

# Welfare Effects of Environmental Policies and Household Energy Choice

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*To my dear parents*

Major G.E. Okonkwo (rtd) & Mrs Chioma Okonkwo

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# Chapter 1

## Introduction to the Dissertation

# Introduction to the Dissertation

This dissertation is a cumulative thesis comprising of three individual research articles which contribute to the environmental, development and energy economics literature. The first two articles underscore how sustainable environmental policies affect individuals and households' welfare. The third article analyzes the impact of women's intra-household bargaining power on household fuel choice decision-making process and further analyzes the determinants of household energy spending after the decision to use a fuel has been made.

Growing concerns about climate change and environmental degradation has led many countries to design and implement more sustainable environmental policies. Although these sustainable policies may improve the current state of the environment, they could be detrimental to some population groups such as the poor who rely on natural resources for their livelihoods (Dasgupta and Maler, 1995; Baland and Platteau, 1996; Baumgärtner, 2007; Christophe et al., 2010; Wunder et al., 2014, Manning et al., 2018). Many of the natural resources do not have effective regulation, making them prone to over-exploitation and depletion. The implementation of a rights-based policy through the introduction of private property use rights (or privatization) is one of the several ways to address the over-exploitation problem. This policy may or may not be pareto-improving for the initial resource users.

The first article of this dissertation (co-authored with Martin Quaas) entitled "*Welfare Effects of Natural Resource Privatization: A dynamic analysis*" seeks to understand welfare changes, particularly for the poor, following the introduction of a rights-based policy. The paper develops a theoretical model that assesses the distributional and welfare effects on individuals when there is an equal distribution of private use rights on an open access resource. In contrast to the previous literature that mostly considers static settings, this paper explicitly models resource dynamics and the transition from an open access steady state to a new steady state under private property rights. Furthermore, conditions are derived

under which privatization leads to better or worse welfare outcomes for initial resource users.

The results suggest that privatization is not always Pareto improving. Privatization is found to be welfare-enhancing if the natural resource is sufficiently productive, if there is easy access to employment opportunities in the non-resource sector and if there is no discounting. In addition, when the reduction in income from resource harvesting during the transition to a new equilibrium is accounted for, privatization is desirable for the poor only for very productive natural resources and low discount rates.

The paper has been presented in several international conferences and benefited from the comments of esteemed colleagues. I contributed substantially to the paper at all stage of the research process from the design of the research question to the writing and revising stages. The paper has been published in *Environment and Development Economics* (<https://doi.org/10.1017/S1355770X19000342>).

The second research article entitled “*Welfare Effects of Carbon taxation on South African Households*” provides empirical evidence on how an environmental policy impacts welfare. South Africa committed to a 45% reduction in greenhouse gas emissions by 2025. To achieve these ambitious target, the South African government implemented a new carbon tax policy in June 2019. The policy imposes a tax of R120 per ton of carbon dioxide equivalent of greenhouse gas emissions.

The second paper seeks to answer the question, how would the newly implemented carbon tax policy in South Africa affect consumers’ welfare? The costs and burden resulting from the tax would be different across income groups. Hence, it is essential to understand the distributional effects of the carbon tax policy. Using the Quadratic Almost Ideal Demand model (Banks et al., 1997) and household survey data, the study predicts welfare losses resulting from the tax policy. The study also analyses income groups with different expenditure shares and uses elasticities to determine how households would respond to energy price changes that arise from the introduction of carbon tax.

The study’s findings have relevant policy implications. I find that an increase

in electricity and public transport prices resulting from the implementation of the carbon tax policy is regressive, while an increase in motor fuel prices is progressive. In addition, the simultaneous price increases for both electricity, motor fuels and public transport lead to a higher welfare loss for the poorest and middle income households compared to the richest households. This implies that low-income households would experience larger tax burdens that would further decrease their meagre disposable income. Thus, complementary policies such as tax revenue transfers to low-income households would be helpful in offsetting the welfare loss.

This article is single-authored. It was presented at the 2019 IAEE annual conference and several research seminars. I acknowledge the helpful comments I received from Martin Quaas and other esteemed colleagues to improve the manuscript. The paper is forthcoming in *Energy Economics* (<https://doi.org/10.1016/j.eneco.2020.104903>).

While the first two articles of this dissertation contribute to the literature on welfare effects of environmental policies, the third article contributes to the household fuel choice literature. Household air pollution is one of the major causes of premature deaths in developing countries. This results from household reliance on solid fuels (e.g. wood, crop wastes, animal dung) and the use of inefficient stoves which produce high levels of health-damaging pollutants. Exposure to these pollutants is particularly high among women and children in developing countries who are responsible for household cooking. The adoption of improved cooking technologies depends on household decision making, and particularly how women's preferences, opportunity cost of time and well-being are reflected in the decision-making process.

In the light of this, the third article entitled, "*Gender, Energy Expenditure and Household Cooking Fuel Choice in Nigeria*" focuses on the impact of women intra-household bargaining power in household fuel choice decision-making process. It provides a better understanding of the need for women's participation in the household decision-making process to mitigate adverse health impacts of indoor air pollution. It also goes further to analyze the determinants of household energy

expenditure conditional on fuel use. The study uses a nationally representative dataset from Nigeria and employs the multinomial logit and log linear regression models for the analysis.

My findings have three important policy implications for energy transition in developing countries. First, I do not find significant effects to conclude that households with female heads are less likely to choose traditional fuels and more likely to opt for modern fuels as their main cooking fuel. This implies that gender does not significantly influence the adoption of modern fuels in Nigeria. Second, income and education are important determinants of household modern energy use and expenditure. Thus, investments in education would positively influence the uptake of modern fuels. Third, access to electricity does not guarantee the use of electricity for cooking. This is probably because public power supply in Nigeria is intermittent and unreliable. The reliability of electricity supply is a key component of determining whether or not households use electricity for cooking.

This article is also single-authored. It has been presented at the iDiv Biodiversity Economics Group Retreat. I acknowledge the discussions I had and suggestions I received from Martin Quaas to improve the overall quality of the manuscript. This paper has undergone the first review process and is to be revised and resubmitted to *The Energy Journal* (Manuscript Reference Number: EJ 20-083).

Overall, the dissertation emphasizes that the welfare and distributional impacts of environmental policies should be fully accounted for during the policy design phase. While poorly designed environmental policies could decrease the welfare of vulnerable groups in the economy and intensify inequality problems, policies that accommodate such potential outcomes are more likely to achieve sustainable growth without harming welfare or worsening inequality.

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## Chapter 2

# Welfare Effects of Natural Resource Privatization: A Dynamic Analysis

# Welfare Effects of Natural Resource Privatization: A Dynamic Analysis

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## **Abstract**

This paper sets up a dynamic model to study the distributive effects of privatizing an open access resource. We show that with or without discounting, privatization is not always Pareto improving. We further derive conditions under which the poor are made worse off when private use rights are equally distributed compared to situation with open access resource. These conditions imply that privatization is Pareto improving if the natural resource is sufficiently productive, inequality in alternative private project opportunities is low, and if there is no discounting. In addition, we show that once reduction in income from resource harvesting during the transition to a new steady state is accounted for, privatization is desirable for the poor only for very productive natural resources and low discount rates.

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# 1 Introduction

A majority of the world's poor rely on open access resources such as fisheries, forests and lands to meet their basic needs. These natural resources play a vital role for economic development as they contribute to people's livelihoods. Several economic and natural resource studies have emphasized the importance of these resources in serving as safety nets for those who cannot find employment elsewhere, say in the service or manufacturing sectors (Dasgupta and Maler, 1995; Baland and Platteau, 1996; Baumgärtner, 2007; Delacote, 2007; Bene et al., 2010; Wunder et al., 2014, Manning et al., 2018). However, many of these resources do not have enforced property rights or effective regulation, making them prone to resource overuse, overexploitation and depletion, with negative repercussions on the harvesters' incomes (Stavins, 2011; Costello et al., 2012; Noack et al., 2018). These negative consequences, including the problem of rent dissipation, render the open access regime inefficient, thereby creating a need for action.

Broadly speaking, there are two ways to address the problem of resource overuse under open access conditions. One option is to introduce an authority that is responsible for controlling resource use and harvesting behavior. This authority could be the government or a common property institution developed by the resource users. Research on common property management has been widely studied (Ostrom, 1990; Bromley, 1992; Gebremedhin et al., 2003). A second option is privatization, which entails the distribution of resource ownership rights among individuals. Each individual has an exclusive right over his/her resource allocation (Demsetz, 1967; Smith, 1981; Birdyshaw and Ellis, 2007).

In this paper, we focus on the second approach, privatization. Several resource economists favor privatization of access to natural resource, mostly on the basis that it improves overall economic efficiency (Grafton et al., 2005; Grafton et al.,

2007; Grainger and Parker, 2013; Grainger and Costello, 2014). Privatization results in an efficiency improvement, as private resource users have an incentive to restrict harvesting effort, and as harvesting restrictions increase future resource productivity. Despite these overall efficiency gains, privatization does not necessarily imply a Pareto improvement over an open-access regime. Rather, whether an individual benefits or loses from a shift in the property right regime from open access to privatization depends on the distribution of resource-use rights.

Typical approaches to distribute resource use rights are grandfathering or an equal distribution of rights. We focus on the scenario of equal distribution of private rights where the individual share of resource rents may not necessarily be sufficient to compensate for the lost opportunity to generate income in resource harvesting. This would be especially the case for the poor, who particularly benefit from free access to the resource. We, therefore, study the question, 'Under which conditions would privatization with an equal distribution of use rights increase or decrease the welfare of the poor?'

Previous literature has investigated the distributive and welfare impacts of privatizing an open access resource mostly in a static setting. Weitzman (1974) and Samuelson (1974) laid the foundation for this line of research. They developed theoretical models to compare the allocation of resources under open access and private property ownership equilibria and argue that labor is always better off in an equilibrium with inefficient open access rights than in the efficient private property ownership equilibrium. This result follows from their theoretical set up where the main inefficiency in the open-access regime is the inefficiently high labor (effort) use compared to the private property regime. de Meza and Gould (1987) consider a different model of resource use and find that workers may be better off in the privatization regime compared to open access. This result is also based on their theoretical model set up where depletion of resource productivity is the

main inefficiency in the open-access regime.

Baland and Francois (2005) analyze the welfare impacts of privatizing a common resource when individuals differ with regards to their income possibilities outside resource use. They show that although privatization could be a worthy solution to resource overuse, common insurance dominates privatization with insurance when markets are incomplete. Only few papers study the distributional effects of privatization in a dynamic framework. Baland and Bjorvatn (2013) argue that even if traditional users of open access resources are restricted from owning the resource, they may gain from privatization. Considering a harvesting technology with stock-independent harvesting costs, they show that employment falls in the short run but rises in the long run. The long-run effect dominates leading to an increase in both labor incomes and total employment, thereby benefiting initial resource users. Quaas et al. (2018) show for the case of Baltic cod fishery that the distributional impacts of more efficient management depend on the initial size of the resource stock. Grainger and Costello (2016) show that especially the most efficient fishermen would oppose the transition to a property-rights fishery unless a sufficiently large share of harvesting rights is allocated by means of grandfathering.

In this paper, we study a dynamic model to assess the distributive and welfare effects of individuals when an open access resource is equitably privatized. We derive conditions under which privatization leads to better or worse welfare outcomes for initial resource users. First, we show that privatization reduces labor allocation on the resource and therefore increases stock level. Thus, the steady state resource stock is greater in a privatization regime than in an open-access regime. Next, we compare steady states incomes in the open-access and the privatization regimes with and without discounting and derive conditions under which steady state incomes of the poor are higher in the open-access regime. For the case with

a positive discount rate, we further consider transition dynamics from the open access steady state to the privatization steady state and show that this transition period will in particular harm the poor resource users. We use numerical examples to illustrate our analytical results.

This paper comprises of four sections. Section 2 presents the model framework in both the open-access and privatization regimes. Section 3 analyses the steady state equilibrium, compares incomes from the two different regimes and provides the transitional dynamics of the model. Lastly, section 4 discusses and concludes the paper.

## **2 A Dynamic Model of Regime Change with Open Access Resources**

We consider a small economy with a continuum of individuals with a total mass of one. Each individual is endowed with one unit of labor and chooses to work either in resource harvesting or in private project (a resource-independent sector). Returns from the private project differ across individuals, but are constant for each individual. The resource is harvested by means of a technology that uses the resource and labor as inputs, and is available to all individuals in the economy. Access to the resource is free for all in the open-access regime. In the privatization regime, resource-harvesting individuals need use rights, using their own endowment of these private rights and/or rented use rights from other owners. Returns in resource harvesting depend on the resource stock  $x$  which changes over time depending on natural regeneration and harvesting. However, since resource harvesting is competitive, all individuals in resource harvesting receive the same return, equal to the value of the marginal product of resource harvesting. Given these assumptions, every individual will specialize and work with his/her

full amount of time (one unit) in either resource harvesting or the private project.

In the open-access regime, all those individuals whose return in the private project is not more than the current value of the marginal product of resource harvesting will work in resource harvesting. All these ‘poor’ individuals benefit from free access to the resource, as they receive the value of the marginal product of the resource instead of the lower return from their private project. All individuals with a private project return greater than  $\theta^O$ , the value of the marginal product in resource harvesting, choose to work on private project. Their income is higher in proportion to the return of their private project. All individuals with a return from private project equal or below  $\theta^O$  choose to work in resource harvesting and thus all receive the same income  $\theta^O$  of resource harvesting.

In the privatization regime, resource use rights are equally distributed across individuals. Only those individuals whose return from the private project, plus the rental price of the use right, is not more than the current value of the marginal product of resource harvesting will work in resource harvesting. The ‘cutoff’ level of productivity in the private project,  $\theta^P$ , is lower in the privatization regime than in the open-access regime, since the rent for the use right of the resource is positive. Thus, fewer individuals will harvest the resource in the privatization regime compared to the open-access regime, and their individual income from resource harvesting will be lower. Yet, all individuals will also receive their share of the resource rent,  $R$ . This is an extra benefit for those individuals who did not work in resource harvesting even in the open-access regime. For the initial resource users - the poor - the extra income in form of resource rents may or may not be sufficient to compensate for the loss of income from resource harvesting.

The question is thus, under which circumstances is the effect of privatization on the overall incomes of the poor positive or negative. The answer to this question depends not only on resource dynamics but also on harvesting technology and the

distribution of private returns. To study this question, we set up the formal model and derive some preliminary results for the open-access regime scenario and then turn to the analysis of the privatization regime.

## 2.1 Model set up and resource use in the open-access regime

In both regimes, individuals choose how much time they work in resource harvesting and how much time they work on a private project. Since each individual has one unit of labor, and the total mass of individuals is one, the sum of labor in resource harvesting  $L^O$  and private projects  $L^P$  is one,

$$L^O + L^P = 1.$$

Returns from private project,  $\theta_i$ , differ across individuals, and are assumed to be uniformly distributed between a minimum of  $\underline{\theta}$  and a maximum of  $\bar{\theta}$ . The spread between  $\underline{\theta}$  and  $\bar{\theta}$  is a measure for the inequality in alternative private project opportunities.

To simplify expressions, we normalize the minimum return that can be obtained from a private project to zero,  $\underline{\theta} = 0$ .<sup>1</sup> Thus,  $\theta_i \sim \mathcal{U}[\underline{\theta}, \bar{\theta}] = \mathcal{U}[0, \bar{\theta}]$  with a cumulative distribution function (CDF)

$$F(\theta) = \frac{\theta - \underline{\theta}}{\bar{\theta} - \underline{\theta}} = \frac{\theta}{\bar{\theta}}. \quad (1)$$

We model the bio-economic dynamics in a standard fashion. The growth function,  $g(x)$  is a logistic function where  $r > 0$  is the intrinsic growth rate and  $k > 0$  is

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<sup>1</sup>This assumption completely innocuous. As the value or the marginal product in resource harvesting is always positive, the assumption  $\underline{\theta} = 0$  rules out a corner solution with zero employment in resource harvesting.

the environmental carrying capacity,

$$g(x) = r x \left(1 - \frac{x}{k}\right). \quad (2)$$

The harvesting productivity  $q(x)$  is linear in  $x$ , and labor is the only variable factor in harvesting, such that total harvest is given by

$$h = q(x) L^O = q x L^O \quad (3)$$

with  $q > 0$ . Normalizing the price of the resource good to one, the value of the marginal return of labor in resource harvesting is constant and equal to  $q x$ . In equilibrium, resource harvesting will be the preferred occupation for all those individuals whose return from the private project does not exceed the return of labor in resource harvesting. The marginal employee in resource harvesting is indifferent between earning this return of labor in resource harvesting to receiving the returns from the private project. This individual's return from working on the open access resource,  $\theta^O$ , is defined by the equation

$$\theta^O = q x. \quad (4)$$

All individuals  $i$  with  $\theta_i \leq \theta^O$  choose to work in resource harvesting. Their share in the total labor force equals

$$\int_0^{\theta^O} f(\theta_i) d\theta_i = F(\theta^O) \stackrel{(4)}{=} F(q x), \quad (5)$$

such that total harvest is

$$h = q x F(q x). \quad (6)$$

Since individuals work in either resource harvesting or private project, their income is defined by the return of labor in resource harvesting,  $q x$ , or by the return from private project,  $\theta_i$ . The income of an individual  $i$  depends on the return  $\theta_i$  from private project as

$$y^O(\theta_i) = \begin{cases} q x^O & \text{for } \theta_i \leq \theta^O \\ \theta_i & \text{for } \theta_i > \theta^O. \end{cases} \quad (7)$$

The resource grows over time with dynamics given by the difference between natural growth  $g(x)$  and aggregate harvest  $h$ , given by (6),

$$\dot{x} = r x \left(1 - \frac{x}{k}\right) - q x F(q x). \quad (8)$$

By setting  $\dot{x} = 0$ , and solving the equation, we derive the steady-state resource stock under open access (see appendix A) as

$$x^O = \frac{\bar{\theta} r k}{k q^2 + \bar{\theta} r}. \quad (9)$$

The steady state resource stock is a function of the upper bound of returns from working on a private project, carrying capacity, the intrinsic growth rate and the harvest productivity. The steady-state incomes are obtained by inserting (9) into (7).

The steady state stock in the open-access regime is always positive, i.e. there is no resource collapse. This is because both the marginal productivity of labor (cf. equation 3 and the amount of labor employed in resource harvesting (equation 5) are linear in the resource stock. Thus, harvest is quadratic in stock size, whereas growth  $g(x)$  is linear in stock size at sufficiently small stock sizes. As a result, net growth is always positive for very small stock sizes, and thus, a zero stock size is

ruled out as a steady state outcome.

## 2.2 Model set up and resource use in the privatization regime

In the privatization regime, resource harvesting individuals require use rights to work on the open access resource. This could be their own endowment of private use rights and/or rented use rights from other owners. Using  $\rho$  to denote the rental price of the right to harvest one unit of the resource and given the normalization that the price of the resource good is one, the value of the marginal product of labor in resource harvesting is

$$\theta^P = (1 - \rho) q x, \quad (10)$$

and the amount of labor in resource harvesting is  $L^P = F(\theta^P)$ , analogous to the case in the open-access regime.

Owners of private resource use rights choose the supply of harvest so as to maximize the present value, at discount rate  $\delta$ , of revenues from renting out the quantity  $q x L^P$  of resource-use rights at a price  $\rho$ ,  $\rho q x L^P$ , subject to the resource dynamics of the stock. Since there is a one-to-one relationship between harvest and labor input into harvesting, cf. (3), we can equivalently state the resource-owners problem as an optimization over the time path of  $L^P$ . From (10) we obtain the rental value of resource-use rights as  $\rho q x L^P = (q x - \theta^P) L^P$ . Thus, supply of use rights over time is determined by the solution of

$$\max_{\{L^P\}_0^\infty} \int_0^\infty e^{-\delta t} (q x - \theta^P) L^P dt \text{ subject to } \dot{x} = g(x) - q x L^P. \quad (11)$$

The current-value Hamiltonian for the optimization problem is given by:

$$\mathcal{H} = (q x - \theta^P) L^P + \mu (g(x) - q x L^P) \quad (12)$$

The Hamiltonian includes the labor use,  $L^P$ , the state variable  $x$ , and the associated co-state variable  $\mu$ . The first order conditions are given as

$$\frac{\partial \mathcal{H}}{\partial L^P} = (1 - \mu) q x - \theta^P = 0 \quad (13a)$$

$$\frac{\partial \mathcal{H}}{\partial x} = q'(x) L^P + \mu (g'(x) - q'(x) L^P) = \delta \mu - \dot{\mu} \quad (13b)$$

$$\frac{\partial \mathcal{H}}{\partial \mu} = g(x) - q(x) L^P = \dot{x} \quad (13c)$$

with transversality condition  $\lim_{T \rightarrow \infty} \mu x = 0$ . As discussed above, the amount of labor in resource harvesting is given by  $L^P = F(\theta^P)$ .

Equating Condition (13a) for the optimal supply of use rights with Condition (10) for the labor demand by resource harvesting we find the following result.

**Lemma 1.** *The rental price of resource-use rights is just equal to the shadow price of the resource stock,  $\rho = \mu$ .*

The total revenues of renting out resource-use rights are  $\rho q x L^P = \rho q x \theta^P$ . Under an equal distribution of private rights, every individual gets the same share, which is numerically equal to  $\rho q x \theta^P$ , since we normalized the mass of individuals to one. Under privatization with an equal distribution of resource use rights the incomes thus are:

$$\theta^P + \mu q x F(\theta^P) \quad \text{for individuals } i \text{ with } \theta_i \leq \theta^P = (1 - \mu) q x \quad (14a)$$

$$\theta_i + \mu q x F(\theta^P) \quad \text{for individuals } i \text{ with } \theta_i > \theta^P. \quad (14b)$$

Incomes under the privatization regime are defined by the sum of the return

obtained from working on the common resource and the resource rents. Incomes change over time, as  $\mu$ ,  $\theta^P$ , and  $x$  change in the transition towards the privatization steady state. The steady state values for resource stock size, rents and incomes in the privatization regime are derived in Appendix B.

