Essays on Industrial Organization and Development Economics

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Chapter 1

Introduction

The research presented in this dissertation uses tools from Industrial Organization to study resource allocation in developing countries. Chapter 1 analyzes South Africa's Free Basic Water Policy, under which households receive a free water allowance equal to the World Health Organization's recommended minimum of 6 kiloliters per month. I structurally estimate residential water demand, evaluate the welfare effects of free water, and provide optimal price schedules derived from a social planner's problem. I use a unique dataset of monthly metered billing data for 60,000 households for 2002-2008 from a particularly disadvantaged suburb of Pretoria. The dataset contains rich price variation across 18 different nonlinear tariff schedules, and includes a policy experiment which removed the free allowance. I find that without government subsidy, the mean monthly consumption would decrease from 12.6 to 5.6 kiloliters, which is below the clean water consumption recommended by the WHO. However, it is possible to reallocate the current subsidy to form an optimal tariff without a free allowance, which would increase welfare while leaving the water provider's revenue unchanged. This optimal tariff would also reduce the number of households consuming below the WHO-recommended level.

Chapter 2 measures input misallocation among small manufacturing firms in Ghana by explicitly estimating their production function. It quantifies the extent of capital misallocation and studies whether excess labor is used to substitute for capital. The paper uses data from the Ghanaian Manufacturing Survey 1991-1998. I find that adjusting capital by one unit in the optimal direction at every firm, holding all else constant, raises average value added by 0.67-2.55 percent. I also find that 58 percent of the firms in the sample use less than optimal capital. On average, firms would need to have 4 times more capital and 40 percent less labor to efficiently produce the current level of output. Firms with the smallest value added, which operate with the largest missing capital ratio, substitute capital with labor and operate with the biggest labor excess.

Chapter 2

The Value of Free Water: Analyzing South Africa's Free Basic Water Policy

"Water is life, sanitation is dignity."

Motto of the Department of Water and Sanitation,

City of Tshwane

2.1 Introduction

As exemplified by the opening quote, it is difficult to overestimate the significance attached to running water in many developing countries. The provision of affordable water to households requires not only developing the infrastructure for piped water and proper sanitation, but also determining the price of water for residential use. Throughout the developing world, governments and utilities are experimenting with various pricing structures, including unlimited free water (Tanzania before 1991), zero marginal rates with fixed fees (India, Pakistan, Zimbabwe, Kenya), uniform rates (Uganda), or standard block prices with multiple tiers (Ghana, Ivory Coast).[1]

The literature has addressed the impact of adequate water supply on water borne diseases (Zwane and Kremer, 2007), child mortality (Gamper-Rabindran, Khan and Timmins, 2007), educational attainment (Gould, Lavy, and Paserman, 2009), women's empowerment (Ivens, 2008), as well as its connection to corruption (Anbarci et al., 2009) and different systems of government (Deacon, 2009). The choice of a pricing scheme, which has received little attention, has similar far-reaching implications and it is one of the central problems for local governments and utilities.

Water pricing is an especially salient issue in post-apartheid South Africa, where who has access to water and how much they are charged for it is closely tied to issues of social justice. After the democratic elections of 1994, every household's right to a monthly allowance of free water was codified in the constitution. The resulting unique pricing scheme, the Free Basic Water

[1]A block rate structure is one that defines different unit prices for various quantity blocks. See Whittington (1992), World Bank (1993), Berg and Mugisha (2008), and Diakite et al. (2009) for more information on the pricing practices in these countries.

Policy, was introduced in 2001 and provides 6 kiloliters of water per month at no cost to households, regardless of income or household size. While the term "free water" is sometimes used in the literature to describe a situation with zero marginal price where households pay a fixed fee for the first units of water,[2] the South African scheme, which is motivated by equity concerns and in which water is actually free, is one of a handful such policies in the world.

The goal of this paper is to analyze the welfare effects of free water and provide an optimal pricing scheme. To do this, I collected a unique dataset containing seven years of monthly meter reading data for every household served by a local water provider (about 60,000 households) in a particularly disadvantaged suburb of the City of Tshwane (the metropolitan area around Pretoria, the country's administrative capital). The dataset contains rich price variation across 18 different tariff schedules, which allows the identification of structural parameters and a counterfactual analysis without free water. I find that without government subsidy, the mean monthly consumption would decrease from 12.6 to 5.6 kl, which is below the clean water consumption recommended by the WHO. However, it is possible to reallocate the current government subsidy to form an optimal tariff without a free

[2]For example, Gibbs (1978), Dandy (1997), Castro et al. (2002), and Martinez-Espineira (2002). These pricing schemes are often used to make utilities' revenues more predictable, and the fixed fee tends to be large (often equal to the average price for a similar quantity on a different part of the tariff schedule) In other cases, utilities may have a small free tariff block for administrative reasons, e.g., to simplify billing for a vacant apartment where a minor leak or water testing produces positive consumption.

allowance, which would increase welfare while leaving the water provider's revenue unchanged. This optimal tariff would also reduce the number of households consuming below the WHO-recommended level of clean water.

The dataset used in this paper is exceptional in coverage and quality. I observe individual monthly meter reading data for every household served by a local water provider from January 2002 to December 2008. This is a low-income population where a large number of households have monthly water consumption near subsistence levels. This population is 99% Black, with monthly household income between 170-300 USD. About 17% of the households have running water but no sanitation, and over 30% consume not more than 6 kiloliters of water per month, which is the WHO-recommended clean water consumption for a 5 person household. Consumption is recorded using modern technology and is therefore observed without measurement error. The dataset provides a sufficiently long purchase history and over 3 million monthly observations, which contributes to a precise estimation and circumvents the typical problems of datasets used to estimate price elasticities in developing countries.

I observe administrative data on prices, and the seven-year period I consider contains much richer price variation than datasets used in similar studies.[3] During the observed period, the water provider experimented with

[3]For example, Nauges and van den Berg (2006) do not observe any price variation and use the choice of vendor to estimate demand. Diakite, Semenov and Thomas (2009) study a 3-block structure which does not vary over time or in the cross-section.

18 different tariff structures, leading to substantial changes in prices over and above the inflation adjustments (including changes in the number of tariff blocks and changes from increasing to decreasing marginal prices). In addition, I take advantage of a 2007 policy experiment in which, in an effort to cut costs, Tshwane's Water Department introduced a new pricing policy that raised the free water allowance for low-income households (from 6 to 12 kl) while removing the allowance for all other households, who therefore experienced a dramatic price increase. The rich price variation in the dataset allows me to identify the structural parameters of a demand model and perform a counterfactual analysis without free water.

Because the water utility uses a complex block pricing structure, reduced form estimation methods would result in biased estimates. Rational households base their consumption decisions on the entire price schedule rather than on a specific marginal or average price. In this sense, it is important to estimate the consumers' block choice in an integrated way. To identify the demand parameters necessary for a counterfactual analysis and the optimal pricing exercise, I pursue a structural estimation approach. To structurally estimate water demand under the complex block pricing system used in Tshwane, I use an extension of the Burtless and Hausman (1978) demand model developed for labor supply. This model assumes heterogenous preferences among households with an unobserved taste parameter in the utility function. As a consequence I am able to recover household-level marginal effects and estimate household level price elasticities.

Applying the Burtless and Hausman (1978) model to water and other commodities with nonlinear prices raises several difficulties, some of which have been overlooked in previous studies of demand estimation.[4] First, while previous studies considered systems with continuously increasing or decreasing marginal prices, the schedules analyzed in this paper feature a combination of increasing and decreasing marginal prices and, as a result, the econometric model becomes more complex. I show how to proceed with the estimation and derive the maximum likelihood function under these conditions. Second, if convexity of preferences is not satisfied, applying the estimation method mechanically will produce negative probabilities in the likelihood function. Because I work with an explicit utility structure, I am able to solve this problem by restricting the distribution of preference heterogeneity such that convexity is satisfied. Considering these additions to previous estimation methods, this paper provides the most comprehensive demand estimation with nonlinear prices in the literature. The analysis can be directly applied to other markets with similar pricing structures, including electricity and wireless phone service.

In analyzing the Free Basic Water Policy, I study a counterfactual scenario in which consumers do not receive any free water. Currently, the

[4]Most earlier papers use reduced form analyses, summarized in Arbues et al. (2003) and Olmstead (2009). Structural studies include Hewitt and Haneman (1995), Pint (1999), and Olmstead, Hanemann and Stavins (2007). Reiss and White (2005) use similar techniques to estimate electricity demand.

water provider assigns positive accounting prices to free water in order to receive a subsidy from the central government. This allows me to analyze a counterfactual scenario where I replace the zero prices with these positive prices. I find that without free water, a high percentage of households would consume below the WHO-recommended level of 6 kl per month, with an average consumption of 5.6 kiloliters. Based on this result, I conclude that the government subsidy is beneficial in raising the amount of clean water consumed. However, the current policy of providing some water for free is only one possible way of allocating the government subsidy. Is there a welfare-improving way to subsidize water consumption?

To investigate whether the pricing system of Tshwane can be improved, I consider an optimal pricing problem. I assume that a social planner maximizes consumers' total expected utility subject to the water provider's revenue and the total consumption being unchanged. The second constraint guarantees that the water provider's capacity constraint is satisfied. I consider tariff structures with the same tiers as the one currently employed, with or without a free water allowance. I find that the optimal tariff contains gradually increasing positive marginal prices with no free allowance. This corresponds to the current government subsidy being spread more evenly across the lower segments. The optimal tariff increases welfare substantially while reducing the percentage of consumers with consumption less than 6 kl per month. The intuition behind increased consumption is that consumers currently attempt to stay within the free allowance in order to avoid paying the higher marginal prices. I calculate the compensating variation to compare households' welfare under the optimal tariff and the one currently in effect. I find that in each given period, the average utility gain among households is about 1% of their income, or 10-20% of the amount spent on water.

Even though pricing the existing water supply is a central concern to policymakers in many developing countries, the majority of water-related papers in the development literature focus on the availability of water rather than on pricing. One major obstacle to demand estimation is the lack of data as individual meters are still not common in low-income areas of the developing word. A group of studies attempt to overcome this difficulty by using surveys to evaluate households' willingness to pay for various water sources without observed consumption data. For example, Davis et al. (2001) asked 358 small business owners in Uganda about their willingness to pay for improved water connections, Whittington et al. (2002) surveyed 1500 households in Nepal, Pattanayak et al. (2006) surveyed 1800 households in Sri Lanka, and Akram and Olmstead (2009) report on a survey about service quality improvements of 197 households in Pakistan. Some of the disadvantages of these contingent valuation surveys in the context of demand estimation are discussed in World Bank (1993). One common difficulty is that respondents often do not understand the terms used in the surveys.[5] I am aware of two previous studies which are based on observed consumption data from a developing country. Diakite, Semenov, and Thomas (2009) study water demand data in Cote d'Ivoire using aggregate consumption data at the community level. Strand and Walker (2005) have access to billing data for about 1000 households from six cities across Central America. However, these observations come from different years and different months of the year (each household is observed only once), and it is unclear what population is represented by this data. To my knowledge, this is the first paper to estimate water demand using administrative, individually metered consumption data for large numbers of low-income households.[6]

In summary, this paper makes four contributions to the existing literature. First, this is the first paper to analyze the welfare effects of free water. Second, the quality and size of the dataset used to estimate water demand in a developing country, where consumption is near the WHO-recommended minimum, also makes this exercise unique. Third, my estimation handles price schedules with a combination of increasing and decreasing marginal prices and explicitly includes convexity conditions on preferences. Finally, I

[5]Upon being asked about his maximum willingness to pay for water, one respondent in Haiti asked the interviewer, "What do you mean the maximum I would be willing to pay? You mean when someone has a gun to my head?" (World Bank, 1993, 49).

[6]There are two studies about South African water consumption. Jensen and Shulz (2006) estimate water demand in Cape Town for 275 households using survey data and IV estimation, and Smith and Hanson (2003) present descriptive evidence from a survey of 120 households. Neither study uses a statistical method that properly addresses the block pricing structure, nor do they offer any analysis of the Free Basic Water Policy.

use the results of the structural estimation to derive optimal price schedules from a social planner's problem and I provide a structural statement about the welfare implication of the different price scenarios.[7]

The remainder of the paper is organized as follows: Section 2 describes the institutional context and introduces the dataset, Section 3 presents a reduced form analysis, Section 4 provides the demand model, and Section 5 presents the details of the structural estimation. Section 6 presents the estimation results and Section 7 provides the welfare analysis of the Free Basic Water Policy. Section 8 describes and analyzes an optimal price schedule, and Section 9 concludes.

2.2 Data and background

Most of the Tshwane metropolitan area is served by a national bulk water supplier. However, several smaller areas inside the municipality boundaries are served by smaller public utilities. The city council faced political and social pressure to improve the quality of life of households living in "townships" (poor suburbs / villages) in the area. One key aspect of the development plan was to create designated institutions focusing on servicing specific less-developed areas. One of these institutions, Odi Water, provides water to particularly under-developed townships in the North-Western part

[7] As Reiss and White (2005, 877) note, "Despite a great deal of work in the theoretical literature on efficient nonlinear pricing schemes, there are as yet few (if any) detailed empirical studies."

of Tshwane, where average monthly household income is less than 300 USD and over 99% of the population is Black. This area is a mixture of government housing projects and informal shacks. Piped water is available to all households, but 17% of the households have no water-using sanitation. In this sense, the area is a collection of typical South African townships in an urban area. The Appendix illustrates some of the relevant features of this environment.

2.2.1 Water consumption data

I collected the data used in this paper directly from Odi Water. This dataset contains monthly residential water billing data for all their customers, or about 60,000 households, for the period 2002-2008. All households in the dataset have individually metered running water on their property.[8] Since most of the area had no running water 10 years ago, the utility had to develop the entire infrastructure at that time. This included the installation of the individual meter reading devices using modern technology.

The final dataset includes 2,904,366 monthly observations, and was generated as follows. I dropped from the data Odi Water's commercial and institutional consumers (1 % of the data). I also dropped accounts showing zero consumption.[9] The employees of Odi Water inspect the water meter

[8] In particular, there are no shared connections.

[9] In some cases zero consumption refers to vacant land, closed accounts etc., a total of 410,184 monthly observations.

each month at meter-reading. If there is a problem with the meter, employees record the code of the problem which is also included in my dataset. Accordingly, I drop observations where the meter reader recorded any problems which prevented properly reading the meter.[10] In addition, the meter reader tests the tap for any water leaks and reports the problem. I drop the observations with problems reported (1.3%). Because of the regular quality checks, illegal tapping in this area is virtually non-existent, in contrast to many other developing countries or even other parts of South Africa.

Based on my conversations with Odi Water officials, the utility has difficulty distinguishing commercial and residential consumers if the consumer is running a small business from his home. These small businesses include hair salons, car washing facilities, small restaurants etc. Since Odi Water made efforts to identify these households and re-categorize them as commercial units, there are several account numbers whose status changed from domestic to commercial during the observed period. I drop the entire accounts with changing status from the sample (less than 0.5%). Lastly, I drop observations where monthly consumption is higher than 50 kl, which is 5 times the average consumption (2 %) These consumption levels are most likely associated with either unreported leaks or with commercial activities not yet categorized as such by Odi Water.

[10]These problems include the following: dirty dial, meter covered, meter stuck, meter damaged, meter dial is missing, meter tampered with, meter obstructed, water leak or meter removed.

Given the sophisticated individual meters and Odi Water's tight quality control, the consumption data can be considered free of measurement error.[11] In addition, since I observe the entire population of consumers, the dataset is free of the selection problems which sometimes arise with survey data.[12]

2.2.2 Household characteristics

Income. Based on government documents, average household income is less than \$ 300 in the entire area where Odi Water provides water. I do not observe household level income directly.[13] However, households need to register with the municipality as "indigent" to receive various government subsidies (such as discounted electricity), and I can identify the accounts of indigent households on a monthly basis. To qualify for indigent status, a household should meet the following criteria: Total gross monthly income of all the members of the household does not exceed R 1700 ($\simeq$ \$170), the

[11] In this area, no close substitutes for piped water are available. In particular, communal taps are only available in neighboring areas which do not have water connections, and there is no resale of piped water.

