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TABLE OF CONTENTS

1. Introduction
2. Literature Review
3. Methodology
   a. Empirical Model
   b. Empirical Implication
   c. Data
   d. Data Summary Statistics
4. Estimation Results
   a. Factors Influencing Groundwater Use
   b. The Impact of Piped Water Price Changes
   c. Welfare Effects from Tariff Rebalancing
5. Conclusion and Policy Implications
6. References
7. Appendix

Water source choice and price regulation: the case of households in South Africa

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Summary:

The choice of water for use in residential households is usually always limited to either the more regulated piped water or less regulated groundwater sources such as boreholes or wellpoints. Many households find it beneficial to secure access and consumption by investing in the less regulated groundwater sources, consequently, putting the groundwater resource at risk of excessive extraction. This paper contributes to the small existing literature on the substitution or complementary threshold of piped and groundwater in developing countries. Our analysis explicitly considers groundwater as an unregulated substitute for piped water. We use a simple utility maximization model that yields both a water-type choice model and a demand specification whose parameterization allows examining households' responses to regulated price changes. For our estimation we employ the five waves of the South African National Income Dynamics Study (NIDS) datasets and the water tariff publications of each of the country's nine provinces. Our analysis shows empirical evidence in favour of certain determinants of households' choice of water type. Specifically, ownership of dwellings, large household size, participation in agricultural activities, ownership of vehicle, and number of rooms within household dwellings are factors that explain the reason for high groundwater usage share. Our estimation also shows evidence for the increased household choice of piped water when a counterfactual price rebalancing strategy that influences the fixed charge and variable volumetric charge does exist. Furthermore, we provide insights on the potential effect of the piped water rebalancing strategy on welfare changes.

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Abstract

The choice of water for use in residential households is usually always limited to either the more regulated piped water or less regulated groundwater sources such as boreholes or wellpoints. Many households find it beneficial to secure access and consumption by investing in the less regulated groundwater sources, consequently, putting the groundwater resource at risk of excessive extraction. This paper contributes to the small existing literature on the substitution or complementary threshold of piped and groundwater in developing countries. Our analysis explicitly considers groundwater as an unregulated substitute for piped water. We use a simple utility maximization model that yields both a water-type choice model and a demand specification whose parameterization allows examining households' responses to regulated price changes. For our estimation we employ the five waves of the South African National Income Dynamics Study (NIDS) datasets and the water tariff publications of each of the country's nine provinces. Our analysis shows empirical evidence in favour of certain determinants of households' choice of water type. Specifically, ownership of dwellings, large household size, participation in agricultural activities, ownership of vehicle, and number of rooms within household dwellings are factors that explain the reason for high groundwater usage share. Our estimation also shows evidence for the increased household choice of piped water when a counterfactual price rebalancing strategy that influences the fixed charge and variable volumetric charge does exist. Furthermore, we provide insights on the potential effect of the piped water rebalancing strategy on welfare changes.

Keywords: Piped water, groundwater, residential water demand, utility maximization model, South Africa

JEL codes: Q21; O54; Q 25; L 95; R22

1. Introduction

Water is fast becoming a scarce and expensive good in many parts of the world. Due to its value and relevance for (human) life and economic development, it is a resource that should be positioned in

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the centre of public and private interest. However, the availability of water resources to residential households is limited by climate change, population growth, the strategies of regulatory water agencies, and changes in lifestyles and eating habits of consumers (Lange & Hassan, 2006; UNESCO, 2009). Despite many improvements in efficiency recorded in the water industry, provision and services still lag far behind the per capita demand because many countries are poorly equipped to anticipate and adapt to the economic consequences of water scarcity.

Typically, there are two types of policy responses to the water scarcity problem. One is supply-oriented and focuses on the exploitation of new resources and expansion of the network infrastructure. This policy response has been traditionally followed in water resource management. However, the expensive infrastructures needed to meet demand have placed cost recovery at the fore for water utilities. And this has led to a call for setting cost recovery policies that invariably increase tariff in order for water supply to cover the full cost of service provision in the short-term, as well as the long-run marginal costs (LRMC) of supply (Dinar et al., 2015; Olmstead & Stavins, 2009; Sibly, 2006). Hence, when supply-oriented policies are not carefully implemented, they could impact consumers' demand and welfare and result in reduced piped water subscription, tariff default, or even high levels of investment in less regulated alternatives. The second policy approach is demand-oriented, and it is increasingly viewed as a necessary complement to, or even substitute for, the supply-oriented measure. This is because demand-driven solutions attempt to understand and influence the determinants of demand and ensure resource sustainability (Dolan et al., 2021; Mancosu et al., 2015; Mu et al., 1990). In this study, we will focus on presenting demand-oriented solutions that can be implemented alongside the more common supply management measures to respond to the water scarcity problem effectively.

In the case of residential households, sources of water for use are usually limited to either the heavily regulated piped supply from water utilities or the less regulated groundwater sources such as boreholes or wellpoints (or both). However, given the scarcity and market imperfection that characterizes the water industry and the nature of water as a commodity, many households find it beneficial to secure water consumption by investing in the less regulated groundwater sources. For instance, recent studies by Rinaudo et al. (2015), Simpson et. al. (2020), and Ziervogel (2019) have shown that higher intensity of drought and drastic changes in piped water prices has led to reduced piped water subscriptions on the part of water users and a subsequent increase in groundwater infrastructure investment. The development of domestic groundwater self-supply as a substitute for public water supply has occurred in very different institutional, economic, and climatic contexts. In most countries it is considered a source of problems (e.g. France, Belgium, India and South Africa), because increased demand can involve serious negative externalities and put groundwater at the risk of exploitation and acute aquifer depletion (McDonald *et al*., 2014; Montginoul & Rinaudo, 2011; Rinaudo et al., 2015). The risk of groundwater contamination is also increased in areas characterized by high borehole and well-point density. Because these private infrastructures often connect previously distinct hydrogeological layers and become multiple contamination vectors for groundwater resources. The development of private groundwater sources also increases total water abstraction, as households having free access to cheap groundwater will use more than when they entirely rely on municipal supply. Therefore, understanding the effect of water pricing structures and regulations on the substitution threshold of piped water and groundwater is essential for a better planning of water supply systems. However, the investigation of such effect remains scant.

The overall consensus from literature is that the current situation is non-sustainable in many countries and regions. This present paper contributes to the still short literature on residential water demand in developing countries by investigating the effect of water tariffs and other factors on the choice of water source. We look at how changes in the piped water price would affect investment in alternative groundwater supply sources (boreholes and wellpoints) in the residential sector. Using household data from South Africa, we examine how the pricing structure and many different households' socio-economic characteristics would influence the choice of water source. Our model specification allows for the understanding of measures to reduce and manage the extraction of the groundwater resources while simultaneously increasing piped water subscription and access.

South Africa's population is highly urbanized, with more than 50% living in urban centres. Despite being considered a water-scarce country, the national average water consumption is 235l/c/d (litres per capita per day), which is far above the world average of 185 l/c/d (Mckenzie et al., 2012; Wilkinson et al., 2018). Recently, the Eastern Cape, one of the nine Provinces of the country, was declared a drought disaster region due to the impact of excessive drought. In the Western Cape province, despite the government's efforts to maintain a well-functioning piped water system, a significant proportion of Cape Town's four million residents have secured their consumption capacity and buffered against the piped water tariff structure through unrestrained drilling of boreholes and wellpoints (Simpson et al., 2019). The total nationally accessible groundwater potential is about 4,500 million m^3/a (cubic metres per annum), of which between 2,000 and 3,000 million m^3/a is being utilized (DWS, 2019).