### 3 Welfare effects of privatizing an open access resource

Our main interest is to compare incomes – especially of the poor resource users – in the open-access and privatization regimes. We proceed in three steps. First, we compare steady state incomes without discounting. This corresponds to the static setting considered by most of the literature, albeit we derive it from a dynamic model. Second, we compare incomes in the steady state with discounting. Finally, we include the effect of transition dynamics from an initial steady state in the open-access regime to the new steady state in the privatization regime with discounting.

#### 3.1 Distributive effects of privatization without discounting

For the case of no discounting, it is sufficient to compare steady state incomes. These are determined by the steady-state stock sizes

$$x^O = k \frac{\bar{\theta} r}{k q^2 + \bar{\theta} r} \qquad x^P = k \frac{q^2 k + \bar{\theta} r}{2 q^2 k + \bar{\theta} r}. \qquad (15)$$

In Appendix B, we show that steady state stock sizes are positive and less than carrying capacities, and in Appendix C we show that the steady state stock size in the privatization regime is larger than in the open-access regime,  $x^P > x^O$ .

This is attributed to the open access feature of the resource which allows free entry/harvesting on the resource. It is expected that the equilibrium resource stock would be lower in an open-access regime compared to a privatization regime because of the tendency for the open access resource to be overexploited and overused.

Steady state incomes in the open-access and in the privatization regimes are given by

$$\theta^O = \frac{\bar{\theta} r q k}{q^2 k + \bar{\theta} r} \quad \theta^P + R = \frac{\bar{\theta} r q k}{2 q^2 k + \bar{\theta} r} + \frac{r q^4 k^3}{(2 q^2 k + \bar{\theta} r)^2} \quad (16)$$

where  $R$  is the resource rent, which we derive in Appendix D.

We find that  $\theta^O > \theta^P$ , but also  $R > 0$ . This result is plausible because labor allocation in the open-access regime is greater than in the privatization regime, thus, the returns from working on the resource in the open-access regime would be greater than in the privatization regime. This is also in line with Grainger and Costello (2016) who noted that the introduction of property rights effectively levels the playing field across all resource owners by transferring some of the inframarginal rent to resource rent. One of the aims of privatization is to solve the problem of resource overuse and depletion. To achieve this, labor allocated on the resource is reduced. However, resource rents may more than compensate for this loss.

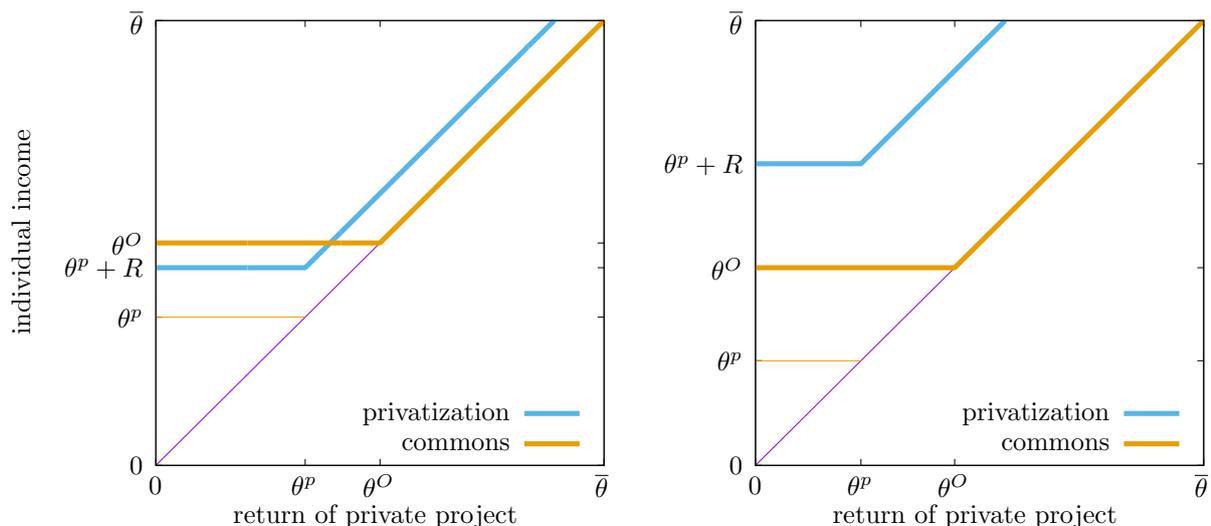


Figure 1: Incomes in the open-access and privatization regime.

In the left panel, the incomes of the poor in the privatization regime are less than in the open-access regime,  $\theta^P + R < \theta^O$  (model parameters values are  $q = r = k = \bar{\theta} = 1$ ). The opposite is the case in the right panel, where  $\theta^P + R > \theta^O$  (same model parameter values, except  $q = k = 2$ ).

Possible relationships between the incomes in the open-access and privatization regime are illustrated in Figure 1. The left panel in this figure shows a case where the poor – in particular those with productivity of the private project below  $\theta^P$  – are worse off in the privatization regime. The rich, of course, are better off, as they receive the resource rent in addition to the return from their private projects. The right panel shows a case where privatization is a strict Pareto improvement. All individuals are better off in the privatization regime.

The following proposition derives the condition under which privatization with an equal distribution of resource use rights is (or is not) Pareto improving compared to the open-access regime.

**Proposition 1.** *Assuming discount rate is zero,  $\delta = 0$ , incomes of the poor are lower / equal / higher in the privatization regime compared to the open-access*

regime according to

$$\theta^P + R \underset{>}{\overset{\leq}{\leq}} \theta^O \quad \Leftrightarrow \quad \frac{\theta^P}{\theta^O} = \frac{q^2 k + \bar{\theta} r}{2q^2 k + \bar{\theta} r} \underset{>}{\overset{\leq}{\leq}} \frac{\bar{\theta}}{qk}. \quad (17)$$

*Proof.* See Appendix D. □

Note that the left-hand side of the condition in (17) is always smaller than one. Given Proposition 1, we thus have three possible outcomes. Firstly, if  $\bar{\theta} > qk$ , always  $\theta^P + R < \theta^O$ , no matter what the exact values of  $r$ ,  $k$ ,  $q$ , and  $\bar{\theta}$  are. Some poor people are worse off with privatization when the highest possible return from the private project,  $\bar{\theta}$ , is greater than the maximum harvest in resource harvesting,  $qk$ . As  $\bar{\theta}$  is a measure of inequality in alternative private project opportunities, and  $qk$  can be interpreted as a measure of resource productivity, Proposition 1 says that privatization is harmful for the poor if the inequality in private income opportunities is high relative to resource productivity. Recall that the individuals who work on private projects are those whose returns are greater than the returns gotten from working on the commons. In the equitable privatization regime, where property rights are distributed to all individuals in the economy regardless of where they originally work, those individuals who relied on resource harvesting will be made worse off. They no longer have full access to the common resource and they do not earn any additional returns from outside options. Of course, those who work on private projects will be better off because, in addition to the returns gotten from their private projects, they also gain rents from owning the resource.

Secondly, if  $\frac{qk}{2} > \bar{\theta}$ , always  $\theta^P + R > \theta^O$ : all incomes in the privatization regime are strictly higher than the incomes under open access if the harvest productivity at the maximum sustainable yield stock size  $k/2$  is greater than the highest possible return from private projects. This means that the higher the

resource productivity, the more beneficial privatization would be. It suggests that privatization would yield better outcomes when resources have not been overused or overexploited.

Thirdly, if  $\frac{qk}{2} < \bar{\theta} < qk$ , the relationship between incomes from the privatization and open-access regime can be either way. For some sets of parameter values of  $r$ ,  $k$ ,  $q$ , and  $\bar{\theta}$ , Condition (17) is satisfied, for others it is not.

### 3.2 Distributive effects of privatization with discounting

Without discounting, i.e. for  $\delta = 0$ , individuals care only about the long-term equilibrium outcomes. This is different with discounting, i.e. where  $\delta > 0$ , as then the present value of incomes depend on the intertemporal distribution of incomes. Since we are interested in the effects of privatizing an open access resource, we take the steady state in the open-access regime as a starting point.

When remaining in the open-access regime, the present value of income of an individual with return from the private project equal to  $\theta$  is given by:

$$PV^O = \int_0^{\infty} e^{-\delta t} \max\{\theta, \theta_c\} dt = \frac{\max\{\theta, \theta_c\}}{\delta} \quad (18)$$

Since the initial steady state is the open-access regime steady state, income will stay constant, and the present value is simply the annual income divided by the discount rate. For the same individual, the present value of income in the privatization regime is given by:

$$PV^P = \int_0^{\infty} e^{-\delta t} \max\{\theta, \theta_p(t)\} dt + \int_0^{\infty} e^{-\delta t} \left( q(x) F(\theta^P(t)) - \int_0^{\theta^P(t)} \theta^P(t) F(\theta^P(t)) dt \right) dt \quad (19)$$

The first term is the present value of income from either resource harvesting – if  $\theta \leq \theta^P(t)$  – or the private project, if  $\theta > \theta^P(t)$ . Note that during the transition

phase,  $\theta^P(t)$  changes over time, so over time there will be a changing mass of persons working in resource harvesting. The second term is the resource rent, i.e. the difference between the gross return and the opportunity costs of resource harvesting. In the privatization regime considered here, each individual gets the same fraction of resource rent – as we have normalized the mass of individuals to one, it is numerically equal to the total resource rent.

We proceed with the comparison of incomes in the two regimes in two steps. First, we compare incomes in the two steady states i.e. the open-access and privatization regimes. In the second step, we include the effect of transition dynamics (Section 3.3).

Appendix B shows that the steady state resource stock in the privatization regime with a positive discount rate  $\delta > 0$  is given by

$$x^P = k \frac{(q^2 k + \bar{\theta} r)(r - \delta) + \sqrt{4(2q^2 k + \bar{\theta} r)\bar{\theta} r^2 \delta + ((q^2 k + \bar{\theta} r)(r - \delta))^2}}{2(2q^2 k + \bar{\theta} r)r}. \quad (20)$$

We start our analysis by studying the comparative statics of  $x^P$ ,  $\theta^P$ , and  $R$  with respect to the discount rate  $\delta$ . The following proposition summarizes the results.

**Proposition 2.** *The steady-state stock size and resource rent are monotonically decreasing with the discount rate  $\delta$  to the levels of the open-access regime,*

$$\frac{dx^P}{d\delta} < 0; \quad \lim_{\delta \rightarrow \infty} x^P = x^O \quad (21)$$

$$\frac{dR}{d\delta} < 0; \quad \lim_{\delta \rightarrow \infty} R = 0 \quad (22)$$

*Thus, as  $\delta \rightarrow \infty$  the incomes in the two regimes converges i.e.  $\theta^P + R = \theta^O$ .*

*Proof.* See Appendix E □

Taking into account the discount rate reveals the relationship between the

discount rate, resource stock and incomes. The intuition behind this proposition is straightforward. The steady state resource stock under privatization decreases with the discount rate. Resource users prefer to harvest more today rather than in the future. The maximum steady state for the privatization regime is  $x^P$  with a discount rate equal to zero. As the discount rate increases, the stock decreases. In the other extreme, if the discount rate approaches infinity, the stock converges to the open access steady state which is the initial steady state. This also leads to the convergence of both steady state incomes.

Similarly, as the discount rate increases, steady state resource rents fall. This relationship is derived from the negative association between the resource stock and the discount rate. Higher discount rate implies that resource users have strong preference for present consumption and a higher willingness to harvest now. Although harvesting increases during this period, the declining stock requires more effort than was previously needed to harvest a certain amount of output. It is also less productive, hence a decrease in the resource rents.

To proceed with the analysis we consider the steady state income in the privatization regime as a function of the steady state resource stock size  $x^P$  – keeping in mind that  $x^P$ , in turn, is a function of parameter values, in particular a function of the discount rate  $\delta$ . We find that steady state income in the privatization regime is a hump-shaped function of steady state stock size  $x^P$ , as stated in the following proposition. We also know from Proposition 2 that the actual steady state stock sizes, considered as a function of  $\delta$ , lie between a minimum  $x^O$  – for  $\delta \rightarrow \infty$  – and a maximum  $x^* \equiv x^P|_{\delta=0}$ . Thus, depending on the other parameter values, we can have three cases, as characterized in the following proposition. We will consider all these cases below.

**Proposition 3.** *There exist a maximum  $\hat{x} = \arg \max (\theta^P + R)$  when  $\frac{d(\theta^P + R)}{dx^P} = 0$ . Given this maximum, we distinguish three cases (using  $x^* = x^P|_{\delta=0}$ ),*

(I) If  $\hat{x} < x^O$ , steady-state income monotonically increases with the discount rate. This case prevails if and only if  $\bar{\theta} > qk$ .

(II) If  $\hat{x} > x^*$ , steady-state income monotonically decreases with the discount rate. This case prevails if and only if  $\bar{\theta} < qk(1 - 2\frac{q}{r})$

(III) If  $x^O < \hat{x} < x^*$ , steady-state income first increases with the discount rate and then decreases, asymptotically approaching  $\theta^O$  for  $\delta \rightarrow \infty$ . This case prevails for  $qk(1 - 2\frac{q}{r}) < \bar{\theta} < qk$ .

*Proof.* See Appendix F □

Note that Case (I) coincides with the case where, without discounting, the poor is always better off in the open-access regime than in the privatization regime (cf. Proposition 1). In this case, increasing the discount rate brings the steady state in the privatization regime closer to the better (open-access) steady state.

Without discounting, the privatization regime is always better than the open-access regime if  $\bar{\theta} < qk/2$ , i.e. if the maximum productivity of the private project is relatively small. In a similar fashion, the incomes of the poor monotonically decreases with the discount rate (Case II) if the inequality of private project productivities is low, here if  $\bar{\theta}$  is below the threshold  $qk(1 - 2q/r)$ . This threshold is increasing in resource productivity, measured both in terms of carrying capacity  $k$  and in terms of intrinsic growth rate  $r$ . In Case (II), increasing the discount rate decreases income ultimately towards the lower income in the open-access regime.

The relationship between the steady state incomes of the poor and the discount rate is non-monotonic, i.e. first increasing and then decreasing (Case III). Note that the critical value for  $\bar{\theta}$  below which the steady state income monotonically decreases with the discount rate is different from the critical value below which steady state income with discounting is larger than income in the open-access regime. Thus it may be that the steady-state income in the privatization regime

is higher than the steady state income in the open-access regime, no matter the discount rate. This is the case if  $qk(1 - 2q/r) < \bar{\theta} < qk$ , but  $\bar{\theta} < qk/2$ . Yet, it is also possible that for small discount rates, income in the privatization steady state is below income in the open-access steady state. But with increasing discount rate, steady state income in the privatization regime would eventually exceed steady state income in the open-access regime. This is the case if  $qk(1 - 2q/r) < \bar{\theta} < qk$ , and  $qk/2 < \bar{\theta} < qk$ .

The four-quadrant plots in Figures 2 to 4 illustrate these results. In all three figures the panel in the top right shows the relationship between the discount rate and steady state income in the privatization regime. The other three quadrants illustrate how this is obtained. The panel in the bottom right shows how the steady state resource stock depends on the discount rate. In all cases, it is monotonically decreasing from  $x^* = x^P|_{\delta=0}$  to  $x^O$  for  $\delta \rightarrow \infty$ . The graph in the top left quadrant shows the relationship between steady state resource stock size and steady-state income. It is always non-monotonic, assuming a maximum at some value  $\hat{x}$ . In Case (I), shown in Figure 2, this maximum is at a stock size smaller than the steady state stock size in the open-access regime,  $x^O$ . As a consequence, the steady state income monotonically increases with the discount rate, ultimately approaching the open access income from below. Figure 3 illustrates Case (II) where the steady state income is monotonically decreasing with  $\delta$ . In this case the maximum of the curve in the top left panel is at a stock size larger than  $x^*$ .

Figure 4 illustrates Case (III) where the steady state first increases and then decreases with the discount rate. In the case shown in the figure, steady state income in the privatization regime for zero discounting is larger than income in the open-access regime. With increasing discount rate, it assumes a maximum even above this income and then decreases to the income in the open-access regime from above. Another possibility (not shown) is that the income in the privatization

regime starts, with zero discount rate, at a level smaller than in the open-access regime, then exceeds the income in the open-access regime for some value of  $\delta$ , and ultimately approaches  $\theta^O$  from above.

### 3.3 Transition Dynamics

We have shown that  $x^P > x^O$  for all finite discount rates  $\delta$ . Thus, starting in an open-access regime steady state, privatization always implies a phase of stock rebuilding with reduced harvesting effort, i.e.  $\theta^P$  will be below its steady state level during the transition towards the steady state. This, of course, imposes an extra cost on the poor resource harvesters who do not find employment in resource harvesting during this transition phase. This implies that privatization reduces the incomes of the poor both in steady state and during transition phase towards the new steady state even in the case where steady state incomes in the privatization regime are lower than the incomes in the open-access regime. Thus, we immediately obtain the following result.

**Proposition 4.** *In Case (I), the present value of income for poor resource harvesters is below the present value of income in the open-access regime for any value of the discount rate  $\delta$ .*

In Cases (II) and (III) there is a critical value for the discount rate  $\hat{\delta}$  such that the present value of income for poor resource users is below the present value of incomes in the open-access regime for all discount rates above this threshold level, i.e. for all  $\delta > \hat{\delta}$ . This is because during the beginning of the transition phase, employment in resource harvesting is always in the privatization regime lower compared to the open-access regime, due to the necessity of stock rebuilding.

This finding is illustrated using the numerical example shown in Figure 5. The figure shows the incomes in both the open-access and privatization steady states

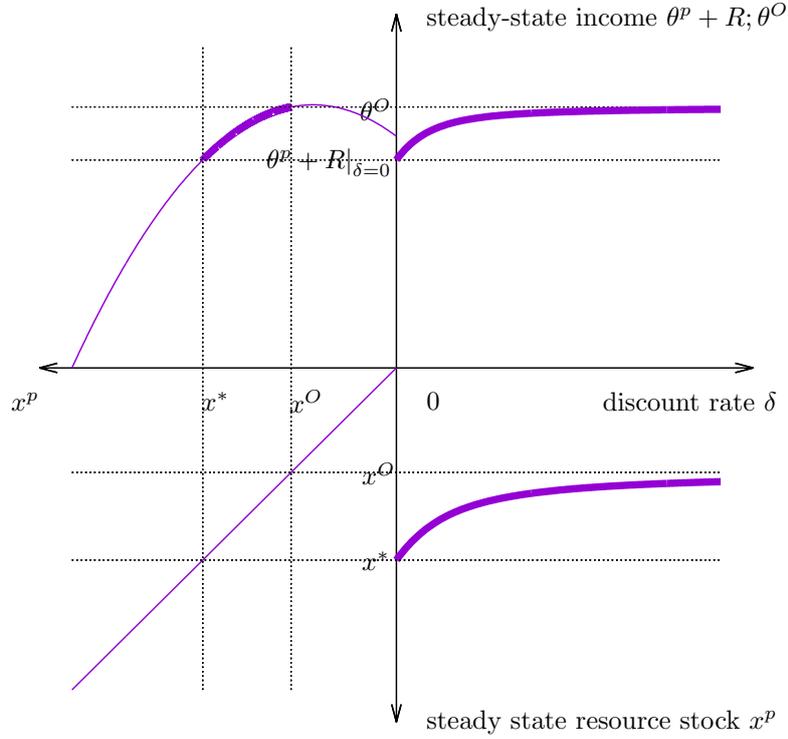


Figure 2: Case (I) when  $\hat{x} < x^O$ , i.e.  $\bar{\theta} > qk$ , here  $q = 2.5, \bar{\theta} = 3, r = 1, k = 1$ . The quadrant on the upper right shows the relationship of interest: steady state income in the privatization regime as a function of the discount rate. In this case, it monotonically increases towards the steady state income in the open-access regime. The three other quadrants show the logic behind: The lower right graph shows how the steady state resource stock in the privatization regime decreases with the discount rate. The graph on the upper left shows how the steady state income in the privatization regime changes with the steady state stock size. Under the conditions of Case (I), both  $x^*$  and  $x^O$  are above the stock size  $\hat{x}$  at which steady state income peaks.

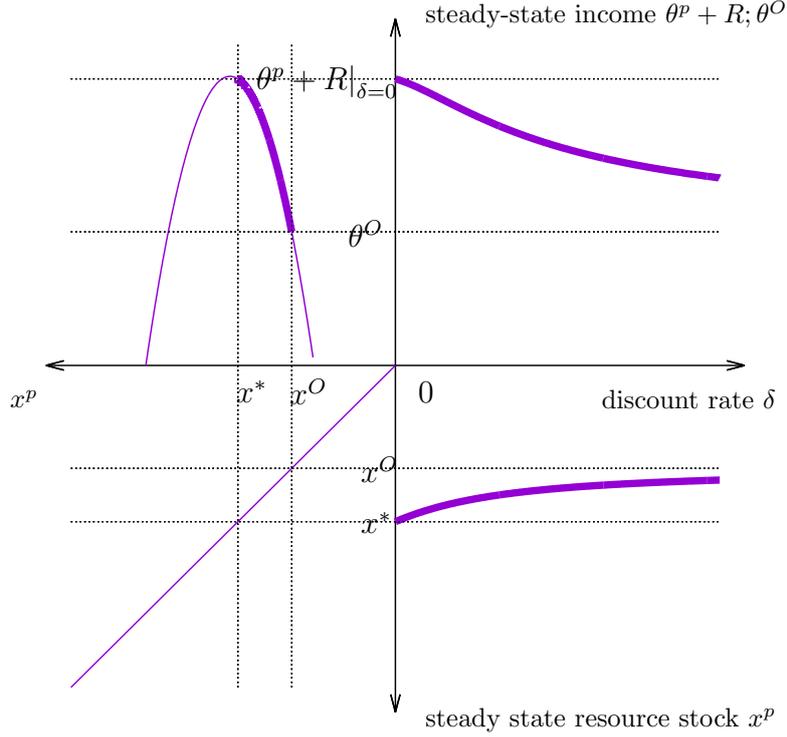


Figure 3: Case (II) when  $\hat{x} > x^*$ , i.e.  $\bar{\theta} < qk(1 - 2q/r)$  and  $q = 1.3, \bar{\theta} = 0.2, r = 6, k = 1$ .

The explanation of the four quadrants is the same as in Figure 2. Note the difference in the quadrant on the upper left: in Case (II), both  $x^*$  and  $x^O$  are *below* the stock size  $\hat{x}$  at which steady-state income peaks.

and the annuity on income in the privatization regime including the transition dynamics – i.e., the constant annual income that gives rise to the same present value as the time-varying income in the privatization regime including transitional dynamics.

