transportation, even higher than the elasticities for modern fuels presented in Table 1. In the long run, a 1 percent income increase translates into an increase of approximately 0.9 percent in the energy use of the industrial sector. In the transportation sector, such an increase in income translates into 1.3 percent higher energy use.[10]

Across all the models, modern energy demand in LAC is more responsive to income changes than demand in the rest of the world, in both the short and long runs. This pattern suggests that economic growth in the LAC residential sector is highly dependent on modern energy supply. However, as these estimations are based on pooling countries at different stages of development, there may be significant differences in the relationship between income and energy consumption depending on the degree of economic development in a given country. The following subsections explore how the income elasticity and levels of energy use change along the income distribution.

[10] These estimates should be taken carefully, as the cointegration relationship between income and energy consumption of the transportation and industrial sectors is unclear.

Table 2. Elasticities for Domestic Energy Consumption

Dependent var.:	Share			Modern fuels			Transitional fuels			Traditional fuels			TFC, residential		
Estimator:	FE	MG	CCE	FE	MG	CCE	FE	MG	CCE	FE	MG	CCE	FE	MG	CCE
World															
Short run															
ln(gdp per capita)	0.20	0.08	0.03	1.22	0.50	0.33	-0.69	0.38	0.25	0.60	0.02	-0.04	0.23	0.22	0.20
	0.03	0.02	0.01	0.15	0.11	0.07	0.16	0.15	0.12	0.18	0.05	0.05	0.07	0.05	0.05
ln(oil price)	0.01	0.00	.	0.05	-0.02	.	-0.14	-0.04	.	-0.06	0.01	.	0.02	-0.01	.
	0.00	0.00	.	0.03	0.01	.	0.03	0.03	.	0.03	0.01	.	0.01	0.01	.
Long run															
ln(gdp per capita)	0.13	0.08	0.05	0.94	0.58	0.44	-0.84	0.45	0.28	0.45	0.05	0.00	0.23	0.24	0.26
	0.02	0.02	0.01	0.13	0.13	0.08	0.25	0.17	0.17	0.18	0.10	0.05	0.07	0.07	0.07
ln(oil price)	0.00	0.00	.	-0.08	-0.03		-0.33	-0.06	.	-0.02	0.01	.	-0.04	-0.02	.
	0.01	0.00	.	0.05	0.02		0.12	0.03	.	0.09	0.01	.	0.04	0.01	.
Obs.	4,472	4,472	4,472	4,472	4,472	4,472	4,472	4,472	4,472	4,472	4,472	4,472	4,472	4,472	4,472
Countries	104	104	104	104	104	104	104	104	104	104	104	104	104	104	104
LAC															
Short run															
ln(gdp per capita)	0.19	0.09	0.06	1.08	0.54	0.55	-0.90	0.16	0.54	-0.44	-0.09	0.04	0.12	0.13	0.22
	0.04	0.03	0.03	0.17	0.10	0.16	0.44	0.39	0.37	0.26	0.12	0.11	0.15	0.12	0.11
ln(oil price)	0.01	-0.01	.	0.03	-0.04	.	-0.16	-0.04	.	-0.02	0.03	.	0.00	0.02	.
	0.01	0.01	.	0.04	0.03	.	0.11	0.07	.	0.05	0.03	.	0.03	0.02	.
Long run															
ln(gdp per capita)	0.19	0.14	0.09	1.23	0.79	0.79	-1.11	0.20	0.34	-0.59	-0.21	-0.01	0.31	0.15	0.16
	0.05	0.04	0.03	0.22	0.15	0.22	0.80	0.32	0.21	0.36	0.23	0.21	0.25	0.17	0.15
ln(oil price)	-0.03	-0.02	.	-0.12	-0.07	.	-0.36	-0.04	.	0.21	0.05	.	0.02	-0.01	.
	0.02	0.01	.	0.09	0.03	.	0.30	0.09	.	0.16	0.03	.	0.12	0.03	.
Obs.	946	946	946	946	946	946	946	946	946	946	946	946	946	946	946
Countries	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22