[12] For example, the dataset of Mayer et al. (1988), widely used in the water literature, contains about 1200 households from 16 different utility areas from the US and Canada surveyed by mail. In this dataset, 28.2% of the respondents had a BA degree, 13.3% a Masters degree, and 7.1% a Doctoral Degree. Not surprisingly, educated households were more likely to respond to a mail-in survey. There is a similar bias if we consider household income, home value, home size etc. since these variables are all correlated with educational attainment.

[13] Based on my experience in the field, the possibilities for getting household level income data from townships are limited. Survey data would be misleading as information about household income is not shared among family members. Wives, who would be most likely to answer such a survey, frequently have no information about the actual monthly income of their husband.

applicant should be the owner of the property, and must be a South African citizen.[14] The percentage of registered households is stable at around 10 percent for most of the 7 year period, with a 3 percentage point increase in registration in the second half of 2007, when the utility discontinued the provision of free water without registration. I include a dummy variable for indigent households. (Of course, even though registration is based on income, there might also be behavioral differences among indigent and non-indigent households.) Some of the income variance among households is captured by the household level random taste parameter, as described in section 2.5.3.

Restriction. About 25% of the households in the Odi Water area receive restricted service. Restriction will apply if the household has an unpaid balance for more than 40 days. The water flow is limited using a wide range of restriction devices for these households.[15] The main reason for non-payment seems to be high water bills due to negligence, such as leaving the tap running throughout the day. Some households also use water for luxury items they cannot afford, such as watering the lawn or a flowerbed in an arid African area. Restricted households get the 6 kl free water through a limited flow. Until the balance is fully paid they have the option to prepay for additional kiloliters, which are added to the free amount and divided

[14] 1 USD $\approx$ 10 South African Rand based on the January 2009 exchange rate.

[15] Restriction means a water flow of around 1 liter / minute, depending on the device. At this rate, it takes about 20 minutes to fill a standard container used for bathing.

throughout the month by the controlled flow. For this reason even restricted consumers may be price sensitive. The average duration of restriction is 5 months. In the estimation a dummy variable is included for restricted consumers for the duration they had the restriction device on their tap.

Sanitation. Odi Water serves several townships and areas in the North-Western part of Pretoria. Some of the area is undeveloped, and households may have metered running water on their property but no water-using sanitation.[16] For these households, comprising 17% of the population, the municipality provides chemical toilets, or they use shared sanitation facilities. These households use on average 25 percent less water than similar households with water-using sanitation facilities. In addition, they need to pay only water and not the separate sanitation charge (see the next section). I include a dummy for households without sanitation.

Other characteristics. I observe detailed area codes and include three dummies (Area 1, 2 and 3) to capture possible differences across neighborhoods. I also include the average maximum daily temperature per month to capture weather-related consumption changes. Table 3.1 shows the summary statistics.

[16]Households do not choose whether to have sanitation. Some areas simply lack the infrastructure necessary for sanitation, and all households have sanitation when it is available.

Table 2.1: Summary statistics

Variable	Mean	Std. dev.	Min	Max	N. Obs.
Consumption, kl/month	13	9.81	1	50	2,904,366
Restricted 0/1	0.18	0.38	0	1	2,904,366
Indigent 0/1	0.11	0.31	0	1	2,904,366
Sanitation 0/1	0.83	0.37	0	1	2,904,366
Average max daily temperature (F)	71.67	6.18	59.13	82.75	

2.2.3 Tariff structure

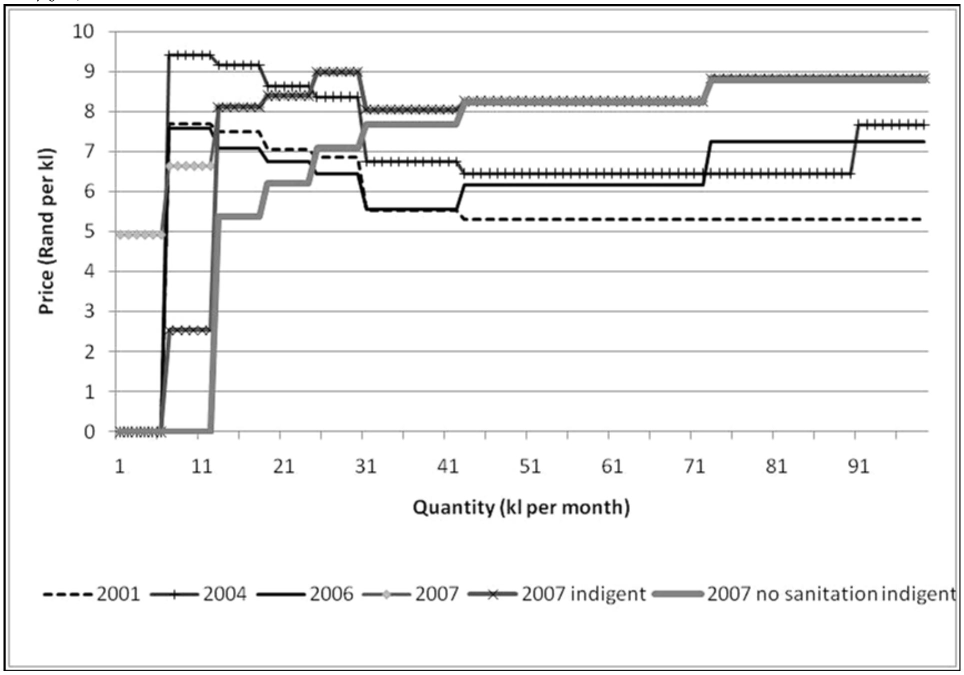
The tariff structure considered in this paper has a unique feature: It contains a mixture of increasing and decreasing block tariffs. Because Odi Water needs to price water and sanitation separately due to accounting reasons, they designed the block tariff structures separately. Both charges are based on a single water meter reading, thus water and sanitation cannot be consumed separately. Although both the water and the sanitation charge forms a regular increasing/decreasing price structure when taken separately, their sum does not follow any usual structure for block pricing.

I have administrative tariff data from January 2002 to December 2008. Tariff structures are reviewed each year in July, so my data contains up to 8 different tariff structures for both water and sanitation. Water tariffs are given in increasing block tariffs, where consumers pay a lower price for each unit up to a certain quantity, and then a higher price. The number of block tariffs, as well as the threshold quantities vary substantially in the data. There are 7 blocks in the first three tariff years, 8 in the fourth, 6 in the fifth and sixth, and 8 in the last two tariff years. The sanitation charge consists of two different elements. First, there is a sanitation charge per kl which is a uniform price in the first 5 tariff years, a continuously decreasing block tariff structure in the sixth year, and an increasing block tariff structure in the last two years. The second component of the sanitation charge is a multiplier which determines the fraction of the consumed water after which a sanitation charge is paid. The multiplier changes with the consumption level, but this structure is fixed over the observed period. There is no sanitation charge for households without water-using sanitation facilities. Sanitation multipliers and summary statistics of the tariff structures are in Appendix 4.1.8.

Based on my experience in the field, the local government makes extensive efforts to advertise the tariff structure, and tariff changes when they occur. This includes special flyers as well as announcements in the local newspaper and at community meetings. In addition, the provider employs "education officers" who regularly educate households about different aspects of water consumption: they teach them about water conservation, explain how the water meter works and how to read the water bill, etc. Given these efforts, most households should have an adequate understanding of the prices they face.

As the above description of the tariff structures shows, Odi Water experimented with many different tariff structures over the years. Typical studies using US datasets have much less price variation, since US water tariffs are usually fixed over time after adjusting for inflation. Odi Water's frequently

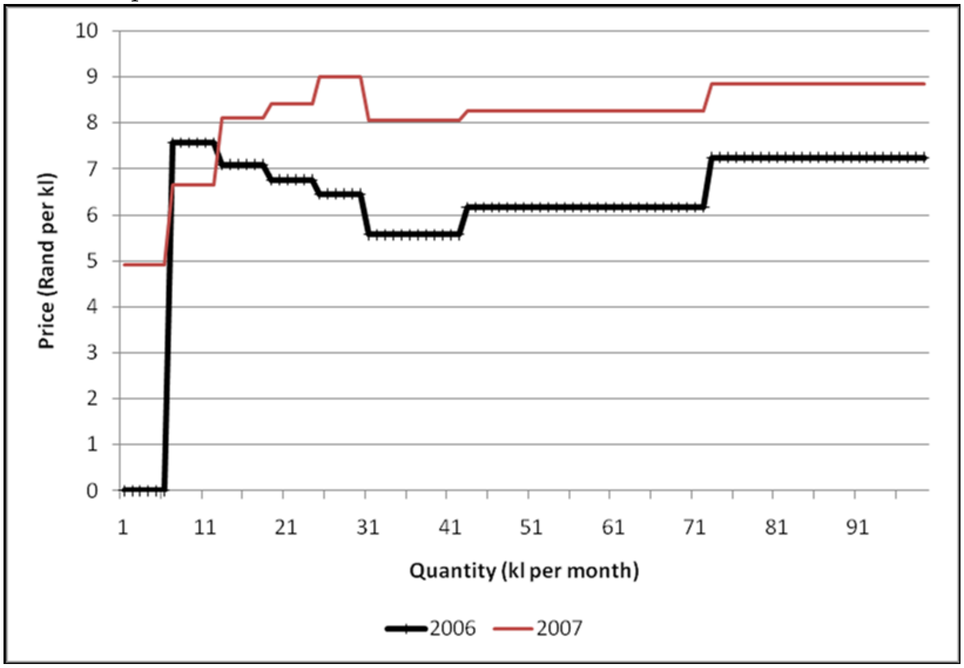
Figure 2.1: Selected tariff structures. All prices are in 2002 Rand and include 14% VAT



changing tariff structure provides another source of identification in the data (Figure 2.1, all nominal values are in 2002 Rand).

The observed period includes a policy change in 2007, when the utility created separate tariff structures for low-income registered households. Previously, consumers received the first 6 kl water for free. From July 2007, Odi Water charged non-indigent households from the first kl they consumed. Registered indigent households continued to receive 6 kl free water for sanitation and the municipality increased the free 6 kl amount to 12 kl. The tariff changes are shown on Figure 2.2 and 2.3 separately for registered and non-registered households. This policy change will provide a crucial source

Figure 2.2: Policy change for non-indigent households, Total Prices, 2006-2007. All prices are in 2002 Rand and include 14% VAT

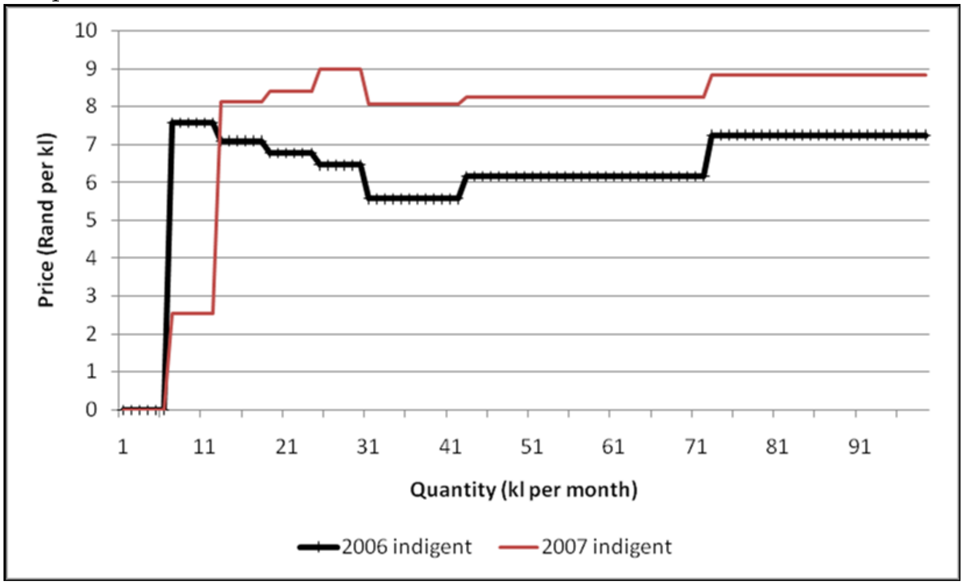


of identification for the counterfactual analysis under alternative price schedules, since it provides positive prices at each kiloliter, including the first 6 kl.

Note that for indigent households, comprising 11% of the data, I never observe positive prices for the first 6 kiloliters. However, there is no evidence of different consumption patterns between indigent and non-indigent households when they are facing the same tariff structure (see Table 2.4). In the analysis below, I include a dummy variable for indigent households.

The mean consumption is 13.0 kiloliters. However, 28.7 percent of the households consume below the free allowance. There is a high concentration

Figure 2.3: Policy change for indigent households, Total Prices, 2006-2007. All prices are in 2002 Rand and include 14% VAT



of consumers (15.4%) around the kink point of the free allowance (between 5-7 kiloliters). Even though the price schedule contains different prices for 42-72, 72-90, and 90+ kiloliters, less than 5 percent of the households consume more than 42 kiloliters. The distribution of the consumers by consumption is shown in Table 2.2.

2.3 Reduced Form Analysis

As Olmstead (2009) notes, "... of 400 price elasticity studies of water demand produced between 1963 and 2004, only three employed [structural] models, [...] despite the fact that in at least 140 study samples, prices were

Table 2.2: Distribution of consumers by consumption, N=2,904,366

Rate boundary, kl	% of consumers	No. Obs.
0-6 kl/m	28.65	859,527
7-12 kl/m	27.77	831,168
13-18 kl/m	18.02	540,527
19-24 kl/m	10.25	307,514
25-30 kl/m	5.61	168,432
30-42 kl/m	5.06	151,996
42+ kl/m	4.66	139,955
5,6,7 kl/m*	15.35	459,207

*Note: The free allowance is 6 kiloliters. This row shows the consumption around this kink.

either increasing or decreasing block." To relate my work to this earlier literature, this section estimates a linear demand function with OLS, reviews why these estimates are likely to be biased, explains why some widely used IV methods are not able to correct this bias, and argues that it is crucial to introduce a structural model for further analysis of optimal consumption in the presence of complex nonlinear tariff structures.

In the reduced form regressions the dependent variable is monthly metered consumption, and the regressors are observed individual household characteristics (registration as indigent household, restriction, availability of water using sanitation on the property), weather characteristics (average maximum daily temperature) and the price of water. To include the complex price schedule in this regression, one has to use proxies, typically the average price for each unit of observed consumption, or simply the marginal price of observed consumption. Results using the average price are in Table

4.1 in Appendix 4.1.7.

The use of the average or marginal price in the OLS regression introduces an upward bias in the presence of increasing block tariffs, and a downward bias when the block pricing is decreasing. For example, an increasing block structure automatically creates a positive correlation between the marginal or average price and the error term, since above-average consumption levels are necessarily associated with higher prices. While under an everywhere-increasing or everywhere-decreasing tariff structure this bias can at least be signed a priori, this is not possible in my data featuring a mixture of increasing and decreasing price segments.[17]

Several water studies attempt to find instrumental variables to correct the bias of the OLS estimates. The idea is to instrument the marginal or average price with various summary statistics of the nonlinear price schedule. For example, one might take, for each tariff year, the marginal prices corresponding to specific predetermined quantities (such as the kink points). The price variable is then instrumented with these characteristics of the price schedule. Essentially, this amounts to approximating the nonlinear price schedule with a linear function of the marginal prices. This procedure is valid to the extent that this linear approximation holds (so that the observed marginal prices are strongly correlated with the instruments) and

[17]The results in Table 4.1 show that the OLS estimates produce an upward sloping demand curve. Similar results are obtained with separate regressions for the pre- and post-policy sample, or including household-level fixed or random effects.

to the extent that the error term is uncorrelated with the characteristics of the tariff structure used as instruments (so that the exclusion restriction is satisfied). Results from this exercise are in the last column of Table 4.1.