The Residential water tariff structure is made up of both a volumetric charge and fixed basic delivery charge. The tariff rate is estimated based on the availability of water, quality of water and the distribution distance. In Cape Town, residential water tariff rate varies from 12.85R/kl to 39.39R/kl (Rand per kilolitre),[2] while in eThekkwini municipality the rate ranges from 18.63R/kl to 49.73R/kl, and in Johannesburg it could range between 8.28R/kl to 45.19R/kl (GreenCape, 2019). Luker & Harris (2019) and Seyler et al. (2019) report that the recurrence of drought and constant change in the water tariff structure has influenced households' risk diversification strategy on a national level and induced increased investment in groundwater infrastructures.

In this paper, we use a simple utility maximization model that yields both a water-source choice and a demand specification whose parameterization allows examining water choice predictors and households' responses to regulated price changes. First, we investigate determinants of households' decision to use piped and groundwater supply. Second, we determine the distributional impact of a counterfactual price rebalancing scenarios that influence the fixed charge and variable volumetric charge of piped water users. Third, we estimate the elasticities of both piped water and groundwater demand. Lastly, this paper also provides policy implications for the better planning of residential water supply systems.

From here on the paper is structured as follows: The next section (2) delivers an overview review of the existing literature. Section 3 presents the empirical model and describes the employed data. The section also defines the central variables of the study. Section 4 outlines the estimation approach and reports the results for our main regressions. Section 5 summarizes the main results and concludes with some policy implications.

2. Literature Review

One of the earliest studies on the choice of water supply source is Briscoe, Chakraborty & Ahmed (1981), which examines the factors that influence the choice of drinking water source for a sample of about 150 families in a rural village in Bangladesh. They point out that water quality is an important

[2] Exchange rate is R14.43 to 1USD

determinant of the choice of the drinking water source. Since then, the role of environmental policy in water demand and choice of water source has been widely studied in the economic literature (Arbués et al., 2003, 2010; Bontemps & Couture, 2002; Dandy et al., 1997; Expósito, 2018; Li et al., 2021; Nieswiadomy, 1992; Romano et al., 2014; Schleich & Hillenbrand, 2009; Schoengold et al., 2006). Existing studies range from the agricultural (Huang et al., 2017; Kanazawa, 1992; Paudel et al., 2016; Sunding, 2005), to the industrial (Angulo et al., 2014; Gracia-de-Rentería et al., 2021; Gracia-de-Rentería & Barberán, 2021; Renzetti, 1992; Rooy, 1974; Worthington, 2010) and residential sectors (Acuña et al., 2020; Coulibaly et al., 2014a; Gaudin, 2006; Gebremichael et al., 2021; Grafton et al., 2011; Keshavarzi et al., 2006; Totouom & Fondo, 2012).

In high-income countries, it is typical for all or nearly all household water needs to be supplied by a single source: high-quality municipal piped water, occasionally supplemented with bottled water. In contrast, in low- and middle-income countries, households often use varying sources to meet their water needs, with choice of sources influenced by the unreliability of piped-water supply, household activities, government regulations, and socioeconomic factors (Elliott et al., 2017; Foster & Hope, 2017; Tucker et al., 2014). For instance, Thompson et al. (2016) report on changes in the residential water supply choice in nine East African urban centres over ten years. The authors show that in many cases, households rely on secondary and tertiary water sources to cater for short and longer-term shortages and the intermittent failure of their primary piped systems. Their findings confirm that groundwater facilities such as wells and boreholes are used by slightly more than 32 percent of all households as their alternative source in cases of piped supply failure. Devoto et al. (2012) study the impact of granting households in Morocco the option to purchase piped water on credit. Data collected from 845 households were used in a randomized experimental design. The results show that households' willingness to pay for piped water is high when it can be purchased on credit.

Mu, Whittington & Briscoe (1990) used a multinomial logit model to analyse the choice of a water source for a sample of 69 households in Kenya. Households in the sample choose among three types of drinking water sources (vendor, well, and kiosk), which differ by travel time spent to access them, price, and taste. They found travel time and price to be the significant determinants of choices of water sources. Other studies include Madanat & Humplick, (1993) in Pakistan, Asthana (1997) in rural India and Persson (2002) in the Philippines, who all used the conditional logit model to examine household's choice of water source. These studies report that the time it costs to access water and the quality and price of piped water are strong determinants of a household's choice of supply sources. Some other studies also examined the importance of time used in water collection in influencing decisions of drinking water sources selection. Nankhuni & Findeis (2004) investigate the effect of the time spent in water collection on households' livelihood in Malawi. The study reports that having piped water access at home (that is, tap water) significantly reduces the time spent in water collection. They also report that having access to piped water is positively associated with the likelihood of children attending school.

In a more recent study, Boone, Glick & Sahn (2011) estimate a discrete choice model of household water supply choice. The study points out strong substitution effects between various water supply sources. For instance, they show that increasing the distance to a public tap by 1 km increases the probability of using a wellpoint by 43 percent in urban areas. Table 1 further shows more studies on the factors that influence the choice of water source. Some studies highlight household behaviour and water end-use as determinants of the choice of water source. Usually, these studies highlight two types of activities based on place of dominant use: indoor and outdoor use (Brennan et al., 2007; Brent et al., 2015; Hussien et al., 2016; Kiesau, 2020; Manouseli et al., 2019; Mansur & Olmstead, 2012). They report that households with significant water need for outdoor activities demand more water than those whose water use is mainly limited indoor (Domene & Saurí, 2006; Hall et al., 1988; Syme et al., 2004). Also, such households are more likely to choose a less regulated water source such as groundwater as their water source (Cooley et al., 2019; Huang et al., 2017; Meyer & Jacobs, 2019).

Using data obtained from 552 households in the Zarqa governorate region in Jordan, Coulibaly et al. (2014) estimate a demand system for water from four different sources. The elasticity estimates from the study indicate that water demand for the piped water system is more price-elastic (−1.33) than most estimates found in the literature. For instance, in the review of water demand in developing countries conducted by Nauges & Whittington (2010), they showed that own-price elasticity estimates ranged from −0.3 to about −0.6. Basani et al. (2008) used cross-sectional household-level data from seven towns in Cambodian. They estimated the price elasticity of water demand of connected households to lie in a range between −0.4 and −0.5. Also, Nauges & Strand (2007) used household survey data from El Salvador and Honduras to estimate water demand of non-piped households in four cities. They found non-tap water demand elasticities with respect to total water cost (defined as the sum of water price and collection time costs) of between −0.4 and −0.7. The findings of Coulibaly et al. (2014) suggest that essential water sources are more price elastic than has been previously believed. The study concludes that the choice to use other alternative sources is impacted by the attributes of the public system such as reliability, colour, taste, odour, and other health-related factors. Only a few studies have shown elasticity estimates to be less than −1.0. Another of such study is by Rietveld et al. (2006), they estimated the price elasticity of water demand at -1.2 using data for connected households from Indonesia.