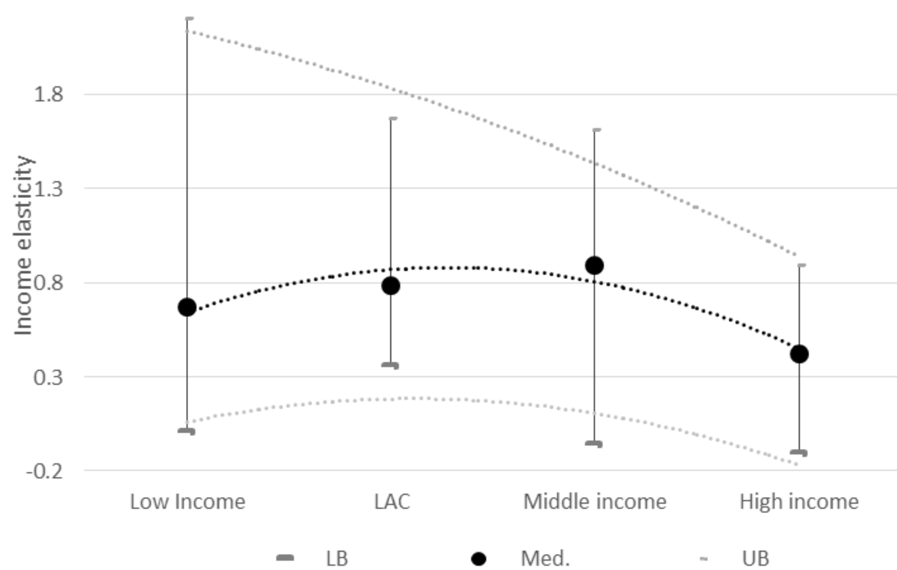
Source: Authors' calculations.

Note: Coef./SE. Short-run elasticities correspond to equation (1). Long-run elasticities are derived from equation (2); standard errors are estimated using the delta method. See full regression results of the dynamic model in Annex C. All specifications contain the share of power generated with hydro, and net exports of fossil fuels. All regressions correct for heteroscedasticity. MG and CCE include country-specific trends. CCE corrects for cross-sectional correlation. CCE = common correlated effects; FE = fixed effect; LAC = Latin America and the Caribbean; MG = mean group; TFC = total final consumption.

Elasticities by Income Level

This subsection explores whether the energy income elasticities are constant along the income distribution, that is, if energy consumption increases at a constant rate independent of income level. Figure 6 presents bands of elasticities by income group, where the lower (LB), median (Med), and upper (UB) bands are, respectively, the minimum, median, and maximum of the set of estimations returned under the FE, MG, or CCE models. In general, the results suggest that income elasticities decrease as countries reach higher income levels, but with a great degree of heterogeneity within each income group. At the highest income level, the elasticity actually becomes negative, indicating that for some countries income increments have led to reductions in their per capita domestic consumption. This result supports the concavity observed in Figure 1 (to the right of the income axis). Annex F presents the regression results.

Figure 6. Estimator Band of Long-Run Income Elasticity of Modern Fuels by Income Classification



Source: Authors' calculations.
Note: The lower (LB), median (Med.), and upper (UB) bands are the minimum, median, and maximum of the set of estimations in each income group. Countries are grouped into low, middle, and high income according with the World Bank income classification; LAC = Latin America and the Caribbean. Regression results are presented in Annex F.

To provide a view of how the elasticities translate into energy consumption, we also estimate the residential use of modern energy for each income level. We use the FE estimator with a polynomial specification of income. This specification provides flexibility in analyzing the relationship between energy and income, allowing for potential nonlinearities. In the case of modern fuels, the best fit was found to be a third-degree polynomial.[11] The main results are summarized in Figure 7. They resemble a concave curve, indicating that energy consumption would increase at a decreasing rate as a country's income level rises. That is, the income elasticity of energy demand would be negative at some point to the right of the world income distribution, in accordance with the negative income elasticities toward the lower bands of Figure 6. This pattern of reduced energy consumption resembles recent trends in aggregate energy consumption observed in the United States and OECD countries (BP 2016).

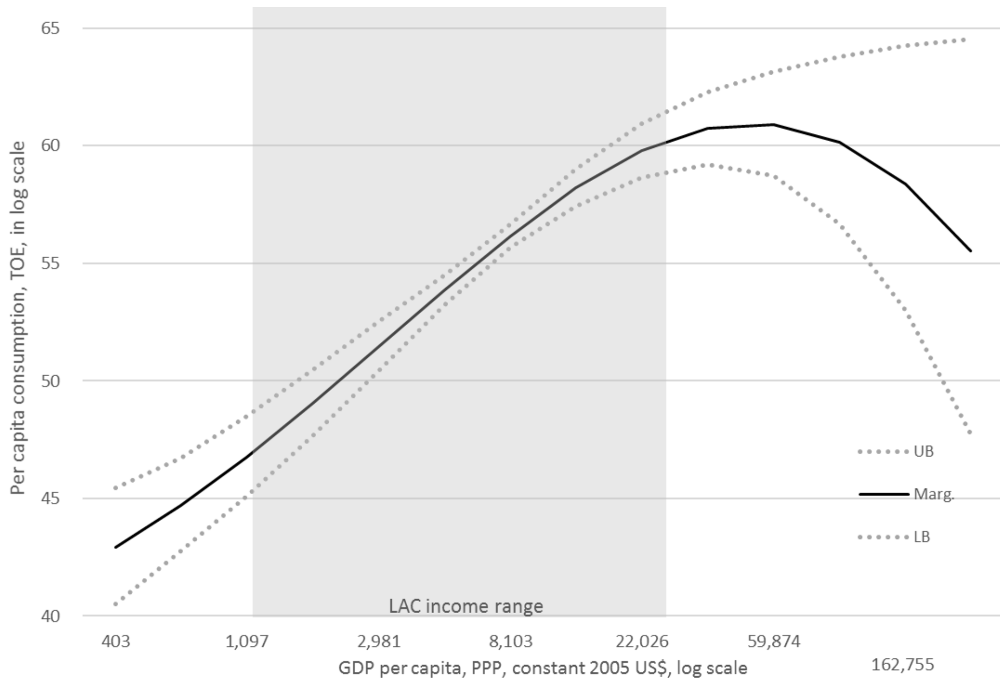
It is unclear what the roots of the concavity may be. Two potential explanations are a possible satiation point in energy consumption for households, or net energy efficiency gains that are more pronounced at high income levels. In the case of the United Kingdom, Fouquet (2014) argues that while energy efficiency improvements may have a significant rebound effect at middle-income levels, at higher levels those improvements translate into net energy savings, explaining to some extent the reduction in income elasticities for modern fuels.[12]