The above instruments are unlikely to be valid in the present context. First, there is no guarantee that the price schedule can be represented in a meaningful way using marginal prices or other summary statistics. As described above, the price schedule I analyze is the sum of a separate water and sanitation charge, both of which were subject to yearly reviews during the observed period. Moreover, not just the marginal prices, but also the kink points were changed. Second, as the structural analysis below will make explicit, optimizing consumers base their choices on the entire price schedule. They choose the block in which to consume based on all the marginal prices, and the quantity consumed in a specific block based on the marginal price in that block. Therefore, if the error term contains a preference shock upon which optimizing consumers base their choices, it will be correlated with not just the marginal price of the observed consumption, but also with any other characteristic of the tariff schedule. Particular features of the price schedule, such as a list of marginal prices, are unlikely to be valid instruments. Finally, the histogram of consumption levels in my dataset features some clustering around the kink points (see more on this in Section 2.5 below). While this follows naturally from a framework with consumer optimization, reduced form regressions would require special assumptions on the error structure to be consistent with such a pattern. Therefore, I turn to a structural model of water consumption. Throughout, I also present the reduced form results for comparison.

2.4 Consumer choice under increasing or decreasing block prices

Consider a general model of a consumer facing a piecewise linear budget constraint. This generalizes the treatment in Burtless and Hausman (1978) or Moffitt (1986) who focus on the case of everywhere increasing or everywhere decreasing prices. The consumer consumes water w and a composite good x, and his utility is $U(w, x)$, where U is strictly quasi-concave and increasing in both goods. The tariff schedule is written as $P(w)$. It is piecewise linear with a finite number K of segments, where segment k has a marginal price P_k between consumption levels $\overline{w}_{k-1}$ and $\overline{w}_k$ (referred to as "kink points"):

$$P(w) = \begin{cases} P_1 & if \quad w \in [0, \overline{w}_1] \\ P_2 & if \quad w \in (\overline{w}_1, \overline{w}_2] \\ ... & ... \quad ... \\ P_K & if \quad w \in (\overline{w}_{K-1}, \infty) \end{cases}$$

Given income Y, the consumer solves the problem

$$\max_{w} U(w, Y - M(w)), \tag{2.4.1}$$

where $M(w) = \int_0^w P(u)du$ is total expenditure on water. While this problem is conceptually straightforward, not every solution procedure is equally amenable to estimation. The following procedure will be particularly convenient.

To solve problem (2.4.1), consider first the sub-problems of maximizing utility as if the budget constraint was linear, extending each segment to the entire consumption set as show by the dashed lines on Figure 2.4. For each segment k define

$$V_k = \max_{w} U(w, Y - M(\overline{w}_{k-1}) - P_k(w - \overline{w}_{k-1})), \tag{2.4.2}$$

and let $\widetilde{w}_k$ be the solution. Thus, V_k and $\widetilde{w}_k$ are, respectively, the consumer's indirect utility function and demand function corresponding to the extended budget constraints. Next, compare the utility of the solutions which are feasible under the tariff schedule $P(w)$, and the utility of the kinks $\overline{w}_k$, to determine the consumer's demand. For each kink k, let $\overline{U}_k = U(\overline{w}_k, Y -$

$M(\overline{w}_k))$ be the consumer's utility from consuming at kink k. Define

$$\begin{aligned} k_1^* &= \underset{k|\widetilde{w}_k \in [\overline{w}_{k-1}, \overline{w}_k]}{\arg\max} \{V_1, V_2, ..., V_K\} \\ k_2^* &= \arg\max_k \{\overline{U}_1, \overline{U}_2, ..., \overline{U}_{K-1}\}. \end{aligned} \tag{2.4.3}$$

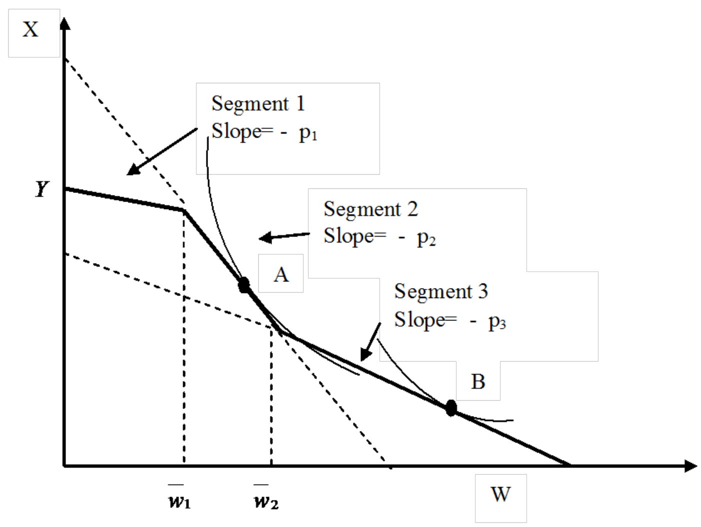
k_1^* is the segment giving highest utility under the tariff schedule $P(w)$, while k_2^* is the highest utility kink. Consumer demand is

$$w^*(P(\cdot)) = \begin{cases} \widetilde{w}_{k_1^*(P(\cdot))}(P(\cdot)) & if\ V_{k_1^*} > \overline{U}_{k_2^*} \\ \overline{w}_{k_2^*} & otherwise \end{cases} \tag{2.4.4}$$

where dependence of demand on the tariff is made explicit. In words, (2.4.4) says that consumer demand is either a kink point, or it is the regular demand of a consumer facing a linear budget constraint with income $Y - M(\overline{w}_{k-1}) + P_k\overline{w}_{k-1}$ and price P_k.

The approach of solving the subproblem (2.4.2) corresponding to each segment is useful because the tariff structure is not differentiable, and not necessarily convex. The lack of differentiability prevents the use of first order conditions at the kink points. The lack of convexity means that, on the segments, the first order conditions of the consumer's problem (2.4.1) may yield multiple solutions. Consider for example Figure 2.4. In this example, the best choice on segment 2 (point A), is a local optimum. But it is not a global optimum. There is another local optimum on segment 3 (point B)

Figure 2.4: Budget set with mixed price blocks



that is preferred to segment 2. The problem arises here because the tariff is not convex. Of course, over a particular linear segment, the problem is convex, so I can use the first-order approach on a particular segment to solve subproblem (2.4.2). Then, by solving (2.4.3), I obtain the global optimum.

2.5 Specification and estimation

2.5.1 Demand specification

To obtain a linear demand function for convenient estimation, I assume that the consumer's direct utility function can be written as[18]

$$U(w,x) = \frac{\gamma w + \alpha}{\gamma^2} \exp\left(\gamma \frac{\gamma x - w + Z\delta + \eta}{\gamma w + \alpha}\right). \tag{2.5.1}$$

Here, Z represents observed consumer characteristics and contains a set of dummy variables such as the availability of water-using sanitation or indigent status, and δ is a vector of corresponding parameters. The role of the parameters $\alpha < 0$ and $\gamma > 0$ will be made clear below, and the term η represents household level heterogeneity (see below). Under (2.5.1), preferences are convex if and only if $\gamma w + \alpha < 0$. Since there are two goods and two parameters (α and γ), the functional form in (2.5.1) is flexible in the sense that the two parameters can be chosen to provide a first-order approximation to an arbitrary utility function at a given point (w, x).[19]

Given a linear budget set with income Y and price P, the indirect utility function and demand function corresponding to (2.5.1) is

$$V(P,Y) = \exp(-\gamma p)\left(Y + \frac{\alpha}{\gamma}P + \frac{\alpha}{\gamma^2} + \frac{Z\delta + \eta}{\gamma}\right) \tag{2.5.2}$$

[18] A similar functional form is used by Hausman (1980).

[19] In addition, each household characteristic Z has a corresponding parameter δ.

$$\widetilde{w}(P,Y) = Z\delta + \alpha P + \gamma Y + \eta. \tag{2.5.3}$$

Equation (2.5.3) makes it clear that α and γ are, respectively the price and income coefficients in the demand function. Using this specification, we may write demand on segment k as $\widetilde{w}_k = \widetilde{w}(P_k, Y - M(\overline{w}_{k-1}) + P_k\overline{w}_{k-1})$, and the corresponding utility as $V_k = V(P_k, Y - M(\overline{w}_{k-1}) + P_k\overline{w}_{k-1})$.

This specification gives rise to the following econometric form of the consumer's demand (2.4.4):

$$w_{it} = w^*(P(\cdot)) + \varepsilon_{it} = \begin{cases} Z_{it}\delta + \alpha P_{it} + \gamma Y_{it} + \eta_{it} + \varepsilon_{it} & if\ V_{k_1^*} > \overline{U}_{k_2^*} \\ \overline{w}_{k_2^*} + \varepsilon_{it} & otherwise \end{cases}. \tag{2.5.4}$$

Here, w_{it} is monthly consumption of household i in billing cycle t. Households have an individual meter on their properties and they pay a monthly bill, so there are no data aggregation issues either across time or among households. Household level heterogeneity is modeled as a time-varying term η_{it} (preference error). This is observed by the household but not by the econometrician. Finally, ε_{it} is a random optimization error not observable by either the households or the econometrician. For example, it might represent leaks not noticed by the households or other unforeseen events causing desired consumption to differ from actual consumption.

To see why introducing the optimization error is necessary note that, given some distribution of η, the theory predicts (i) a zero probability of consuming at non-convex kink points, and (ii) a strictly higher probability of consuming exactly at a convex kink point than in a small neighborhood around it. By contrast, my data shows some clustering of consumption around the kink points. The error term ε will contribute to explaining consumption in the neighborhood of convex kinks as well as consumption at non-convex kink points.

In standard demand estimation, η_{it} and ε_{it} cannot be distinguished, but that is not the case in the present context. When utility is maximized on a segment, observed consumption contains two error terms, as in (2.5.4). When utility is maximized at a kink point, observed consumption is equal to the kink value plus the optimization error only, since the preference error is already "included" in the kink point (Hausman, 1985).

2.5.2 The social planner's problem

As mentioned in the introduction, the optimal pricing of water is a major concern for governments and water providers throughout the developing world. To study this issue, I use the estimated parameters to derive an optimal pricing schedule from a social planner's problem. Specifically, I consider the problem of a social planner maximizing total consumer welfare subject to the following constraints:

1. (Revenue neutrality) The water provider should operate with the same

economic loss/profit than under the current (2008/2009) price scheme, assuming a risk neutral water provider.

2. (Capacity constraint) The new tariff structure should not increase the current total consumption.

I also take as given the eight tariff tiers of the current schedule. This formulation is useful since I do not have information about the specifics of the production cost of the water provider.[20] It implies that the possible welfare changes come from the reallocation of the current consumption and payments across consumers.

In addition to the two constraints described above, I also investigate the effect of restricting the first price block (0-6 kiloliters) to have zero marginal price. Specifically, in a separate exercise, I provide optimal price schedules where the first marginal price is zero all households or for indigent households only.

Because of the random taste parameters η_{it}, consumer welfare in a given year is a random variable. The optimal tariff will be one which maximizes the expected welfare of consumers subject to the revenue and capacity constraints holding in expectation. I assume that the marginal cost of water distribution is zero, and restrict attention to increasing price schedules.

[20]However, based on my conversations with Odi Water staff, a new tariff schedule satisfying the revenue neutrality and capacity constraints would be feasible to implement.

Denote the current total revenue with $\overline{R} = \sum_{i=1}^{I} \int_{0}^{w_i^*(P^{08}(\cdot))} P^{08}(w)dw$ where I is the number of consumers and $P^{08}(w)$ is the current (2008/09) price schedule. Similarly, let current total consumption be $\overline{C} = \sum_{i=1}^{I} w_i^*(P^{08}(\cdot))$. Let F_i denote the cdf of η_i and E the expectation operator over $(\eta_1, ..., \eta_I)$. The problem of the social planner is

$$\max_{P(\cdot)} E\left[\sum_{i=1}^{I} U_i(w,x)\right] = \sum_{i=1}^{I}\left[\int_{-\infty}^{\bar{\eta}_i} U_i(w_i^*(P(\cdot),\eta_i), x^*(P(\cdot),\eta_i))dF(\eta_i)\right] \tag{2.5.5}$$

s.t.

$$\sum_{i=1}^{I} E\left[w_i^*(P(\cdot),\eta)\right] \leq \overline{C} \tag{2.5.6}$$

$$\sum_{i=1}^{I} E\left[\int_{0}^{w_i^*(P(\cdot),\eta_i)} P(w)dw\right] \geq \overline{R}.$$

As above, $F_i(\eta)$ is assumed to be truncated-Normal, where the truncation $\bar{\eta}_i$ depends on individual consumer characteristics. For example, for the case of two price segments with $P_1 > P_2$, each term in (2.5.5) can be written as

$$\int_{-\infty}^{\theta_{11}} V_i(P_1,Y)dF(\eta_i)+\int_{\theta_{11}}^{\theta_{12}} U_i(\overline{w}_1, Y-P_1\overline{w}_1)dF_i(\eta_i)+\int_{\theta_{12}}^{\bar{\eta}_i} V_i(P_2,Y_2^0)dF_i(\eta_i). \tag{2.5.7}$$

Here, the three terms correspond to the utility the consumer achieves from consuming on the first segment, the kink, or the second segment, respectively. Using the parameter estimates together with the functional forms in (2.5.1) and (2.5.2) and the distribution of η (specified below), numerical maximization of (2.5.5) subject to (2.5.6) is straightforward.

2.5.3 Estimation

I now derive the econometric form of the demand function based on (2.5.4) for the situation shown in Figure 2.4. The demand function for the 8-segment tariff schedules I observe in the data can be derived similarly. First, consider the following notation:

$$
\begin{aligned}
Y_k^0 &= Y - M(\overline{w}_{k-1}) + P_k \overline{w}_{k-1} \\
w_k^0 &= Z\delta + \alpha P_k + \gamma Y_k^0 \\
\theta_{jk} &= \overline{w}_j - w_k^0
\end{aligned}
\tag{2.5.8}
$$

From the conditions in (2.4.3), consuming on a particular segment or kink requires two types of conditions to hold: the specific quantity has to be (i) feasible, and (ii) yield higher utility than other feasible quantities. Using the functional form in (2.5.2), these conditions can be written as follows.

First, the regular demand corresponding to segment 1, $w_1^0 + \eta$, is (i) feasible iff $\eta < \theta_{11}$, and (ii) yields higher utility than the demand $w_3^0 + \eta$ corresponding to segment 3 if $V(P_1, Y) > V(P_3, Y_3^0)$ whenever $\theta_{23} < \eta$. Note that here feasibility of $w_1^0 + \eta$ implies that neither the kink nor $w_2^0 + \eta$ is feasible, so these are all the conditions we need.