We are considering a parameter set corresponding to Case (II): income in the privatization regime is above the income in the open-access regime for all values of the discount rate. This is still true, including transition dynamics, if the discount rate is sufficiently low. For large enough discount rates, however, the damage done to the poor resource harvesters in the rebuilding phase becomes so important that they are worse off in the privatization regime.

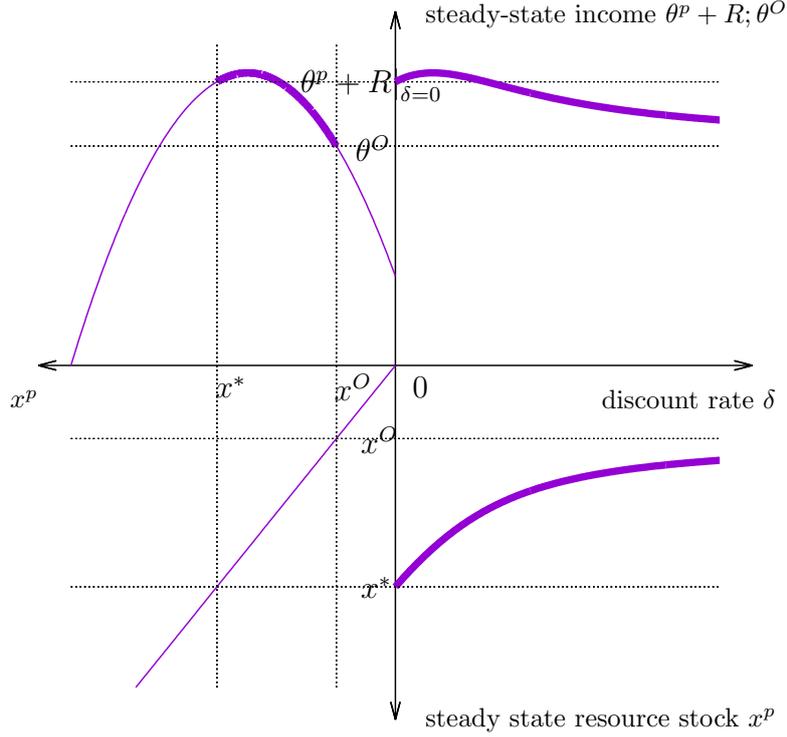


Figure 4: Case (III) when  $x^O < \hat{x} < x^*$  and  $q = 3, \bar{\theta} = 1, r = 2$ . The explanation of the four quadrants is the same as in Figure 2. Note the difference to the previous cases in the quadrant on the upper left: in Case (III),  $x^*$  is *above*, but  $x^O$  is *below* the stock size  $\hat{x}$  at which steady-state income peaks.

## 4 Discussion and Conclusion

In this paper, we developed a dynamic model to study the distributive effects of privatizing an open access resource, and specifically to derive conditions under which the poor are made worse off when equally distributed private use rights are introduced for a renewable natural resource. Our focus was on the incomes of the poor, as in our setting the rich ones – with a highly productive private project – are always better off in the privatization regime. While it may seem contradictory at first glance, our results are in line with the finding of Grainger and Costello (2016) who show that the most efficient resource users are the ones mostly against privatization. The poor, in our set up, are the ones with the least productive outside option. This means, they have a comparative advantage in

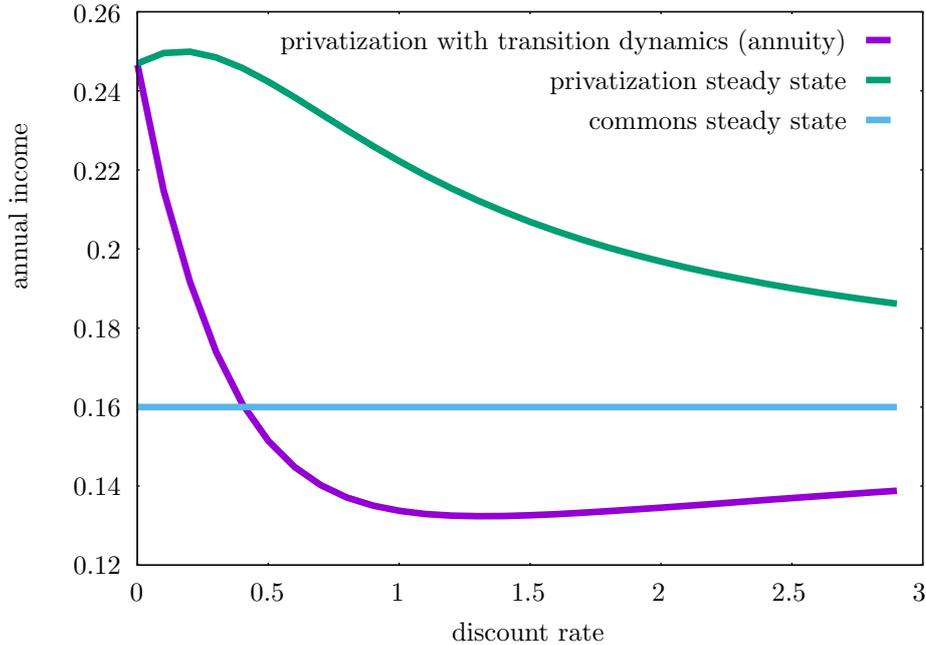


Figure 5: Comparison of incomes in the open-access steady state, privatization steady state and the annuity on income in the privatization regime including transition dynamics – i.e., the constant annual income that gives rise to the same present value as the time-varying income in the privatization regime including transitional dynamics – for varying discount rates. Other parameter values are  $q = 2, \bar{\theta} = 1, r = 1, k = 1$ .

resource harvesting, as the difference between returns from working in resource harvesting and opportunity costs (= the value of the outside option) is largest for them.

We find that with or without discounting, privatization is always Pareto efficient if the steady state stock under the privatization regime is sufficiently large. This is the case if the spread of productivities of the private projects is small and if the carrying capacity of the resource is large. This implies that with a productive resource – in terms of the rate of reproduction – and a more equal society, a privatization policy would improve all individuals' welfare.

Furthermore, we have studied the effect of discounting on the comparison of steady-state incomes in the open-access and privatization regimes. This impact depends on the technical and biological characteristics of resource harvesting. If

the natural resource is sufficiently productive, and inequality in alternative private project opportunities is low, incomes in the privatization regime monotonically decrease with the discount rate. In that case (referred to as Case II above), a privatization policy would improve all individuals' welfare in steady state, no matter the exact value of the discount rate. If, on the other hand, society is very unequal in the sense that the spread of private productivities is high relative to the productivity of resource harvesting (referred to as Case I above), the reverse is true: Incomes are higher in the privatization steady state, and the effect becomes more pronounced the lower the discount rate is. For intermediate resources (referred to as Case III above), the relationship between the resource and the discount rate is non-monotonic, and the ranking of steady state welfare in the open-access and privatization regime depends on the discount rate.

Taking into account the transition from the open-access regime steady state to the privatization steady state always decreases the attractiveness of privatization for the poor. This is because during the transition phase, employment in resource harvesting is reduced to allow the stock to regenerate. We find that even in cases where the comparison of steady state incomes would favor privatization, the additional sacrifice during the transition phase makes privatization less attractive. We have seen that for large discount rates, the present value of incomes in the open-access regime will always be higher than the present values of incomes in the privatization regime with an equal distribution of use rights.

As a general conclusion, privatization with an equal allocation of resource use rights is detrimental for the poor in situations where the resource is not very productive, inequality in the private economy is high, and discount rates are high.

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# Appendix

## A Steady state in the open-access regime

To derive the steady state equilibrium stock in the open-access regime, we set  $\dot{x} = 0$  in Equation (8), which then can be written as

$$\frac{r\bar{\theta} + kq^2}{k\bar{\theta}} x^2 - rx = 0. \quad (23)$$

We ignore the trivial solution  $x^O = 0$ . The positive solution of this quadratic equation is given in Equation (9).

With regards to equilibrium incomes, all individuals  $i$  working in resource harvesting receive

$$\theta^O = qx^O = q \frac{\bar{\theta}rk}{kq^2 + \bar{\theta}r}. \quad (24)$$

while individuals  $i$  working on the private project receive  $\theta_i$ .

## B Steady state in the privatization regime

To derive the steady state equilibrium stock in the privatization regime, we use the conditions  $w = \theta^P$  and  $L^P = F(\theta^P) = \theta^P/\bar{\theta}$  for labor-market equilibrium in the first-order conditions (13) and set the time derivatives equal to zero. This yields

$$(1 - \mu)qx = \theta^P \quad (25a)$$

$$(1 - \mu)q \frac{\theta^P}{\bar{\theta}} = \mu \left( \delta - r \left( 1 - \frac{2x}{k} \right) \right) \quad (25b)$$

$$rx \left( 1 - \frac{x}{k} \right) = qx \frac{\theta^P}{\bar{\theta}}. \quad (25c)$$

Using (25a) and (25c) in (25b) and yields

$$\frac{\bar{\theta}r}{q^2x} \left( 1 - \frac{x}{k} \right) r \left( 1 - \frac{x}{k} \right) = \left( 1 - \frac{\bar{\theta}r}{q^2x} \left( 1 - \frac{x}{k} \right) \right) \left( \delta - r \left( 1 - \frac{2x}{k} \right) \right). \quad (26)$$

Solving gives the steady-state resource stock in the privatization regime as

$$x^P = k \frac{(q^2 k + \bar{\theta} r)(r - \delta) \pm \sqrt{4(2q^2 k + \bar{\theta} r)\bar{\theta} r^2 \delta + ((q^2 k + \bar{\theta} r)(r - \delta))^2}}{2(2q^2 k + \bar{\theta} r)r} \quad (27)$$

For the case without discounting,  $\delta = 0$ , this simplifies to

$$x^P = k \frac{2(q^2 k + \bar{\theta} r)r}{2(2q^2 k + \bar{\theta} r)r} = k \frac{q^2 k + \bar{\theta} r}{2q^2 k + \bar{\theta} r}. \quad (28)$$

Clearly,  $0 < x^P < k$ .

## C Comparison of steady states without discounting

To prove that  $x^P > x^O$  consider

$$\begin{aligned} & k \frac{q^2 k + \bar{\theta} r}{2q^2 k + \bar{\theta} r} > \frac{\bar{\theta} r k}{q^2 k + \bar{\theta} r} \\ \Leftrightarrow & \frac{q^2 k}{2q^2 k + \bar{\theta} r} > \frac{\bar{\theta} r(2q^2 k + \bar{\theta} r - q^2 k - \bar{\theta} r)}{(q^2 k + \bar{\theta} r)(2q^2 k + \bar{\theta} r)} \\ \Leftrightarrow & \frac{q^2 k}{2q^2 k + \bar{\theta} r} > \frac{q^2 k}{2q^2 k + \bar{\theta} r} \times \frac{\bar{\theta} r}{q^2 k + \bar{\theta} r}, \end{aligned} \quad (29)$$

which holds true as  $\frac{\bar{\theta} r}{q^2 k + \bar{\theta} r} < 1$ .

## D Proof of Proposition 1

To prove proposition 1, we need to first derive steady-state resource rent  $R = \mu q x^P F(\theta^P)$ , cf. (14). Substituting the steady state resource stock in the privatization regime and the corresponding shadow price (see Appendix B) we get

$$\begin{aligned} R &= \mu q x^P \frac{\theta^P}{\bar{\theta}} = \left(1 - \frac{\bar{\theta} r}{q^2 x^P} \left(1 - \frac{x^P}{k}\right)\right) q x^P \frac{\theta^P}{\bar{\theta}} \\ &= \theta^P \left(\frac{q k}{\bar{\theta}} \frac{q^2 k + \bar{\theta} r}{2q^2 k + \bar{\theta} r} - \frac{r}{q} \frac{2q^2 k + \bar{\theta} r - (q^2 k + \bar{\theta} r)}{2q^2 k + \bar{\theta} r}\right) \\ &= \frac{\theta^P}{\bar{\theta}} \frac{q^3 k^2}{2q^2 k + \bar{\theta} r} = \frac{r q^4 k^3}{(2q^2 k + \bar{\theta} r)^2}. \end{aligned} \quad (30)$$

Using this value of  $R$ , we can compare incomes in the open-access regime and the privatization regime. We have  $\theta^P + R \stackrel{\leq}{\geq} \theta^O$  if and only if

$$\frac{r q k \bar{\theta}}{2 q^2 k + \bar{\theta} r} + \frac{r q^4 k^3}{(2 q^2 k + \bar{\theta} r)^2} \stackrel{\leq}{\geq} \frac{\bar{\theta} r q k}{q^2 k + \bar{\theta} r} \quad (31)$$

$$\Leftrightarrow q^5 k^3 + q^3 k^2 \bar{\theta} r \stackrel{\leq}{\geq} 2 \bar{\theta} q^4 k^2 + \bar{\theta}^2 r q^2 k \quad (32)$$

$$\Leftrightarrow \frac{\theta^P}{\theta^O} = \frac{q^2 k + \bar{\theta} r}{2 q^2 k + \bar{\theta} r} \stackrel{\leq}{\geq} \frac{\bar{\theta}}{q k}. \quad (33)$$

## E Proof of Proposition 2

To save notation, we define  $A = q^2 k + \bar{\theta} r$ . Thus,

$$x^P = \frac{k}{2 (2 q^2 k + \bar{\theta} r) r} \left( A(r - \delta) + \sqrt{4(A + q^2 k)(A - q^2 k)r \delta + A^2 (r - \delta)^2} \right) \quad (34)$$

$$= \frac{k}{2 (2 q^2 k + \bar{\theta} r) r} \left( A(r - \delta) + \sqrt{-4 q^4 k^2 r \delta + A^2 (r + \delta)^2} \right). \quad (35)$$

The sign of  $\frac{dx^P}{d\delta}$  is thus the same as the sign of the derivative of the expression in brackets,

$$\frac{d}{d\delta} \left( A(r - \delta) + \sqrt{-4 q^4 k^2 r \delta + A^2 (r + \delta)^2} \right) = -A + \frac{-4 q^4 k^2 r + 2 A^2 (r + \delta)}{2 \sqrt{-4 q^4 k^2 r \delta + A^2 (r + \delta)^2}} < 0, \quad (36)$$

which is negative, as

$$-2 q^4 k^2 r + A^2 (r + \delta) < A \sqrt{-4 q^4 k^2 r \delta + A^2 (r + \delta)^2} \quad (37)$$

$$\Leftrightarrow (-2 q^4 k r + A^2 (r + \delta))^2 < A^2 (-4 q^4 k^2 r \delta + A^2 (r + \delta)^2) \quad (38)$$

$$\Leftrightarrow q^2 k < A = q^2 k + \bar{\theta} r. \quad (39)$$

This proves the first statement. Next, we show that  $\frac{dR}{d\delta} < 0$ . Note that  $\frac{dR}{d\delta} = \frac{dR}{dx^P} \frac{dx^P}{d\delta}$ , and remember

$$R = \frac{1}{(qk)^2} r(k - x^P)(q^2 k x^P - \bar{\theta} r(k - x^P)) \quad (40)$$

Thus,

$$\frac{dR}{dx^P} = \frac{r}{(qk)^2} (-(q^2 k x^P - \bar{\theta} r(k - x^P)) + (k - x^P)(q^2 k + \bar{\theta} r)) \quad (41)$$

$$= \frac{r}{(qk)^2} (\bar{\theta} r k - x^P(q^2 k + \bar{\theta} r) + (k - x^P)(q^2 k + \bar{\theta} r)) \quad (42)$$

$$= \frac{r}{(qk)^2} (\bar{\theta} r k + (k - 2x^P)(q^2 k + \bar{\theta} r)) \quad (43)$$

$$= \frac{r}{(qk)^2} (2(k - x^P)(q^2 k + \bar{\theta} r) - q^2 k^2). \quad (44)$$

The expression above holds for any  $x^P$ . Note that  $d^2R/dx^{P2} < 0$ . Thus,  $dR/dx^P > 0$  for all  $x^P$  if  $dR/dx^P > 0$  for the largest potential value of  $x^P$  which is  $x^P$  when  $\delta = 0$ .

Substituting  $x^P$  from (15) in (44) we find

$$\frac{dR}{dx^P} > 2 \left( k - k \frac{q^2 k + \bar{\theta} r}{2q^2 k + \bar{\theta} r} \right) (q^2 k + \bar{\theta} r) - q^2 k^2 \quad (45)$$

$$= \frac{2q^2 k^2(q^2 k + \bar{\theta} r) - q^2 k^2(2q^2 k + \bar{\theta} r)}{2q^2 k + \bar{\theta} r} \quad (46)$$

$$= q^2 k^2 \frac{\bar{\theta} r}{2q^2 k + \bar{\theta} r} > 0. \quad (47)$$

In the limit  $\delta \rightarrow \infty$ , we obtain, using the abbreviation  $\Delta = 1/\delta$ , and applying

L'Hospital's rule,

$$\lim_{\delta \rightarrow \infty} x^P = \frac{k}{2(2q^2k + \bar{\theta}r)r} A \left( r + \lim_{\Delta \rightarrow 0} \frac{-1 + \sqrt{-4q^4k^2r \frac{\Delta}{A^2} + (\Delta r + 1)^2}}{\Delta} \right) \quad (48)$$

$$= \frac{k}{2(2q^2k + \bar{\theta}r)r} A \left( r + \lim_{\Delta \rightarrow 0} \frac{-4q^4k^2r \frac{1}{A^2} + 2r(\Delta r + 1)}{2\sqrt{-4q^4k^2r \frac{\Delta}{A^2} + (\Delta r + 1)^2}} \right) \quad (49)$$

$$= \frac{k}{2(2q^2k + \bar{\theta}r)r} A \left( r - 2q^4k^2r \frac{1}{A^2} + r \right) \quad (50)$$

$$= \frac{k}{(2q^2k + \bar{\theta}r)r} \frac{2q^2kr^2\bar{\theta} + r^3\bar{\theta}^2}{q^2k + \bar{\theta}r} = \frac{\bar{\theta}rk}{q^2k + \bar{\theta}r} = x^O \quad (51)$$

Also,

$$\lim_{\delta \rightarrow \infty} R = \frac{1}{(qk)^2} r(k - x^O)(q^2kx^O - \bar{\theta}r(k - x^O)) \quad (52)$$

$$= \frac{r}{q^2k^2} \frac{q^2k^2}{q^2k + \bar{\theta}r} \left( \frac{\bar{\theta}r q^2k^2}{q^2k + \bar{\theta}r} - \bar{\theta}r \frac{q^2k^2}{q^2k + \bar{\theta}r} \right) = 0. \quad (53)$$

## F Proof of Proposition 3

The derivative of  $\theta^P$  with respect to the steady-state stock size  $x^P$  is

$$\frac{d\theta^P}{dx^P} = \frac{d}{dx^P} \frac{\bar{\theta}r(k - x^P)}{qk} = -\frac{\bar{\theta}r}{qk} < 0. \quad (54)$$

The derivative of total steady state income of the poor with respect to the steady-state stock size is, using (44)

$$\frac{d}{dx^P} (\theta^P + R) = -\frac{\bar{\theta}r}{qk} + \frac{r}{(qk)^2} (2(k - x^P)(q^2k + \bar{\theta}r) - q^2k^2) \quad (55)$$

The second derivative is negative,

$$\frac{d^2}{dx^2} (\theta^P + R) = -\frac{2r}{(qk)^2} (q^2k + \bar{\theta}r), \quad (56)$$

thus we are indeed considering a maximum. Solving  $\frac{d}{dx^P} (\theta^P + R) = 0$ , we find

$$\bar{\theta} q k + q^2 k^2 = 2(k - x^P)(q^2 k + \bar{\theta} r) \quad (57)$$

$$\Leftrightarrow x^P = \frac{k}{2} \frac{q^2 k + \bar{\theta} (2r - q)}{q^2 k + \bar{\theta} r} \quad (58)$$

$$= \frac{k}{2} \left( 1 + \bar{\theta} \frac{q - r}{q^2 k + \bar{\theta} r} \right). \quad (59)$$

Thus,  $\hat{x} < x^O$  if and only if

$$\frac{k}{2} \frac{q^2 k + \bar{\theta} (2r - q)}{q^2 k + \bar{\theta} r} < k \frac{\bar{\theta} r}{q^2 k + \bar{\theta} r} \quad (60)$$

$$\Leftrightarrow q^2 k + \bar{\theta} (2r - q) < 2\bar{\theta} r \quad (61)$$

$$\Leftrightarrow q k < \bar{\theta}. \quad (62)$$

We further have  $\hat{x} > x^*$  if and only if

$$\frac{k}{2} \frac{q^2 k + \bar{\theta} (2r - q)}{q^2 k + \bar{\theta} r} > k \frac{q^2 k + \bar{\theta} r}{2q^2 k + \bar{\theta} r} \quad (63)$$

$$\Leftrightarrow (q^2 k + \bar{\theta} (2r - q)) (2q^2 k + \bar{\theta} r) > 2(q^2 k + \bar{\theta} r)^2 \quad (64)$$

$$\Leftrightarrow (q^2 k + \bar{\theta} r + \bar{\theta} (r - q)) (2q^2 k + \bar{\theta} r) > 2(q^2 k + \bar{\theta} r)^2 \quad (65)$$

$$\Leftrightarrow \bar{\theta} (r - q) (2q^2 k + \bar{\theta} r) > (q^2 k + \bar{\theta} r) \bar{\theta} r \quad (66)$$

$$\Leftrightarrow (r - q) (2q^2 k + \bar{\theta} r) > (q^2 k + \bar{\theta} r) r \quad (67)$$

$$\Leftrightarrow q k r > 2q^2 k + \bar{\theta} r \quad (68)$$

$$\Leftrightarrow \bar{\theta} < q k \left( 1 - 2 \frac{q}{r} \right). \quad (69)$$



## Chapter 3

# Welfare Effects of Carbon Taxation on South African Households

# Welfare Effects of Carbon taxation on South African Households

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## **Abstract**

This paper evaluates the welfare impacts of carbon taxation on South African households. Using household survey data for the period 2009 - 2015, I estimate the Quadratic Almost Ideal Demand System (QUAIDS) model to obtain elasticities and use them to simulate consumer responses to price changes resulting from carbon taxation. Results show that an increase in electricity and public transport prices following a carbon tax policy is regressive while a price increase in motor fuel is progressive. In addition, when there is a simultaneous increase in the prices of energy goods, the poorest and middle income households disproportionately suffer a higher welfare loss compared to the richest households. Revenue recycling in terms of lump-sum transfers of the tax revenue to households below the national poverty lines and the bottom 40% would offset the welfare loss from a carbon tax policy in South Africa.