Figure 7 also shows the relative position of LAC countries, by income per capita, within the global predictions (the shaded area), suggesting that the stage of development of LAC coincides with a path of almost linear association between energy consumption and income. Along with previous average estimates, this suggests that LAC income growth is highly dependent on the supply of modern energy, meaning that as the region continues to develop economically over the next few decades, it may tend to move to the right or be more concentrated at the upper-middle-income level, with corresponding increases in energy requirements.

[11] Detailed results are available upon request.

[12] This analysis focuses on residential energy consumption. In the case of industrial (or aggregate) energy consumption, another explanation may be the displacement of energy-intensive productive activities to developing countries, therefore reducing the overall energy requirements of rich economies.

Figure 7. Long-Run Estimated Income Effects of Modern Energy Consumption



Source: Authors' calculations.
Note: Scales are in logs. The estimation is based on 104 countries, including 22 in LAC. In-sample predictions. The predicted margins are based on a polynomial of degree 3 for GDP per capita. The model was selected on the basis of adjusted R^2, RMSE, BIC and AIC. AIC = Akaike information criterion; BIC = Bayesian information criterion; GDP = gross domestic product; LAC = Latin America and the Caribbean; RMSE = root mean square error; TOE = tons of oil equivalent.

Distribution of Elasticities (KRLS Results)

Table 3 reports the results from the KRLS estimator by fuel type, showing marked coefficient heterogeneity. In the case of modern fuels, the distribution of the income coefficients ranges from 0.68 in the 25th percentile to 1.62 in the 75th percentile. That is, the coefficients tend to be greater than the estimation in the parametric setting. Figure 8 (a) presents a histogram of the income coefficients, showing that the distribution is left-skewed with over 60 percent of the density concentrated between 1.0 and 1.8.

Conditional on the income level, the distribution of $\hat{\alpha}$ –the income elasticity of modern energy consumption– shows a clear inverse U-shape pattern; the sensitivity to income increases up to a maximum (< 2) and then decreases as income continues to rise, see Figure 8 (b). This pattern is consistent with previous results, in the sense that the higher the development stage of a country, the less sensitive domestic demand for modern energy will be to further income changes. The distribution also suggests that the high values of $\hat{\alpha}$ in Table 2 are mainly a result of the sample composition, since 60 percent of the observations belong to the income interval from US$2,000 to US$22,000.