Table 1: More studies on factors that influence choice of Residential water source

Studies	Methodologies	Main factors that Influence choice of water source	Locations	Main findings
Nauges and van den Berg (2009)	Probit model	Distance and inefficient piped water network	Sri Lanka	Easy access to alternative water sources dampens the willingness to pay for improved piped water services.
Rauf et al., (2015)	Multinomial logit model	Family size and numbers of rooms	Punjab, Pakistan	Providing quality drinking water through a public arrangement in the form of tap water enhance household productivity
Persson (2002)	Discrete-choice approach	Time cost and water quality	Cebu, Philippines	Households' knowledge of water quality from different sources is an important determinant of choice of water.
Huang et al., (2015)	Risk Exposure Assessment	Health implication	Chenzhou City, China	Households making safer water choices were correlated with household income level, family size, the household income mainly being used for food, and food supply source.
Cheesman et al. (2008)	Demand system estimation and Probit Model	Water storage and supply infrastructure, and socioeconomic attributes	Vietnam	households using municipal water exclusively have very price inelastic demand
Wagner et al. (2019)	Discrete-continuous demand model	Price, proximity and taste	Kenya	Own-price elasticities estimates range between − 0.13 and − 1.33
Amoah & Moffatt (2021)	the contingent valuation method (CVM) and the travel cost method (TCM)	Household income	Ghana	Willingness to pay for reliable piped water services: evidence from urban Ghana

Nunoo et al. (2017)	Tobit regression analysis	Travelling time	Ghana	compared to pipe in dwelling/yard/plot, all other sources of water to the households come with greater levels of water deficiency
Fotue and Sikod (2012)	Multinomial logistic regression model	Distance, household size and expenditure.	Cameroon	Consideration must be given to households' time allocation patterns since they seem to be more concerned with the distance to the source than the type of water source.
Elliott et al., (2019)	Literature review	Health, water price and climate impact	Multiple locations	Understanding multiple water source use is essential for adequately designing research studies and water supply projects.

Almost all the prior studies suffer from a common limitation. They did not account for the potential influence of regulatory practices on the decision of households to select particular drinking water sources. This is despite the fact that regulatory policies are significant determinants of household decisions to consume from particular water sources, since they may act as incentives or constraints to drive institutional and behavioural changes. Another difference between previous studies and our paper is that we did not consider the influence of time used in water collection. The water sources (piped water and groundwater) we investigate in this study are located within household premises. Our model specification allows for measuring the performance characteristics of piped water and groundwater, the household-specific preferences for each water source, and the difference between the prices of piped water and groundwater sources. Thus, the model presented in this paper advances the water demand literature well beyond the single-equation model often used in developed countries (e.g., Dalhuisen et al., 2003 and Olmstead et al., 2007). This study will also contribute to the very limited literature on the impact of pricing structures on household water supply choice by estimating water-type choice and demand models using microdata gathered from household expenditure surveys.

3. Methodology

3.1 Empirical Model

This study presents a simple model for examining the impact of price changes in the market for piped residential water given the availability of a substitute source of tap (piped) water, namely groundwater (boreholes and wellpoints). Households' decision to drill can be analysed from a utilitarian perspective, assuming they seek to maximize the benefit they derive from water use. Self-supply can be a strategy to maximise utility, in particular where the performance of public schemes is mediocre. This paper builds on Deaton & Muellbauer (1980) and Casarin (2014) by constructing a utility-maximizing model of demand for two water types. We start by assuming that the heterogeneous population of water consumers in South Africa consists of a number of households i (with income y_i) who are served by piped (tap) water. Households are also able to choose which type of water to use, that is, they can choose to connect to the piped water from the municipality, or they can choose not to connect to it but rather invest in groundwater infrastructure for private water access, provided they are both of similar quality. This investment in groundwater is materialized by the drilling of groundwater supply infrastructures within the premises. We assume that households maximize utility according to:

$$U_i = \{\alpha(q_{pw} - \lambda_x) + \sigma(q_{gw} - \lambda_x)\}^{\beta} \cdot (q_b - \lambda_b)^{(1-\beta)} \qquad (1)$$

where q_{pw} is the consumed quantity of piped water, q_{gw} is the consumed quantity of groundwater, q_b is the quantity of a (Hicksian) composite commodity consisting of all other goods but water. λ_x and λ_b are the levels of committed consumption for each commodity group (water and the composite commodity). This is the share of household's committed expenditure on each commodity, the expenditure on water is expected to differ seasonally. α and σ are specifications of piped and groundwater respectively, while β is a parameter to be estimated, with $q_m > \lambda_n$ when households only purchase necessary quantities of the various goods $(\lambda_1, \ldots, \lambda_n)$ and q_m is the quantity of good m $(q_m = q_{pw}, q_{gw}, q_b)$ while $0 \leq \beta_m \leq 1$ and the restriction $\sum_m \beta_m = 1$ holds. The parameter β_m is referred to as the marginal budget share. The standard assumption of this study is that consumers (i.e: households) have rational expectations about their usage of various water sources and choose the utility-maximizing option. This means that consumers maximize equation (1) subject to a budget constraint defined as follows in Equation (2) below:

$$y_i - F = q_{pw}c_{pw} + q_{gw}c_{pw} + q_b c_b \qquad (2)$$

Where c_{pw} and c_{gw} are the costs paid by households to access piped water and the cost of groundwater collection respectively. c_{gw} varies depending on the type of groundwater infrastructure the household drills (borehole or wellpoint). c_b is the cost component households pay to purchase the composite good and F is a fixed fee charged, also called basic charge or connection charge by the water utility, which is associated with the consumption of piped water in a two-part tariff system. Fixed fees have a potential impact on choice when consumers face discrete choices among substitutable alternatives such as piped water and groundwater (Balac *et al.,* 2019; Train, Ben-Akiva, & Atherton, 1989). Our model further assumes risk neutrality on the part of consumers with respect to water expenditure. This implies that consumers are therefore locally risk neutral in income over the small amounts of money expensed on water. The marginal utility of income is assumed to be constant and we specify utility net of fixed payments, which then affects consumer surplus similarly to an income effect (Miravete, 2002). The utility function in equation (1) is consistent with additive separability and implies two-stage budgeting. The utility function also assumes that households' preferences are separable in the consumption of the two water types.

We follow Deaton & Muellbauer (1980) and Casarin (2014) by initially assuming that a household can't consume both water types simultaneously if the ratio of water specifications α/σ differs from the ratio c_{gw}/c_{pw}. This assumption is further relaxed to account for situations where households could combine the usage of both piped and underground water sources. Deaton & Muellbauer (1980) argue that it is not unreasonable to assume that, in this case, households will use some quantities of both water supply sources. However, utility theory cannot tell us how households choose the combination of both sources.

In the initial assumption, this means, household i will choose piped water rather than groundwater if the sub-utility of expenditure in piped water exceeds the sub-utility of expenditure in groundwater (i.e: $\alpha/c_{pw} - \sigma/c_{gw} > 0$). Following Deaton and Muellbauer (1980), Casarin (2014) and Stoneman and Battisti (2000), we suppose that α and σ can be written as $\log\alpha = \log(\mu_{pw}, V_{pw}) + \varepsilon_{pw}$ and $\log\sigma = \log(\mu_{gw}, V_{gw}) + \varepsilon_{gw}$ respectively, where μ is a vector of parameters, V_{pw} and V_{gw} are vectors of variables that capture the performance characteristics of the two water types and household preferences, and ε_{pw} and ε_{gw} are unobserved factors that may also affect the specification of α and σ. Taking logs of prices, piped water is chosen if:

$$\varepsilon_{pw} - \varepsilon_{gw} > \log(\mu_{gw}, V_{gw}) - \log(\mu_{pw}, V_{pw}) + \log(c_{pw}) - \log(c_{pw}) \quad (3)$$

We further assume that ε_{pw} and ε_{gw} are independently and identically distributed in accordance with the Weibull distribution. Domencich & McFadden (1975) show that if both ε_{pw} and ε_{gw} follow the Weibull distribution with parameters φ_{pw} and φ_{gw}, then the probability P_i that a randomly chosen household i will actually use piped water is given by:

$$P_i = C(\varepsilon_{pw} - \varepsilon_{gw} > d) = \frac{1}{1+e^{d}} \quad (4)$$