JEL codes: D1, H2, I3, Q4

Keywords: Welfare, Carbon Tax Policy, South Africa, Household

# 1 Introduction

Many countries are currently transitioning to low-carbon economies with South Africa at the forefront of this transition among African countries. South Africa committed to reductions in greenhouse gas emissions of 34% by 2020 and 42% by 2025 against current emission levels. To achieve these ambitious targets, the South African government implemented a new carbon tax policy in June 2019. The policy imposes a tax of R120 per ton carbon dioxide (CO<sub>2</sub>) equivalent of greenhouse gas emissions. Designed to be implemented in two phases, the first phase of the tax is from 1 June 2019 to 31 December 2022, and the second phase is from 2023 to 2030. The introduction of this carbon tax begs the question, how would this new tax policy affect consumers' welfare? It is crucial to understand the distributional effects of this policy because various income groups would most likely experience different costs and burden resulting from the carbon tax.

The goal of this paper is to understand the incidence of a carbon tax policy in South Africa. I estimate a household demand system using the Quadratic Almost Ideal Demand System (QUAIDS) model (Banks et al. 1997) to evaluate the distributional and welfare impacts of carbon taxation in South Africa. Using South African household survey data with about 73,000 observations and five expenditure categories – electricity, motor fuels, public transport, food and other goods – income and price elasticities are derived. These elasticities are then used to simulate the effects of energy price changes on South African Households.

This study is the first to provide empirical evidence on the distributional effects of the newly implemented carbon tax policy in South Africa by using microdata to predict welfare losses from the policy. In addition, contrary to other existing studies on South Africa, it uses the QUAIDS model which analyses income groups with different expenditure shares and uses elasticities to determine how households would respond to changes resulting from the introduction of a carbon tax. This approach would provide a detailed representation of the micro level impacts of the new policy on consumer welfare as opposed to the commonly used CGE model which focuses on the overall macro effect

on the economy.

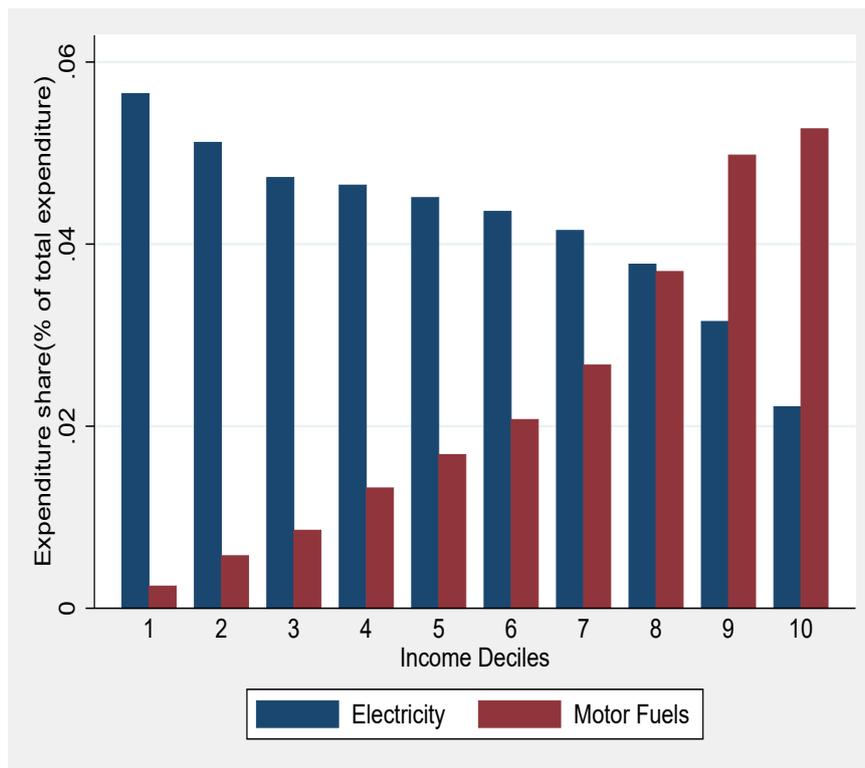
I find three main results. First, an increase in electricity and public transportation prices as a result of the carbon tax policy is regressive. In contrast, an increase in motor fuel prices is progressive. Second, simultaneous price increases for energy goods lead to a higher welfare loss for the poorest and middle income households compared to the richest households. Third, tax revenue redistribution to the poorest households would attenuate the adverse effects of the carbon tax policy on South African households.

Discussions about the carbon tax implementation in South Africa started when the 2010 Carbon Tax Discussion Paper was published. However, the first Carbon Tax bill was only published in 2015 for public comments. The aim of the carbon tax is twofold: first, to enable South Africa achieve its nationally-determined contribution (NDC) commitments with regards to the 2015 Paris Agreement, and second, to mitigate greenhouse gas emissions in line with the National Climate Change Response Policy and National Development Plan. Quantifying and understanding the impacts of this environmental policy would provide policymakers with information on how best to implement the tax.

South Africa is a worthy case study because apart from the fact that it is taking the lead in implementing a carbon pricing policy in Africa, it also accounts for over 35% of Africa's total emissions, with its per capita CO<sub>2</sub> emissions being higher than the global average. According to the World Resources Institute Climate Analysis Indicator Tool, South Africa's greenhouse gas profile is dominated by emissions from the energy sector. In 2012, energy accounted for 84% of its total emissions. Of the emissions from the energy sector, 60% were from electricity and heat, 15% from manufacturing and construction, 12% from transportation, and 12% from other energy subsectors. The introduction of a carbon tax to mitigate emissions is expected to be followed by an increase in the prices of energy-related products. Households are likely to experience a significant impact on their income since energy expenditure is a substantial fraction of household incomes. Household survey data shows that in 2015, expenditure on housing, water, electricity, gas and other fuels and transportation accounted for almost 50% of total annual household consumption expenditure in South Africa.

Households are heterogeneous in terms of economic, socio-economic, demographic and physical features. Thus, energy usage patterns differ substantially from one household to another, especially across income groups (Farrell 2017; Ye et al. 2018). Energy expenditure among various South African income groups differs significantly (See Figure 1). Households in the lowest income decile, on average, spend 6% of their income on electricity compared to the richest households who spend only about 2% of their income. On the other hand, the richest households spend up to 5% of their income on the purchase of motor fuels while the share is almost zero for the poorest households. Hence, it is most likely that the tax burden would be unequal across income groups. The tax payments of households in different income groups does not only depend on the increased product prices but also on the expenditure shares of the income group (Kerkhof et al. 2008).

Figure 1: Average Household Energy Expenditure Shares by Income Deciles



Source: Own Calculations based on Living Conditions of Households in South Africa 2014/2015

*Note:* This figure plots the proportion of annual income spent on electricity and motor fuels by different South African income deciles in 2015.

## 2 Previous Literature

This study is closely related to two strands of literature. The first assesses the impact of carbon taxation in South Africa. All the existing literature in this area of research employ the Computable General Equilibrium (CGE) model. The authors focused on different questions but found similar results (van Heerden et al. 2006; Pauw 2007; Devarajan et al. 2009; Alton et al. 2014; PMR 2016). van Heerden et al. 2006 use a South African CGE model to find the potential for a double or triple dividend if revenues from energy-related environmental taxes are recycled to households by reducing existing taxes. They find a triple dividend – reduced poverty, decreased emissions and increased economic growth – when any of the simulated environmental taxes is recycled through a reduction in food prices. Pauw 2007 examine the economic impacts of different mitigation scenarios and find that at levels beyond R75 per ton of CO<sub>2</sub>, and despite using the most efficient of the revenue recycling options available, the economic impact will be negative. Higher levels of taxation would cause a decrease in production and employment levels. He also find that GDP may fall between a 2% – 7% range for a R250 tax, and between 9% - 17% for a tax of R750 per ton of CO<sub>2</sub>.

After evaluating the socioeconomic consequences of carbon taxes, including implications for economic growth, employment and the distribution of household incomes, Alton et al. 2014 find similar results with Pauw 2007. They find that relative to a baseline with free disposal of CO<sub>2</sub>, constant world prices and no change in trading partner behavior, the preferred tax scenario reduces national welfare by 1.2% and employment by 0.6%. Devarajan et al. 2009 focused on the economic costs of the distortions created by different taxes applied to mitigate carbon emissions. Their results show that the welfare costs of achieving substantial reductions in CO<sub>2</sub> emissions are quite small and that welfare losses from a tax on carbon are small regardless of the elasticities of substitution in production. Although, if the tax revenue is recycled to reduce existing tax distortions, the net welfare cost becomes negligible.

A more recent study by the World Bank Partnership for Market Readiness (PMR 2016) also used a CGE model to analyze the implications of the South African carbon

tax. This paper is the first and so far only paper to model the actual design features of the carbon tax that was implemented in South Africa in 2019. The results reveal that the carbon tax will lead to a decrease in emissions of 13 - 14.5% by 2025 and 26 - 33% by 2035 compared with the baseline emission level. The paper uses macroeconomic aggregates such as employment, consumption and real wages to proxy the distributional impact of the tax. However, it does not provide an in-depth understanding of the welfare impacts of households as a result of the tax. This paper aims to complement this study by using household data to evaluate direct distributional effects of the newly implemented carbon tax on households in various income groups. In addition, contrary to other studies on South Africa which uses the CGE model, my study adopts the QUAIDS model because it provides a more detailed understanding of the direct effects of carbon tax on households as compared to the CGE model. Also, since my research question is focused on a specific sector - households - of the economy, the QUAIDS model is more appropriate.

The second strand of literature analyses the welfare effects of carbon taxation on households using the QUAIDS model (West and Williams 2004; Rosas-Flores et al. 2017; Moshiri and Martinez Santillan 2018; Renner et al. 2018). West and Williams 2004 study the distributional effects of a gasoline tax increase on U.S consumers. Their results show that when revenues are not recycled, a gasoline tax is regressive. However, using the additional gas tax revenue to fund labor tax cuts makes the policy substantially less regressive while using the revenue to fund lump-sum transfers actually makes it progressive. Rosas-Flores et al. 2017 and Renner et al. 2018 use the QUAIDS model to study the effect of environment taxes on Mexican households. They find that tax on electricity, gas and transport is regressive while tax on gasoline and motor fuel is progressive. Unfortunately, the results from these studies cannot be extrapolated to South Africa given the differences in income and consumption patterns in the countries. Hence, the need to study the South African case.

### 3 Methodology and Data

#### 3.1 Methodology

Demand systems are crucial in assessing the impacts of tax policy reforms. They are usually consistent with consumer theory and can match patterns of observed consumer behavior, which allows for welfare analysis. Consumer demand vary significantly across households in different income groups and demographics. Expenditure on goods can be either linear or non-linear in total expenditure. Results are biased when a non-linear expenditure pattern is estimated with a linear demand system (Banks et al. 1997). The Quadratic Almost Ideal Demand System (QUAIDS) model allows for non-linearity by including a quadratic expenditure term that varies with prices. I, therefore employ the QUAIDS model to predict the welfare losses of carbon taxation on South African Households.

The QUAIDS model is a rank 3 quadratic logarithmic budget share system. The rank of a demand system is the space dimension defined by its Engel curves when every consumer characteristics except income is held constant. The rank shows the maximum number of linearly independent price function vectors (LaFrance and Pope 2006). The indirect utility function of the model is given by:

$$\ln V = \left\{ \left[ \frac{\ln m - \ln a(\mathbf{p})}{b(\mathbf{p})} \right]^{-1} + \lambda(\mathbf{p}) \right\}^{-1} \quad (1)$$

where  $m$  is the total expenditure.

$\ln a(\mathbf{p})$  is the transcendental log function defined by:

$$\ln a(\mathbf{p}) = \alpha_0 + \sum_{i=1}^n \alpha_i \ln p_i + \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n \gamma_{ij} \ln p_i \ln p_j \quad (2)$$

$b(\mathbf{p})$  is the Cobb-Douglas price aggregator

$$b(\mathbf{p}) = \prod_{i=1}^n p_i^{\beta_i} \quad (3)$$

$\lambda(\mathbf{p})$  is a differentiable, homogeneous function of degree zero of log prices

$$\lambda(\mathbf{p}) = \sum_{i=1}^n \lambda_i \ln p_i \quad (4)$$

Applying Roy's Identity to the indirect utility function (equation 1) gives the expenditure share equation system defined by:

$$w_i = \alpha_i + \sum_{j=1}^n \gamma_{ij} \ln p_j + \beta_i \ln \left[ \frac{m}{a(\mathbf{p})} \right] + \frac{\lambda_i}{b(\mathbf{p})} \left\{ \ln \left[ \frac{m}{a(\mathbf{p})} \right] \right\}^2 + \epsilon_i \quad (5)$$

where  $\alpha_i$ ,  $\gamma_{ij}$ ,  $\beta_i$  and  $\lambda_i$  are parameters to be estimated by the model.

Furthermore, in order to reduce the number of parameters to be estimated and to ensure that each household maximizes utility, the model imposes three - adding up, homogeneity and symmetry - restrictions:

(a) Adding up implies that the budget shares sum to one.

$$\sum_{i=1}^n \alpha_i = 1; \quad \sum_{i=1}^n \gamma_{ij} = 0; \quad \sum_{i=1}^n \beta_i = 0; \quad \sum_{i=1}^n \lambda_i = 0$$

(b) Homogeneity of degree zero in prices and total expenditure.

$$\sum_{j=1}^n \gamma_{ij} = 0$$

(c) Slutsky symmetry deals with the substitution effect between commodities.

$$\gamma_{ij} = \gamma_{ji}$$

Estimates from the demand model is used to compute the demand elasticities.

### 3.1.1 Demand Elasticities

One of the main advantages of the QUAIDS model is the ability to estimate demand elasticities which shows how household demand responds to changes in expenditure and

prices. In order to obtain the model elasticities,  $\mu_i$  and  $\mu_{ij}$  are calculated by differentiating the expenditure share equation (5) with respect to  $\ln m$  and  $\ln p_j$ , respectively:

$$\mu_i \equiv \frac{\partial w_i}{\partial \ln m} = \beta_i + \frac{2\lambda_i}{b(\mathbf{p})} \left\{ \ln \left[ \frac{m}{a(\mathbf{p})} \right] \right\} \quad (6)$$

$$\mu_{ij} \equiv \frac{\partial w_i}{\partial \ln p_j} = \gamma_{ij} - \mu_i \left( \alpha_j + \sum_k \gamma_{jk} \ln p_k \right) - \frac{\lambda_i \beta_j}{b(\mathbf{p})} \left\{ \ln \left[ \frac{m}{a(\mathbf{p})} \right] \right\}^2 \quad (7)$$

Then, the budget elasticities  $e_i$  are derived using:

$$e_i = \frac{\mu_i}{w_i} + 1 \quad (8)$$

The uncompensated (Marshallian) price elasticities are given by:

$$e_{ij}^u = \frac{\mu_{ij}}{w_i} - \delta_{ij} \quad (9)$$

where  $\delta_{ij}$  is the Kronecker delta.

Lastly, the compensated (Hicksian) price elasticities are derived using the Slutsky equation. The compensated price elasticities measures the substitution effects of price changes on the demand for other goods.

$$e_{ij}^c = e_{ij}^u + e_i w_j \quad (10)$$

### 3.1.2 Simulation of Welfare effects

The simulation is used to illustrate welfare impacts on different households due to energy price changes resulting from carbon taxation. To calculate the welfare impacts, price changes are simulated for different scenarios, where the price change per good  $i$  is given by:

$$\frac{\Delta p_i}{p_i^0} = \frac{p_i^1 - p_i^0}{p_i^0} \quad (11)$$

where  $\Delta p_i$  is the price change on good  $i$ ,  $p_i^0$  is the price before the implementation of carbon taxes and  $p_i^1$  is the new price resulting from a tax on carbon.

The new price level after the implementation of a carbon tax is:

$$p_i^1 = \left(1 + \frac{\Delta p_i}{p_i^0}\right) p_i^0 \quad (12)$$

After obtaining the new prices, they are substituted into the  $\ln a(\mathbf{p})$  and  $b(\mathbf{p})$  equations and are used to compute predicted budget shares for each household in equation 5. Household demographics and nominal expenditure remain unchanged. The residual term  $\epsilon_i$  contains unexplained household-specific effects not included in the model specification.

Next, the first- and second-order approximations to tax and price changes are derived. The first-order approximation shows the marginal effects of these changes but does not incorporate substitution effects (Feldstein 1972; Stern 1987).

First-order welfare losses are calculated as:

$$FO = \sum_{i=1}^n w_i \left(\frac{\Delta p_i}{p_i^0}\right) \quad (13)$$

However, the second-order approximation depend on the distribution of substitution elasticities and can produce improvements in welfare measurements (Banks et al. (1996)). Second-order welfare losses is based on the second-order Taylor expansion of the expenditure share function. Following Renner et al. (2018), the estimated coefficients are used to calculate the second-order approximation to the Compensating Variation (CV):

$$CV = FO + \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n w_i e_{ij} \left(\frac{\Delta p_i}{p_i^0}\right) \left(\frac{\Delta p_j}{p_j^0}\right) \quad (14)$$

Finally, I simulate a lump-sum transfer of the tax revenue to the poorest households. The price change in equation 11 can be interpreted as an ad valorem tax rate,  $t_i$  such that the tax payments per household is given by:

$$T = \sum_{i=1}^n t_i \frac{exp_i^1}{1 + \frac{\Delta p_i}{p_i^0}} \quad (15)$$

The total tax revenue for the economy is calculated by multiplying equation 15 with the household weights and summing over the transfer recipients. Then, the total tax revenue is redistributed in the form of direct cash transfers to households below the national poverty lines or those in the bottom 40% of the income distribution.

### 3.2 Data

The South African Income and Expenditure Survey (IES) and the Living Conditions Survey (LCS) data were used to estimate the demand system. Both surveys use similar methodology for data collection and are conducted by the South African national statistics service - Statistics South Africa (Stats SA) (see table 1 for details). The similarities between the IES and LCS datasets enabled me to merge them effortlessly into a pooled cross-sectional dataset for three survey periods, 2009, 2011 and 2015, consisting of a total of 72845 observations. The data provides a detailed account of household consumption expenditure on households across twelve expenditure areas and disaggregates that information by both geography and demographics of the household head.

The survey used a combination of the diary and recall methods. Households were required to record their daily purchases in diaries provided by Stats SA for a period of two weeks and to answer several questions from the household questionnaire administered by a Stats SA official over a four-week period. This two-weeks information was used to compute annualized household expenditures. The surveys also used the Classification of Individual Consumption according to Purpose (COICOP) technique to classify expenditure items.

Table 1: Description of South African Household Expenditure Surveys (LCS & IES)

		<b>LCS 2008/2009</b>	<b>IES 2010/2011</b>	<b>LCS 2014/2015</b>
Sample size		25,075 households	25,328 households	23,380 households
Methodology		Diary and recall	Diary and recall	Diary and recall
Expenditure data collection approach	Goods	Acquisition and payment approaches	Acquisition approach	Acquisition approach
	Services	Payment approach	Payment approach	Payment approach
	Own production	Consumption approach	Consumption approach	Consumption approach
Dates		August 2008 - September 2009	August 2010 - September 2011	October 2014 - October 2015
Response rate		88%	91.6%	84.9%
Classification of expenditure items		COICOP	COICOP	COICOP

Source: Statistical Release on Living Conditions of Households in South Africa 2014/2015 (StatSA)

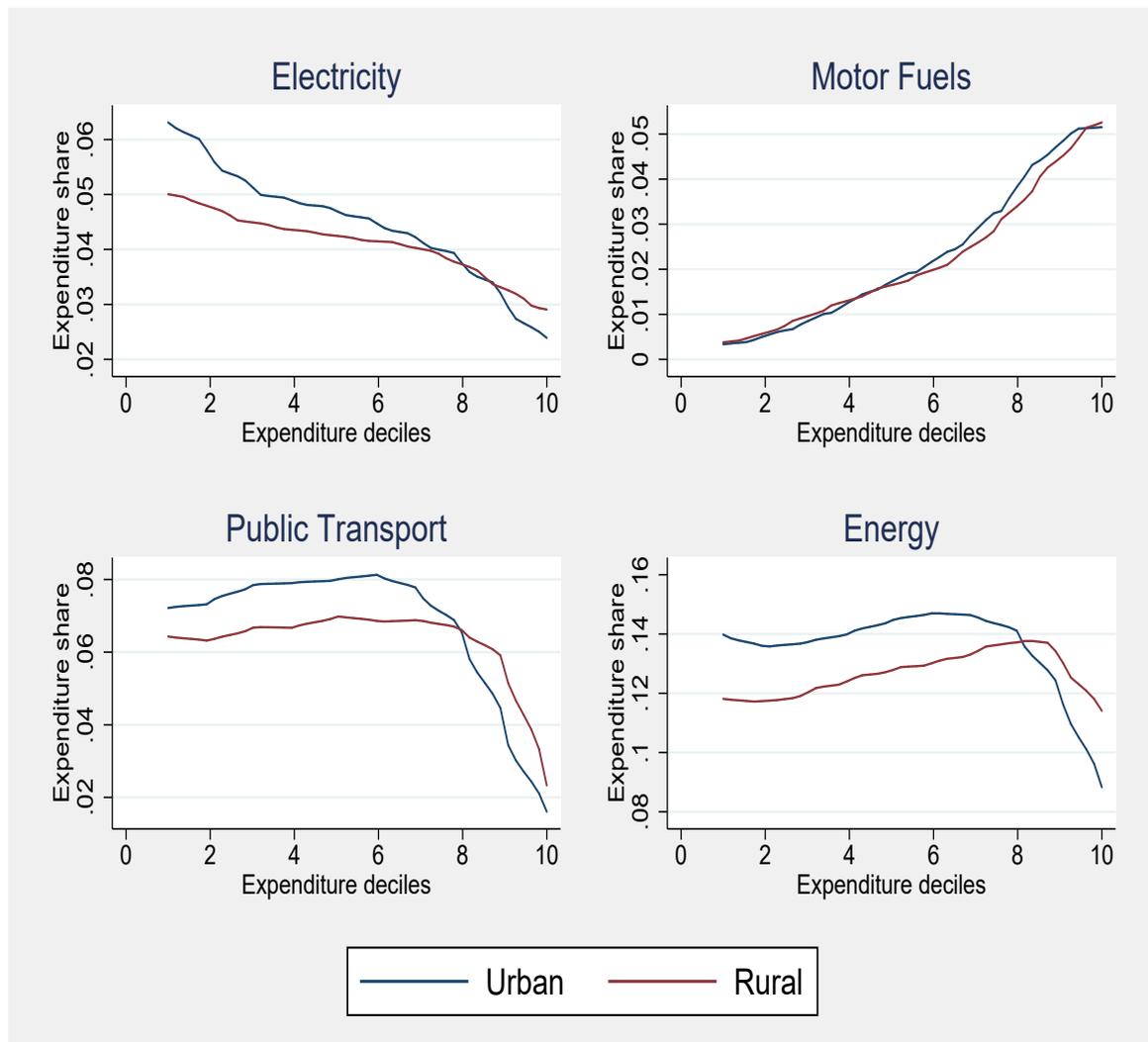
*Note:* This table shows the comparison among the different household surveys that were used in the study. Although the 2010/2011 IES survey is different from the LCS, it is very similar in terms of methodology and the classification of expenditure item. Thus, the three surveys could be merged without any problems

As mentioned in the introduction, household energy expenditures vary with income levels. Figure 2 shows that the expenditure share for motor fuels is similar for both rural and urban households. However, the expenditure shares on electricity and public transportation vary between rural and urban households. Urban households in the lower income deciles spend a greater proportion of their budget on electricity and public transportation compared to rural households in the same income group. The reverse is true for households in the top 20% of the income distribution.