Next, it is easily checked that $V(P_1, Y) = V(P_3, Y_3^0)$ has a unique solution in η, which we denote η_{13}. It is also easily verified that $V(P_1, Y) > V(P_3, Y_3^0)$ iff $\eta < \eta_{13}$. Therefore, the kink point $\overline{w}_1$ is feasible when $\theta_{11} < \eta < \theta_{12}$, and optimality requires that $\overline{U}_1 > V(P_3, Y_3^0)$ whenever $\theta_{23} < \eta$. From (2.5.1) and (2.5.2) it may be verified that $\overline{U}_1 > V(P_3, Y_3^0)$ iff $u_{13}^L < \eta < u_{13}^U$, where $u_{13}^L < u_{13}^U$ are the two roots of the equation $\overline{U}_1 = V(P_3, Y_3^0)$ in η.[21]

These observations may be used to derive the corresponding conditions for segments 2 and 3, yielding the following specification of observed consumption:

$$w = \begin{cases} w_1^0 + \eta + \varepsilon & \text{if } \eta < \theta_{11} \text{ and } (\eta < \eta_{13} \text{ when } \theta_{23} < \eta); \\ \overline{w}_1 + \varepsilon & \text{if } \eta \in (\theta_{11}, \theta_{12}) \text{ and } (u_{13}^L < \eta < u_{13}^U \text{ when } \theta_{23} < \eta); \\ w_2^0 + \eta + \varepsilon & \text{if } \eta \in (\theta_{12}, \theta_{22}) \text{ and } (\eta < \eta_{23} \text{ when } \theta_{23} < \eta); \\ & \text{if } \theta_{23} < \eta \text{ and } (\eta > \eta_{13} \text{ when } \eta < \theta_{11}) \\ w_3^0 + \eta + \varepsilon & \text{and } (\eta \notin (u_{13}^L, u_{13}^U) \text{ when } \eta \in (\theta_{11}, \theta_{12})) \\ & \text{and } (\eta > \eta_{23} \text{ when } \eta \in (\theta_{12}, \theta_{22})). \end{cases} \tag{2.5.9}$$

A more general version of (2.5.9) can be found in Appendix 4.1.6. It is also shown there that the demanded quantity in (2.5.9) is uniquely defined for any η.

Once a distribution for ε_{it} and η_{it} is specified, (2.5.9) can be used to estimate the parameters of interest using Maximum Likelihood. Two features

[21] This equation may also have 1 or 0 roots, in which case $\overline{U}_1 \leq V(P_3, Y_3^0)$ for all η.

of the above framework make this exercise non-trivial.

First, as explained in Section 2.4, the presence of a mixture of increasing and decreasing prices requires comparing the utility of feasible *and only of feasible* ordinary demands. This is apparent in (2.5.9), where, e.g., a positive probability of observing $w_1^0 + \eta + \varepsilon$ requires that $\eta < \eta_{13}$ ($w_1^0 + \eta$ yield higher utility than $w_3^0 + \eta$) *only* if $\theta_{23} < \eta$ also holds ($w_3^0 + \eta$ is feasible). This introduces considerable computational difficulties beyond the case of everywhere-increasing prices (where no comparisons are necessary) or everywhere-decreasing prices (where performing all comparisons at once yields valid results).

Second, a difficulty arises from the recognition that demand in (2.5.9) is uniquely defined only if $\theta_{11} < \theta_{12}$ or, equivalently, if $w_1^0 > w_2^0$. If this failed, implying non-convex preferences, for $\eta \in [\theta_{12}, \theta_{11}]$ optimal consumption could be located on the first *or* the second segment. For $w_1^0 > w_2^0$ to hold, the substitution effect of the change in price from P_1 to P_2 must not be dominated by the income effect of the extra $Y_2^0 - Y = (P_2 - P_1)\overline{w}_1$. All previous water studies that I know of simply assume that this holds. However, most of these studies use demand data either from the US or Canada, where a typical household uses around 48 kiloliters of water per month, and spends about 0.4 percent of its monthly income on water.[22] In contrast, in my dataset the average monthly consumption is 13 kiloliters, and house-

[22] E.g., Mayer at al. (1988).

holds spend 5-10 percent of their monthly income on water. Based on this fact, income effects might be substantial and there is no reason to expect the convexity constraint not to bind.

In the framework used here, convexity can be guaranteed by performing the estimation subject to the constraint that $\gamma W + \alpha < 0$. Under (2.5.1), this is necessary and sufficient for preferences to be convex. Rewriting this constraint using (2.5.4) and (2.5.8), we get $\eta < -w_k^0 - \frac{\alpha}{\gamma}$. To guarantee that this holds for every segment, we require that $\eta < \min_k(-w_k^0) - \frac{\alpha}{\gamma}$. Note that this automatically guarantees that preferences are convex over kink points $\overline{w}_k$ for which $\overline{w}_k < w_l^0$ for all l, i.e., for all the kink points at which the consumer might possibly want to consume. Since w_k^0 differs across billing periods t and consumers i, in practice I impose

$$\eta < \overline{\eta}_i \equiv \min_{tk}(-w_{itk}^0) - \frac{\alpha}{\gamma}.$$

The truncation point $\overline{\eta}_i$ differs across consumers (but is the same for a consumer in all billing cycles). I specify the distribution of η_{it} as truncated-Normal, from a Normal distribution with mean 0 and variance σ_η^2, truncated at $\bar{\eta}_i$. Appendix 4.1.1 explains the truncation in more detail.

Truncation guarantees that demand is unique for every consumer, even for counterfactual realizations of η that would result in consumption on different segments of the budget constraint. This will allow me to perform counterfactual experiments in a consistent manner. In the literature on utilities the only paper I know of that addresses the problem of uniqueness is the electricity demand estimation of Herriges and King (1994). However, their solution amounts to imposing convexity only in the neighborhood of observed consumption levels. This is problematic because if uniqueness of demand is not guaranteed for all possible values of the preference error, expected consumption cannot be computed.[23] This makes any counterfactual analysis impossible.

To derive the likelihood function based on (2.5.9), I assume that η_{it} is i.i.d. across billing cycles t for each household. The optimization error ε_{it} is assumed to be i.i.d. across households and billing cycles and drawn independently of η_{it} from a distribution $N(0, \sigma_{\varepsilon}^2)$. The resulting likelihood function is given in the Appendix 4.1.2. It is continuous, but may not be everywhere differentiable in the parameters. Consistency of the MLE follows from Theorem 2' of Manski (1988). See Appendix 4.1.5.

Maximization of the likelihood function is implemented in MATLAB using a quasi-Newton method. Starting values for the maximum likelihood program are set equal to the IV parameter estimates. To make sure that the global maximum was reached, a different type of quasi-Newton method was used to verify the parameter estimates. The covariance matrix of the

[23] The authors compute expected consumption by restricting the distribution of η to put 0 probability on values yielding multiple optima (p429). Thus, they use different distributions to estimate the parameters and to compute expected consumption given those parameters.

parameter estimates is obtained by estimating the inverse of the information matrix. The model predicted values are computed using the formula given in Appendix 4.1.3 for expected consumption. Because of the computational complexity, the estimation must be done on a subsample of the data.[24] I draw a random sample of 10,000 monthly observations and the subsequent estimation is done for this sample. Out of sample tests are performed. Appendix 4.1.4 contains a step-by-step summary of the estimation procedure.

2.6 Results

2.6.1 Parameter estimates and model performance

Table 2.3 presents the parameter estimates from the maximum likelihood estimation. All parameters are significant at the 1 percent level, and the signs of the parameters are as expected. To further interpret the effect of variables on the expected consumption marginal effects need to be calculated, which will be done in the next section. The mean truncation point for the normal distribution is 3.267, which is not a drastic truncation for a normally distributed random variable.

Table 2.4 presents actual means computed form the data and the model-predicted mean consumptions for different consumer groups. The average

[24]Pint (1999) uses a simplified version of this likelihood function to estimate water demand in California for about 36,000 observations. He reports that the model required approximately 500 hours of offpeak computer time to converge using GAUSS software.

Table 2.3: Parameter estimates, ML

Variables	Parameters	t-value
Constant	37.40	12.02
Indigent	-8.60	-12.97
Restricted	2.49	4.28
Sanitation	4.86	7.37
Area 2	-2.98	-4.75
Area 3	4.00	8.22
Average max daily temperature	0.12	4.89
Price	-4.70	-16.52
Income	0.10	14.91
σ_ε	3.88	48.85
σ_η	1.85	59.33

Table 2.4: Model performance

Water consumption per household, in kl	Actual mean	Predicted mean	Average error
All	12.38	12.30	0.08
Indigent	11.13	9.84	1.29
Non-indigent	12.58	12.69	-0.11
Restricted	12.85	12.09	0.76
Non-restricted	12.27	12.35	-0.08

error is not substantial, the model performs well. Looking more closely at the distribution of consumption predicted by the model, I find that the model underestimates high consumption levels (above the 95th percentile). This is due to the long right tail of the distribution of water consumption in my dataset.

To investigate the out-of-sample performance of the model, recall that the dataset contains the 2007 policy change when the free allowance was

Table 2.5: Model performance: out of sample test

Water consumption, kl	Actual mean Pre-policy	Actual mean After policy	Model predicted MLE	Average error MLE	Average error OLS	Average error IV
All	13.00	10.41	9.32	1.09	-11.41	-3.28
Indigent	11.46	9.84	9.30	0.54	3.49	-0.79
Non-indigent	13.26	10.49	9.32	1.17	-13.14	-0.79
Restricted	13.46	10.74	9.35	1.39	-9.92	-2.37
Non-Restricted	12.88	10.33	9.31	1.02	-11.72	-3.47

increased to 12 kl for low-income households but removed for the rest of the population. The new tariff resulted in a considerable decrease in the average price for low-income households, while other households experienced an increase in average price. I estimate the model only for a pre-policy sample, and use these parameter estimates to predict consumption after the policy change. Table 2.5 presents the model predicted means after the policy, which are close to the actual means observed in the data.

An important feature of the data after the 2007 policy change is a decrease in average consumption in response to an increase in the free allowance. In particular, Figure 2.5 suggests that some indigent households consuming more than 12 kl before the policy decreased their consumption below 12 kl after the policy was introduced to avoid paying the higher marginal prices.[25] This is of course consistent with a model of rational consumer behavior in the presence of nonlinear prices, where the consumer chooses both

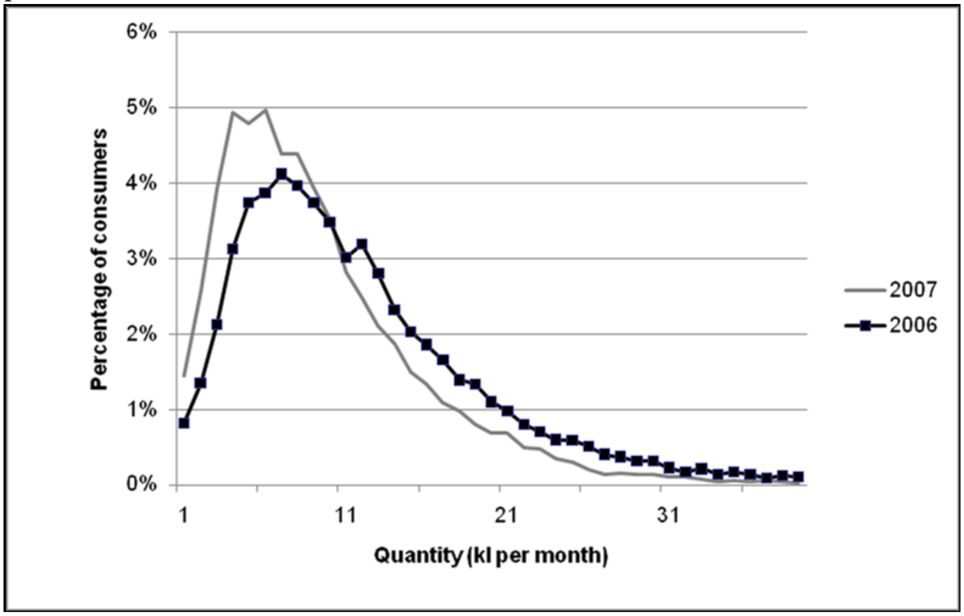
[25]Contrary to a standard demand curve with linear pricing, demand here is measured in terms of the number of customers purchasing the q-th unit at the marginal price p. This function is called a demand profile in the literature.

the price segment and water consumption on that segment. Indeed, Table 2.5 shows that the model used here is able to predict the decrease in consumption. Note however that, under this policy, the average price for consuming less than 27 kl actually decreased (see Figure 2.3). Not surprisingly, as the fifth column shows, a regression where the nonlinear price schedule is proxied by the average prices cannot explain the decrease in consumption following the policy change.

More generally, the findings reported above provide evidence that in the poor South African townships considered here consumers do take into account the nonlinearities in their price schedule, and choose the price segment on which to consume. This is in contrast to the findings of most US studies. For example, Borenstein (2008) writes that "it seems likely that the vast majority of [electricity] customers in California not only do not know what tier their consumption puts them on, but even that the rate structure is tiered at all" (page 25).[26] To the extent that my findings generalize to other developing countries, they have two main implications. First, in these environments, complex pricing schedules may have an impact, and consequently changes in prices or in the amount of free water provided can have substantial welfare effects. Second, future studies analyzing demand under nonlinear price schedules should choose the estimation method tak-

[26]Similarly, Liebman and Zeckhauser (2005) argue that people are likely to fail to perceive the true prices that they face when pricing schedules are complex. In particular, they argue that "schmeduling" is more common in the presence of nonlinear pricing when there is a potential to confuse average and marginal prices.

Figure 2.5: Consumption decrease among indigent households due to the price reduction



ing into account this potential difference between developed and developing countries. In particular, modelling the block choice seems to be especially important in the latter case.

2.6.2 Marginal effects and price elasticities

To interpret the effect of our variables on expected consumption, marginal effects need to be calculated. This is the effect of a unit increase in a given explanatory variable on monthly consumption, holding everything else constant. For dummy variables, it is the effect of a uniform change in the variable (from 0 to 1). Marginal effects can be obtained by recalculating

Table 2.6: Marginal effects

Explanatory variables	*Effect on kl consumed per month*			
	All	Indigent	Non-indigent	Restricted
Price (0.01 Rand / kl)	-0.014	-0.011	-0.015	-0.014
Virtual income (Rand)	0.191	0.155	0.195	0.205
Mean of max daily temperature (F)	0.069	0.056	0.070	0.074
Dummy variables				
Indigent	-3.781	-3.954	-3.759	-4.11
Restricted	0.982	0.804	1.005	1.014
Sanitation	2.126	1.594	2.194	2.261
Area 2	-1.371	-1.056	-1.411	-1.461
Area 3	1.667	1.305	1.713	1.767

the model (optimal consumptions at different marginal prices with the corresponding income and the probability that the consumer will consume on that segment) for a change in each explanatory variable. I calculate household level marginal effects, and then average across households to get the average marginal effect. I do this separately for indigent non-indigent households as well as the restricted group. The results are in Table 2.6.

The magnitudes of the estimates are reasonable. Indigent households consume less on average. Having water-using sanitation increases average monthly consumption by 2.1 kl.

Following the literature, I define the price elasticity under block prices as the percentage change in household consumption resulting from a one percent increase in each price block. Since I have zero prices in the first block in most tariff years, I change those prices from 0 to 1 Rand. The first column of Table 2.7 shows the average household level price elasticities.

Table 2.7: Price elasticities by consumption level

	MLE	OLS	IV
All households	-0.175	1.015	-0.422
Indigent	-0.106	0.997	n/a
Non-indigent	-0.184	1.016	-0.431
Restricted	-0.135	1.078	-0.99

Note: n/a: No significant parameter estimates at conventional levels

Table 2.8: Price elasticities by consumption level

		Price elasticity		
Quartile	Quartile range	MLE	OLS	IV
By household monthly water consumption:				
1-st	1-6	-0.215	-0.042	-0.218
2-nd	7-10	-0.173	0.148	-0.061
3-rd	11-17	-0.162	0.212	-0.120
4-th	18-	-0.140	1.361	n/a

Note: n/a: No significant parameter estimates at conventional levels.

The results show that households respond to price changes, with an average price elasticity of 0.18 percent. Based on the results, indigent households are less price sensitive than high income consumers. It is possible that indigent households have difficulties understanding the price schedule, monitoring their consumption and generally in making changes to their water consumption.

For comparison, the second column of Table 2.7 shows price elasticity estimates from the OLS regression specified in Section 2.3. As can be seen, the OLS estimates cannot capture even the correct sign of the price effect.