This is a logistic function with argument $d = \{log(V_{gw}) - \log(V_{pw}) + \log(c_{pw}) - \log(c_{gw})\}$. The choice specification in equation (4) thus predicts that the choice of water type depends through a logistic function on (i) the performance characteristics of piped water and groundwater, such as the relative ease of access to the supply source, supply interruption and quality (ii) the household preferences or taste for which water source to choose and (iii) the difference between the prices of piped water and groundwater sources. Our first solution to the choice problem indicates that the household will use either piped water or groundwater at any given point in time but not both simultaneously. This is true in many developing countries where most households either choose to connect or not connect to the centralized public water supply network, in the latter case, investment in a groundwater infrastructure is made within the household premises (Furlong & Kooy, 2017). Many households may generally not afford to invest in both water supply sources at once. They are prompted to secure their consumption through groundwater sources during a drought crisis and when there are inefficiencies in the piped water supply, thereby totally abandoning public piped water supply in some cases (Balac et al., 2019; Simpson et al., 2019; Srinivasan & Kulkarni, 2014). If the household chooses piped water, for example, then the utility function in equation (1) can be re-written as:

$$U_i = \{\alpha(q_{pw} - \lambda_x)\}^{\beta} \cdot (q_b - \lambda_b)^{(1-\beta)} \quad (5)$$

To ensure robustness in our analysis, we went further to determine solutions associated with situations where the ratio of water specifications α/σ is identical to the ratio c_{gw}/c_{pw}, this accounts for situations where groundwater is combined with piped water to fulfil water consumption within the households. In this case, we follow the two-good random utility model of Gentzkow (2007), where the households' conditional indirect utilities from the two water types are super-additive and both are gross complements. The utility a household derives from connecting to piped water is given as U_{pw} and U_{gw} is the utility derived from investment in groundwater supply source. Each utility accounts for the supply source's price; thus, for example, an increase in the price of piped water corresponds to a reduction in U_{pw} for every household. Following Berry *et al.* (2017) and Gentzkow (2007) we normalize the utility of our composite commodity (q_b) to zero (U_0) and present the utility from combining both piped water and groundwater as

$$U_{(pw|gw)} = U_{pw} + U_{gw} + \Gamma \qquad (6)$$

Where Γ is an interaction term[3] that indicates complementarity between the two water supply sources when $\Gamma > 0$. It is constant across households and measures how the added utility of piped water increases if groundwater is also used within the household.

The maximization of utility subject to the budget constraint gives an expenditure function for good m of the form:

$$c_m q_m = c_m \lambda_m + \beta_m \{(y_j - F) - \sum_m c_m \lambda_m\} \qquad (7)$$

The parameter β_m is referred to as the marginal budget share, $c_{pw}, c_{gw}, c_b = c_m$ and the utility function reduces to the Cobb-Douglas specification when λ_m= 0. If the λ_m's are all positive and income is greater than $\sum_m c_m \lambda_m$, then it is possible to describe the household as purchasing necessary quantities of the various goods $(\lambda_1, \dots, \lambda_n)$ and dividing its remaining or "supernumerary" income $\{(y_j - F) - \sum_m c_m \lambda_m\}$ across the goods in fixed proportions ($\beta_1, \dots, \beta_n$).

Under reasonable assumptions (i.e. as shown in equations (5) and (6)) the model introduced here predicts both a water type choice and a short-run demand specification that can be examined empirically. The implications of the expenditure function in equation (7) are that a household's water expenditures are independent of the water-type choice but are a function of the consumer's income and the elasticity of the utility function with respect to the quantity of water consumed (the marginal

[3] $\Gamma = \left(U'_{(pw|gw)} - U'_{gw}\right) - \left(U'_{pw} - U'_0\right)$ which is the discrete analogue of the cross-partial of utility. We can define eq. (15) when we normalize utility by U'_0

budget shares). The attractiveness of this approach lies in its ability to predict both specifications from a single utility-maximizing framework.

3.2 Empirical Implication

We derive the logit probabilities under the assumption that the unobserved portions of the decision criteria (ε_{pw} and ε_{gw}) follow a Weibull distribution, as with many literatures on binary choice. The argument d is defined by $V'\mu$, where V is a vector of independent variables affecting the choice decision (prices, water specifications and household preferences) and μ is a vector of parameters. Since the unobserved component is assumed to have zero mean (φ = 0), it follows from Equation (4) that the probability that household i will choose water alternative j can be written as $\frac{1}{1+e^{V\mu}}$. This paper uses the log of the likelihood function ($\log L$) written in equation (8) for its estimation:

$$\log L(\mu) = \sum_{i=1}^{I} \left\{\theta_i \log\left(\frac{1}{1+e^{-V\mu}}\right) + (1-\theta_i)\log\left[1-\left(\frac{1}{1+e^{-V\mu}}\right)\right]\right\} \quad (8)$$

Where θ_i is equal one if household i chooses alternative j and zero otherwise. The probability of household i choosing water type j is obtained by maximizing equation (8) with respect to the parameter vector μ. This maximization problem is solved using the method of maximum likelihood (Train, 1986).

As we conduct our analysis at the household level, we aggregate household-level information on the primary source of water by constructing a water-type variable. We create a dummy variable indicating whether a household uses groundwater or piped water. Recall from the previous section that specification (4) predicts that the choice of water type depends on both the performance characteristics of piped water and groundwater and the household preferences or lifestyle. We account for this by introducing control variables on the household level; we employ data on household size, number of rooms in the dwelling, household income, expenditure on other goods. As for household preference or lifestyle indicators, we create dummy variables indicating whether a household is involved in agriculture production, regularly eats red meat, owns the dwelling, lives in a formal settlement, or has at least one car.

We expect households' choice of groundwater to be positively related to the ownership of a house, family size, the number of rooms in the dwelling, presence of one or more vehicles in the household, household income level, regular consumption of red meat, and the location of household dwelling in formal settlements. We consider that decision to use groundwater source becomes likely if household participates in agricultural activities. We expect piped water usage to be positively related to regular tariff payments and higher amount of available monthly disposable income, i.e., expenditure on other goods. We also posit that the decision to use groundwater may be affected either positively or negatively by the age, level of education or the province (location) of a household.

Table 2: Variables definition for the choice problem

Variable	Description	Expected influence on groundwater use
Water factors		
Water price	The ratio of groundwater price to piped water price (P2/p1)	-
Pay for piped water	= 1, if household pays for piped water; = 0, otherwise	-
Household size	Total number of household members	+
Number of rooms	Number of rooms in the dwelling	+
Head Age	Age of household head	±
Owner	= 1, if household own the house; = 0, otherwise	+
Income	Monthly income of the household in ZAR	+
Expenditure on other goods	Monthly expenditure not including water cost in ZAR	-
Formal dwelling	= 1, if household dwells in a formal housing; = 0, if informal housing	+
Meat in Diet	= 1, if household diet constantly contains red meat; = 0, otherwise	+
Head education	= 1, if the household head has at least completed secondary school; = 0, otherwise	±
Involve in agriculture	= 1, if household is involved in agriculture; = 0, otherwise	+
Vehicle	= 1, if household own atleast a vehicle; = 0, otherwise	+
Location X[a]	=1, if household resides in province X; =0, otherwise	±

[a] The reference household is that of members located in the Western Cape

The household expenditure system consists of equations for water expenditures and expenditures on other goods. We model household expenditure on other goods in an aggregated form, less the monthly water expenses paid by households for water. Consuming groundwater imposes different types of "costs" on a household compared to using piped water. Collection may involve time to go to the source, to wait at the source (queuing), and time to haul the water back home. One may choose to convert collection time into collection costs using an assumed value of time. However, the value of time may differ widely across households depending on who is responsible for collecting water, and even within a specific household over time of day or day of week. Estimating an average value of time for such a study population would largely be guesswork (Nauges & Whittington, 2010). Many analysts thus do not attempt to convert the time cost of water collection into a pecuniary collection cost. In our sample, distance to source, need for hauling, and time factor are practical non-existent since we focused on households with groundwater within their premises. These households usually do not pay any costs for using groundwater, but they rely on electricity to pump groundwater. We, therefore, compute an opportunity cost of the monthly price of groundwater extracted by each household, which would correspond to the (monetary) value of the monthly pumping cost.