For the empirical analysis, I focus on three energy goods, electricity, motor fuels and public transportation, but I also examine the relationship between energy goods and other non-energy goods. The following variables are used in the analysis: expenditure on electricity, motor fuels, public transportation, food and other goods; log prices on electricity, motor fuels, public transportation, food and other goods; age of household head; province; settlement type and household size.

Expenditure on public transportation includes passenger transport by railway, road, air, sea and inland waterways, and other purchased transport services. Food expenditure includes expenditure on all food products and non-alcoholic beverages consumed in South Africa while expenditure on other goods includes all other household consumption products excluding electricity, motorfuels, public transportation and food. The "expenditure on other goods" variable is very important to fulfill the adding-up restric-

Figure 2: Average Expenditure Share on Energy Goods by Settlement Type



Source: Own Calculations based on the pooled cross-sectional South African household survey (2009, 2011, 2015)

*Note:* This figure shows that rural and urban households have similar expenditure shares on motor fuels while there are some differences for the expenditure share on electricity, public transportation and energy goods.

tion of the QUAIDS model. The expenditure on heating is included among housing utilities expenditure, so I have not considered it as a separate expenditure category in this paper.

There are four settlement types in South Africa namely urban formal, urban informal, traditional (tribal) area and rural formal. I grouped these four settlements accordingly into two categories: Urban (urban formal and urban informal) and Rural (traditional area and rural formal). Households were grouped into deciles and settlement types (i.e rural and urban areas) to capture heterogeneous welfare effects of the price changes after the implementation of the carbon tax policy. In addition, I drop observations where the household head is less than 15 years to avoid potential bias from invalid observations.

Similar to Moshiri and Aliyev (2017), average consumer price index for the specific goods (electricity, motor fuels, public transportation, food and other goods) are used as a proxy for prices since actual prices for the goods are not available. The data is sourced from Statistics South Africa website. Monthly consumer price index data is provided for each good, I averaged the monthly data to get annual price data for the years used in the study. Thus, each good has an annual average price index for each of the nine South African provinces. Therefore, I assign this average price to all households living in the province. This means that the price variable is in provincial level. The description of variables and summary statistics for each survey period are provided in appendix A.

In addition, I used the Stata *quaid*s command for estimating the demand system equation. This command allows for the specification of demographic variables which are incorporated into the model using Ray's method (Ray 1983). The parameters of the model are estimated by the iterated feasible generalized nonlinear least-squares (ifgnls) estimation via Stata's *nl*sur command with the *ifgnls* option. In order to avoid a singular error-covariance matrix, the *quaid*s command automatically omits the last equation before calling *nl*sur. The *ifgnls* estimator is equivalent to the multivariate normal maximum-likelihood estimator for this class of problems (Poi 2012). Post-estimation commands allow for the computation of the budget elasticities as well as the computa-

tion of the compensated and uncompensated price elasticities.

## 4 Results

The estimated coefficients of the QUAIDS model are reported in Appendix B. Even though these coefficients have no direct economic interpretation, they are used to calculate the elasticities presented in Table 2 by using the incomes, prices and expenditure shares of the average household. The budget elasticities for electricity, public transport and food are less than one which indicate that for the average South African household, electricity, public transportation and food are necessities. On the contrary, motor fuels are seen as luxury goods, given that the budget elasticity is greater than one. In South Africa, income is an important factor in determining the demand for motor fuel use when price changes. Although, the budget elasticity for "other goods" is greater than one, this does not mean that all other goods are luxury goods. There is no direct economic interpretation for this variable because it comprises of all sorts of goods and it is constructed to fulfill the adding-up restrictions for the QUAIDS model.

The statistically significant compensated and uncompensated own-price elasticities exhibit the expected negative signs. This implies that an increase in the price of an energy good would result in a decrease in the demand for that good. Additionally, South African families show an inelastic response to changes in the price of electricity and an elastic response to motor fuels and public transportation price changes. Cross-price elasticities between the energy goods - electricity, motor fuels and public transportation - show positive signs which indicate that the goods are substitutes and the relationship is symmetric. However, electricity and food are complements, implying that an increase in electricity prices would, on average, results in a decrease in the demand for food. This suggests that the average South African household would reduce their food expenditure to accommodate an electricity price increase.

Table 2: Demand Elasticities for Average South African Household

		Price				
		Electricity	Motor Fuels	Pub. Transport	Food	Other goods
<i>Budget elasticities</i>		0.632 (0.007)	1.769 (0.008)	0.682 (0.006)	0.942 (0.002)	1.095 (0.002)
<i>Compensated elasticities</i>						
Demand	Electricity	-0.595 (0.043)	0.696 (0.103)	0.859 (0.037)	-1.694 (0.115)	0.734 (0.099)
	Motor Fuels	1.261 (0.186)	-1.232 (0.499)	0.092 (0.133)	-9.978 (0.468)	9.857 (0.372)
	Pub. Transport	0.576 (0.025)	0.035 (0.049)	-1.496 (0.065)	2.368 (0.118)	-1.483 (0.114)
	Food	-0.168 (0.011)	-0.545 (0.026)	0.349 (0.017)	0.060 (0.070)	0.305 (0.062)
	Other goods	0.071 (0.009)	0.518 (0.020)	-0.210 (0.016)	0.293 (0.060)	-0.672 (0.058)
<i>Uncompensated elasticities</i>						
Demand	Electricity	-0.622 (0.043)	0.682 (0.103)	0.819 (0.037)	-1.964 (0.115)	0.454 (0.099)
	Motor Fuels	1.186 (0.186)	-1.273 (0.499)	-0.019 (0.133)	-10.734 (0.468)	9.071 (0.372)
	Pub. Transport	0.547 (0.025)	0.019 (0.049)	-1.539 (0.065)	2.077 (0.118)	-1.786 (0.114)
	Food	-0.208 (0.011)	-0.568 (0.026)	0.289 (0.017)	-0.342 (0.070)	-0.114 (0.062)
	Other goods	0.024 (0.009)	0.492 (0.020)	-0.279 (0.016)	-0.175 (0.059)	-1.158 (0.058)

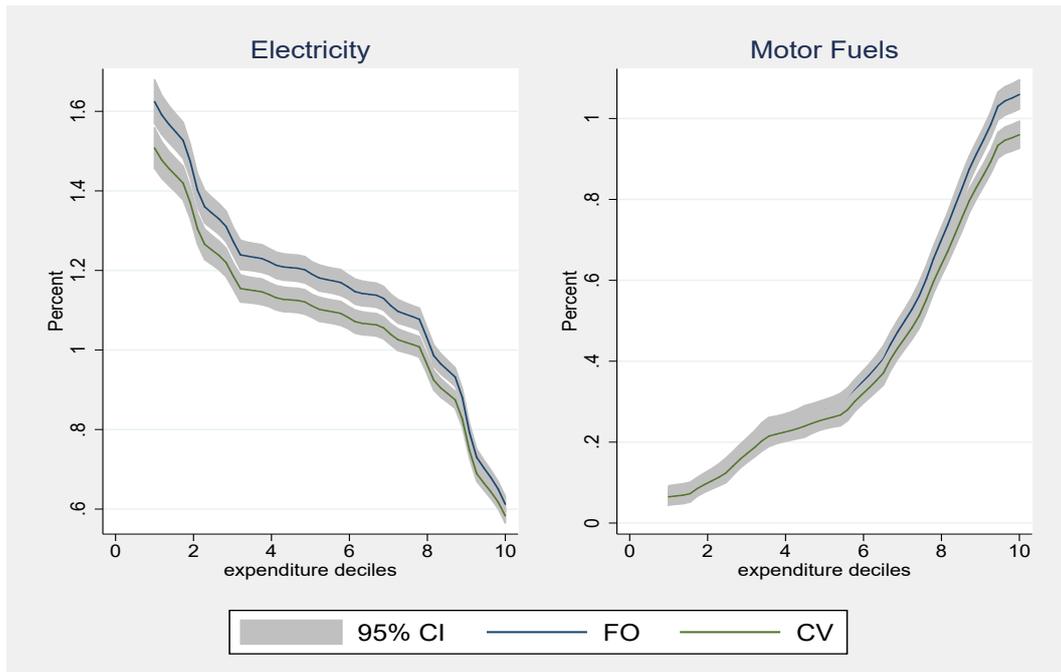
Standard errors in parentheses

*Note:* This table shows the budget, compensated and uncompensated elasticities for the goods. Electricity, public transportation and food are necessities while motor fuels is seen as a luxury good by the average South African Household

## Welfare Analysis

Stylized energy price changes of 5%, 10% and 20% are simulated to determine consumers' responses to these changes. For brevity, only the results of the 20% energy price changes are reported in this paper given that the 5% and 10% price changes have similar patterns, with only a difference in the magnitude of the welfare losses. This paper assumes that 20% is the upper bound of potential change in energy prices as a result of carbon taxation in the short run since the South African government designed the tax to prevent substantial energy price changes. The reported price change scenarios are therefore: (a) Only electricity prices increase by 20% (b) Only motor fuel prices increase by 20% (c) Only public transportation prices increase by 20% (d) The prices of all energy goods - electricity, motor fuel, public transportation - increase by 20%.

Figure 3: Welfare losses from a 20% price increase of electricity and motor fuels

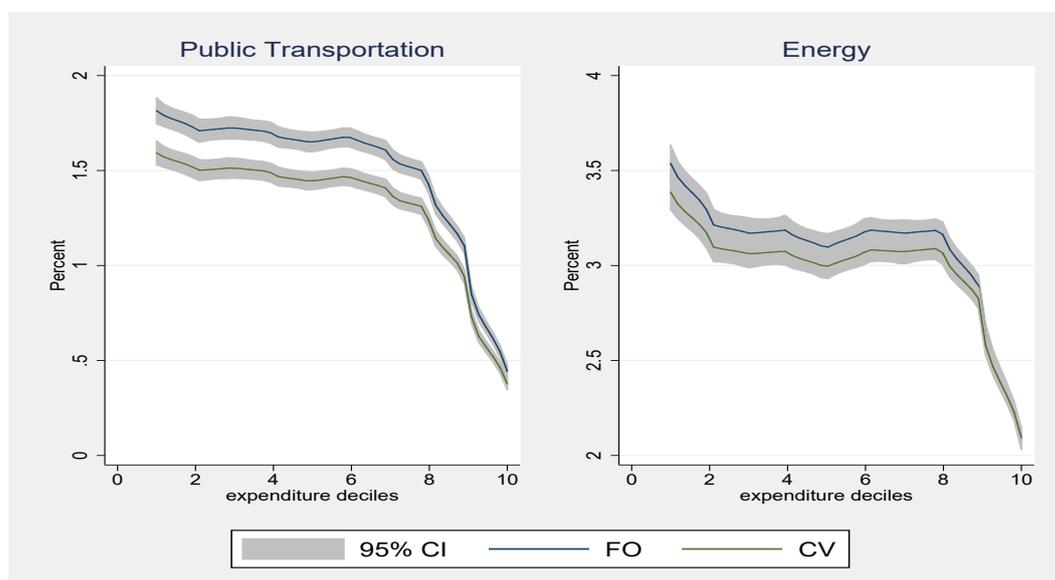


*Note:* The left plot shows that a 20% increase in electricity prices is regressive while the right plot shows that a 20% increase in the price of motor fuels is progressive. The plots also show that the first order (FO) welfare effects overestimates the welfare loss compared to the second order (CV).

The first and second order welfare effects for electricity, motor fuels, public trans-

portation and all energy goods price changes are shown in figures 3 and 4. The first order results overestimate the welfare loss in all the price change scenarios, thereby underscoring the importance of calculating the second order effects. Except for electricity and public transportation, there is no significant difference between the first and the second order welfare effects at a 95% confidence interval for a 20% price increase. The results also show that a 20% increase in electricity and public transport prices is regressive. For instance, households in the lower income deciles lose about 2% while those in the top 10% of the income distribution lose as low as 0.6%. On the contrary, a change in motor fuel prices is progressive. The right panel of figure 4 shows a simultaneous 20% increase in electricity, motor fuels and public transport prices. The lowest income households experience a higher welfare loss of approximately 3.5% compared to a loss of 2% for the richest households. In addition, the welfare loss from the simultaneous price increase of all energy goods is higher than the welfare loss from the price increase of a single energy good.

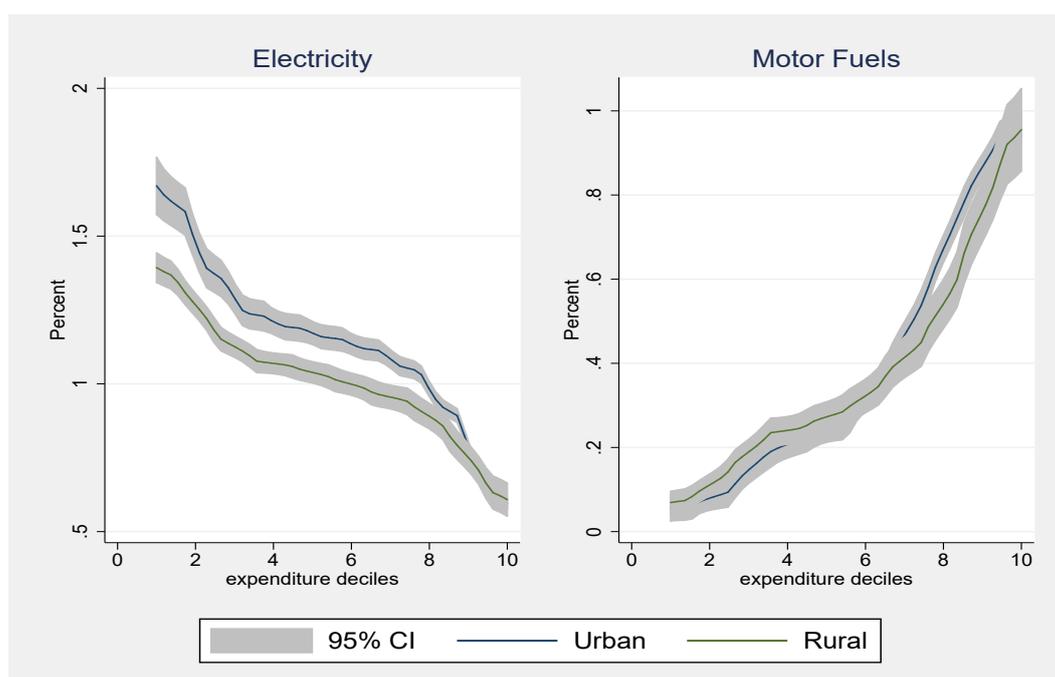
Figure 4: Welfare losses from 20% price increase in public transportation and energy goods



*Note:* This figure shows that the lowest and middle income deciles suffer higher welfare loss compared to the highest income deciles from an increase in public transportation and a simultaneous increase in both electricity, motor fuels and public transport prices.

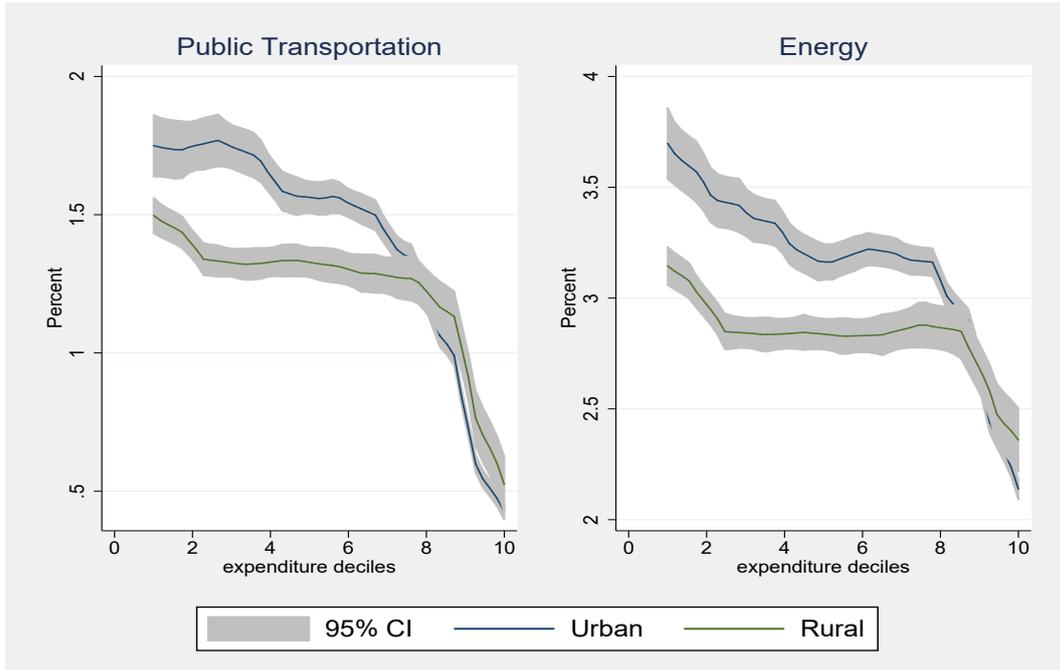
Furthermore, considering households' welfare losses based on settlement type provides better insights on the effects of energy price changes. Similar to the full sample results, when the household settlement type is accounted for, electricity and public transport price changes are regressive while motor fuel price changes is progressive. However, the degree of welfare loss is not always consistent across income deciles in rural and urban areas. On average, urban households experience higher welfare loss from electricity price changes than rural households. This is as a result of high electricity consumption among urban households compared to rural households. Results from public transportation and simultaneous energy goods price changes reveal that urban households in the bottom 80% experience a higher welfare loss compared to their rural counterparts while rural households in the top 20% of the income distribution suffer a slightly higher welfare loss than urban households in the same income group.

Figure 5: Welfare losses by settlement type



*Note:* This figure shows the differences between urban and rural households. The left plot shows that urban households experience a higher welfare loss than their rural counterparts when electricity price changes. The right plot shows only a slight differences in the welfare losses between urban and rural households when the price of motor fuels increases.

Figure 6: Welfare losses from energy goods by settlement type



*Note:* The figure shows that low and middle income urban households suffer a higher welfare loss compared to their rural counterparts. On the contrary, high income urban households are slightly better off than rural high income earners.

Revenue recycling is one of the support policies to be implemented by the South African government to cushion the adverse effects of the carbon tax policy. Therefore, I analyze the effect of a lump-sum transfer of the tax revenues to the poorest households i.e. households in the bottom 40% of the income distribution and those below the national poverty lines. In 2015, the share of income going to the bottom 40% of households in South Africa was 8.3% of total income. Hence, the bottom 40% is a worthy representation of the poorest households in South Africa. In addition, there are three official poverty lines to capture the different levels of poverty in South Africa. They are the food poverty line (FPL), the lower-bound poverty line (LBPL) and the upper-bound poverty lines (UBPL). The FPL is the income threshold below which individuals are unable to purchase or consume enough food to supply them with the minimum requirement for adequate health. Individuals at the LBPL are unable to purchase sufficient food and nonfood items and are therefore obliged to sacrifice food to obtain essential

non-food items. While the individuals at the UBPL can purchase both adequate levels of food and non-food items (StatsSA 2017).

The results of the redistribution policy scenarios are presented in figures 7 and 8 in Appendix C. The effects of the lump-sum transfer of the tax revenue to the households below the poverty lines and the bottom 40 are similar. The tax revenue redistribution to the poorest households yields a progressive outcome. For a 20% change in the prices of electricity, motor fuels and public transportation, the poorest households experience up to 20% welfare gains. A simultaneous change in the price of energy goods lead to welfare gains of up to 90% for the poorest decile.

## 5 Conclusion and Policy Implications

This paper investigates the welfare effects of carbon taxation on South African households in order to provide a deeper understanding of how the newly implemented carbon tax policy would affect South African households in different income groups. The study is based on a pooled cross-sectional data from the South African Income and Expenditure Survey and the Living Conditions Survey.

The findings reveal that the welfare loss resulting from an increase in electricity and public transportation prices is regressive, while it is progressive for motor fuels. A simultaneous increase in the price of the energy goods considered in this paper shows that the poorest and middle income households suffer a higher welfare loss than the richest households. The results also show that the first-order effect overestimates the welfare loss and that the rural and urban households are affected differently. Other existing studies also find regressive effects of energy price increase on electricity (Moshiri and Martinez Santillan 2018; Renner et al. 2018; Schulte and Heindl 2017). However, contrary to Moshiri and Martinez Santillan (2018) who find regressive welfare effect of gasoline price increases, this paper finds a progressive effect of an increase in motor fuel prices. This could be as a result of the difference in the expenditure pattern between Mexico and South African households.