Table 2.8 shows price elasticities by consumption level. I find that elasticities are lower for households that use more water. One explanation of this finding is that high consumption is associated with higher income levels where the total expenditure on water is a smaller percentage of household income, and these households are therefore less price sensitive.[27] Alternatively, this finding might be a consequence of the free water allowance. In some years, indigent households consume more water on average, and for them water is free until 12 kl, so the effect of a one percent price change in each segment is softened by the zero prices. When designing an optimal price schedule (see Section 2.6.4), this relationship suggests that welfare may be higher if the marginal price changes are larger for households using more water.

It is difficult to compare the elasticity measures above to previous estimates as studies typically find a wide range of price elasticities. Most differences are due to the different estimation methods employed. For example, Arbues et al. (2003) report reduced-form price elasticity estimates from 65 different studies, ranging from -1.64 to +0.332. Structural estimates of Pint (1999) imply elasticities between -0.04 and -1.24, while Olmstead et al. (2007) find elasticities between -0.589 and -0.330. There are two previous elasticity estimates for developing countries using observed consumption

[27]Studies using US data typically find price elasticities which rise with income. One explanation for this difference is that in South Africa few (if any) households use water on luxury items (e.g., swimming pools) which tend to increase price elasticity in the US.

data: Strand and Walker (2005) find elasticities between -0.1 and -0.3 in Central American cities, and Diakite et al. (2009) report an elasticity of -0.816 using aggregate data from Cote d'Ivoire.

2.6.3 Analyzing the Free Basic Water Policy

The most interesting question from a development perspective is how consumption and expenditure would change in the absence of the free water allowance. One of the difficulties in answering this question is to determine the unobserved positive prices which would replace the zero marginal prices. Fortunately, in the case of Odi Water, this can be done in a straightforward manner. The Free Basic Water Policy is subsidized by the central government. When the utility sets the tariff structure, they report a positive "effective price" for the block with 0 consumer price, and this effective price forms the basis of the rebate received from the central government.

In a counterfactual exercise, I replace zero prices from 2002-2008 with the effective price the utility reports to the government, holding everything else constant.[28] Results are shown in Table 2.9. Note that the change in consumption is computed keeping everything else constant. Specifically, the marginal prices of the different segments were left intact, which also means that the size of the cross-subsidies among different groups of consumers

[28]Note that this counterfactual exercise is different from the actual 2007 policy change where free water was taken away from a large number of households but the rest of the price schedule was also changed substantially.

Table 2.9: Household consumption and expenditure changes

Means per household	All	Indigent	Non-indigent	Restricted
Consumption (kl/month)				
With free water	12.78	12.87	12.10	14.52
Without free water	5.64	9.42	5.50	6.73
Change (%)	-56	-27	-55	-54
Expenditures (Rand/month)				
With free water	40.01	29.77	41.32	47.73
Without free water	22.66	19.68	22.77	24.73
Change (%)	-43	-34	-45	-49

Note: All monetary amounts in constant 2002 Rand. The exercise without free water replaces 0 prices with the effective price the utility reports to the government.

are unchanged. In this counterfactual scenario, consumption decreases substantially. Average consumption is 5.6 kl, which is 56% lower than under the current policy with the free allowance. The decrease in consumption is driven by the change among non-indigent households, whose price elasticity is higher (see Table 2.7).

In this counterfactual experiment, the average consumption of 5.6 kl is just below the WHO recommendation of 6 kl clean water per household. Health concerns associated with insufficient consumption of clean water are particularly relevant in the South African case due to the constant threat of cholera outbreaks. As recently as 2008-09, a cholera outbreak in Zimbabwe, South Africa, Angola and Mozambique killed more than 1,000 people and affected another 32,000.[29] The spread of this disease can be easily constrained with such simple measures as washing hands with clean water after

[29] The Weekender, January 17-18, 2009, p1.

using toilets or before preparing food. It is thus particularly important that the pricing policy ensure that households consume enough clean water, and discourage them from supplementing their water needs by fetching water from contaminated sources such as rivers and streams.

With detailed information on the health risks associated with consuming specific quantities of clean water, it would be possible to quantify the health implications of proposed and actual policies.[30] Clearly, the valuation of these effects, including the externalities associated with any diseases, is important to assess the overall welfare implications of water pricing policies. In this sense the above results regarding the impact of a free water allowance on consumption are a first step towards establishing the social value of free water. In the pricing exercise below, I restrict attention to consumer utility derived directly from water consumption.

2.6.4 Optimal pricing scheme

The previous section suggests that government subsidies are important to raise the consumption of clean water in this setting. But is a free water allowance the best way to provide such a subsidy? To investigate this issue, this section solves the social planner problem introduced in Section 2.5.2.

In this problem, total expected consumer welfare is maximized subject

[30] It should be noted that the 2007 policy change which removed the free allowance for non-indigents also led to a substantial increase in the fraction of households consuming less than 6 kl water (from 27.3 to 37.1%).

Table 2.10: Description of the optimal tariff structures

Optimal tariff	Description
OT 1	Eight-tier tariff. The blocks are the same as in the current price schedule. Same tariff structure for all households. All prices obtained from the optimization problem.
OT 2	OT 1 but $P_1 = 0$ for indigent households.

to a revenue and a capacity constraint. I consider two different optimal tariff structures. The first is an eight-tier tariff structure with the same kink points as in the actual tariff, where all eight prices follow from an optimization problem as in (2.5.5)-(2.5.6). The second structure modifies this benchmark to include the 6 kl free allowance for indigent households, while the other prices follow from the social planner's problem. Table 2.10 summarizes these two cases.[31] For this exercise, I ignore households without sanitation, since they have a separate water schedule without sanitation prices. The calculations below are performed using a random sample of 1000 households.

The resulting optimal tariff structures are shown in Figures 2.6 and 2.7. In contrast to the current tariff structure, the prices in the optimal tariff schedules are lower in the first five blocks and higher in upper blocks. The price difference between blocks is also higher than in the current schedule.

[31] I also ran the optimalization routine assuming price structures where every household receives 6 kiloliters for free. There were no feasible solutions. The reason is that the provider's revenue significantly increased after the 2007 policy change and this increased revenue cannot be guaranted with the reintroduction of free water.

Figure 2.6: Optimal tariff schedules for non-indigent households. All prices are in 2002 Rand

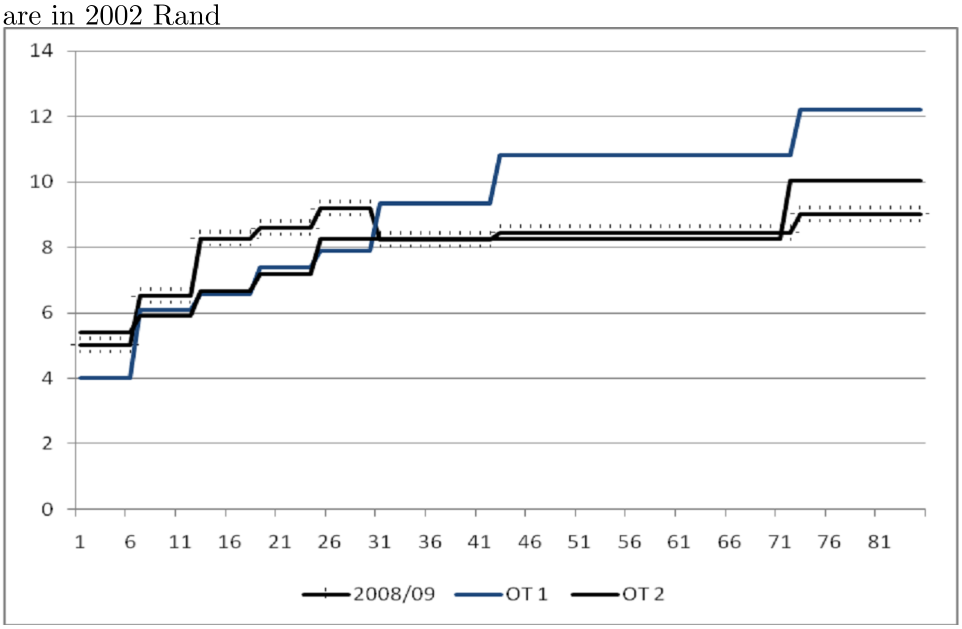


Figure 2.7: Optimal tariff schedules for indigent households. All prices are in 2002 Rand

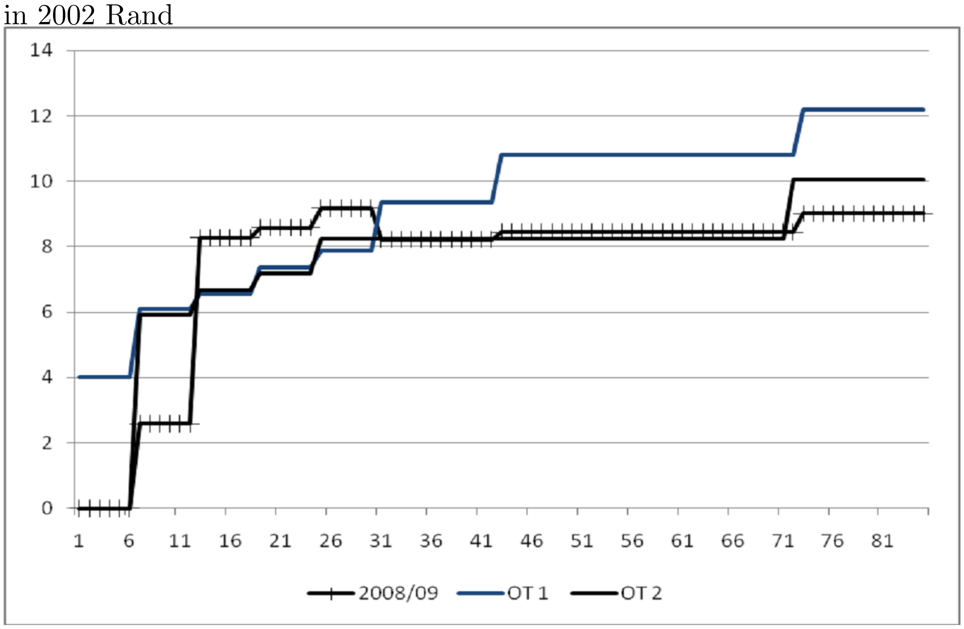


Table 2.11: Consumption under the optimal price schedules

	2008/2009	OT 1	OT 2
Consumption distribution (%)			
0 - 6	31.4	6.5	22.2
7 +	68.6	93.5	77.8
Mean Consumption			
All	7.74	8.8	7.74
Indigent	14.72	6.92	7.95
Non-indigent	6.71	9.07	7.71
Restricted	8.99	9.17	7.98
Non-restricted	7.37	8.68	7.67

Table 2.11 shows the change in mean consumption among different consumer groups under the three different optimal tariff structures. Since the optimization was done under the constraint that total consumption should not exceed the current total consumption, there is little change in the total mean consumption among tariff structures. However, there are large differences in the distribution of consumption. Both OT 1 and OT 2 reduce the proportion of consumers under 6 kiloliters. In particular, under OT 1, only 6.5% of households consume under the WHO-recommended 6 kiloliters despite the fact that the free allowance has been removed. In this price structure, the price for the first 30 kiloliters is lower than under the current tariff. The consumption increase is the consequence of the marginal price decrease on these segments. Relative to OT 1, introducing the free allowance in OT 2 not only reduces welfare, but also raises substantially the proportion of consumers under 6 kl.

I calculate the compensating variation to measure the change in consumers' welfare as a consequence of the introduction of the new tariff structures. Specifically, I calculate the change in a consumer's income that equates utility under the current (2008/09) price schedule and expected utility under the alternate price schedules (OT 1 or OT 2). For example, for two price segments (2.5.7) implies that the compensating variation C is defined implicitly by

$$U_0 = \int_{-\infty}^{\theta_{11}} V_i(P_1, Y + C) dF(\eta_i) + \int_{\theta_{11}}^{\theta_{12}} U_i(\overline{w}_1, Y + C - P_1\overline{w}_1) dF_i(\eta_i) +$$

$$\int_{\theta_{12}}^{\bar{\eta}_i} V_i(P_2, Y_2^0 + C) dF_i(\eta_i),$$

where U_0 is the baseline utility level. A negative value of C indicates that the consumer is better off than under the baseline.

Expenditure changes and the compensating variation are in Table 2.12. Introducing any of the tariff structures would induce substantial expenditure differences among consumers based on consumption level. Under OT 1, indigent households would decrease their consumption, resulting in a lower bill, while non-indigent households would slightly increase their consumption and experience an average increase of 14% in their monthly bill. Average consumer welfare increases under OT 1 and OT 2. Since indigent households currently receive 12 kiloliters of water for free, the welfare change is

Table 2.12: Change in expenditure and utility under the optimal tariff structures

	2008/2009	OT 1	OT 2
Expenditure			
All	35.76	41.04	38.87
Indigent	38.5	29.82	12.72
Non-indigent	35.36	42.69	42.71
Restricted	39.75	43.46	37.47
Non-restricted	34.58	40.32	39.28
Compensating Variation (in 2002 Rand)			
All		-22.14	-10.23
Indigent		28.23	13.73
Non-indigent		-26.28	-16.36
Restricted		-7.80	-1.10
Non-restricted		-22.70	-12.94

negative for them under these optimal price scenarios. Non-indigent households benefit the most under OT 1. The overall compensating variation of 22 Rand per household per month under OT1 corresponds to 5 kiloliters of water and is equal to about 1 percent of household income.

In summary, an optimal tariff structure with no free allowance raises welfare, and substantially lowers the proportion of households under the WHO-recommended 6 kl.

2.7 Conclusion

This paper analyzes the welfare effects of free water using the South African Free Basic Water Policy. It provides the most comprehensive demand estimation with nonlinear prices in the literature on public utilities and derives optimal pricing schedules using the structural estimates. The dataset stands out in quality and coverage among usual datasets used to estimate water demand from developing countries. The 3 million household level observations and the price variation in the period covered allow the precise estimation of the parameters of interest.

The results have three main implications. First, the paper asks how consumption and welfare would change in the absence of free water. As part of a counterfactual exercise, I replace zero prices from 2002-2008 with the effective prices the provider reports to the government, holding everything else constant. I find a substantial decline in consumption, with average consumption below the WHO-recommended level of clean water per household. Considering the potential negative health effects of low water consumption, this result shows the importance of subsidizing water.

Second, I find that the optimal tariff schedule does not contain zero marginal prices, but rather divides the government subsidy more evenly across blocks. The continuously increasing eight-tier tariff structure I derive also reduces the percentage of consumers below 6 kl, improving the situation of those who consume the least water.

Finally, under block prices, economic theory suggests that consumers should take into account the marginal prices on different segments. However, some empirical studies find that consumers respond to average prices or total expenditure rather than marginal prices. My results provide evidence that consumers are rational in their decisions in this setting. This result underscores the importance of estimation methods that are able to capture utility-maximizing behavior and, from a policy perspective, justifies the application of complex price schedules in this setting.

Chapter 3

Input misallocation in developing countries: Missing capital and excess labor in Ghana

3.1 Introduction

It is a well known fact that factor markets are not working efficiently in developing countries and input usage (such as labor and capital) is far from the neoclassical ideal. As a result, output is not produced in the most efficient way possible and resource misallocation is recognized to be a major obstacle to growth. Understanding which types of firms are most likely to be capital constrained is crucial to evaluate the impact of market inefficiency, and would also give valuable insights into how interventions designed to remedy these inefficiencies, such as microfinance programs, should operate. However, only a handful of existing micro-level studies are able to provide direct evidence on the magnitude of these inefficiencies. This paper uses firm level data on interest rates, capital, labor and output from a manufacturing survey in Ghana, 1991-1998. Using direct production function estimates, I investigate the quantified effects of input misallocation, focusing on the misallocation of capital. I also study which types of firms are most likely to be constrained, how much capital would be required to produce the current output level efficiently, and whether labor is used to substitute for the missing capital.