Our model also includes dummies for years that indicate when (the wave) the household was surveyed. We estimated the expenditure elasticity for piped water price, groundwater and other goods households spend their income using the quadratic almost ideal demand system (QUAIDS) to identify the demand pattern of these three goods (Poi, 2012). The QUAIDS allows for non-linear Engel curves by including a quadratic term for expenditure, which varies with prices. This specification implies that goods can be luxuries or necessities at different expenditure levels. The model is estimated for the total sample size and population weights (by provinces) are included in all estimations.

We consider a consumer's demand for a set of m goods (made up of piped water, groundwater and composite good) for which the household has budgeted y units of household income. The expenditure share equation for good g takes the form

$$w_g = \alpha_g + \sum_{j=1}^{m} \xi_{gj} lnp_j + (\beta_g + \eta_g' z) ln\left\{\frac{y}{\bar{y}_0(z)a(p)}\right\} + \frac{\lambda_m}{b(p)c(p,z)}\left[ln\left\{\frac{y}{\bar{y}_0(z)a(p)}\right\}\right]^2 \qquad (9)$$

Where $c(p,z) = \prod_{j=1}^{m} p_j^{\eta'_j z}$. We use z to represent a vector of s characteristics. For instance, z could be a scalar representing the number of people in a household. η_j represents the jth column of sxm parameter matrix η and $a(p)$ is the price index in the expenditure share equation. The adding-up condition requires that $\sum_{j=1}^{m} \eta_{rj} = 0$ for $r = 1, \ldots\ldots, s$. If we set $\lambda_g = 0$ for all g, we are left with the AIDS model with demographics used by (Ray, 1983). p_g is the price of good g for $g = 1, \ldots., m$ while $b(p)$ is the Cobb–Douglas price aggregator $b(p) = \prod_{g=1}^{m} p_g^{\beta_g}$ and $\lambda(p) = \sum_g^m \lambda_g ln p_g$.

The expenditure (income)elasticity for good i is then given has

$$\mu_g = 1 + \frac{1}{w_g}\left[\beta_g + \eta'_g z + \frac{2\lambda_g}{b(p)c(p,z)} ln\left\{\frac{y}{\bar{y}_0(z)a(p)}\right\}\right] \quad (10)$$

3.3 Data

3.3.1 Household Data

For our empirical analysis, we use the South Africa National Income Dynamics Study (NIDS). The NIDS is a panel dataset and is an initiative of the Department of Planning, Monitoring, and Evaluation (DPME) and is implemented by the Southern Africa Labour and Development Research Unit (SALDRU) based at the University of Cape Town's School of Economics. The survey started in 2008 (wave 1) with a nationally representative sample of over 28,000 individuals in 7,300 households across the country's nine (9) provinces. The core survey has been repeated with this household member every two to three years, with the latest interview round conducted in 2017 (wave 5). This paper used the whole panel dataset (waves 1 to 5) in its estimations.

The household data contains a wide range of information such as household demographics, education, access to basic amenities, health, employment, income and expenditures. This information is not only available at the household level, but the survey also contains information on the household-member level. Typically, each survey wave tracks the livelihoods of individuals over time and provides information about how households cope with shocks, including water scarcity, access, and use. The data allows us to differentiate between households whose only water source is piped water and those that use groundwater. In addition, the dataset is complemented by a large set of socioeconomic variables.

While the NIDS is nationally representative and comprehensive, it does not present information on alternative sources of water used by households when their primary water source becomes temporarily unavailable. Consequently, this limits our estimation to only households that use either piped water or groundwater, with no possibility of combining both[4]. Also, our dataset does not constitute a balanced panel due to the need to drop observations where households' primary water source change between waves from either piped water or groundwater to other sources such as public tap, rainwater, streams and springs. The data enables us to only focus our estimation on households that use either piped water, whether in the house or on-site, and those that use groundwater exclusively, even if the household appears in only one wave or all the five waves. The NIDS does not disclose the exact location of each sampled household; we therefore restrict our estimations to the province-level since a tariff schedule can be unequivocally linked to the households in each province. Our final sample size totals 28,619 observations.

3.3.2 Water Price Data

Recall also that specification (4) predicts that the choice of water type depends on the price difference between both water types. The piped water tariff data we employed in our subsequent empirical analysis comes from various sources, including the Department of Water & Sanitation (DWS), municipal reports, and provincial gazettes and publications. Most provinces have separate tariffs for residential, commercial, and industrial water users and may provide a free basic water allowance to indigent households (up to 6 kl per month). Water from the piped network is charged through an increasing four-block tariff, and all piped households have to pay a fixed basic delivery charge, whatever their monthly consumption. The first block has the lowest tariff rates and is usually between the use of zero and six kilolitres (0-6kl) of water in a given month. The second block is next with an increased tariff rate when household water consumption is between 6-10.5kl, then the third block from 10.5-35kl, and the last block have the highest rate when household consumption is above 35kl per month. We limit our estimation to the 2017/2018 average provincial water tariff rate based

[4] The South Africa General Household Survey (GHS) reports information on use of both water types as well as the combination of both, however the GHS is not a panel dataset. As we are interested in using panel data, we use the NIDS survey. Nevertheless, estimation done with the GHS is presented in Table A1 in the appendix section.

on the end-year of the most recent NIDS survey used in this study. Tariff data collected include both the published average volumetric charges and the fixed basic delivery charges for each province.

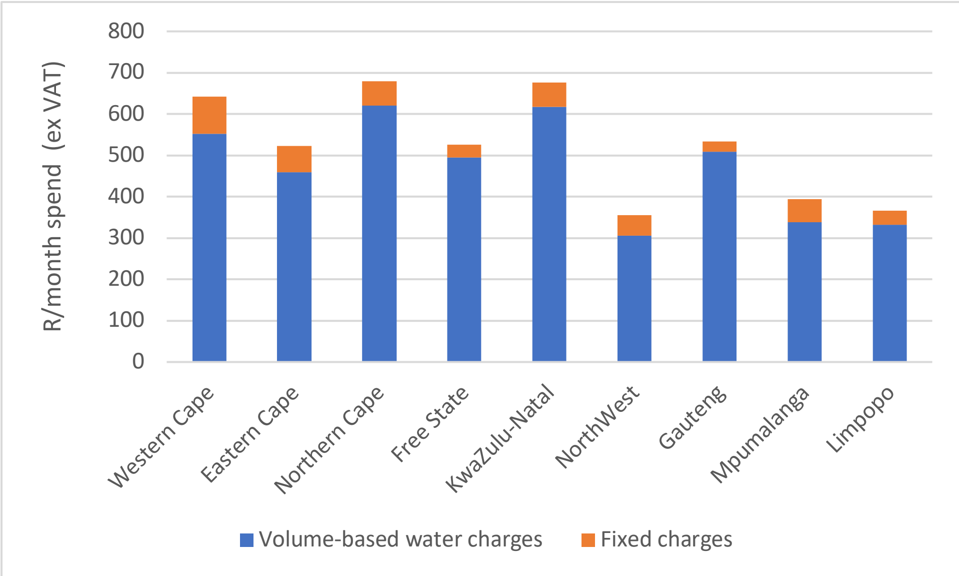

Figure 1: Comparison of average monthly household water costs for 28 kl/month in 2017/18 across various provinces

Costs borne by households collecting water from private groundwater sources have already been discussed (see Sect. 3.2). Households in our sample do not pay for the daily consumption of groundwater, whatever the source (borehole or wellpoint). However, households collecting water from these sources have to rely on electricity for pumping. In principle, in the absence of direct pricing of groundwater to internalize the open-access problem, correct pricing of electricity for pumping, in a situation where pumping costs are the only costs expended by households to withdraw groundwater, would imply an electricity provision cost. By following Banerji et al. (2006) and Strand (2010) we estimate a shadow price of groundwater based on the monthly household electricity usage. We believe that deriving the shadow price of groundwater from the monthly electricity cost for pumping could serve as the opportunity cost of extracted volume.