Although access to electricity in South Africa has risen over the years with national

access being over 85% of total population, so many poor households have no access to basic electricity services. To address this problem, the Free Basic Electricity (FBE) was introduced in 2003, as part of the National Indigent Policy, to provide 50kwh of electricity per month to poor households. Despite the existence of this program, on average, poor families spend a high fraction of their budget on electricity compared to the rich, hence experiencing a higher welfare loss. This implies that the government needs to monitor the FBE program to ensure that the services are properly targeted and reach the poor households especially in times of rising electricity prices.

Furthermore, the result for the simultaneous increase in energy prices imply that direct carbon taxation will disproportionately reduce the welfare of the poorest households. Low income households would experience larger tax burdens which would further decrease their already meagre income. Complementary policies such as tax revenue redistribution to households below the national poverty lines or the bottom 40 would be helpful in offsetting the welfare loss.

The distributional effects of the carbon tax are different for rural and urban households, especially in terms of public transportation price increases. Poor urban households experience a higher welfare loss from an increase in public transport prices compared to poor rural households. This mainly stems from two reasons, first South Africa already has a high cost of public transportation in urban areas. Further increasing the price of public transportation would affect poor urban households negatively. Second, a high percentage of the rural population do not have access to public transportation services.<sup>1</sup> The public transport system in South Africa has several challenges including the increased travel times of especially metropolitan commuters, high transport costs, limited number of buses and poor roads (StatsSA 2013). Addressing these challenges would lessen the adverse effects of the expected increase in transport prices that would result from the carbon tax policy.

This study does not look at the impact of the actual carbon tax because of the unavailability of  $CO_2$  emission intensities data and the environmentally extended input-

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<sup>1</sup><https://www.gov.za/about-sa/transport>

output table for South Africa. Rather, the study is based on the assumption that the carbon tax would be passed onto consumers in the form of energy price increases. The results do not hold if this assumption fails. In terms of observable price increases, the most immediate impact of the implementation of the carbon tax for consumers is the increase in retail fuel price of 7 cents per litre for petrol and 8 cents per litre for diesel. Although electricity tariff and taxi transport prices have increased by about 10%, this has been as a result of the debt crisis suffered by Eskom and the coronavirus pandemic respectively.

While this study attempts to provide insights on the welfare effects of carbon tax on South African households, the results should be interpreted with caution. Since the survey data used a diary and recall method for a two-week time period, the data does not take into account seasonal changes in household expenditure. Ignoring seasonal and time effects could bias the model results. Furthermore, the model presented is a short-run analysis which does not reveal the distributional impacts of the carbon tax in the long run. Finally, the welfare analysis is based on elasticities from the QUAIDS model which would be different for dramatic price changes.

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## Appendix

### Appendix A: Summary Statistics by Survey Period

Table A1: Summary Statistics for 2009

Variable	No. of Obs	Mean	Std. Dev.	Min	Max
<i>Expenditure in South African Rand</i>					
Electricity	24,396	1546.5	3985.5	0	333257
Motor fuel	24,396	1838.5	6918.3	0	597021
Public Transport	24,396	2048.0	4108.2	0	175817
Food	24,396	25182.8	34766.0	0	727994
Other goods	24,396	29580.5	63057.5	190	2352410
Total	24,396	60196.5	93795.2	1191	2593743
<i>Expenditure shares</i>					
Electricity	24,396	0.037	0.041	0	0.673
Motor fuel	24,396	0.016	0.045	0	0.929
Public Transport	24,396	0.056	0.066	0	0.913
Food	24,396	0.488	0.175	0	0.964
Other goods	24,396	0.404	0.170	0.019	0.984
<i>Log prices</i>					
Electricity	24,396	3.741	0.066	3.601	3.821
Motor fuel	24,396	4.098	0.006	4.087	4.106
Public Transport	24,396	4.134	0.077	3.983	4.224
Food	24,396	4.111	0.019	4.074	4.136
Other goods	24,396	4.194	0.010	4.178	4.206
<i>Other variables</i>					
Age of head	24,396	47.640	15.963	15	95
Province	24,396	5.134	2.579	1	9
Settlement type	24,396	2.273	1.483	1	5
Household size	24,396	3.874	2.487	1	26

Table A2: Summary Statistics for 2011

Variable	No. of Obs	Mean	Std. Dev.	Min	Max
<i>Expenditure in South African Rand</i>					
Electricity	25,076	2038.0	3679.1	0	121026
Motor fuel	25,076	3542.5	7507.2	0	122323
Public Transport	25,076	2792.1	5114.8	0	121413
Food	25,076	26732.7	37140.3	0	835237
Other goods	25,076	42657.9	85723.2	51	3134597
Total	25,076	77763.2	119170.6	219	3615312
<i>Expenditure shares</i>					
Electricity	25,076	0.035	0.043	0	0.922
Motor fuel	25,076	0.030	0.070	0	0.805
Public Transport	25,076	0.062	0.087	0	0.844
Food	25,076	0.401	0.174	0	0.980
Other goods	25,076	0.472	0.179	0.015	1.000
<i>Log prices</i>					
Electricity	25,076	4.076	0.028	4.023	4.113
Motor fuel	25,076	4.266	0.006	4.254	4.274
Public Transport	25,076	4.187	0.067	4.061	4.262
Food	25,076	4.170	0.019	4.135	4.196
Other goods	25,076	4.279	0.009	4.262	4.289
<i>Other variables</i>					
Age of head	25,076	48.14	15.89	15	95
Province	25,076	5.12	2.62	1	9
Settlement type	25,076	2.16	1.47	1	5
Household size	25,076	3.75	2.35	1	21

Table A3: Summary Statistics for 2015

Variable	Obs	Mean	Std. Dev.	Min	Max
<i>Expenditure in South African Rand</i>					
Electricity	23,373	3050.1	3906.6	0	73105.34
Motor fuel	23,373	3699.2	10446.9	0	348705.9
Public Transport	23,373	3484.5	7243.6	0	474861.8
Food	23,373	29320.6	42570.3	0	1107364
Other goods	23,373	47258.9	94622.6	0	2343466
Total	23,373	86813.3	134617.1	1445.53	2601671
<i>Expenditure shares</i>					
Electricity	23,373	0.056	0.056	0	0.791
Motor fuel	23,373	0.024	0.059	0	0.643
Public Transport	23,373	0.071	0.083	0	0.979
Food	23,373	0.392	0.181	0	0.976
Other goods	23,373	0.457	0.181	0	0.991
<i>Log prices</i>					
Electricity	23,373	4.460	0.007	4.445	4.469
Motor fuel	23,373	4.585	0.002	4.582	4.588
Public Transport	23,373	4.560	0.033	4.516	4.600
Food	23,373	4.443	0.016	4.422	4.470
Other goods	23,373	4.508	0.008	4.497	4.528
<i>Other variables</i>					
Age of head	23,373	49.228	16.103	15	103
Province	23,373	5.109	2.612	1	9
Settlement type	23,373	2.281	1.488	1	5
Household size	23,373	3.803	2.515	1	27

## Appendix B: Estimation Results

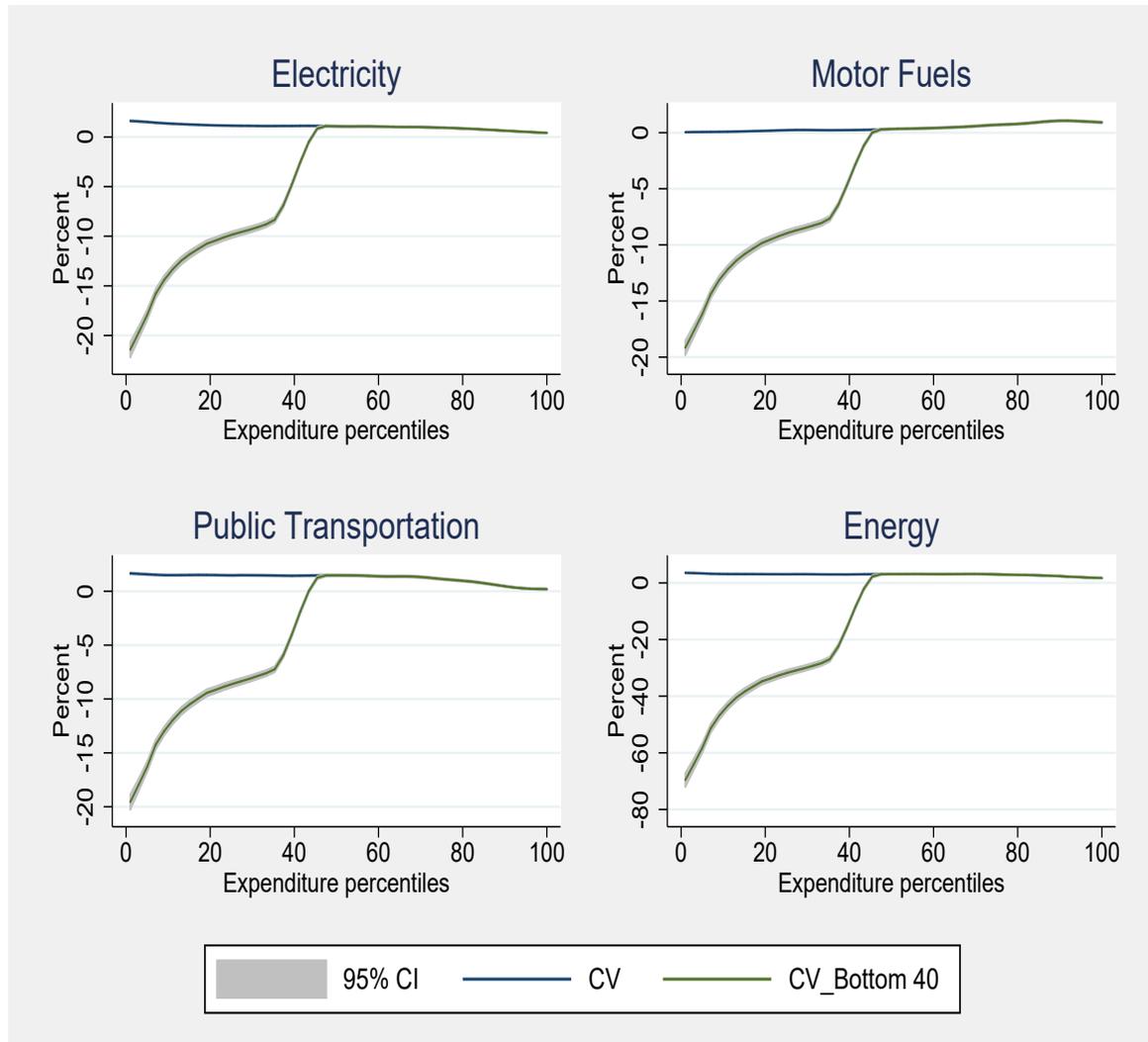
Table B1: Demand System Estimation Results

		Electricity	Motor Fuels	Pub. Transport	Food	Other goods
Constant	$\alpha_i$	0.073*** (0.001)	-0.026*** (0.002)	0.114*** (0.001)	0.435*** (0.004)	0.404*** (0.003)
Expenditures	$\beta_i$	-0.025*** (0.001)	0.030*** (0.001)	-0.020*** (0.001)	0.006** (0.003)	0.008*** (0.003)
Electricity price	$\gamma_{i1}$	0.015*** (0.002)	0.029*** (0.004)	0.033*** (0.002)	-0.090*** (0.005)	0.013*** (0.004)
Motorfuels price	$\gamma_{i2}$		-0.007 (0.012)	0.001 (0.003)	-0.243*** (0.011)	0.219*** (0.009)
Pub. Transport price	$\gamma_{i3}$			-0.036*** (0.004)	0.122*** (0.007)	-0.121*** (0.007)
Food price	$\gamma_{i4}$				0.268*** (0.030)	-0.058** (0.026)
Other goods price	$\gamma_{i5}$					-0.054** (0.026)
Expenditure squared	$\lambda_i$	0.002*** (.000218)	-0.001*** (.000141)	-0.002*** (.000233)	-0.017*** (.000498)	0.017*** (.000513)
Age of head	$\eta_a$	.000063*** (4.8e-06)	-.000082*** (8.0e-06)	-.000023** (.00001)	.000162*** (.000022)	-.00012*** (.000025)
Province	$\eta_p$	-.000473*** (.00003)	.000387*** (.000054)	.000493*** (.000056)	-.00373*** (.000156)	.00333*** (.000173)
Settlement type	$\eta_s$	-.000323*** (.000069)	-.00173*** (.0001)	.000886*** (.000122)	.0113*** (.000268)	-.0102*** (.0003)
Household size	$\eta_h$	.000204*** (.000028)	-.000644*** (.000048)	.00053*** (.000053)	.00415*** (.000139)	-.00424*** (.000143)
No. of Obs		72845	72845	72845	72845	72845

Robust standard errors in parentheses \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

## Appendix C: Redistribution policy

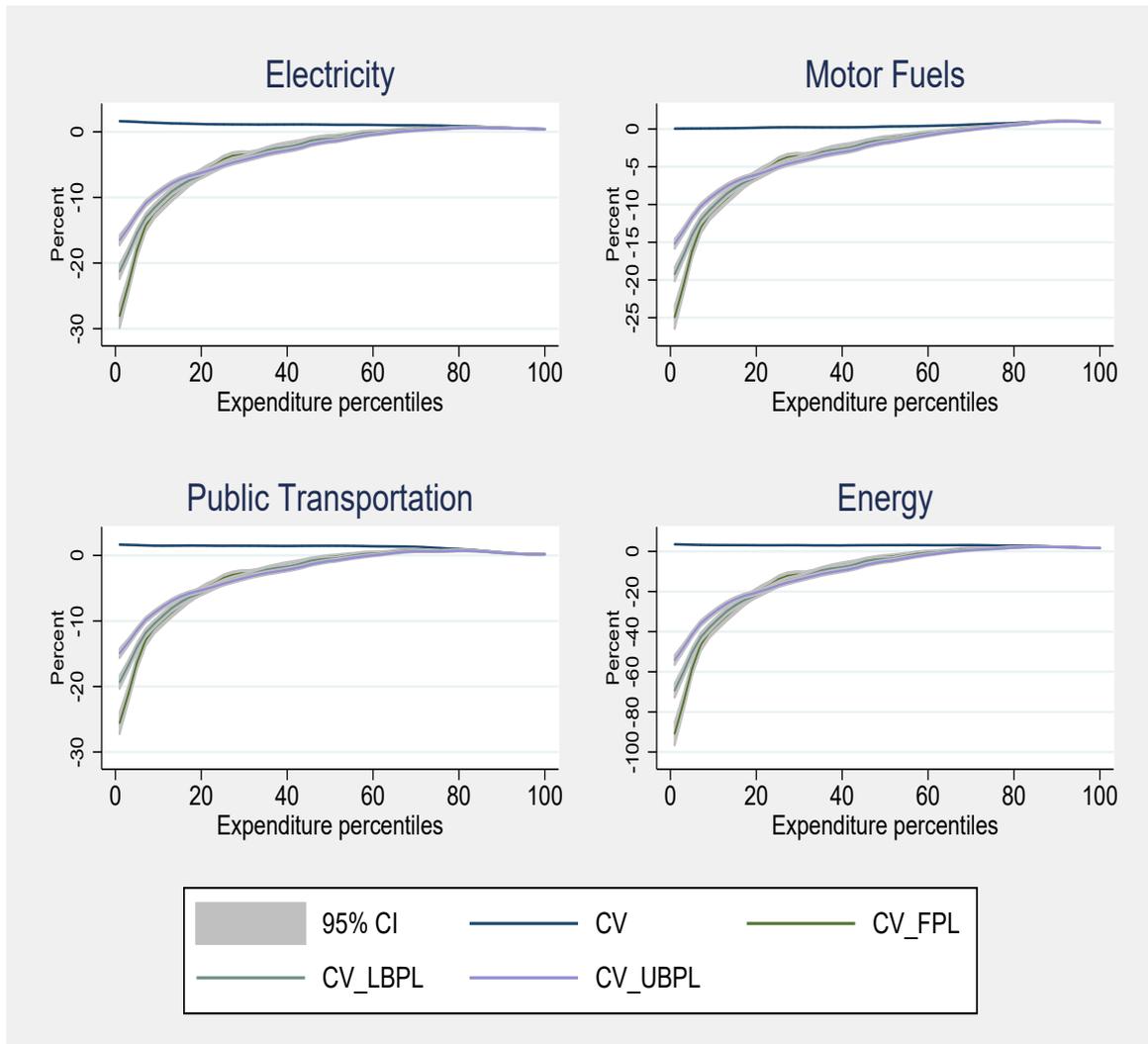
Figure 7: Welfare effects with a Lump-sum Transfer to the Bottom 40%



Source: Author's calculation

*Note:* The redistribution of tax revenue to the bottom 40% of the South African population yields a progressive outcome. For a 20% change in the prices of electricity, motor fuels and public transportation, the poorest households experience up to 20% welfare gains. A simultaneous change in the price of energy goods lead to welfare gains of up to 70% for the poorest decile.

Figure 8: Welfare effects with a Lump-sum Transfer to Households Below the Poverty Line



where FPL = Food Poverty Line; LBPL = Lower Bound Poverty Line; UBPL = Upper Bound Poverty Line.

*Note:* This figure shows the lump-sum redistribution of tax revenue to household below different poverty lines. The results are similar to that of the bottom 40%.



## Chapter 4

# Gender, Energy Expenditure and Household Cooking Fuel Choice in Nigeria

# Gender, Energy Expenditure and Household Cooking Fuel Choice in Nigeria

*This chapter is to be revised and resubmitted to The Energy Journal*

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## **Abstract**

Using a nationally representative dataset from Nigeria, this article explores the impact of women's bargaining power in intra-household decision making process and further analyzes the determinants of household energy expenditure conditional on fuel use. The results reinforce the importance of women's participation in household fuel choice and energy transition from traditional to modern fuel. In addition to gender, other household characteristics such as income and education are found to be important factors which affect household main cooking fuel choice and energy spending. These findings imply that energy transition policies need to take into account gender dynamics and women's preferences.

JEL codes: D12, I3, Q40, O13

Keywords: Women, Fuel Choice, Expenditure, Household

# 1 Introduction

Household air pollution is one of the major causes of premature deaths in developing countries. According to the World Health Organization, about 3 billion people globally still rely on solid fuels (e.g. wood, crop wastes, animal dung) to meet basic energy needs. The reliance on solid fuels and the use of open fires and inefficient stoves produce high levels of health-damaging pollutants such as particulate matter, methane, carbon monoxide and poly-aromatic hydrocarbons. Exposure to these pollutants is particularly high among women and children in developing countries who are responsible for household cooking (WHO 2016). This emphasizes the importance of the gender dimension for household energy transition to modern fuels (e.g. LPG, electricity).

Women and children in developing countries disproportionately suffer from the adverse effects of the use of solid fuels because of several societal and cultural factors. Gender norms typically assign women and children the role of collecting firewood from the forests. Firewood collection is time-consuming and requires physical effort for cutting, gathering and transporting the firewood back home. The daily tasks of collecting, processing and using firewood leave women and children with little to no time for education, rest or leisure (Köhlin et al. 2011; WHO 2016). Women in developing countries usually have lower status than their spouse and so their preferences are not always accounted for in household decisions. The adoption of improved cooking technologies depends on household decision making, and particularly the extent to which women's preferences, opportunity cost of time and well-being are reflected in the decision-making process.

Against this backdrop, this paper examines women's bargaining power in intra-household decision-making for household fuel choice. In particular, it provides a better

understanding of the need for women's participation in the household decision-making process. Studying this has meaningful policy implications and contributes to the growing literature on energy and gender. I conjecture that households with female heads are more likely to adopt modern cooking fuels than those with male heads. This is because the adoption of modern fuels directly improves the welfare of women in terms of better health outcomes and reduced cooking time.

The household decision of which fuel to adopt is not the only important aspect of energy transition from traditional to modern fuels. Understanding the determinants of household energy spending is also crucial in the design of effective modern energy transition policies. For instance, households who spend a large fraction of their income on modern fuels will have a lower purchasing power for other consumption goods, thereby reducing overall welfare. Considering this, this article further investigates the determinants of household energy expenditure once the decision to use a fuel has been made. This is also crucial because the factors determining household fuel choice may be different from those that influence energy spending (Adusah-Poku and Takeuchi 2019).

Moreover, the allocative decision of how to distribute limited energy budget among different fuel types is important for healthy and productive outcomes for households. If households spend their income on modern fuels rather than traditional fuels, then they can enjoy the benefits that accrue from modern fuel usage. Some of these benefits identified in the literature include improved health, reduced cooking time and more time for leisure/education and improvements in overall productivity (Köhlin et al. 2011; Pachauri and Rao 2013; WHO 2016).

Household energy transition is rooted in the energy ladder theory which postulates that as income increases, households switch from traditional fuels to modern and more efficient fuels (Hosier and Dowd 1987; Lay et al. 2013; van der Kroon et al. 2013). The

energy ladder model suggests three fuel switching phases. The first phase involves the sole use of traditional fuels such as biomass. In the second phase, households move from the use of traditional to transition fuels such as kerosene and charcoal. In the third and final phase, households exclusively use modern fuels such as LPG or electricity. However, different studies have found contrary evidence which reveal that households in developing countries do not entirely switch to a new phase but use a combination of fuels simultaneously from different phases of the energy ladder (Masera et al. 2000; Hanna and Oliva 2015).

Several empirical studies have evaluated the effects of gender on household energy choice. The existing literature has been conducted in several countries namely Bhutan (Rahut et al. 2014), Bolivia (Israel 2002), China (An et al. 2002) India (Farsi et al. 2007; Mohapatra and Simon 2017), Sri Lanka (Wickramasinghe 2011), Burkina Faso (Ouedraogo 2006) and Ghana (Karimu et al. 2016). These studies use already existing household survey data or conduct their own surveys. In terms of estimation methodology, the papers employ different approaches to address their research questions including heckman selection, logit, multinomial logit/probit and ordered probit models.