Table 3. KRLS Pointwise Derivatives

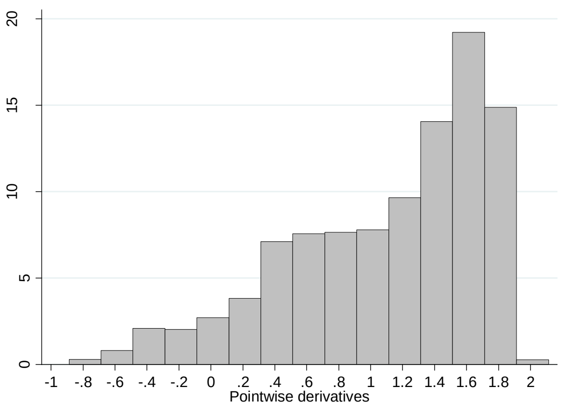
	Avg.	SE	t	p-value	P25	P50	P75
Modern fuels							
ln(gdp per capita)	1.11	0.01	109.9	0.00	0.68	1.28	1.62
ln(oil price)	0.09	0.02	4.61	0.00	-0.35	-0.02	0.37
ln(Share hydro)	2.45	0.36	6.73	0.00	1.02	2.6	3.99
ln(XN fuels)	-0.03	0.02	-1.92	0.06	-0.15	-0.06	0.08
R2=0.86 ; Eff. Df=59.46							
Transitional fuels							
ln(gdp per capita)	0.54	0.02	24.72	0.00	0.09	0.6	0.99
ln(oil price)	-0.43	0.04	-10.33	0.00	-1	-0.25	0.19
ln(Share hydro)	-2.76	0.8	-3.44	0.00	-10.59	-5.17	1.64
ln(XN fuels)	-0.23	0.04	-5.9	0.00	-0.65	-0.2	0.2
R2=0.40 ; Eff. Df=63.39							
Traditional fuels							
ln(gdp per capita)	-0.85	0.02	-37.02	0.00	-1.22	-0.87	-0.52
ln(oil price)	0.21	0.04	4.82	0.00	-0.25	0.1	0.53
ln(Share hydro)	22.25	0.85	26.13	0.00	13.7	24.86	34.78
ln(XN fuels)	0.13	0.04	3.25	0.00	-0.06	0.13	0.34
R2=0.49 ; Eff. Df=63.39							

Source: Authors' calculations.
Note: Avg. = average coefficient ; SE = standard error ; XN = net exports.

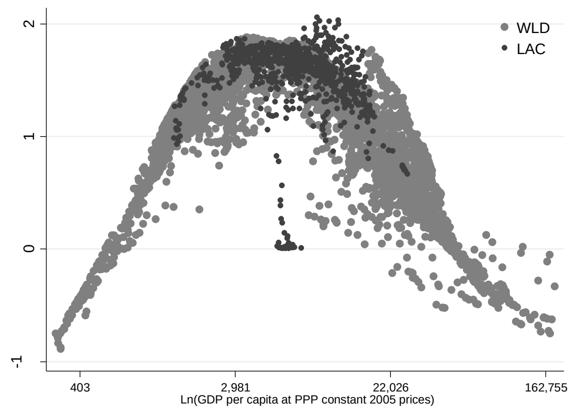
Following the energy consumption hypotheses (ladder and portfolio), the estimated income sensitivity of transitional fuels exhibits an inverse U-shape along the world income distribution. At early stages of development, transitional fuel consumption tends to respond positively to income changes; however, after reaching relatively high income levels, the income elasticity becomes negative, indicating a reduction in consumption. Along the same lines, traditional fuels are concentrated at negative values, in accordance with the theoretical expectation. In comparison with the elasticities in Table 2, these results offer greater clarity on the association between income and domestic energy consumption.

Figure 8. Estimated Income Pointwise Derivatives along the Income Distribution

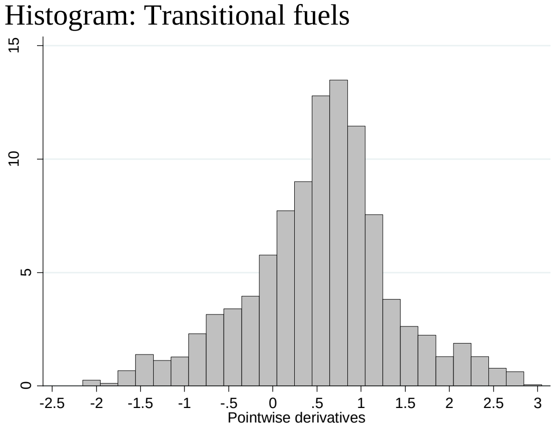
(a) Histogram: Modern fuels



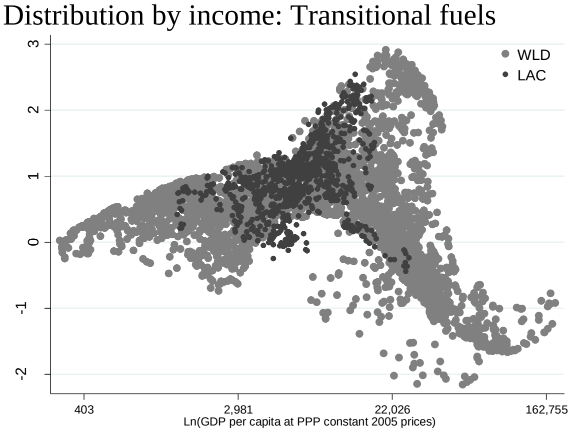
(b) Distribution by income: Modern fuels