3.4 Data summary statistics

Our primary aim is to study determinants of households' decision to use piped and groundwater supply and the influence of piped water price on its use. The summary statistics of the households in our dataset are presented in Table 3. The sample size for total groundwater use is 1,909 observations. Kwazulu-natal has the highest number of households using groundwater as their primary water source, while Gauteng province shows the highest average monthly water tariff. Overall, about 40.3% of piped water users pay a monthly tariff, and the highest number of payments occurs in the Western Cape. Gauteng province has both the highest monthly household income and expenditure while Kwazulu-Natal has the least. The summary statistics report also shows that the Eastern Cape province has the highest frequency of house ownership even though the province has one of the lowest average monthly incomes. Kwazulu-Natal province has the highest number of representations in our sample size with 5,677 observations, while North-West province has the least representation with 1,796 observations. Western Cape has the highest red meat consumers while Limpopo has the highest number of households participating in agricultural production; we expect these to positively influence groundwater use in both provinces. Table 3 also shows that 8.6% of respondents live in informal housing units such as shacks, squatter settlements, tents, caravans, and farms.

Table 3: Mean values of the National Income Dynamics Study Wave 1 – 5 (2008 to 2017)

Variable	All Province	WC	EC	NC	FS	KZN	NW	GP	MP	LP
Groundwater use (sample size)	0.067 (1,909)	0.008 (33)	0.150 (416)	0.026 (62)	0.014 (33)	0.138 (783)	0.086 (154)	0.009 (43)	0.065 (143)	0.115 (242)
Monthly piped water tariff (ZAR)	252.286	242.274	221.905	247.018	208.497	242.470	239.005	332.570	244.507	200.175
Pay for piped water	0.403	0.565	0.391	0.476	0.392	0.300	0.356	0.430	0.372	0.306
Household size	3.943	3.837	3.807	4.094	3.737	4.666	3.909	3.144	3.911	4.382
Number of rooms	4.000	3.545	3.914	3.999	3.927	4.373	4.080	3.412	4.231	5.046
Head age	52.061	53.373	54.798	53.322	51.926	52.263	52.278	47.015	52.045	55.553
Owner	0.675	0.595	0.745	0.731	0.747	0.670	0.718	0.548	0.742	0.803
Monthly Income	7995.777	9924.620	6532.887	8435.500	6449.149	6153.920	6810.367	10442.31	8730.508	6716.475
Expenditure	5842.843	7281.43	4988.233	5647.588	4687.702	4390.939	4921.583	8135.97	5917.452	4815.420
Meat diet	0.538	0.663	0.565	0.564	0.429	0.540	0.448	0.537	0.506	0.448
Head education	1.866	1.998	1.809	1.776	1.843	1.639	1.827	2.223	1.811	1.669
Involve in agriculture	0.075	0.037	0.076	0.058	0.076	0.124	.040	0.025	0.073	0.190
Formal dwelling	0.914	0.907	0.960	0.906	0.873	0.961	0.904	0.857	0.879	0.981
Vehicle	0.219	0.316	0.162	0.234	0.183	0.145	0.228	0.268	0.227	0.190
Total Sample Size	28,619	4,331	2,781	2,383	2,403	5,677	1,796	4,923	2,213	2,112
Population[5]	56,521,900	6,510,300	6,498,700	1,214,000	2,866,700	11,074,800	3,856,200	14,278,700	4,444,200	5,778,400

WC= Western Cape, EC= Eastern Cape, NC = Northern Cape, FS= Free State, KZN = Kwazulu-Natal, NW= North-West, GP = Gauteng, MP = Mpumalanga, LP = Limpopo

[5] STATS SA. Statistics South Africa. Statistical Release P0302. Mid-Year Population Estimates for 2017.

4 Estimation Results

4.1 Factors influencing groundwater use

As the first step of our empirical analysis, we investigate determinants of households' choice of groundwater use. Our dependent variable is a dummy variable that takes the value of one if the water source is groundwater at a given wave and zero if otherwise (if the primary source of water is piped supply). As the left-hand variable is binary, Generalized Linear Models such as the Logit or the Probit model are typically applied to estimate the factors influencing the dependent variable. Since both models give similar results, we chose to evaluate a logit model because it provides a slightly better outcome for the panel dataset.

Our empirical model estimation employed a standard binary logistic model to investigate the likelihood of households choosing between the groundwater and piped water sources. This methodology is preferred as it enables us to evaluate the effect of households' characteristics on their choice of water source over a given period. In this case, a households' choice of groundwater is treated as 1, and piped water 0.

If we assume the log-odds of a household choosing to use groundwater source as $p = \mathrm{P}(q_{gw} = 1)$, given the worker's characteristics, then the standard logistic model can be specified as:

$$l = log_{б} \frac{P}{1-P} = \beta_0 + \beta_i Z_i \qquad (11)$$

Where б is the base of the logarithm and Z_i is vector of household's characteristics. The odds of using groundwater are recovered by expressing the log-odds in exponential form as follows:

$$\frac{P}{1-P} = б^{\beta_0 + \beta_i Z_i} \qquad (12)$$

We present the estimation results in Table 4. Most of the control variables in the regression are significantly different from zero and have the expected signs (except for price difference, dwelling type and regular meat consumption). We find that households that pay for piped water supply are less likely to invest in groundwater, which is significant at 1% significance level. However, the result in Table 4 suggests that groundwater infrastructures such as boreholes and wellpoints are permanent investments that are more likely to be adopted by households who own their houses. Also, participation in agriculture, presence of vehicle, large household sizes and houses with many rooms show statistical significance at 1%, and these variables positively influence households' choice of groundwater for their day-to-day use.

Contrary to expectation, households whose diet regularly include red meat show significantly negative effect, indicating that such households have more likelihood of using piped water supply. This variable is a similar variable for wealth and thus it is consistent with findings in previous work (Lutz et al., 1993; Zhang et al., 2018). The results of education level of the household head and the available expenditure on other goods also provide similar results about effect of wealth on the household on use of groundwater. The price difference variable did not show the expected sign and it is not significant at the 1%, 5% or 10% levels. Other demographic variables that are not statistically different from zero include age of household head and the income of the household. Our result also show that all the provinces are significantly different from zero and households high likelihood of investing in groundwater infrastructure except for households in Gauteng and Free State.

Table 4 Parameter estimates for determinants of water type choice.

Dependent variable: Groundwater Use		
Variables	Estimates	Standard Error
Water price difference	0.096	0.172
Pay for piped water	-1.499***	0.302
LogIncome	-0.075	0.072
Dwelling type	-0.475***	0.176
Log of Expenditure on other goods	-1.116***	0.087
Head Education	-0.454***	0.069
Involve in agriculture	0.924***	0.129
Vehicle	0.370**	0.159
Household Size	0.107***	0.018
Number of rooms	0.122***	0.021
LogAge	0.272	0.203
Meat Consumption	-0.240***	0.092
Owner	0.724***	0.124
Eastern Cape	4.373***	0.335
Northern Cape	1.268***	0.353
Free State	0.041	0.391
KwaZulu-Natal	3.792***	0.314
Northwest	3.258***	0.341
Gauteng	0.0945	0.355
Mpumalanga	2.380***	0.334
Limpopo	3.237***	0.333
Constant	1.097	0.969

Number of Obs:	28,619
Log likelihood	-5032.4226

Notes: The reference households are located in the Western Cape and Wave 1. ***, **, *, next to coefficients represents statistical significance at the 1%, 5%, and 10% respectively.