There is a large literature investigating the misallocaiton of capital due to credit constraints in developing countries. One difficulty in identifying credit constraints and quantifying the misallocation for resources is the lack of data. To follow a direct approach by estimating the production function, one would need to have data on input usage and factor prices, including interest rates, at the firm level. The existing literature measuring credit constraints uses indirect approaches to compute the value of the marginal product of capital. Banerjee and Munshi (2004) and Banerjee and Duflo

(2004) use bank data from India. After a bank reform, interest rates decreased substantially. Their identification strategy is based on the idea that unconstrained firms would pay down current loans, while constrained firms might increase investments after the reform. They find that capital markets in India are very far from the neoclassical ideal. The gap between the marginal product of capital and the market interest rate is at least 70 percentage points, and the gap between the marginal product of capital and the rate paid on deposits is even larger. They also find that investors who on average are less productive may invest as much as three times more than their more productive counterparts. A disadvantage of the bank data is that it does not allow for the estimation of an explicit production function. Moreover, this data does not contain information on firms using informal loans or who do not have access to any loans.

De Mel, McKenzie and Woodruff (2009) perform a randomized field experiment in Sri Lanka, giving firms money and in-kind grants of about 100 USD. From this experiment, they estimate an average real return on capital of 55-63 percent per year, which is substantially higher than the market interest rate (which is 12-20 percent). McKenzie and Woodruff (2008) find even higher marginal products of capital (20-33 percent per month, and between 900 and 3000 percent per year) using data from a similar randomized experiment among very small firms in Mexico.

In contrast to the above mentioned studies, I explicitly estimate a production function using the Levinshon and Petrin (2003) (L-P) procedure. The L-P method is appropriate for typical developing country data sets, where investment is zero for many observations and therefore much information would be lost in dropping these, as would be required by the Olley and Pakes (1996) technique. The measure of allocative inefficiencies is based on the parameter estimates of the production function. I measure whether each input is allocated so that its marginal product is equated to its price. I compute the gap between the input price and the value of the marginal product for capital and labor across firms. Wider gaps indicate more serious constraints in the economy.

Describing inefficiencies using parameters of the production function has several other advantages. It allows me to pursue counterfactual exercises, rather than merely reporting the size of the distortion. First, I follow a recent paper by Petrin and Sivadasan (2010) who show that the average absolute value of the gap across firms between the input price and its marginal revenue product equals the average gain in value added if the input is adjusted by one unit in the optimal direction. I compute this average value added gain for the case of Ghanaian manufacturing firms. I attempt to separate the effect of credit market inefficiencies from other factors which may affect the gap for capital.

Second, I consider conditional input demands under the current output, and compute the gap between optimal and currently used input levels. I calculate how much more capital firms would need to operate efficiently, and consider whether firms substitute capital with labor. I compare the results across different firm categories.

I find that adjusting capital by one unit in the optimal direction at every firm, holding all else constant, raises average value added by 0.67-2.55 percent. I also find that 58 percent of the firms in the sample are capital constrained and only 17.6% are labor constrained. Small firms (with less than 10 employees or in the lowest quartile of production) are especially likely to be capital constrained. On average, firms would need to have 4 times more capital and 40 percent less labor to produce the current output level efficiently. Firms with the smallest value added, which are the most capital constrained, substitute capital with labor and operate with the biggest labor excess.

The paper makes several contributions to the existing literature. In the development literature, previous studies argue that credit constraints exist and attempt to estimate the missing capital. However this is the first paper to my knowledge which uses a firm level manufacturing survey, estimates the production function and directly computes the gap between the interest rate and the value of the marginal product of capital. The results are quantitatively similar to previous estimates, which offers a validation of some previously used methods. Furthermore, the direct approach allows me to go beyond previous analyses by considering counterfactual scenarios. This paper is most closely related to Schundeln (2007a) and Schundeln (2007b). In his paper, Schundeln estimates a dynamic model of firm-level investment in the presence of financing constraints. He uses the same dataset and finds that removing the constraints would imply an economically significant increase in investment. However, he includes only formal loans and does not use the observed firm level interest rate data, but rather estimates the cost of credit from the dynamic model. This paper also relates to a group of papers offering direct production function estimates to measure input misallocation (Petrin and Sivadasan, 2010; Hsieh and Klenow, 2009; Restuccia and Rogersion, 2008; Basu and Fernald, 2002). It complements these by focusing on small firms (less than 30 employees) and capital constraints in a developing country.

The remainder of the paper is organized as follows: Section 2 describes the data used in the empirical analysis. Section 3 presents the production function estimation and Section 4 describes the counterfactual exercises. Section 6 presents the results and Section 7 concludes.

3.2 Data

3.2.1 Ghana dataset

The main data source of this study is the Ghanaian Manufacturing Survey from 1991-1997.[1] The survey was conducted by the World Bank and the Centre for the Study of African Economies at Oxford University.[2] The survey includes an extensive list of questions about general firm characteristics and the labor market and financial market activities of the firms. In the first round of the survey, 200 firms were interviewed, and in subsequent rounds new firms were included to replace exiting firms. In five waves, a total of 278 firms were interviewed, which provided about 200 firms per period. In my analysis, I construct an unbalanced panel as follows. I include only firms with less than 30 employees. The reason for this is twofold. First, small firms are more likely to have similar production technologies regardless of the industry. Second, larger firms might have different opportunities to get financing. For similar reasons, I do not include state and foreign owned firms. The sample is restricted further by the availability of the data necessary to estimate the production function. The final sample consists of 664 firm-period observations. Appendix 1 contains the survey questions used in

[1] Other studies using this dataset include Teal (2002), Frazer (2001, 2005, 2007), Schundeln (2007a, 2007b).

[2] Teal (2002) describes the construction of the dataset. The questionnaire and the data is available from http://www.csae.ox.ac.uk/datasets/Ghana-rped/Ghmain.html. The definitions of the variables used in this study are in Appendix 1.

Table 3.1: Summary statistics - Variables used in production function estimation

	Mean	Std. dev	Min	Max	N
Employment	13.31	10.82	1	88	664
Capital	20.35	60.33	0.006	449.82	664
Value added	8.72	22.73	0.003	371.2	664
Material inputs	15.57	48.58	0.006	881.24	664
Wage	0.15				

the analysis and the definitions of the created variables. Summary statistics are given below.

3.2.2 Output, capital and labor data

For the production function estimation I need data on firms' employment, capital and value added. Capital is measured as the replacement value of the stock of plants and equipment. The capital variable is calculated as described in Teal (2002) assuming a 2 percent depreciation rate. The value added is calculated by taking firm output less intermediate inputs and indirect costs, which include rent, utilities and other overheads. For the Levinsohn - Petrin procedure I also need data to estimate the input demand function. I use the total cost of raw material inputs. I have these data for 664 time-firm points. The summary statistics for these variables are in Table 3.1. Values are deflated to 1991 values (indexes are provided by the survey team) and in million Ghanaian Cedis.

Table 3.2 shows the firms' distribution by sector. Because focusing on

Table 3.2: Firms by sector

Sector	N
Foods/Bakery	138 (20.8%)
Furniture/ Wood	159 (23.9%)
Garment/Textile	190 (28.6%)
Machines/Metal	166 (25%)
Other	11 (1.7%)
Total	664

particular sectors would result in a small number of observations, I pool all sectors together. As the Table shows, the four main sectors have similar proportions in the data.

3.2.3 Interest rate and wage data

The interest rate is an important element of the analysis, and three types of interest rates are used to measure the price of capital. In developing countries, such as in Ghana, borrowing can come from many sources including informal sources, such as family and friends. Different lending sources operate with a wide variety of interest rates. First, I use the highest interest rate at which the firm receives a loan from a formal lender (banks or moneylenders). Second, I include loans from informal sources as well. This interest rate therefore corresponds to the highest interest rate at which the firms receives a loan from any source. Third, since only 32 percent of the sample report receiving any type of loan, I assign the risk free deposit interest rate as the price of capital to firms not having any loans.[3] Table 3.3 shows the summary statistics of the interest rate data used.

As discussed in Schundeln (2007a, p. 29-30), wages are difficult to measure from this survey. Many observations are missing, and it is not clear whether firm owners have included a wage for themselves in the reported wage. Schundeln (2007a) compares the wage data from the survey to an alternative source, the Ghana Living Standard Survey (GLSS) and reports that the annual average wage in the survey seems to match the wages reported in the GLSS fairly well. Next, Schundeln (2007a) calculates two candidate values for the wage as the mean of the per capita annual wage paid by firms in the sample in the first year they are observed (restricting the sample to firms that report a positive wage bill). This is 0.15 million 1991 Ghanaian Cedis. Second, he computes the median per capita wage using the full sample which is approximately 0.17 million 1991 Ghanaian Cedis. Based on this, I use 0.15 million Cedis for the wage in the main analysis. As a robustness check, I report the basic results for 0.1 and 0.25 million Ghanaian Cedis as well.

[3] The yearly risk free deposit interest rate data is from the World Deveopment Indicator database and can be downloaded from the World Bank, http://data.worldbank.org/data-catalog/world-development-indicators.

Table 3.3: Summary statistics - Interest rate

	Mean	Std. dev	Min	Max	N
Highest formal interest rate (%)	32.4	10.1	10	50	100
Highest interest rate (%)	17.4	21.5	0	120	207
Highest interest rate with risk free deposit rates (%)	23.3	13.7	0	120	664

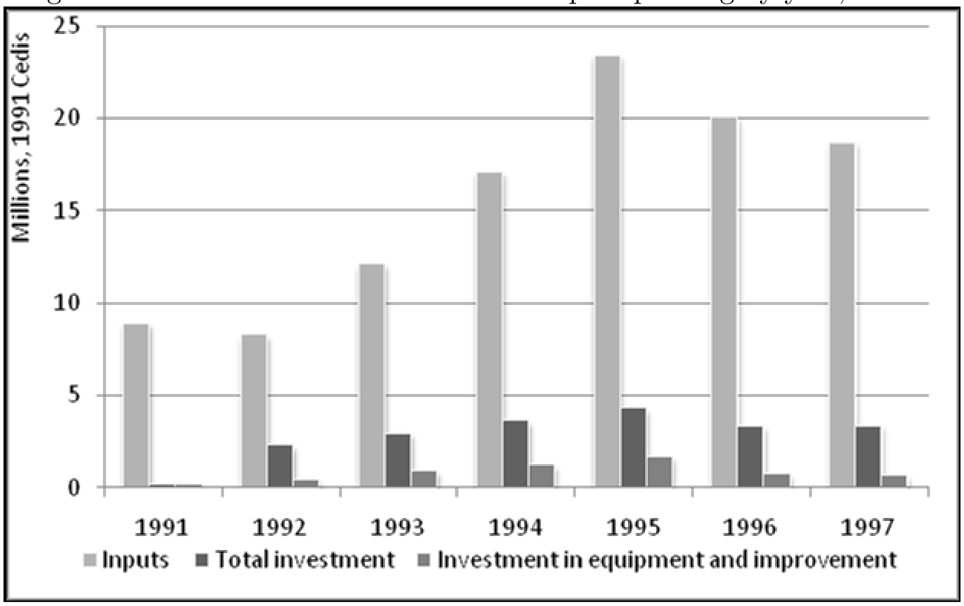
3.3 Production function estimation

The major problem in production function estimation is the simultaneity problem: firms' productivity will be part of the residual of a production function, but will be also correlated with the variable input (such as labor) resulting in biased coefficients on labor and capital. Consequently an OLS estimate of the production function is not valid. This is well recognized and numerous methods are available to handle this simultaneity problem such as in Olley and Pakes (1996), Ackerberg and Caves (2003), Levinshon and Petrin (2003) or Frazer (2004). To handle this simultaneity the residual of the production function is separated into two elements, productivity and a conventional error term, and the productivity term is proxied by a new equation. In Olley and Pakes (1996) an investment equation is used, while Levinsohn and Petrin (2003) use the intermediate input demand. Therefore, to apply the O-P method, I would need to have investment data for each firm. In developing countries firms do not invest regularly, and firms with 0 investment would be dropped from the analysis. In this dataset, every year between 52 and 80 percent of the firms do not report investments above the startup capital. The L-P method, which uses intermediate input data instead of investment is more suitable in this case. To estimate the parameters of the production function, I employ their method. The details of the production function estimation are given below.

One of the assumptions in this estimation procedure is that the input prices are similar among firms. For the present application, this assumption needs to be relaxed, because small firms in Ghana use a variety of financing sources to purchase inputs, including loans from the bank, loans from family, or their own financial assets. Firms using different financing sources effectively face different input prices: for example, if they finance the purchase from bank loans, the corresponding interest rate will increase the price of the intermediate inputs.

The notion that loans are used to purchase inputs may be unfamiliar, as a typical Western firm would use loans mainly for purchasing investment goods. It would deal with liquidity problems using trade credit or other short term business credits, such as overdrafts. By contrast, among small firms in Ghana, investment is not common (see above). At the same time, they accumulate substantial debt which suggests that loans are used to deal with liquidity problems, including the purchase of intermediate inputs. As shown in Figure 3.1, the mean value of intermediate input purchases is on average 22 times higher than the mean value of investment.

Figure 3.1: Investment and intermediate input spending by year, N=664



Since firms that can get lower interest rates are effectively facing lower input prices, the intermediate input demand function without input prices will be inaccurate, which will result in an biased productivity measures. Productivity will be overestimated for firms who can take family loans, and underestimated for firms who have to rely on more expensive formal loans. Input prices are not directly observable in the dataset, and the next section explains how I construct firm-specific input prices. I then describe the L-P estimation method relaxing the common input price assumption.

Table 3.4: Summary statistics - Variables used in interest rate function estimation, Million 1991 Cedis

	Mean	Std. dev	Min	Max	N
Formal loan amount	24.36	46.57	0.017	201	87
Formal interest rate (%)	30.1	11.46	10	50	87
Informal (Family) loan amount	0.998	11.46	0.001	20.98	131
Informal interest rate (%)	2.71	29.18	-100	120	131
Average portfolio interest rate (%)	11.71	27.71	-100	100	185

3.3.1 Calculating the normalized input prices

Since the interest rate will be a substantial part of the input price, I first need to calculate the interest rate on firms' portfolio. Firms use financing from a variety of sources, and some interest rates are not directly observable. In the data, I can observe the loan amount with the interest rate provided by a formal financial institution in a given year. I also have data on the loan amount from various informal sources and the expected repayment (either in 1991 Cedis, or in-kind where the monetary value is given in the survey). Among informal sources, "relatives and close friends" are by far the most common category (over 90% of cases), and this is what I focus on here. I calculate the interest rate for loans coming from family using the loan amount and the expected repayment, and to get the interest rate on the firm's portfolio, I take a weighted average of the formal and informal interest rates, using the relative loan amounts as weights. The summary statistics are in Table 3.

As can be seen from the Table, interest rates on formal and informal loans tend to be very different. As documented in the literature, interest rates from the family are very low, often negative, which means that the loan is not expected to be paid back in full (see, e.g., Banerjee and Munshi, 2004). In my dataset, the median interest rate is zero. This is consistent with the findings in Aryeetey (1998) which show that family members, not having other investment opportunities with a positive interest rate, often provide financial help as a favor. In some cases, even though an investor could get a low positive interest rate on a bank deposit, banks may not be easily accessible, and the monetary and time cost of travel makes a trip to the nearest bank not worthwhile, especially when considering that a future withdrawal would be as difficult as the deposit. As a result, family financing, if available, can substantially lower the interest rate on firms' portfolio.