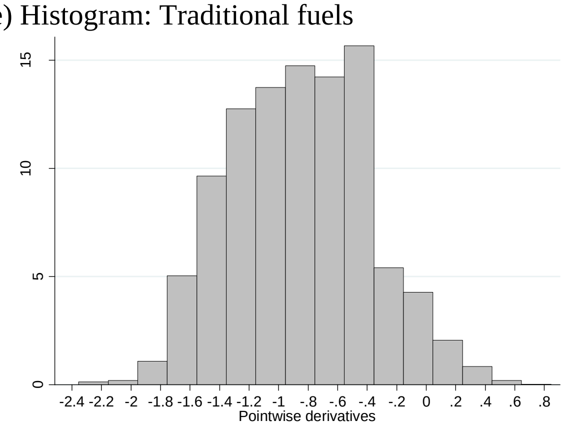
(c) Histogram: Transitional fuels



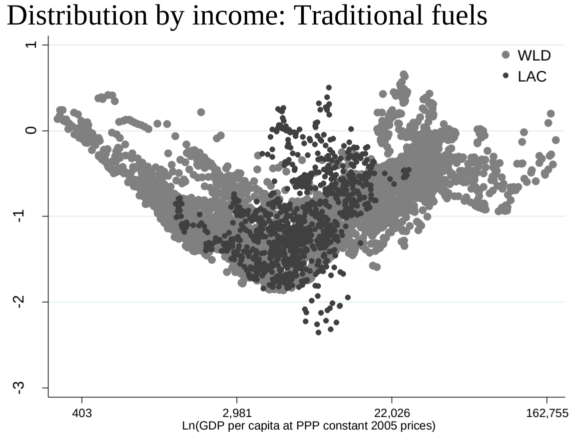
(d) Distribution by income: Transitional fuels



(e) Histogram: Traditional fuels



(f) Distribution by income: Traditional fuels



Source: Authors' calculations.
Note: In the distributions graphs, the x-axes are in log scales.

The other covariates are, on average, also statistically significant; however, their distributions are difficult to interpret (see Table 3). Annex G presents histograms of the price coefficient by type of fuel. In the case of modern fuels, the coefficient for oil prices is negative and symmetrically distributed at the median. On average it is positive and quite small, at less than 0.1 percent. In the case of transitional fuels, which are mainly oil products, the price elasticity is, on average, significantly negative, but with bi-modal distribution with one mode around -1 and the other around 0. In the case of traditional fuels, the estimated price elasticity is positive, which is expected, since for such fuels oil prices may be interpreted as proxies for substitute energy sources. Since international oil prices are not an accurate measure of energy prices, these results should be interpreted with caution. Well-behaved price elasticities for energy demand have been elusive in the empirical literature, particularly in applications at the aggregate level (Dahl and Sterner 1991; Fouquet 2014).

7. Final remarks

In addition to energy consumption rising with income, its composition also shifts toward greater use of modern and more efficient fuels. Over the past four decades, this empirical fact has been clearly observed in the residential sector, where demand for electricity and gas has grown at higher rates than in the transport and industry sectors, replacing demand for dirty fuels. In this process, the income elasticity of residential energy demand evolves, forming an inverse U-shape along the world income distribution. It suggests that household energy use will find a satiation point beyond which net energy savings will begin to reduce per capita energy consumption at high income levels. The pattern prevails in different specifications of the regression and machine-learning methods.

This paper also highlights the importance of taking country heterogeneity into account and distinguishing between energy sources when analyzing the relationship between income and energy use, showing that economic growth is fueled by modern energy sources, rather than traditional or transitional fuels. The results are consistent with previous studies that have emphasized the increasing energy demands of the developing world. In particular, the LAC region is at a stage of economic development where it is highly dependent on modern fuels, implying a significant need for energy infrastructure to sustain its path of economic growth.

At the same time, the results suggest that traditional fuel behaves as an inferior good, meaning that households attach significant value to the health benefits of switching to modern fuels. Because in poor countries a substantial share of residential energy use is composed of dirty fuels, finding ways to help poor families access and afford modern energy sources is an important policy challenge. Programs that facilitate access to modern energy sources have been effective at fostering fuel switching. On the other hand, development of a diversified sustainable energy matrix may reduce energy costs and help ensure supply. Energy efficiency and conservation measures may also reduce the cost of energy services while promoting energy savings.

It remains to be determined what policies might reduce energy dependence. Further research on the microeconomic causes that shape energy demand of households and firms may contribute to the identification of strategies to that end. In developing countries, a severe constraint is the limited information available on energy consumption and energy prices at the end-user level, which severely restricts what can be learned from energy consumption behavior and how it responds to different environments or policies.