The findings from these studies have been contradictory. While some studies find evidence that female-headed households prefer modern fuels to traditional fuels (Israel 2002; Farsi et al. 2007; Wickramasinghe 2011; Rahut et al. 2014; Karimu et al. 2016; Mohapatra and Simon 2017), others find that the gender of the household head does not determine household fuel choice (An et al. 2002; Ouedraogo 2006) which is more in line with the finding of this paper. The relationship between gender and household fuel choice is context-specific and depends on geographical variation across countries (Schunder and Bagchi-Sen 2019). Hence, the results of other studies are not directly

applicable to the Nigerian context.

A review of the existing literature on women's well-being and energy poverty by Pachauri and Rao (2013) find that more research and empirical evidence is needed to understand the factors that influence women's decision making power in terms of modern energy adoption. Miller and Mobarak (2013) used a randomized controlled trial to study gender and the intra-household dimension of decision making related to improved stove adoption. They find that although women have a stronger preference for improved stoves than men, they do not purchase the stove because of their low decision-making authority within the household. Using several proxies for women's household decision making power, this current study contributes new insights to the existing studies in this research area.

With regards to fuel expenditure, a review of the existing literature reveal that only a few papers have tried to study the factors that affect household energy spending in developing countries (Khandker et al. 2012; Alkon et al. 2016; Mottaleb et al. 2017; Adusah-Poku and Takeuchi 2019). This study makes two significant contributions to the existing literature. First, it focuses on Nigeria where a large proportion (70%) of the population rely on solid fuels as the main energy source of cooking. Since many Nigerian households are yet to adopt modern cooking fuels, there is a need to understand to what extent gender influences fuel choice in Nigeria in order to inform energy transition policies. Therefore, the study provides a nationwide evidence for the Nigerian situation. Second, unlike most studies in the literature, this paper not only examines the impact of women intra-household bargaining power, it also studies household energy spending behavior after they choose a particular fuel.

My findings have several policy implications. First, I do not find significant effects to conclude that households with female heads are less likely to choose traditional fuels

and more likely to opt for modern fuels as their main cooking fuel. This implies that gender does not significantly influence the adoption of modern fuels in Nigeria. Second, income and education are important determinants of household modern energy use and expenditure. Thus, investments in education would positively influence the uptake of modern fuels. Third, access to electricity does not guarantee the use of electricity for cooking. This is probably because public power supply in Nigeria is intermittent and unreliable. The reliability of electricity supply is a key component of determining whether or not households use electricity for cooking.

This paper comprises five sections. Section 2 presents the methodology used in this study. Section 3 describes the data and discusses household energy use patterns in Nigeria. Section 4 reports and interprets the estimation results. Lastly, section 5 concludes the paper.

## **2 Methodology**

The empirical analysis used in this study is presented in two steps. The first step uses a discrete choice modeling technique to examine the impact of household characteristics, most especially women intra-household bargaining power, on fuel choices. The second step uses a log linear regression approach to understand the factors affecting household energy expenditure once the decision to use a particular fuel has been made. The idea for the estimation is derived from the two-part model approach (Cragg 1971). The two-part model has two equations. The first equation is a probit equation which models whether or not a household uses a particular fuel while the second equation is a log linear model to determine the factors affecting energy expenditure for a sub-sample of households with positive expenditure levels. The sub-sample is used to overcome the

problem of zero observations which is common in expenditure datasets. Given that there are multiple cooking fuel options in Nigeria, I use a multinomial model, instead of the probit model, to determine the probability that a household chooses a given fuel.

## 2.1 Discrete Choice Model

Households choose among different cooking fuels based on their preferences and characteristics in order to achieve maximum utility. There are various discrete choice models which are applicable depending on whether the choice set is ordered or unordered. Since cooking fuel types have no intrinsic ordering, households face an unordered multinomial fuel choice. Two models - multinomial logit and multinomial probit - are usually considered to model unordered choice sets. The multinomial probit model is computationally burdensome because of the need to evaluate multiple integrals of the normal distribution (Greene (2018)). Hence, I employ the multinomial logit model which is both simpler to compute and qualitatively similar to the multinomial probit model.

The multinomial logit model is based on the random utility model. Household  $i$  is faced with  $m$  different cooking fuel choices. Suppose the outcome for choosing option  $j$  is given by  $y_i = j$  and its associated utility is:

$$U_{ij} = x'_{ij} \beta + \epsilon_{ij}$$

where  $x'_{ij}$  is a vector of explanatory variables,  $\beta$  is the vector of coefficient parameters and  $\epsilon_{ij}$  is the unobserved random term.

If household  $i$  chooses option  $j$ , then it is assumed that  $U_{ij}$  yields the maximum

utility from the different  $m$  fuel choices. Thus,

$$Prob(y_i = j) = Prob(U_{ij} > U_{il}), \quad \forall l \neq j$$

The multinomial logit model for household cooking fuel choice is:

$$Prob(y_i = j) = \frac{\exp(x'_i \beta_j)}{\sum_{k=1}^m \exp(x'_i \beta_k)} \quad (1)$$

Since the estimated parameters of the multinomial logit model are generally not directly interpretable, I compute and report the average marginal effects. For household  $i$ , the average marginal effect of a change in the  $k$ th regressor on the probability that alternative  $j$  is the outcome is:

$$\frac{\delta p_{ij}}{\delta x_{ik}} = p_{ij} \left( \beta_j - \sum_{k=1}^m p_{ik} \beta_k \right) = p_{ij} (\beta_j - \bar{\beta}) \quad (2)$$

where  $p_{ij}$  is the probability of adopting alternative  $j$ ,  $\delta x_{ik}$  measures the impact of a variation of an explanatory variable  $x_{ik}$  on the probability of choosing fuel  $j$  and  $\bar{\beta}$  is a probability weighted average of  $\beta_k$ . The marginal effects is computed from the parameter estimates and vary with the point of evaluation,  $x_{ik}$ .

## 2.2 Log Linear Regression Model

I employ a log linear regression model to investigate the determinants of household energy expenditure once the decision to use a fuel has been made. I use a sub-sample of the households who already use kerosene and electricity as their main cooking fuel. Using the sub-sample addresses the problem of zero observations which is common in expenditure data by focusing on only households with positive kerosene or electricity

expenditure. Since most of the people who use firewood collect them for free from the forests, I omit firewood expenditure in this analysis. The regression equation is given as:

$$\log(e_i|I_i > 0) = \beta_0 + \beta_i X_i + u_i \quad (3)$$

where  $e_i$  is kerosene or electricity expenditure.  $I_i$  is the indicator for households with positive kerosene or electricity expenditure.  $\beta_i$  is the vector of coefficient estimates and  $X_i$  is a vector of control variables which could influence energy expenditure levels. Lastly,  $u_i$  represents the error term. Equation 3 is estimated with the Ordinary Least Squares Estimator.

### 3 Data

This paper employs the 2015/2016 Nigerian General Household Survey (NGHS), a comprehensive nationally representative household survey. Although, 2015/2016 dataset contains a sample of 4,581 households, after merging the different data files the full sample size used for the study analysis reduces to 4,027 households. However, after model estimation the maximum number of observations is 4000. The NGHS dataset provides necessary information needed for the analysis. Since the NGHS dataset does not provide information on prices, electricity prices were gotten from the Nigerian Electricity Regulatory Commission website and kerosene prices were gotten from an African Development Bank sponsored database - the Nigerian Data Portal. Fuel prices are state-specific. Households are assigned a particular fuel price depending on their state of residence.

Households in the NGHS survey were asked what their main source of cooking fuel is. They could choose from several fuel options such as firewood, grass, coal, kerosene, generator, electricity or gas. Using the typical household fuel classification derived from the energy ladder, I group the cooking fuels into three categories: Traditional fuels (firewood, grass), Transition fuels (kerosene, coal, generator) and modern fuels (LPG and Electricity). This is also the classification used for the dependent variable in the multinomial analysis with  $j = 1$  for traditional fuels (firewood),  $j = 2$  for transition fuels (kerosene) and  $j = 3$  for modern fuels (electricity).

Most Nigerian households rely heavily on traditional fuels for cooking. In contrast, modern fuels are used less often for cooking purposes. Table 1 shows the main energy sources for cooking in Nigeria. Almost three-quarter of Nigerian households (72%) use traditional fuels as their main source of cooking and only 23% and 3% use transition and modern fuels respectively. There are significant differences between the main cooking fuels used in urban and rural Nigeria. Compared to urban Nigeria where the primary cooking fuel is kerosene (49%), the predominant cooking fuel among rural households is firewood (88%). In addition, there are also obvious disparities between female-headed and male-headed households. About 74% of the male households use firewood for cooking compared to 63% of the female households. This suggests that households with female heads are less likely to use traditional fuels than male households.

Although the sample is unbalanced and biased towards firewood use (72%) compared to other types of fuel use, this is unlikely to bias the model estimates, since the sample is a representative of the true proportion of the overall Nigerian population and the multinomial logit regression might be bias in small samples (under about 200) which is not the case in this study. <sup>1</sup>.

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<sup>1</sup><https://eml.berkeley.edu/~mcfadden/discrete/ch2.pdf>

Table 1: Household Energy Consumption Patterns

Cooking Fuels		Full Sample	Rural	Urban	Female Headed households	Male headed households
<i>Traditional</i>						
Firewood	users (%)	72.0	87.9	38.4	63.1	73.8
	average expenditure (₦)	742.0	677.7	880.0	1015.7	695.0
	per capita expenditure	210.6	194.3	246.1	588.1	145.3
<i>Transition</i>						
Kerosene	users (%)	23.0	8.6	48.9	32.4	21.4
	average expenditure (₦)	1743.0	1233.6	2842.0	3528.6	1594.7
	per capita expenditure	749.6	547.0	1188.9	2091.8	517.4
<i>Modern</i>						
Electricity	users (%)	0.9	0.7	1.2	0.4	0.9
	average expenditure (₦)	2801.3	1633.4	5321.1	4533.2	2502.5
	per capita expenditure	1155.1	698.8	2144.5	2480.6	925.7
Gas	users (%)	3.4	1.5	7.5	3.6	3.4
	average expenditure (₦)	549.8	256.0	1183.7	885.5	492.4
	per capita expenditure	244.2	106.3	543.2	536.4	193.7

Source: Nigerian General Household Survey 2015/2016

With regards to energy expenditure, the table indicates that for the national sample and all sub-samples, households spend the most on electricity compared to other fuels. Also, urban and female-headed households spend more on fuels than rural and male-headed households. Table 1 also shows that although a lower proportion of the female households use traditional fuels as their primary cooking fuel compared to the households with male heads, their average firewood expenditure is greater than that of the male-headed households.

### **3.1 Variables of Interest**

One of the objectives of this study is to investigate the gender dimension of household fuel choice. Thus, the main variable of interest for the multinomial logit model is women's intra-household bargaining power. The Nigerian survey data does not provide information on the person responsible for household consumption decision making, therefore I use a proxy variable to measure women's bargaining power in the household. Given that in most cases the household head is the primary decision maker, the female-head variable is a natural proxy to measure the decision-making power of women. Household headship indicates control and power to influence certain household choices.

Existing evidence suggests that being older than a spouse or more educated is associated with a higher relative intra-household bargaining power (Lundberg and Pollak 1994; Lundberg and Pollak 1996; Miller and Mobarak 2013; Schaner 2017). For instance, when a wife is more educated than her husband, she has greater power to negotiate the adoption of modern fuels. To check the robustness of female bargaining power, relative spouse education and age variables are also used as proxies. To construct these variables, I divide the spouse's years of schooling (age) by the husband's

for a sub-sample of households with a male head and a female spouse.

The key variables of interest for the log linear regression on fuel expenditure are household income, fuel prices and gender. These variables are identified in the literature as important determinants of household energy spending. I used household total expenditure as a proxy for household income because as documented in the literature, there is the tendency for households in developing countries to misreport their actual incomes during surveys. Thus, total expenditure reflects a better measure of long-term income ( Deaton 1997; An et al. 2002; Edwards and Langpap 2005; Gupta and Köhlin 2006; Akpalu et al. 2011; Muller and Yan 2018; Gould et al. 2020). Household income and gender are expected to be positively associated with kerosene and electricity expenditure. The fuel price impact could be negative or positive depending on the fuel type. For example, an increase in the kerosene price is likely to be correlated with a decrease in kerosene expenditures and an increase in electricity expenditures.

Households tend to use and spend on certain types of fuels depending on their characteristics, location, preferences and wealth status. Considering this, several control variables such as age of head, household size, home tenancy status, education, connection to the electricity grid, settlement type and geopolitical zone dummies are included in the analysis. A description of all variables used in this study are provided in table 4 in the appendix.

## 4 Results

### 4.1 Multinomial Logit Regression Results

Household cooking fuel decisions are analysed using the multinomial logit regression model. The coefficient estimates are presented in the appendix because they are difficult to interpret and do not present any economic intuition. Alternatively, the average marginal effects estimated from the regression are informative. Thus, I report and explain the average marginal effects shown in table 2. The multinomial logit regression is estimated using different specifications. Specification (a) is the baseline model which contains only the main variable of interest in this study, (b) includes other control variables and (c) contains both control variables and the regional dummies. The signs on variables with significant marginal effects are the same across all specifications.

The marginal effects of the female-head variable on firewood adoption is negative and significant which implies that compared to male headed households, female headed households have a lower probability to choose firewood as their primary cooking fuel. However, the marginal effect becomes nonsignificant after controlling for household characteristics and regional dummies. This suggests that the effect of the female-head variable is overestimated when the control variables are excluded from the analysis. Nevertheless, the negative effect is in line with my expectation that households with female heads are less likely to use traditional fuels than households with male heads.

In order to check the robustness of the results, I use alternative proxy variables for female intra-household bargaining power. In different model specifications, I substituted the female-head variable with relative spouse education and relative spouse age.

Table 2: Average Marginal Effects from Multinomial Logit for Cooking Fuel

	Firewood			Kerosene			Electricity		
	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
Female	-0.096*** (0.018)	-0.396 (0.260)	-0.068 (0.249)	0.097*** (0.017)	0.264 (0.260)	-0.050 (0.251)	-0.002 (0.009)	0.132 (0.149)	0.117 (0.147)
Income		-0.126*** (0.010)	-0.117*** (0.010)		0.076*** (0.011)	0.067*** (0.011)		0.049*** (0.005)	0.050*** (0.005)
Fem*Tot_exp		0.032 (0.021)	0.006 (0.021)		-0.022 (0.021)	0.003 (0.021)		-0.011 (0.012)	-0.010 (0.012)
Kero. Price		0.199*** (0.033)	0.095*** (0.032)		-0.186*** (0.036)	-0.099*** (0.035)		-0.012 (0.020)	0.004 (0.019)
Elec. Price		0.084 (0.053)	0.053 (0.061)		-0.049 (0.054)	-0.009 (0.062)		-0.035 (0.027)	-0.044 (0.031)
Age		0.001 (0.000)	0.001*** (0.000)		-0.001* (0.000)	-0.001*** (0.000)		0.000 (0.000)	0.000 (0.000)
HH size		0.032*** (0.010)	0.010 (0.010)		-0.050*** (0.010)	-0.031*** (0.010)		0.018*** (0.005)	0.021*** (0.005)
Homeowner		0.088*** (0.011)	0.061*** (0.011)		-0.093*** (0.011)	-0.069*** (0.011)		0.004 (0.006)	0.008 (0.006)
Basic Education		-0.070*** (0.017)	-0.027 (0.016)		0.047** (0.019)	0.007 (0.019)		0.023 (0.018)	0.020 (0.018)
Secondary Edu		-0.098*** (0.018)	-0.066*** (0.018)		0.053*** (0.020)	0.023 (0.020)		0.045*** (0.017)	0.043** (0.017)
Tertiary Edu		-0.123*** (0.019)	-0.091*** (0.018)		0.054** (0.021)	0.025 (0.021)		0.069*** (0.017)	0.066*** (0.017)
Electricity		-0.125*** (0.012)	-0.118*** (0.012)		0.108*** (0.014)	0.104*** (0.014)		0.017 (0.010)	0.014 (0.010)
Urban		-0.166*** (0.009)	-0.113*** (0.010)		0.157*** (0.010)	0.111*** (0.011)		0.009 (0.006)	0.002 (0.006)
Forest Cover		-0.003 (0.005)	0.047*** (0.008)		0.002 (0.005)	-0.040*** (0.007)		0.001 (0.003)	-0.007** (0.003)
Geopo. zone	NO	NO	YES	NO	NO	YES	NO	NO	YES
N	4000	3974	3974	4000	3974	3974	4000	3974	3974

Robust standard errors in parentheses \*\*\* p&lt;0.01, \*\* p&lt;0.05, \* p&lt;0.1

The result tables shown in the appendix are similar to the results obtained when the female-head variable was used. Furthermore, I performed a multicollinearity test on the explanatory variables to ensure that they are not collinear. The result presented in table 14 suggests that there is no multicollinearity among the variables.

Using household per capita expenditure as a proxy for income, I find evidence consistent with the energy ladder theory that an increase in income is associated with modern fuel adoption. The findings show that households with higher income levels are less likely to use traditional fuels as their primary cooking fuel and more likely to use transition and modern fuels. More specifically, a one unit increase in household income is correlated with a decrease in the probability of choosing firewood by 12% and an increase in the probability of choosing kerosene and electricity by 7% and 5% respectively.

Regarding fuel prices, although the electricity price impact is not significant across all model specifications, the kerosene price has some significant effects on household fuel choice. Kerosene price has a positive and significant marginal effect on firewood adoption. Households tend to fall back on cheaper traditional fuel sources when kerosene prices increase. This does not suggest a complete switch away from kerosene to firewood because most households in developing countries use multiple fuels simultaneously. Rather it means that households cook more with firewood instead of kerosene. As expected, an increase in the kerosene price is associated with a reduction in the probability of households choosing kerosene as their main cooking fuel.

Age, Household size and Home ownership status have similar effects on the household fuel choice adoption probability. Older household heads are more likely to use firewood as their main cooking fuel and less likely to use kerosene. Although the effect of age in explaining household fuel choice is contradictory in the literature with some

papers finding positive effects (Edwards and Langpap 2005; Démurger and Fournier 2011; Rahut et al. 2014) and others negative effects (Farsi et al. 2007; Özcan et al. 2013), this result is in line with Baiyegunhi and Hassan (2014) who find that in rural Nigeria, older household heads are more likely to use fuelwood.

Education is one of the key drivers of modern fuel adoption because being educated exposes one to information on the benefits of using modern fuels and the adverse effects of using solid fuels. Education also increases the opportunity cost of time for cooking with solid fuels. The results show that compared to households with uneducated heads, households with educated heads are less likely to adopt traditional fuels and more likely to adopt transition and modern fuels. The probability of adoption increases with the level of education. For example, the probability for household heads with at most basic education is 2.7% less likely to use firewood as the main cooking fuel. The probability is 9.1% for household heads with tertiary education. This result is similar to other findings in the literature (Heltberg 2004; Mekonnen and Köhlin 2009; Zhang and Hassen 2017).

The urban variable, access to electricity and proximity to forests show significant effects on household fuel choice. Households with connection to the electricity grid and those who live in urban areas are less likely to mainly use firewood for cooking and more likely to use kerosene. The marginal effects coefficient on electricity is not significant. This is probably because public power supply in Nigeria is erratic and unreliable. Being connected to the electricity grid does not guarantee constant power supply, so it is unlikely that Nigerian households with electricity connection will choose electricity as their main cooking fuel. In addition, proximity to forest cover is correlated with a decrease in kerosene or electricity adoption and an increase in firewood usage, mostly because of the easy access to free firewood from the forests.

## 4.2 Log Linear Regression Results

The log linear regression using the OLS estimator was used to analyse the determinants of household energy expenditure conditional on fuel use. Past literature suggests that income and fuel prices are important determinants of household energy spending. These variables are used in addition to the gender variable in the baseline model specification. Table 3 reports the results for the log linear regression on the sub-sample of households with positive kerosene and electricity expenditure. Similar to table 2, table 3 shows different model specifications and the significant results are consistent across all specifications.

Female household head and income have a positive and statistically significant relationship with both kerosene and electricity expenditure once the decision to use these fuels has been made. This implies that women are more likely to spend on transition and modern fuels conditional on fuel adoption. The effect of income on kerosene and electricity expenditure is consistent with the a priori expectation because kerosene and electricity are normal goods and are also relatively expensive fuels, the amount that is spent to use them increases with household income.

The effect of household size on kerosene and electricity expenditure is negative and significant which is contrary to my expectation. Larger households are expected to spend more on kerosene and electricity because they cook large pots of food and would require more fuel than a smaller household. However, the result could accrue to the fact that most large households are relatively poor compared to smaller households and therefore have lower purchasing power to spend on modern fuels.

All education levels have a positive and significant impact on kerosene expenditure. This implies that being educated increases kerosene expenditure conditional on

Table 3: Log Linear Regression on Households with Positive Kerosene and Electricity Expenditure

	Kerosene Expenditure			Electricity Expenditure		
	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)
Female	0.347*** (0.035)	0.193*** (0.037)	0.116*** (0.036)	0.211*** (0.051)	-0.071 (0.051)	-0.077 (0.052)
Income	0.975*** (0.026)	0.619*** (0.032)	0.596*** (0.033)	0.784*** (0.027)	0.456*** (0.033)	0.455*** (0.035)
Kero. Price	-0.919*** (0.091)	-0.621*** (0.092)	-0.319*** (0.093)	0.068 (0.092)	0.142* (0.085)	0.146* (0.087)
Elec. Price	0.018 (0.150)	0.274* (0.142)	0.104 (0.154)	-0.415** (0.190)	-0.136 (0.182)	-0.336* (0.197)
Age		0.002** (0.001)	-0.001 (0.001)		0.004*** (0.001)	0.004*** (0.001)
HH size		-0.490*** (0.027)	-0.439*** (0.028)		-0.542*** (0.034)	-0.521*** (0.035)
Homeowner		-0.124*** (0.034)	-0.062* (0.033)		0.117*** (0.041)	0.145*** (0.041)
Basic Education		0.290*** (0.039)	0.119*** (0.039)		-0.016 (0.054)	-0.042 (0.054)
Secondary Edu		0.310*** (0.047)	0.195*** (0.047)		-0.035 (0.058)	-0.065 (0.057)
Tertiary Edu		0.308*** (0.050)	0.216*** (0.050)		0.146** (0.060)	0.107* (0.060)
Electricity		0.097*** (0.033)	0.065** (0.032)		-0.065 (0.069)	-0.060 (0.067)
Urban		0.242*** (0.031)	0.238*** (0.032)		0.274*** (0.037)	0.232*** (0.039)
Geopo. Zone	NO	NO	YES	NO	NO	YES
Constant	0.567 (0.759)	2.599*** (0.742)	2.192*** (0.753)	-0.243 (0.799)	2.755*** (0.800)	3.536*** (0.883)
R squared	0.480	0.563	0.594	0.317	0.415	0.424
N	2772	2772	2772	2063	2063	2063

Robust standard errors in parentheses \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

kerosene use. Although basic and secondary education are not significant for electricity expenditure, tertiary education is positive and significant. This means that households with highly educated heads are more likely to spend on electricity than those with uneducated heads.