Denote $DEBT$ a firm's total loans (from formal or informal sources) and $INTEREST$ the average interest rate on its portfolio. After normalizing the market price of inputs (on which I have no data) to 1, I write the input price as follows.

$$PRICE = \begin{cases} 1 \; if \; DEBT \leq 0 \; or \; (DEBT > 0 \; and \; INVESTMENT \geq DEBT) \\ 1 + \left(\frac{INVESTMENT}{DEBT} + \left(1 - \frac{INVESTMENT}{DEBT}\right) \frac{ITEREST}{100}\right) \\ if \; DEBT > 0 \; and \; INVESTMENT < DEBT \\ 1 + \frac{INTEREST}{100} \; if \; DEBT > 0 \; and \; INVESTMENT = 0 \end{cases}$$

Table 3.5: Summary statistics of the PRICE variable

	Mean	Std. dev	Min	Max	N
PRICE	1.038	0.166	0	2.25	497
PRICE conditional on DEBT ¿ 0	1.064	0.231	0	2.2	194
PRICE conditional on DEBT¿0 and INVESTMENT=0	1.086	0.276	0	2.2	109

If the firm does not borrow, or if the investment is bigger than the loan amount, then the firm is assumed to pay the market price (normalized to 1) for the intermediate inputs. This assumes that the firm uses the loan first to purchase investment goods and only the remaining part of the loan is used for purchasing inputs. Similarly, if the firm makes an investment, then only the remaining part of the loan will count toward an increase in the input price. If the firm does not invest, then the firm spends the whole amount of the loan on purchasing intermediate inputs. Table 3.5 shows the summary statistics of the input price variable used in the production function estimation.

3.3.2 Estimation

I follow Levinsohn and Petrin (2003), with the input prices added. Consider a firm with production function given by

$$y_t = \beta_0 + \beta_l l_t + \beta_k k_t + \omega_t + \eta_t,$$

where y_t is value added (gross output net of intermediate inputs), l_t is labor, k_t is capital, and η_t is an error term which is uncorrelated with the firm's input choices. The productivity shock ω_t is assumed to follow a first-order Markov process:

$$\omega_{t+1} = \rho\omega_t + \varepsilon_{t+1},$$

where ε_t is uncorrelated with k_t, but not necessarily with l_t.

The demand for intermediate inputs m_t is assumed to depend on firms' state variables k_t and ω_t, and the price of the inputs, p_t:

$$m_t = m_t(k_t, \omega_t, p_t).$$

Using the assumptions in Olley and Pakes (1996) and in Levinsohn and Petrin (2003), I can invert the intermediate demand function. Appendix 2 shows a version of the proof which includes the price variable. Then ω_t can be written as

$$\omega_t = \omega_t(k_t, m_t, p_t)$$

and substituted into the production function to get

$$\nu_t = \beta_0 + \beta_l l + \beta_k k + \omega_t(k_t, m_t, p_t) + \eta_t$$

Rewriting the production function,

$$\nu_t = \beta_l l + \phi_t(k_t, m_t, p_t) + \eta_t$$

where

$$\phi_t(k_t, m_t, p_t) = \beta_0 + \beta_k k_t + \omega_t(k_t, m_t, p_t).$$

Therefore, I estimate the following system as described in Levinsohn and Petrin (2003),

$$VALUE\ ADDED_t = \beta_l LABOR_t + \phi_t(CAPITAL_t, INPUTS_t, PRICE_t) + \eta_t$$

where

$$\phi_t(k_t, m_t, p_t) = \beta_0 + \beta_k CAPITAL_t + \omega_t(CAPITAL_t, INPUTS_t, PRICE_t).$$

Table 3.6 shows the estimation results. For comparison, I include the results from several estimation methods. The L-P method with prices included somewhat reduced the standard error and increased the significance level as compared to the L-P version without prices. Both production function coefficients are significant at the 5 percent level.

Table 3.6: Production function estimates, N=664

	Coefficient	Std. error	p
Pooled OLS			
α_L	0.514	0.073	0.000
α_K	0.297	0.026	0.000
Random Effects (GLS)			
α_L	0.541	0.087	0.000
α_K	0.289	0.040	0.000
Fixed Effects			
α_L	0.575	0.110	0.000
α_K	-0.085	0.216	0.693
Levinsohn/Petrin[a]			
α_L	0.351	0.083	0.000
α_K	0.319	0.237	0.179
Levinsohn/Petrin with input prices[b]			
α_L	0.339	0.078	0.000
α_K	0.385	0.160	0.017

Notes: [a] L/P estimates are bootstrapped (50 repetitions); Wald test of CRS chi^2 = 4.01
[b] L/P estimates are bootstrapped (50 repetitions); Wald test of CRS chi^2 = 2.10.

3.4 Inefficiencies in the input market

3.4.1 Input misallocation and firm level productivity

After estimating the parameters of the production function, the marginal product of capital multiplied by the firm's output price yields the value of the marginal product of capital, $VMPK_{it}$. Similarly, the marginal value product of labor is given by $VMPL_{it}$. In the absence of constraints, the first order conditions for profit maximization should hold:

$$VMPL_{it} = p\frac{\partial Y_{it}}{\partial L_{it}} = w_t$$

and

$$VMPK_{it} = p\frac{\partial Y_{it}}{\partial K_{it}} = r_{it}$$

where r_{it} is the firm specific interest rate and w_t is the common wage.

In the presence of constraints, the gap between the value of the marginal product and the marginal input price measures the misallocation of inputs:

$$GapK_{it} = |VMPK - r_{it}|$$

$$GapL_{it} = |VMPL - w_t|.$$

In a recent paper, Petrin and Sivadsasan (2010) define input misallocation in a similar way. Inefficiencies can arise from many different sources. Some of these induce lower demand for inputs than would be optimal (for example a tax on capital), so the difference between the value of the input and its marginal product value is positive. On the other hand, some sources of misallocation (e.g., firing costs) lead to higher input usage than would be optimal, resulting in a negative difference. The absolute value of the gap captures both types of allocative inefficiencies. A wider gap corresponds to higher levels of misallocation. Petrin and Sivadsasan (2010) also show that adjusting the input by one unit in the optimal direction at every firm, holding all else constant, leads to an increase in average profitability equal to the absolute value of the gap. Using this connection between the gap and average profits, I compute the potential gain in average profits in the economy.

3.4.2 Missing capital - Excess labor?

Input misallocation can lead to distorted input ratios in the economy. It is well documented that developing countries operate with much higher labor to capital ratios than developed ones. Using the production function parameter estimates, the conditional factor demands can be derived for given output level and factor prices:

$$L^* = Y^{\frac{1}{\alpha+\beta}} \left(\frac{\alpha r}{\beta w}\right)^{\frac{\beta}{\alpha+\beta}} \exp\left(\frac{-\omega}{\alpha+\beta}\right)$$

$$K^* = Y^{\frac{1}{\alpha+\beta}} \left(\frac{\beta w}{\alpha r}\right)^{\frac{\alpha}{\alpha+\beta}} \exp\left(\frac{-\omega}{\alpha+\beta}\right)$$

These expressions can be used to answer the following question: How much capital would firms need to produce the current output with an efficient input-mix? Similarly, how much excess labor do firms use as a result of capital constraints? The answers are given by the following expressions as a fraction of observed input levels

$$MissingK = K^*/K^{observed}$$

$$MissingL = L^*/L^{observed}$$

Note that these expressions hold the factor prices constant. Since increasing the amount of capital available in the economy is likely to reduce its relative price, $MissingK$ is a lower bound on capital needed, while $1/MissingL$ is a lower bound on excess labor.

3.5 Results

3.5.1 Analyzing the gap for capital

Table 3.9 shows the difference between the value of the marginal product of capital and the interest rate. These gaps are presented for three samples: only firms with formal loans (r1), firms with both formal and informal loans

Table 3.7: Gap for capital

		Mean	Std.	Min	Max	N
Lower bound	r1	0.277	0.172	0.012	1.49	100
	r2	0.378	0.743	0.001	8.209	206
	r3	0.446	0.937	0.001	8.969	663
Mean	r1	0.678	1.468	1.408	10.307	100
	r2	1.918	4.828	4.828	53.55	206
	r3	2.559	5.989	5.998	54.553	663
Upper bound	r1	1.245	2.682	0.007	19.123	100
	r2	3.541	8.91	0.006	98.892	206
	r3	4.782	11.019	0.006	100.138	663

Lower and upper bounds are based on the 95% confidence intervals on the parameters.
r1: only formal interest rate
r2: observed interest rate
r3: risk free interest rate added

(r2), and the former with the risk-free interest rate assigned to firms without any form of borrowing (r3). The table also shows the lower and upper bounds of the gap estimates, based on the 95% confidence intervals for the production function parameters. A larger gap corresponds to more inefficient input allocation. Using only the observed interest rates (r2), the mean value of the estimated gap for capital is 0.378, the median is 0.501. The gap is increases with value added: it is 0.32 for the first quartile and 0.71 for the fourth quartile of the distribution of value added (see Appendix 1). The gap is wider for firms using only formal loans. There does not seem to be any important difference across sectors. Since formal interest rates tend to be high, the estimated gaps are smallest for the first sample (r1).

The mean estimated gap of 0.378 corresponds to an average rate of return on capital of about 70 percent. The recent literature in development economics finds similarly high values.[4] Using bank data and an indirect method of computing the value of the marginal product of capital, Banerjee and Duflo (2004) find 74-100 percent per year for India. Udry and Anagol (2006) estimate returns to capital among small agricultural farmers in Ghana, where they find 50-250 percent returns. Kremer at al. (2007) estimate annual returns for rural retail shops in Kenya and find at least 113 percent. Del Mel, McKenzie and Woodruff (2009) implemented a randomized experiment in Sri Lanka, where they gave cash and in-kind grants to small retail firms, which generated an exogenous capital shock. The estimated return to capital was at least 20-33 percent a month.

The studies listed above use different methods to compute the marginal value of capital and none of them uses direct estimates of the production function. Nevertheless, the results are similar. The main advantage of estimating a production function is that it allows one to make counterfactual statements. Petrin and Sivadasan (2010) show that if all firms changed their input demand by one unit in the optimal direction, average profits would increase by the size of the gap. Using their Lemma 1, Table 3.9 can be interpreted as percentage increases in firms' average profit once input changes by one unit in the optimal direction. Not surprisingly, smaller firms,

[4]A good summary of the recent results is in McKenzie and Woodruff (2008).

with no or insufficient formal loans would profit more from a unit increase in capital. Section 3.5.3 discusses this issue further.

3.5.2 Firms with missing capital

Input distortions may emerge from different sources. In developing countries, credit constraints are widely viewed as one of the most important factors causing inefficient capital allocation among firms. Quantifying the distortion due to credit constraints and identifying which firms are most affected by the lack of financing opportunities would give us valuable insights to guide microfinance programs or to adjust the lending structure of the formal banking system. One difficulty however is to separate the effect of improperly working credit markets from any other factor which may affect the gap for capital. This section looks more closely at firms which might be credit constrained, i.e. where the presence of excess capital can be ruled out at the 95% significance level. Table 3.8 shows the fraction of these firms in various categories in the sample.

Firms in Table 3.8 would need to purchase more capital for efficient production. Smaller firms, based on value added or employment, are more likely to have missing capital. 64 percent of the firms with less than 10 employees are capital constrained compared to 37 percent of the firms with more than 20 employees. The results also indicate that the main source of capital constraints is firms not receiving loans at all, rather than firms

Table 3.8: Percentage of firms with less than optimal capital

	Constrained			**N**		
	r1	r2	r3	r1	r2	r3
Sector						
Food/Bakery	0.39	0.44	0.09	56	138	45
Garment/ Textil	0.67	0.47	0.23	69	190	22
Wood/Furniture	0.76	0.47	0.25	38	159	8
Metal/Machinery	0.50	0.36	0.04	40	166	25
Source of financing						
Informal	0.89	0.85		123	131	
Formal	0.14	0.34	0.12	88	84	533
Employment size						
< 10 employees	0.65	0.48	0.11	94	314	37
10 - 20 employees	0.67	0.49	0.19	60	211	26
> 20 employees	0.38	0.27	0.08	53	139	37
Value added						
1 st quartile	0.74	0.35	0.00	47	166	9
2 nd quartile	0.72	0.45	0.18	46	168	17
3 rd quartile	0.62	0.58	0.14	50	166	22
4 th quartile	0.35	0.33	0.12	65	169	52

r1: only formal interest rate
r2: observed interest rate
r3: risk free interest rate added

Table 3.9: Gap for capital among firms with mimssing capital

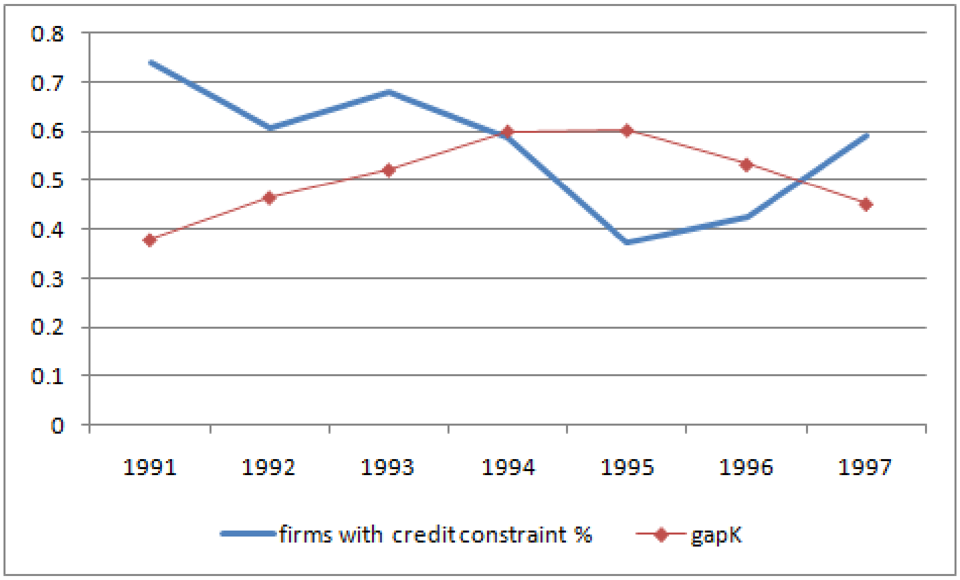
	Mean	Std.	Min	Max	N
Sector					
Food/Bakery	0.41	0.49	0.001	2.29	58
Garment/ Textil	0.49	0.53	0.004	2.49	86
Wood/Furniture	0.48	0.53	0.001	2.97	74
Metal/Machinery	0.53	0.69	0.001	2.95	54
Source of financing					
Informal	0.33	0.48	0.009	2.49	108
Formal	0.60	0.62	0.008	2.99	169
Employment size					
$<$ 10 employees	0.48	0.58	0.001	2.99	140
10 - 20 employees	0.57	0.61	0.015	2.97	100
$>$ 20 employees	0.36	0.51	0.001	2.40	37
Value added					
1 st quartile	0.32	0.50	0.001	2.95	58
2 nd quartile	0.43	0.52	0.001	2.49	70
3 rd quartile	0.51	0.50	0.001	2.29	90
4 th quartile	0.71	0.77	0.005	2.99	61

receiving too little. Among those with formal bank loans, only 14 percent are capital constrained. This reinforces the idea that credit constraints are a major source of missing capital in this sample. Table 3.9 summarizes the size of the gap for firms where this is positive.