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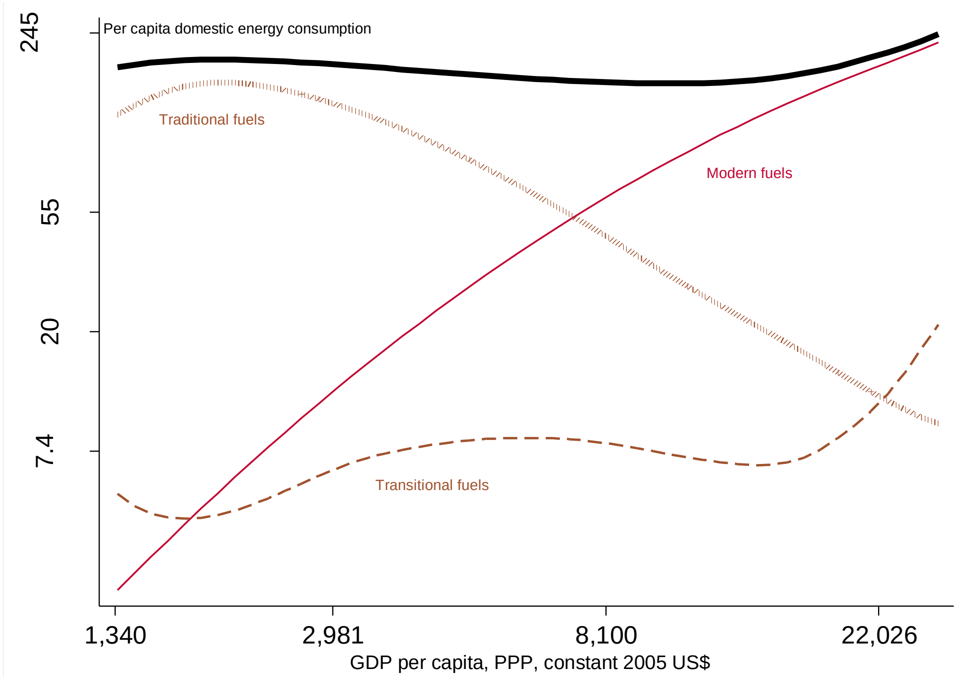
Annex A. Consumption of Domestic Energy along the LAC Income Distribution



Source: Authors' calculations.
Note: Includes 22 LAC countries over 1971 to 2013. The axes are in log scales. Curves are fitted with a polynomial of degree 2. GDP = gross domestic product; Ktoe = kilotons of oil equivalent; LAC = Latin America and the Caribbean; PPP = purchasing power parity.

Annex B. Panel Tests for Cross-Sectional Dependence

	CSD Test	
	Frees	**Pesaran**
Modern fuels		
stat	35.07	162.27
p-value	0.00	0.00
Transitional fuels		
stat	28.84	46.04
p-value	0.00	0.00
Traditional fuels		
stat	30.25	16.69
p-value	0.00	0.00
TFC, residential		
stat	29.72	11.66
p-value	0.00	0.00

Source: Authors' calculations.
Note: All tests were performed after FE regressions. The null hypothesis is cross-sectional independence. CSD = cross-sectional dependence; TFC = total final consumption.

Annex C. Regression Results of the Dynamic Panel Data Model (Equation 2)

	Share (s)			Modern fuels			Transitional fuels			Traditional fuels			TFC, residential		
	FE	MG	CCE	FE	MG	CCE	FE	MG	CCE	FE	MG	CCE	FE	MG	CCE
World															
ln(gdp per capita)	0.01	0.02	0.02	0.07	0.18	0.23	-0.06	0.17	0.14	0.03	0.02	0.00	0.02	0.09	0.12
	0.00	0.01	0.01	0.01	0.04	0.04	0.02	0.06	0.08	0.01	0.03	0.03	0.01	0.02	0.03
ln(oil price)	0.00	0.00	.	-0.01	-0.01	.	-0.02	-0.02	.	0.00	0.00	.	0.00	-0.01	.
	0.00	0.00	.	0.00	0.01	.	0.01	0.01	.	0.01	0.00	.	0.00	0.00	.
ln_shydro	0.02	0.16	0.21	0.04	0.35	0.34	-0.18	-1.18	-1.67	-0.19	-0.04	-0.24	-0.12	-0.35	-0.45
	0.01	0.05	0.05	0.03	0.34	0.33	0.15	0.52	0.62	0.07	0.25	0.14	0.05	0.15	0.19
ln_xnf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
lagged dependent	0.94	0.72	0.52	0.93	0.69	0.49	0.93	0.62	0.49	0.92	0.66	0.50	0.92	0.64	0.53
	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.03	0.01	0.02	0.02
Obs.	4368	4368	4368	4368	4368	4368	4368	4368	4368	4368	4368	4368	4368	4368	4368
Countries	104	104	104	104	104	104	104	104	104	104	104	104	104	104	104
LAC															
ln(gdp per capita)	0.01	0.04	0.04	0.10	0.28	0.35	-0.06	0.07	0.15	-0.04	-0.07	0.00	0.02	0.06	0.08
	0.00	0.01	0.01	0.02	0.04	0.09	0.04	0.12	0.09	0.02	0.08	0.10	0.02	0.06	0.08
ln(oil price)	0.00	0.00	.	-0.01	-0.03	.	-0.02	-0.01	.	0.01	0.02	.	0.00	0.00	.
	0.00	0.00	.	0.01	0.01	.	0.02	0.03	.	0.01	0.01	.	0.01	0.01	.
ln_shydro	0.01	0.12	0.12	0.05	0.20	-0.13	-0.11	-2.36	-1.65	-0.11	-0.18	0.05	-0.07	-0.64	-0.55
	0.01	0.08	0.10	0.02	0.47	0.57	0.10	0.90	1.28	0.04	0.42	0.26	0.02	0.25	0.33
ln_xnf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
lagged dependent	0.94	0.70	0.56	0.92	0.64	0.56	0.95	0.63	0.57	0.94	0.66	0.54	0.94	0.63	0.49
	0.01	0.05	0.04	0.01	0.05	0.06	0.02	0.03	0.03	0.02	0.04	0.06	0.01	0.04	0.06
Obs.	924	924	924	924	924	924	924	924	924	924	924	924	924	924	924
Countries	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22