The urban variable and access to electricity both have positive and significant effects on kerosene expenditure. Compared to rural and unconnected households, households who are connected to the electricity grid and those living in urban areas spend more on kerosene and electricity.

## **5 Conclusion and Policy Implications**

The relative bargaining power of women in household decision-making is a crucial, yet overlooked factor in the adoption and sustained use of modern fuels. This article explores the impact of women's bargaining power in intra-household decision making process and further analyzes the determinants of household energy expenditure conditional on fuel use. Understanding these provide insights for policies that encourage clean fuel adoption. I do not find significant effects to conclude that women's influence in household fuel choice is vital for modern fuel adoption. However, the gender variable is positive and significant for household modern fuel expenditure. In addition, other household characteristics such as income and education are found to be important factors which affect both household main cooking fuel choice and energy expenditure.

The results show that among households who use modern fuels, the households with female heads spend more on these fuels. This implies that households which have women in charge of decision making use modern fuels more often and therefore spend more on using the fuels. This also suggests that although gender does not

influence household energy fuel choice, it influences the amount households spend on modern fuels. Therefore, energy transition policies should take into account the gender dynamics in household energy spending behavior.

Education plays a crucial role in household energy transition from traditional to modern fuels. Education can directly or indirectly influence the uptake of modern fuels. For instance, investments in education would directly create awareness about the benefits of modern fuel adoption and promote its uptake. In terms of indirect effects, education could improve the job prospects of individuals which will in turn increase income and advance the adoption of modern cooking fuels. Particularly, investing in women education and development will increase the opportunity and time cost of cooking with firewood and firewood collection.

The uptake of modern energy can have significant improvements in women's welfare and well-being by preventing diseases resulting from indoor air pollution and reducing cooking time costs. Results show that these improvements can be achieved if policies are properly designed to improve households' income and education. In addition, even though women do not have stronger preference for modern fuels compared to men, barriers such as poverty could limit the actual adoption of modern fuels. Investment in programs that improve household access and affordability of clean fuels would increase usage.

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## Appendix

Table 5: Summary Statistics of Variables

	N	Mean	SD	Min	Max
Log kerosene expenditure	2772	7.28	1.09	1.11	11.06
Log electricity expenditure	2063	8.05	1.00	1.39	12.11
Age	4027	53.27	14.34	18	103
Household Size	4027	5.90	3.28	1	31
Female	4027	0.15	0.35	0	1
Home Ownership	4027	0.75	0.43	0	1
Basic Education	4027	0.25	0.43	0	1
Secondary Education	4027	0.28	0.45	0	1
Tertiary Education	4027	0.16	0.36	0	1
Electricity	4027	0.52	0.50	0	1
Urban	4027	0.32	0.46	0	1
Log income per capita	4027	11.66	0.74	9.43	15.15
Log kerosene prices	4027	5.46	0.19	5.10	6.05
Log electricity prices	4027	3.55	0.10	3.33	3.70
North Central	4027	0.17	0.38	0	1
North East	4027	0.14	0.35	0	1
North West	4027	0.20	0.40	0	1
South East	4027	0.16	0.37	0	1
South South	4027	0.16	0.36	0	1
South West	4027	0.17	0.37	0	1

Table 4: Description of variables used

Variables	Definition
<b>Dependent variables</b>	
<i>Multinomial Logit Model</i>	
Cooking fuel	= 1 if main source of cooking is traditional fuels = 2 if main source of cooking is transition fuels = 3 if main source of cooking is modern fuels
<i>Log Linear Regression Model</i>	
Kerosene expenditure	Log monthly kerosene expenditure in Naira
Electricity expenditure	Log monthly electricity expenditure in Naira
<b>Explanatory variables</b>	
Age	Age of household head
Household size	Number of individuals normally living and eating meals together in the household
Female	= 1 if household head is a woman
Home ownership	= 1 if home is owned by the household
Basic Education	= 1 if household head completed primary school
Secondary Education	= 1 if household head completed secondary school
Tertiary Education	= 1 if household head completed a higher education
Electricity	= 1 if household is connected to the public electricity grid
Urban	= 1 if household lives in urban area
Log Income	Annual household expenditure per capita in Naira
Log electricity prices	Electricity price in the state the household lives in.
Log kerosene prices	Kerosene price in the EA the household lives in.
<i>Geopolitical zones dummy variables</i>	
North Central	= 1 if household lives in North Central geopolitical zone
North East	= 1 if household lives in North East geopolitical zone
North West	= 1 if household lives in North West geopolitical zone
South East	= 1 if household lives in South East geopolitical zone
South West	= 1 if household lives in South West geopolitical zone
South South	= 1 if household lives in South South geopolitical zone

Table 6: Summary Statistics for the Female-Headed Households

Variable	Obs	Mean	Std. Dev.	Min	Max
Basic education	594	0.257576	0.437668	0	1
Secondary education	594	0.121212	0.326649	0	1
Tertiary education	594	0.102694	0.303814	0	1
Household size	594	3.292929	2.321187	1	16
Kerosene expenditure	594	3346.015	4234.996	0	63875
Electricity expenditure	594	4360.627	7987.096	0	91250
Income	594	221155.4	235291.4	23671.93	3802534
Age	594	60.48316	14.37092	22	100
Urban	594	0.417508	0.493564	0	1

Table 7: Multinomial Logit Regression Results

Base category: Firewood						
	Kerosene			Electricity		
	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)
Female	0.563*** (0.099)	3.588 (2.600)	0.288 (2.707)	0.091 (0.236)	6.593 (5.294)	4.125 (5.352)
Income		1.109*** (0.115)	1.115*** (0.124)		2.318*** (0.190)	2.392*** (0.203)
Fem*Income		-0.293 (0.214)	-0.030 (0.223)		-0.536 (0.420)	-0.340 (0.425)
Kero. Price		-2.015*** (0.347)	-1.090*** (0.355)		-1.649** (0.682)	-0.554 (0.666)
Elec. Price		-0.734 (0.540)	-0.419 (0.673)		-1.625* (0.944)	-1.750 (1.144)
Age		-0.007* (0.004)	-0.015*** (0.004)		-0.001 (0.008)	-0.006 (0.008)
HH size		-0.405*** (0.101)	-0.198* (0.107)		0.364** (0.177)	0.588*** (0.190)
Homeowner		-0.937*** (0.113)	-0.720*** (0.119)		-0.428* (0.222)	-0.182 (0.228)
Basic Education		0.640*** (0.163)	0.220 (0.172)		1.160** (0.591)	0.815 (0.598)
Secondary Edu		0.839*** (0.177)	0.574*** (0.188)		2.011*** (0.575)	1.806*** (0.583)
Tertiary Edu		1.000*** (0.193)	0.764*** (0.201)		2.910*** (0.563)	2.713*** (0.569)
Electricity		1.228*** (0.132)	1.273*** (0.139)		1.302*** (0.351)	1.288*** (0.357)
Urban		1.690*** (0.110)	1.268*** (0.122)		1.335*** (0.214)	0.869*** (0.229)
Forest Cover		0.024 (0.052)	-0.500*** (0.085)		0.045 (0.094)	-0.539*** (0.117)
Geopo. zone	No	No	Yes	No	No	Yes
Constant	-1.267*** (0.042)	-1.410 (2.784)	-4.467 (3.228)	-2.941*** (0.088)	-19.827*** (4.996)	-22.975*** (5.446)
N	4000	3974	3974	4000	3974	3974
Psuedo R2	0.006	0.401	0.438	0.006	0.401	0.438

Robust standard errors in parentheses \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 8: Multinomial Logit Regression Results (Relative Education)

Base category: Firewood						
	Kerosene			Electricity		
	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)
Rel. Educ	0.127** (0.063)	0.045 (0.087)	0.075 (0.091)	-0.082 (0.146)	0.016 (0.182)	0.048 (0.189)
Income		1.030*** (0.142)	1.086*** (0.154)		2.284*** (0.217)	2.339*** (0.232)
Kero. Price		-1.526*** (0.458)	-0.750 (0.471)		-2.083** (0.865)	-0.743 (0.900)
Elec. Price		-0.856 (0.720)	-0.611 (0.910)		-1.864 (1.143)	-1.835 (1.431)
Age		-0.015** (0.006)	-0.020*** (0.007)		-0.006 (0.011)	-0.011 (0.011)
HH size		-0.563*** (0.177)	-0.177 (0.192)		0.352 (0.284)	0.806** (0.316)
Homeowner		-1.046*** (0.152)	-0.791*** (0.161)		-0.511* (0.266)	-0.205 (0.275)
Basic Edu		-0.178 (0.210)	-0.409* (0.224)		-1.316*** (0.403)	-1.529*** (0.412)
Secondary Edu		-0.215 (0.181)	-0.232 (0.190)		-0.903*** (0.282)	-0.946*** (0.291)
Electricity		1.295*** (0.191)	1.293*** (0.200)		1.215*** (0.422)	1.169*** (0.430)
Urban		1.790*** (0.149)	1.260*** (0.170)		1.502*** (0.259)	0.980*** (0.282)
Forest Cover		0.106 (0.069)	-0.454*** (0.118)		0.136 (0.113)	-0.501*** (0.149)
Geopo. zone	No	No	Yes	No	No	Yes
Constant	-0.894*** (0.085)	-1.289 (3.566)	-4.354 (4.273)	-2.216*** (0.173)	-13.222** (5.926)	-18.397*** (6.653)
N	1780	1763	1763	1780	1763	1763
Pseudo R2	0.002	0.354	0.395	0.002	0.354	0.395

Robust standard errors in parentheses \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 9: Multinomial Logit Regression Results (Relative Age)

Base category: Firewood						
	Kerosene			Electricity		
	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)
Rel. Age	5.952*** (0.484)	2.800*** (0.616)	1.743*** (0.639)	6.271*** (0.975)	3.287*** (1.130)	2.143* (1.143)
Income		0.950*** (0.128)	0.939*** (0.137)		2.303*** (0.205)	2.338*** (0.220)
Kero. Price		-1.494*** (0.394)	-0.776* (0.401)		-1.181 (0.757)	-0.104 (0.768)
Elec. Price		-1.028 (0.650)	-0.519 (0.815)		-2.005* (1.092)	-2.118 (1.330)
HH size		-0.377** (0.149)	-0.051 (0.160)		0.464* (0.260)	0.828*** (0.280)
Homeowner		-0.975*** (0.133)	-0.792*** (0.141)		-0.569** (0.241)	-0.339 (0.248)
Basic Edu		0.941*** (0.237)	0.475* (0.250)		1.066 (0.793)	0.651 (0.798)
Secondary Edu		1.155*** (0.233)	0.918*** (0.246)		1.694** (0.763)	1.457* (0.767)
Tertiary Edu		1.230*** (0.253)	1.028*** (0.263)		2.678*** (0.752)	2.476*** (0.756)
Electricity		1.371*** (0.168)	1.374*** (0.178)		1.143*** (0.391)	1.056*** (0.399)
Urban		1.802*** (0.133)	1.393*** (0.150)		1.508*** (0.245)	1.097*** (0.263)
Forest Cover		0.092 (0.061)	-0.428*** (0.103)		0.147 (0.110)	-0.436*** (0.137)
Geopo. zone	No	No	Yes	No	No	Yes
Constant	-6.103*** (0.398)	-4.592 (3.233)	-6.761* (3.755)	-7.959*** (0.813)	-23.636*** (5.661)	-25.833*** (6.180)
N	3087	3065	3065	3087	3065	3065
Pseudo R2	0.053	0.427	0.463	0.053	0.427	0.463

Robust standard errors in parentheses \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 10: Average Marginal Effects from Multinomial Logit for Cooking Fuel (Relative Education)

	Firewood			Kerosene			Electricity		
	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
Rel. Educ	-0.021 (0.014)	-0.005 (0.011)	-0.008 (0.010)	0.028*** (0.013)	0.006 (0.011)	0.008 (0.011)	-0.007 (0.009)	-0.001 (0.008)	-0.000 (0.008)
Income		-0.152*** (0.016)	-0.145*** (0.015)		0.072*** (0.016)	0.068*** (0.017)		0.079*** (0.009)	0.077*** (0.009)
Kero. Price		0.201*** (0.055)	0.085* (0.052)		-0.146** (0.060)	-0.073 (0.059)		-0.055 (0.040)	-0.012 (0.041)
Elec. Price		0.125 (0.087)	0.090 (0.101)		-0.061 (0.090)	-0.022 (0.105)		-0.064 (0.050)	-0.068 (0.061)
Age		0.002** (0.001)	0.002*** (0.001)		-0.002** (0.001)	-0.002*** (0.001)		0.000 (0.000)	0.000 (0.000)
HH size		0.053** (0.021)	0.004 (0.021)		-0.087*** (0.022)	-0.047** (0.023)		0.034*** (0.013)	0.043*** (0.014)
Homeowner		0.121*** (0.018)	0.080*** (0.018)		-0.127*** (0.018)	-0.095*** (0.018)		0.006 (0.011)	0.015 (0.012)
Basic Edu		0.043* (0.025)	0.065*** (0.025)		0.015 (0.027)	-0.006 (0.027)		-0.058*** (0.019)	-0.060*** (0.018)
Secondary Edu		0.039* (0.022)	0.038* (0.021)		-0.002 (0.023)	-0.001 (0.022)		-0.037*** (0.012)	-0.037*** (0.012)
Electricity		-0.160*** (0.022)	-0.145*** (0.021)		0.140*** (0.026)	0.130*** (0.026)		0.020 (0.020)	0.016 (0.020)
Urban		-0.218*** (0.015)	-0.139*** (0.017)		0.199*** (0.017)	0.131*** (0.019)		0.019* (0.011)	0.008 (0.012)
Forest Cover		-0.014 (0.008)	0.053*** (0.013)		0.010 (0.008)	-0.043*** (0.012)		0.003 (0.005)	-0.010* (0.005)
Geopo. zone	NO	NO	YES	NO	NO	YES	NO	NO	YES
N	1780	1763	1763	1780	1763	1763	1780	1763	1763

Robust standard errors in parentheses \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 11: Average Marginal Effects from Multinomial Logit for Cooking Fuel (Relative Age)

	Firewood			Kerosene			Electricity		
	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
Rel. Age	-1.010*** (0.071)	-0.254*** (0.052)	-0.146*** (0.050)	0.830*** (0.068)	0.207*** (0.055)	0.115** (0.054)	0.181** (0.037)	0.047 (0.032)	0.031 (0.032)
Income		-0.100*** (0.010)	-0.092*** (0.010)		0.049*** (0.011)	0.040*** (0.011)		0.051*** (0.005)	0.051*** (0.006)
Kero. Price		0.129*** (0.033)	0.056* (0.031)		-0.120*** (0.036)	-0.067* (0.035)		-0.008 (0.022)	0.011 (0.022)
Elec. Price		0.103* (0.056)	0.060 (0.065)		-0.062 (0.057)	-0.007 (0.066)		-0.041 (0.030)	-0.052 (0.035)
HH size		0.024* (0.013)	-0.005 (0.013)		-0.044*** (0.013)	-0.020 (0.013)		0.020*** (0.007)	0.025*** (0.008)
Homeowner		0.082*** (0.011)	0.059*** (0.011)		-0.082*** (0.011)	-0.064*** (0.011)		0.001 (0.006)	0.005 (0.007)
Basic Edu		-0.085*** (0.021)	-0.041** (0.021)		0.070*** (0.025)	0.030 (0.025)		0.015 (0.023)	0.010 (0.023)
Secondary Edu		-0.109*** (0.021)	-0.081*** (0.020)		0.079*** (0.024)	0.055** (0.024)		0.030 (0.023)	0.026 (0.022)
Tertiary Edu		-0.126*** (0.022)	-0.099*** (0.021)		0.069*** (0.026)	0.046* (0.025)		0.057*** (0.022)	0.053** (0.022)
Electricity		-0.119*** (0.014)	-0.108*** (0.013)		0.109*** (0.016)	0.103*** (0.016)		0.009 (0.011)	0.006 (0.011)
Urban		-0.156*** (0.010)	-0.110*** (0.011)		0.144*** (0.011)	0.104*** (0.012)		0.013* (0.006)	0.007 (0.007)
Forest Cover		-0.009* (0.005)	0.035*** (0.008)		0.006 (0.005)	-0.030*** (0.008)		0.003 (0.003)	-0.005 (0.003)
Geopo. zone			0.129***			-0.115***			-0.014
N	3087	3065	3065	3087	3065	3065	3087	3065	3065

Robust standard errors in parentheses \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 12: Log Linear Regression on Households with Positive Kerosene and Electricity Expenditure (Relative Education)

	Kerosene Expenditure			Electricity Expenditure		
	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)
Relative Education	0.047** (0.023)	0.008 (0.023)	0.000 (0.023)	0.052** (0.026)	0.034 (0.024)	0.044* (0.025)
Income	0.798*** (0.041)	0.569*** (0.045)	0.538*** (0.047)	0.732*** (0.037)	0.466*** (0.042)	0.473*** (0.044)
Kero. Price	-0.908*** (0.145)	-0.610*** (0.145)	-0.345** (0.146)	0.101 (0.132)	0.186 (0.120)	0.263** (0.128)
Elec. Price	-0.206 (0.209)	0.166 (0.202)	0.071 (0.214)	-0.226 (0.241)	0.077 (0.233)	-0.084 (0.251)
Age		0.002 (0.002)	-0.001 (0.002)		0.003 (0.002)	0.003 (0.002)
HH size		-0.606*** (0.050)	-0.543*** (0.053)		-0.581*** (0.058)	-0.528*** (0.062)
Homeowner		-0.146*** (0.047)	-0.108** (0.046)		0.109** (0.051)	0.140*** (0.051)
Basic Education		0.038 (0.053)	-0.036 (0.051)		0.021 (0.063)	0.014 (0.062)
Tertiary Education		-0.018 (0.051)	0.002 (0.050)		0.191*** (0.057)	0.176*** (0.057)
Electricity		0.125*** (0.048)	0.107** (0.048)		0.029 (0.086)	0.036 (0.085)
Urban		0.223*** (0.043)	0.224*** (0.046)		0.344*** (0.051)	0.284*** (0.054)
Geopo. Zone	NO	NO	YES	NO	NO	YES
Constant	3.436*** (1.038)	4.103*** (1.041)	3.495*** (1.076)	-0.578 (1.016)	1.577 (1.004)	1.662 (1.142)
R squared	0.347	0.442	0.469	0.268	0.361	0.369
N	1351	1351	1351	1133	1133	1133

Robust standard errors in parentheses \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 13: Log Linear Regression on Households with Positive Kerosene and Electricity Expenditure (Relative Age)

	Kerosene Expenditure			Electricity Expenditure		
	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)
Relative Age	1.156*** (0.163)	0.649*** (0.151)	0.346** (0.146)	0.811*** (0.190)	0.476** (0.189)	0.342* (0.200)
Income	0.912*** (0.033)	0.622*** (0.037)	0.581*** (0.038)	0.715*** (0.034)	0.461*** (0.038)	0.455*** (0.040)
Kero. Price	-0.812*** (0.100)	-0.472*** (0.102)	-0.212** (0.102)	0.077 (0.099)	0.152 (0.094)	0.151 (0.096)
Elec. Price	0.100 (0.179)	0.255 (0.169)	0.117 (0.185)	-0.316 (0.206)	-0.131 (0.201)	-0.344 (0.219)
HH size		-0.530*** (0.040)	-0.454*** (0.041)		-0.547*** (0.050)	-0.523*** (0.052)
Homeowner		-0.138*** (0.040)	-0.092** (0.039)		0.182*** (0.044)	0.204*** (0.043)
Basic Education		0.332*** (0.049)	0.139*** (0.049)		-0.024 (0.068)	-0.060 (0.067)
Secondary Educ		0.316*** (0.052)	0.210*** (0.051)		-0.080 (0.065)	-0.111* (0.064)
Tertiary Education		0.282*** (0.058)	0.198*** (0.057)		0.107 (0.070)	0.066 (0.069)
Electricity		0.084** (0.040)	0.054 (0.039)		-0.036 (0.077)	-0.030 (0.077)
Urban		0.272*** (0.037)	0.275*** (0.039)		0.375*** (0.042)	0.339*** (0.044)
Geopo. Zone	NO	NO	YES	NO	NO	YES
Constant	-0.489 (0.877)	1.499* (0.827)	1.465* (0.836)	-0.515 (0.867)	2.379*** (0.870)	3.372*** (0.983)
R squared	0.430	0.517	0.553	0.275	0.369	0.378
N	1999	1999	1999	1525	1525	1525

Robust standard errors in parentheses \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 14: Multicollinearity diagnostics

Variable	VIF	1/VIF
Female	1.31	0.762923
Income	2.25	0.443885
Kerosene price	1.24	0.804818
Electricity Price	1.61	0.621791
Age	1.28	0.781758
Household size	1.9	0.527692
Homeowner	1.37	0.732305
Basic Education	1.64	0.611518
Secondary Education	1.7	0.588969
Tertiary Education	1.77	0.565017
Electricity Price	1.58	0.63357
Urban	1.53	0.654528
North Central	2.57	0.389738
North West	2.56	0.390835
North East	2.32	0.430177
South South	2.24	0.446791
South East	2.14	0.468303
Mean VIF	1.82	



**Declaration to confirm that the dissertation  
has been produced independently:**

I hereby declare that I have produced my doctoral thesis "Welfare Effects of Environmental Policies and Household Energy Choice" independently and without external assistance, and that I have made a significant contribution as co-author to other scientific articles. I have identified all word-for-word quotations of other authors, as well as comments based closely on other authors' ideas, and I have cited the sources according to the guidelines I received.

Date

Signature