Due to the limitation of our panel dataset, we cannot examine the determinants of situations in which households use both piped and groundwater sources simultaneously. We compensate in a separate analysis using a 3-year cross-sectional dataset that accounts for where households can choose between the two water types or both at once. We report the estimation result in Table A1 in the appendix. The estimation of the determinants of the choice of groundwater sources using cross-sectional data essentially shows a consistent result with Table 4, where we used a panel dataset. However, ownership of a vehicle and large household size lost statistical significance. However, unlike Table 4, Table A1 shows that households that live in formal dwellings and those with older household heads are more likely to use groundwater sources. We also estimate the determinants of the simultaneous use of both piped and groundwater sources by a household. Estimation results show that regular tariff payments, participation in agriculture, and a higher amount of available monthly disposable income, i.e., expenditure on other goods, are positively related to the concurrent use of piped and groundwater.

4.2 The impact of piped water price changes

This section presents our estimates on how relative water prices affect water type choice and impact the welfare of residential piped water users. We examine the effect of a counterfactual tariff rebalancing scenario whereby only the level of piped water tariff changes. To this end, we consider a rebalancing strategy that leads to a 20% decrease in piped water volumetric charge (Rand per kilolitre), with a consequent increase in fixed charges. The computations are restricted to those households covered by the piped water network, but that choose not to use piped water. Using QUAIDS, we estimate an expenditure system such that the sum of the expenditure shares must be equal to one, and household income is spent on water and a composite good. Our first expenditure model is based on when households only pay the normal piped water tariff. While the second model is for when households only pay the rebalanced piped water tariff. The third model is for the composite good.

The results of the QUAIDS analysis show that household characteristics, location, and survey year are almost all significant at either 1% or 5%. Specifically, all independent variables show statistical significance for the normal piped water expenditure share (Good 1) and the composite good (Good 3). The marginal budget share of "Good 1" positively affects the expenditure share, while the marginal budget share of the rebalanced scenario has adverse effects on the expenditure share. In the "Good 2", the household size variable is negative and significant; this implies that the per capital expenditure on the rebalanced piped water tariff declines due to reallocation of resources with a member added into a household. A similar interpretation can be used to explain the other variables. In the "Good 2", which has the computed rebalanced Price for groundwater users, the results suggest rebalancing the piped water price in the Northern Cape, Free State, Kwazulu-Natal, North-West and Limpopo leads to an increase in the probability of connecting to the piped water supply. The individual coefficients provide limited insightful information on their own and are further used to calculate elasticities.

Table 5: Parameter estimates for the expenditure system

	Dependent variables: Expenditure shares		
	Good 1: Regular Piped Water Price (Standard Error)	**Good 2: Rebalanced Price (Standard Error)**	**Good 3: Composite good (Standard Error)**
Marginal budget share	0.371***	-0.054***	0.683***
	(0.005)	(0.005)	(0.007)
Type of Dwelling	0.003***	-4.372e-04***	-0.003***
	(1.97e-04)	(4.17e-05)	(1.68e-04)
Vehicle	0.007***	-0.001***	-0.001***
	(1.25e-04)	(2.83e-05)	(2.83e-05)
Meat	0.002***	-1.55e-04***	-0.002***
	(1.11e-04)	(2.27e-05)	(9.48e-05)
Household Size	4.70e-04***	-6.7e-05***	-4.03e-04***
	(2.05e-05)	(4.31e-06)	(1.75e-05)
Own Household	3.10e-04***	-1.67e-05	-2.93***
	(1.18e-04)	(2.4e-05)	(1.05e-04)
Number of Rooms	0.001***	-6.47e-05***	-6.38e-04***
	(2.42e-05)	(5.19e-06)	(2.07e-05)
Eastern Cape	-0.001***	5.16	0.001***
	(2.11e0-4)	(4.1e-05)	(1.83e-04)
Northern Cape	-0.002***	2.89e-04***	0.002***
	(2.17e-04)	(4.14e-05)	(1.89e-04)
Free State	-0.001***	5.75e-05	0.001***

	(2.18e-04)	(4.31e-05)	(1.89e-04)
KwaZulu-Natal	-0.004***	0.001***	0.004***
	(5.14e-04)	(3.61e-05)	(1.55e-04)
Northwest	-0.002***	4.01e-04***	-0.002***
	(2.41e-04)	(4.94e-05)	(2.07e-04)
Gauteng	0.001***	-3.27e-05	0.001***
	(1.73e-04)	(3.3e-05)	(1.51e-04)
Mpumalanga	0.003***	-0.001***	-0.003***
	(2.23e-04)	(4.54e-05)	(1.92e-04)
Limpopo	-0.001***	1.48e-04***	-4.13e-04)***
	(2.39e-04)	(5.04e-05)	(2.03e-04)
Wave 2	0.015***	-0.017***	0.002***
	(4.98e-04)	(4.91e-04)	(5.13e-04)
Wave 3	0.002***	-0.001***	-0.001***
	(1.71e-04)	(7.24e-05)	(1.68e-04)
Wave 4	0.006***	-0.001***	-0.005***
	(5.51e-04)	(7.55e-05)	(1.62e-04)
Wave 5	0.007***	-0.001***	-0.006***
	(1.6e-04)	(7.51e05)	(1.55e-04)
Observations	28619		
Log-likelihood	88943.589		

Notes: The reference households are located in the Western Cape and Wave 1. ***, **, *, next to coefficients represents statistical significance at the 1%, 5%, and 10% respectively. Standard errors in parentheses.

4.2.1 Expenditure Elasticities

Table 6 presents the expenditure elasticities for the full sample and each of the nine provinces. For the first good, the expenditure elasticity is positive for the full sample and all provinces except for the Western Cape, Northwest, Gauteng, Mpumalanga, and Limpopo. This implies that household income increases the demand for piped water in the full sample size, particularly in the Eastern Cape, Northern Cape, Free State, and KwaZulu Natal. For the second good, the expenditure elasticity is negative for the full sample and all provinces except the Eastern Cape, Northern Cape, Free State, KwaZulu Natal, and Mpumalanga. This implies that an increase in household income decreases the demand for the rebalanced piped water in the overall sample size, particularly in the Western Cape, Northwest, Gauteng, and Limpopo. This result suggests the possibility of welfare loss due to tariff price rebalancing in the affected provinces.

In most provinces, household expenditure on the rebalanced piped water shows the highest inelasticity of the three goods. This implies that household use of piped water is more stable relative to expenditure changes. Also, the expenditure elasticity of piped water estimates is closer to zero than for any of the other two goods; this implies that piped water is necessary for all households.

The expenditure elasticity for the composite good is greater than one, meaning that most households' expenses on such goods are seen as luxury based on their income. However, the "composite goods" classification is not disaggregated in our dataset, and we cannot identify the exact goods that are referred to as luxuries.