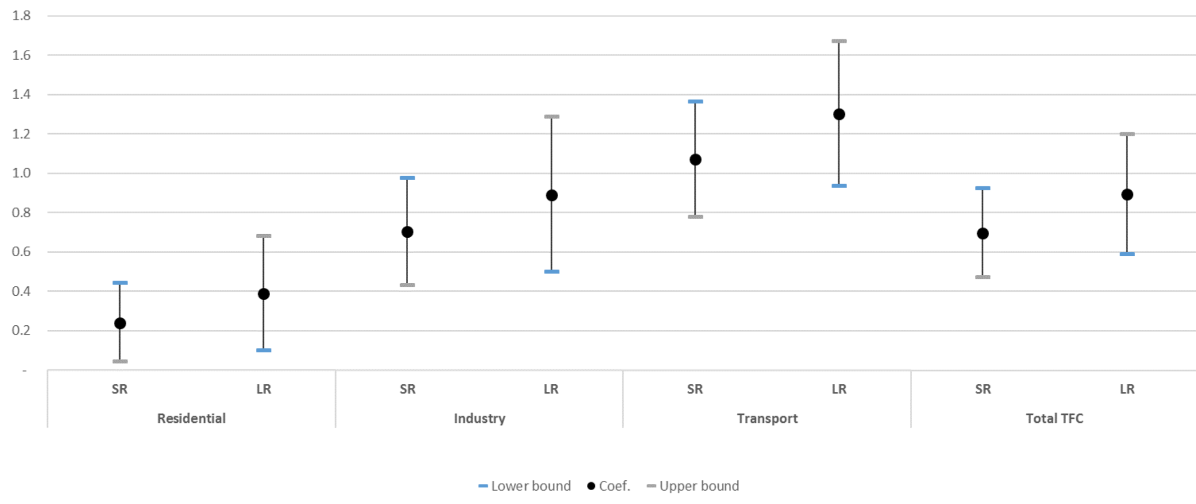
Source: Authors' calculations.
Note: All regressions correct for heteroscedasticity; MG and CCE include country-specific trends. CCE = common correlated effects; FE = fixed effect; LAC = Latin America and the Caribbean; ln_shydro = share of hydro in generation matrix; ln_xnf = net exports of fossil fuels; MG = mean group.

Annex D. Panel Regressions of Modern Fuels Including Structural Break Dummies

Dependent: Modern fuels	Short run			Long run		
Estimator:	FE	MG	CCE	FE	MG	CCE
World						
ln(gdp per capita)	0.886	0.609	0.371	0.065	0.219	0.271
	0.155	0.097	0.067	0.012	0.039	0.048
ln(oil price)	0.005	-0.018		-0.006	-0.011	
	0.021	0.010		0.003	0.005	
ln_shydro	0.317	0.509	0.099	0.026	0.077	0.256
	0.461	0.648	0.323	0.029	0.330	0.260
ln_xnf	0.013	0.001	0.001	0.002	0.000	0.001
	0.007	0.001	0.001	0.002	0.000	0.001
lagged dependent				0.923	0.633	0.384
				0.009	0.023	0.027
Break dummy	0.578	0.112	0.084	0.014	0.023	0.041
	0.077	0.030	0.021	0.009	0.008	0.012
Obs.	4472	4472	4472	4368	4368	4368
Countries	104	104	104	104	104	104
LAC						
ln(gdp per capita)	0.841	0.636	0.557	0.107	0.342	0.354
	0.146	0.167	0.160	0.024	0.051	0.075
ln(oil price)	-0.002	-0.042		-0.011	-0.028	
	0.027	0.024		0.007	0.011	
ln_shydro	0.926	0.960	0.063	0.041	0.205	-0.377
	0.192	1.134	0.570	0.019	0.455	0.556
ln_xnf	-0.008	0.003	0.001	-0.002	0.000	-0.001
	0.015	0.002	0.001	0.002	0.001	0.001
lagged dependent				0.904	0.612	0.532
				0.018	0.052	0.064
Break dummy	0.449	0.068	0.034	0.016	0.025	0.008
	0.074	0.041	0.029	0.012	0.009	0.018
Obs.	946	946	946	924	924	924
Countries	22	22	22	22	22	22

Source: Authors' calculations.
Note: CCE = common correlated effects; FE = fixed effect; LAC = Latin America and the Caribbean; MG = mean group.

Annex E. Short- and Long-Run Income Elasticities by Sector



Source: Authors' calculations.
Note: SR = short run elasticities; LR = long run elasticities.

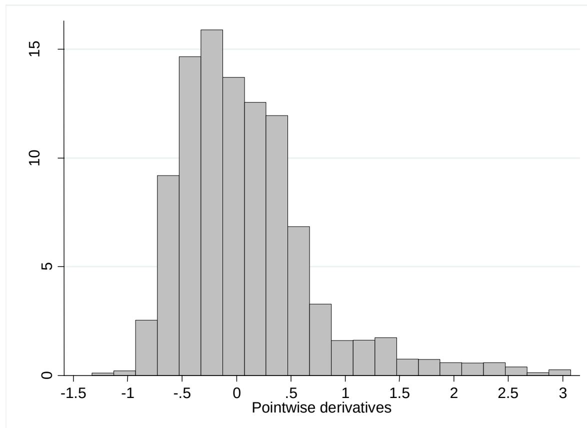
Annex F. Short- and Long-Run Income Elasticities by Income Group

Dependent: ln(modern fuels consumption)	**Income group**			**LAC**
	High	**Middle**	**Low**	
Lagged dependent	0.78	0.79	0.74	0.71
	0.03	0.05	0.03	0.04
Ln(GDP ppp per capita)	0.10	0.23	0.20	0.24
	0.06	0.10	0.06	0.03
Ln(oil price)	-0.01	-0.02	0.01	-0.02
	0.01	0.02	0.01	0.01
Trend	0.00	0.00	0.01	0.00
	0.00	0.00	0.00	0.00
Constant	0.25	-1.03	-1.22	-1.02
	0.61	0.82	0.42	0.36
Income elasticity	0.48	1.08	0.77	0.83
	0.29	0.53	0.24	0.17
Observations	1638	630	1176	882
Countries	39	15	28	21
chi2	927.4	246.1	776.8	321.9

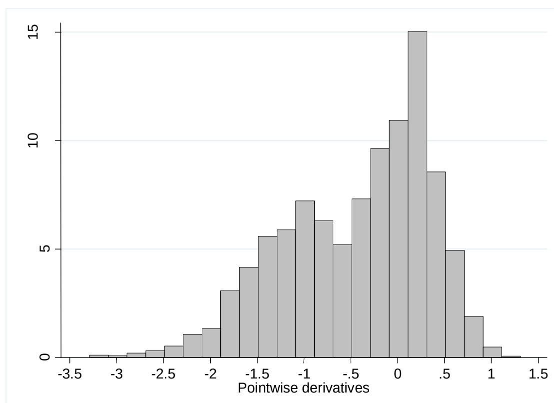
Source: Authors' calculations.
Note: Long-run elasticities are estimated through a dynamic version of equation (2), and their variances are estimated by the delta method. GDP = gross domestic product; LAC = Latin America and the Caribbean; PPP = purchasing power parity.

Annex G. Histograms of Price Pointwise Derivatives

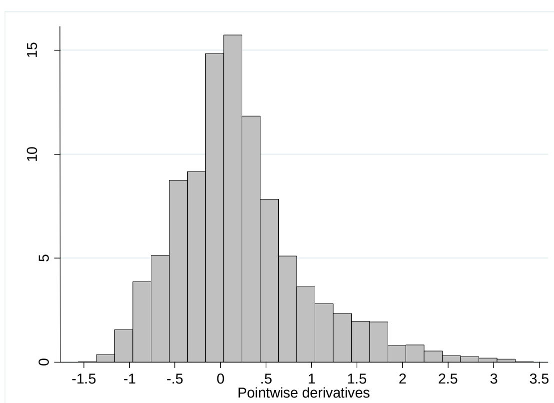
a. Modern fuels



b. Transitional fuels



c. Traditional fuels



Source: Authors' calculations.