Table 6: Expenditure Elasticities Result

	Good 1 (Regular pipe water price)	Good 2 (Rebalanced water price)	Good 3 (Composite good)
Full Sample	0.159	-0.088	1.045
Western Cape	0.011	-0.061	1.129
Eastern Cape	0.054	0.011	1.127
Northern Cape	0.127	0.125	1.146
Free State	0.134	0.129	1.133
KwaZulu-Natal	0.145	0.102	1.150
Northwest	-0.211	-0.204	1.104
Gauteng	-0.043	-0.002	1.124
Mpumalanga	-0.472	0.472	1.088
Limpopo	-0.922	-0.884	1.106

4.2.2 Price Elasticity of Demand

The uncompensated price elasticities and the compensated elasticities are reported in Table 7. The diagonal elements show own-price elasticities (boldened), implying the responsiveness of quantity demanded to a change in the good's own price. The non-diagonal entries are the cross-price elasticities, and they measure the responsiveness of demand for a good to a change in the price of another good. Also, own and cross-price elasticities are important because they show whether the two goods are complements or substitutes. Complementary goods have a negative cross-price elasticity because as the price of one good increases, the demand for the second good decreases. On the other hand, Substitute goods have a positive cross-price elasticity because as the price of one good increases, the demand for the other good increases. It is worthy of note that cross-price elasticities are not symmetric, meaning that the household's response for a commodity to a change in the price of another good is not necessarily the same as the household's response for the other good to a change in the price of the commodity in question.

The full sample estimation results in Table 8 show that the own-price elasticities for the three goods are negative as expected. On the other hand, some cross-price elasticities are negative, and some are positive. Negative cross-price elasticities imply that the relevant items tend to be complementary, while positive ones imply that they are substitutes. As expected, Table 8 also shows that the cross elasticity of piped water with rebalanced piped water is positive for the full sample.

Table 7: Own and Cross Price Elasticity Estimates for the demand system

	Commodity	Good 1 (Regular pipe water price)	Good 2 (Rebalanced water price)	Good 3 (Composite good)
Uncompensated (Marshallian)	Good 1	-0.527	0.080	0.288
	Good 2	0.145	-0.960	0.903
	Good 3	-0.016	-0.003	-1.026
Compensated (Hicksian)	Good 1	-0.108	0.030	0.168
	Good 2	0.130	-0.815	0.603
	Good 3	-0.006	-0.001	-0.907

4.3 Welfare effects from tariff rebalancing

However, the counterfactual rebalancing strategy discussed in the previous section could affect the welfare of existing water users. To further substantiate the welfare effects, we evaluate welfare effects using the compensating variation (CV) measure. This measure captures the variation in income required to compensate the household for the new equilibrium to yield the original utility level. Households that suffer a utility loss following the tariff rebalancing have a positive CV. We recognize the importance of determining how different population groups are affected in different ways by the price change. Consequently, we illustrate how the price changes impact different income groups by disaggregating the CV measure into five income groups (quintiles). Finally, because the NIDS survey is a probability sample of the population (at the census level), each observation is associated with a weight to ensure that metrics derived from the data set are representative of the population. We use these weights to compute an estimate of the CV for the population of each income group. Table 8 shows the results.

Results indicate that, on aggregate, the tariff rebalancing scenario leads to an average monthly welfare gain of 2.97%. On the contrary, the rebalancing does not lead to a welfare gain for the lowest income households. This is intuitive because most of these households identify as indigents and have free access to 6kl of water per month. The average monthly impact (gain) of the price rebalancing scenario on the full sample is R232.63 and about R573.49 for the highest-income households. However, the CV estimate for the full-sample population, shown in the last column of the table, indicates that such a tariff rebalancing leads to a monthly welfare gain of R26million. These gains arise because losers account for a smaller proportion of the total population.

Table 8: Compensating Variation due to Tariff Rebalancing

	Impact on the per capita well-being (in Rand)	Impact on household well-being (%)	Population Δ CV (in million Rand)
Full Sample	-232.63	-2.97	-26.0
Income group			
1st Quintile	-1.26	0.01e-10	-0.1
2nd Quintile	-161.83	-5.71	-3.7
3rd Quintile	-169.12	-3.64	-3.8
4th Quintile	-245.56	-3.12	-5.5
5th Quintile	-573.49	-2.37	-12.9

5. Conclusion and Policy Implications

The choice of water for residential households is usually always limited to either the more regulated piped water supply or the less regulated groundwater sources such as borehole and wellpoint. However, the piped water supply of most countries is consistently being impacted by climate change and the market imperfection that characterizes the water industry. Many households find it beneficial to secure access and consumption by investing in the less regulated groundwater sources, consequently putting groundwater resources at the risk of exploitation, acute aquifer depletion, and contamination. This present paper contributes to the still short literature on residential water demand in developing countries by investigating the effect of water tariffs and other factors on the choice of water source.

Our empirical analysis of the determinants of households' decision to use piped water or groundwater supply concludes that ownership of dwellings, large household size, household participation in agricultural activities, presence of at least one vehicle in the household and those with many rooms within their residence are factors that explain the reason for high groundwater usage in South Africa. Due to the high quantity of water needed to process red meat, our analysis attempted to investigate if the constant presence of red meat in households' diets is a predictor of groundwater. However, our result shows this to be negatively correlated. This implies that the heavy water footprint of beef and red meat does not apply to the residential sector but may be more likely limited to other processing stages.

We also determine the distributional impact of a counterfactual price rebalancing scenario that influences the fixed and variable volumetric charges of piped water. This strategy increases the likelihood of increased piped water subscription in the Northern Cape, Free State, Kwazulu-Natal, North-West and Limpopo provinces. We suspect that this is due to the high level of groundwater usage in these provinces. Our result implies an overall increase in the likelihood of use of piped water. This result is essential in the policy discussion of water price regulation in South Africa since high regulated price levels are frequently blamed for shortfalls in households' access rates. The analytical framework that we use to analyze the potential effect of piped water rebalancing on welfare changes is based on the compensating variation, assuming that households are entitled to their pre-shock level of utility. Our results indicate that, on aggregate, the tariff rebalancing scenario could lead to an average monthly welfare gain of 2.97%.

Some limitations to this research should be noted. In high-income countries, it is typical for all or nearly all household water needs to be supplied by a single source, usually a high-quality municipal piped water. However, this is not the case in most developing countries. Households rely on multiple alternative sources such as water carriers or tankers, flowing streams, public taps and other offsite sources for water. A limitation of our study is that we only investigate two water sources and do not consider conditions under which a household would depend on multiple alternative sources for their water need. Due to limitations arising from our panel dataset, we are unable to investigate situations in which households simultaneously use piped and groundwater. However, we attempt to compensate for this in a separate estimation using a cross-sectional dataset across three years.

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Appendix

Table A1: Parameter Estimates results of the 2018 General household survey of South Africa

Variables:	Dependent variable: Groundwater Use Coefficients (Standard Error)	Dependent variable: Both Water types Coefficients (Standard Error)
Constant	-4.084*** (0.104)	-0.187*** (0.050)
Pay for piped water	-4.603*** (0.174)	0.193*** (0.027)
LogIncome	4.64e-08 (2.84e-08)	-0.000** (0.000)
Dwelling type	1.049*** (0.090)	-0.412*** (0.041)
Log of Expenditure on other goods	-0.010** (0.004)	0.004** (0.002)
Involve in agriculture	0.098*** (0.023)	2.116*** (0.020)
Vehicle	0.049 (0.048)	0.021 (0.028)
Household Size	0.004 (0.008)	-0.032*** (0.006)
Number of rooms	0.036*** (0.004)	0.003 (0.003)
LogAge	0.010*** (0.001)	-0.009*** (0.001)
House owner	0.623*** (0.047)	-0.168*** (0.027)
Number of Obs: Log-likelihood	47,692 -9486.4874	47,692 -21908.859

Cross Sectional Data (2016, 2017, 2018). ***, **, *, next to coefficients represents statistical significance at the 1%, 5%, and 10% respectively. Standard errors in parentheses.