It is interesting to plot the fraction of firms with missing capital and the gap for capital over time during Ghana's bank reform which took place in the observed period. Beginning in 1989, Ghana implemented a financial sector reform program. In the first wave of the program (1990-1991), most nonperforming loans were swapped with interest-bearing bonds issued by the Bank of Ghana and guaranteed by the government. A total of 62 billion Cedis worth of nonperforming loans were removed from banks' portfolios. The second wave of the program started in 1992, and focused on increasing competition and efficiency in the system. The World Bank and the IMF continuously provided help with Ghana's macroeconomic transformation. The early banking reforms of Ghana were considered one of the most successful ones in Africa. Macroeconomic and credit market indicators show a considerable improvement during the survey period, 1991-1998. Claims on the private sector, which include gross credit from the financial system to individuals and enterprises (annual growth as percent of M2) increased from -2 to 14 percent. Domestic credit as a percent of GDP increased from 4 percent to 9 percent.[5] The change in the gap over this period is shown on Figure 3.2. The figure shows that by 1995, the percentage of firms with missing capital decreased considerably. At the same time, however, the estimated gap for capital widened. This is consistent with a story where the total capital in the economy changes little, but is reallocated between firms. As a result, more firms are able to get loans, but receive less than would be efficient.

[5]Source: World Development Indicators.

Figure 3.2: Credit constraints and the gap for capital over time



3.5.3 Counterfactual capital and labor

The size of the gaps for capital and labor suggest that firms' current input usage is not optimal. In particular, firms substitute inputs in which they are constrained with inputs that are more readily available.

Table 3.10 shows the average ratios of the optimal and current capital levels. On average, firms would need to have 4 times more capital to produce the current level of output efficiently. The missing capital ratio is higher in industries currently employing more labor, such as Garment and Textile (5.48) and Wood and Furniture (3.89). Since capital is usually purchased from loans, we expect that firms which are more credit constrained have a higher missing capital ratio. In the dataset, firms not receiving any formal

Table 3.10: Counterfactual capital

	N	Mean	Std.	Min	Max
K observed	180	0.72	0.99	0.01	5.63
K*	180	1.84	1.50	0.11	8.09
K*/Kobserved	180	4.01	2.27	0.89	14.33

loans have a 42 percent higher missing capital ratio than firms with access to bank loans.

Based on value added, the smallest firms (first quartile) have a missing capital ratio of 6.28, compared to 2.64 for the largest ones (fourth quartile). This pattern is consistent with earlier studies showing that, in developing countries, the availability of credit is often connected to observed firm characteristics rather than future profitability. For example Bigsten et al. (2003) show that in six African countries firms in the manufacturing sector are more likely to get a bank loan if they are large. They compute a trade-off between profitability and firm size which explains how banks allocate credit to firms. They find that keeping other characteristics constant, a medium firm would need a profitability ratio of 56 percent, but this ratio increases to more than 200 percent for micro firms. My findings are consistent with this type of credit rationing as well.

As shown above, firms' current capital usage is generally below the optimal level. In this case, we expect that firms substitute the scarcely available capital with more abundant labor. Table 3.11 shows the ratio of the cur-

Table 3.11: Counterfactual labor

	N	Mean	Std.	Min	Max
L observed	664	13.31	10.82	1	88
L*	646	8.81	16.32	0	97
L*/L observed	646	0.59	0.82	0	5

rent and the optimal labor. On average, firms would need to use 40% less labor to produce the current level of output efficiently. Industries currently employing the most labor would need to reduce their labor force most dramatically, for example, by 71% in the Garment and Textile industry. Since labor excess is the consequence of capital constraints, we expect that firms with a higher missing capital ratio operate with more excess labor. Data shows that firms receiving formal loans operate with 30% excess labor, compared to 84% for firms using informal sources. Consistently with the size distribution of the missing capital ratios, as value added increases, the size of the excess labor ratio declines. The smallest firms (first quartile) should decrease their employment by 70 percent, while the largest (fourth quartile) would need to hire 8 percent more.

3.6 Conclusion

This paper directly estimates the value of marginal product of capital in Ghana using firm level data. I find that adjusting capital by one unit in the optimal direction at every firm, holding all else constant, raises average value added by 0.67-2.55 percent. I also find that 58 percent of firms in the sample are capital constrained while only 17 percent are labor constrained. The gap between the value of marginal product of capital and its price is 50 percentage points, which indicates that capital allocation is far from the neo-classical benchmark.

On average, firms would need to have 4 times more capital and only 60 percent of their current labor force to efficiently produce the current level of output. The smallest firms (less than 10 employees) operate with the largest capital deficit. Firms with the smallest value added, which are the most capital constrained, substitute capital with labor and operate with the biggest labor excess.

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Chapter 4

Appendix

4.1 Appendix to Chapter 1

4.1.1 Truncation

For a demanded quantity W^*, the utility function in (2.5.1) is quasiconcave around W^* only if

$$\gamma W^* + \alpha < 0.$$

If this fails, demand may not be uniquely defined for a given set of parameter values, and we cannot proceed with the estimation. Assume that demanded quantity falls on segment k: $W^* = w_k^0 + \eta$. Then demand is unique iff $\eta < -w_k^0 - \frac{\alpha}{\gamma}$. To guarantee that this holds for every segment, we require that $\eta < \min_k(-w_k^0) - \frac{\alpha}{\gamma}$. Note that this automatically guarantees that preferences are convex over kink points $\overline{w}_k$ for which $\overline{w}_k < w_l^0$ for all l, i.e., for all the kink points at which the consumer might possibly want to consume. Since w_k^0 differs across billing periods t and consumers i, in practice I impose

$$\eta < \overline{\eta}_i \equiv \min_{tk}(-w_{itk}^0) - \frac{\alpha}{\gamma}. \tag{4.1.1}$$

The truncation point $\overline{\eta}_i$ differs across consumers (but is the same for a consumer in all billing cycles). As is clear from (4.1.1), restricting the distribution of η is the only way to guarantee that demand is uniquely defined for all possible realizations of the data. For example, if η has full support on $(-\infty, +\infty)$, (4.1.1) will fail with positive probability for any $-\frac{\alpha}{\gamma} < \infty$.

There are several options for choosing the distribution of η_i to be consistent with (4.1.1). The most natural extension of the previous literature, and one that makes computation of the likelihood function tractable, is to let η_i be drawn from a truncated normal distribution with truncation point $\overline{\eta}_i$ for each consumer. To economize on the number of parameters to be estimated, I assume that the un-truncated "parent" distribution of η_i is the same for everyone: $N(0, \sigma_\eta^2)$. Denoting ϕ and Φ the standard normal density and cdf, respectively, this yields the following specification of the cdf, pdf, mean and variance of η_i :

$$F_{\eta_i}(x) = \Phi\left(\frac{x}{\sigma_\eta}\right) / \Phi\left(\frac{\overline{\eta}_i}{\sigma_\eta}\right) \text{ if } x < \overline{\eta}_i, \text{ 1 otherwise} \quad (4.1.2)$$

$$f_{\eta_i}(x) = \phi\left(\frac{x}{\sigma_\eta}\right) / \left[\Phi\left(\frac{\overline{\eta}_i}{\sigma_\eta}\right)\sigma_\eta\right] \text{ if } x < \overline{\eta}_i, \text{ 0 otherwise} \quad (4.1.3)$$

$$E(\eta_i) = -\phi\left(\frac{\overline{\eta}_i}{\sigma_\eta}\right) / \left[\Phi\left(\frac{\overline{\eta}_i}{\sigma_\eta}\right)\sigma_\eta\right] \quad (4.1.4)$$

$$Var(\eta_i) = \sigma_\eta^2 \left[1 - \frac{\phi\left(\frac{\overline{\eta}_i}{\sigma_\eta}\right)}{\Phi\left(\frac{\overline{\eta}_i}{\sigma_\eta}\right)} \left(\frac{\overline{\eta}_i}{\sigma_\eta} + \frac{\phi\left(\frac{\overline{\eta}_i}{\sigma_\eta}\right)}{\Phi\left(\frac{\overline{\eta}_i}{\sigma_\eta}\right)}\right)\right] \quad (4.1.5)$$

4.1.2 Likelihood function

Let $\nu = \eta + \varepsilon$ and let F_x and f_x denote, respectively, the cdf and pdf of the random variable x. Based on (2.5.9), for each observed monthly consumption level W, the contribution to the likelihood may be written as

$$\sum_k f_\nu(W - w_k^0)[F_{\eta|\nu=W-w_k^0}(H_k) - F_{\eta|\nu=W-w_k^0}(L_k)] +$$

$$\sum_k f_\varepsilon(W - \bar{w}_k)[F_\eta(h_k) - F_\eta(l_k)]. \quad (4.1.6)$$

The first sum in (4.1.6) is the probability that W is observed given that desired consumption was located on one of the segments $k = 1, 2, ...$ Each term in the sum is the density of ν at $W - w_k^0$ times the probability that desired consumption was located on segment k: H_k and L_k are the upper and lower bounds of η for which this is the case. The second sum is the probability that W is observed given that desired consumption was at one of the kink points $k = 1, 2, ...$ h_k and l_k are the bounds on η corresponding to kink k. The log-likelihood function is the sum, for each observed monthly consumption level W, of the logarithms of the corresponding expressions (4.1.6).

Terms in the second sum in (4.1.6) corresponding to the kink points may be rewritten using (4.1.2) and the fact that

$$f_\varepsilon(W - \bar{w}_k) = \phi(\frac{W - \bar{w}_k}{\sigma_\varepsilon}) \tag{4.1.7}$$

since $\varepsilon \sim N(0, \sigma_\varepsilon^2)$. For the first sum in (4.1.6) corresponding to the segments, we need to find f_ν and $F_{\eta|\nu}$. To find f_ν, use the convolution of f_ε in (4.1.7) and f_η in (4.1.3) to get

$$f_\nu(x) =_{-\infty}^{\overline{\eta}} f_\varepsilon(x - \eta) f_\eta d\eta =_{-\infty}^{\overline{\eta}} \phi(\frac{x - \eta}{\sigma_\varepsilon})\phi(\frac{\eta}{\sigma_\eta})d\eta \frac{1}{\sigma_\eta \Phi(\frac{\bar{\eta}}{\sigma_\eta})}$$

After some algebra, this can be shown to equal

$$\Phi\left(\frac{\bar{\eta}/\sigma_\eta}{\sqrt{1-\rho^2}} - \frac{x}{\sigma_\nu}\frac{\rho}{\sqrt{1-\rho^2}}\right)\frac{\phi(\frac{x}{\sigma_\nu})}{\sigma_\eta \Phi(\frac{\bar{\eta}}{\sigma_\eta})},$$

where $\sigma_\nu = \sqrt{\sigma_\eta^2 + \sigma_\varepsilon^2}$ and $\rho = \frac{\sigma_\eta}{\sigma_v}$.

To find $F_{\eta|\nu}$, use the fact that if for two random variables x_1 and x_2

$$x_1, x_2 \sim N\left[\begin{bmatrix}\mu_1\\ \mu_2\end{bmatrix}, \sum = \begin{bmatrix}\sigma_1^2 & \sigma_{12}\\ \sigma_{12} & \sigma_2^2\end{bmatrix}\right]$$

then

$$x_1|_{x_2=a} \sim N(\overline{\mu}, \overline{\sigma}^2)$$

where

$$\begin{aligned}\overline{\mu} &= \mu_1 + \frac{\sigma_{12}}{\sigma_2^2}(a-\mu_2)\\ \overline{\sigma}^2 &= \sigma_1^2 - \frac{\sigma_{12}^2}{\sigma_2^2}.\end{aligned}$$

Assume for a moment that η is not truncated, i.e. $\eta \sim N(0, \sigma_\eta)$. Since $v = \eta + \varepsilon$, we then have $\eta|\nu \sim N(\rho^2\nu, \sigma_\varepsilon\rho)$. Truncating this distribution at $\bar{\eta}$ gives

$$F_{\eta|\nu}(x) = \Phi\left(\frac{x/\sigma_\eta}{\sqrt{1-\rho^2}} - \frac{\nu}{\sigma_\nu}\frac{\rho}{\sqrt{1-\rho^2}}\right)/\Phi\left(\frac{\bar{\eta}/\sigma_\eta}{\sqrt{1-\rho^2}} - \frac{\nu}{\sigma_\nu}\frac{\rho}{\sqrt{1-\rho^2}}\right).$$

To summarize, for each observed monthly consumption level W, the contribution to the likelihood (4.1.6) is

$$\sum_k \frac{\phi(\frac{W-w_k^0}{\sigma_\nu})}{\sigma_\eta\Phi(\frac{\bar{\eta}}{\sigma_\eta})}\left[\Phi\left(\frac{H_k/\sigma_\eta}{\sqrt{1-\rho^2}} - \frac{W-w_k^0}{\sigma_\nu}\frac{\rho}{\sqrt{1-\rho^2}}\right) -\right.$$

$$\Phi\left(\frac{L_k/\sigma_\eta}{\sqrt{1-\rho^2}} - \frac{W-w_k^0}{\sigma_\nu}\frac{\rho}{\sqrt{1-\rho^2}}\right)$$

$$+\sum_k \frac{\phi(\frac{W-\bar{w}_k}{\sigma_\varepsilon})}{\Phi\left(\frac{\overline{\eta}}{\sigma_\eta}\right)}\left[\Phi\left(\frac{h_k}{\sigma_\eta}\right) - \Phi\left(\frac{l_k}{\sigma_\eta}\right)\right]. \qquad (4.1.8)$$

4.1.3 Expected consumption

Expected consumption can be written as

$$E(W) = \sum_{k=1}^{K}\left(w_k^0 + E(\eta|\eta \in [L_k, H_k])\right)(F_\eta(H_k) - F_\eta(L_k)) +$$

$$\sum_{k=1}^{K-1}\overline{w}_k(F_\eta(h_k) - F_\eta(l_k)),$$

where the first sum is the expected consumption on the segments times the probability that each segment is chosen, and the second sum is each kink times the probability that it is chosen (0 if the kink is concave). These probabilities can be computed using the cdf of η in (4.1.2). The expected value $E(\eta|\eta \in [L_k, H_k])$ is

$$\frac{\phi(L_k/\sigma_\eta) - \phi(H_k/\sigma_\eta)}{\Phi(H_k/\sigma_\eta) - \Phi(L_k/\sigma_\eta)}\sigma_\eta.$$

4.1.4 Estimation procedure

The demand estimation procedure described in Section 2.5 is computationally complex. The following describes the step by step instructions to estimate the demand function in the case of a mixture of increasing and decreasing tariffs. The procedure can be implemented in MATLAB or using similar software.

The following steps should be iterated from initial starting values for the parameters $(\alpha, \gamma, \delta, \sigma_\eta, \sigma_\varepsilon)$ using any minimization procedure until convergence is achieved.

1. Compute the following for each individual:

(a) For each tariff segment k: Y_k^0, $w_k^0 = Z\delta + \alpha P_k + \gamma Y_k^0$, and $\theta_{jk} = \overline{w}_j - w_k^0$, as well as $\bar{\eta} \equiv \min_k(-w_k^0 - \frac{\alpha}{\gamma})$.

(b) *Compare segments to segments.* For each pair of segments i and j : η_{ij}^s which solves $V(P_i, Y_i^0) = V(P_j, Y_j^0)$. Given the functional forms, η_{ij}^s has a closed form solution and is unique.

(c) *Compare convex kink points to convex kink points.* For each pair of convex kink points i and j : η_{ij}^k which solves $U(\overline{w}_i) = U(\overline{w}_j)$. Given the functional forms, η_{ij}^k has a closed form solution and is unique.

(d) *Compare segments to convex kink points.* For each convex kink i and segment $j \neq i \pm 1$: $u_{ij}^L < u_{ij}^U$ which are the two roots of the equation

$U(\overline{w}_i) = V(P_j, Y_j^0)$ in η. Given the functional forms, for given i and j, there are a maximum of two roots which can be computed numerically (no closed form solution).

To make sure that a root exists, I first compute the value of η for which $\partial V/\partial\eta = \partial U/\partial\eta$. Equation $U(\overline{w}_i) = V(P_j, Y_j^0)$ has two roots iff at this value of η, $V_j < U_i$, in which case I proceed to compute the roots numerically starting the search from a sufficiently low or from a sufficiently large starting point. If $V_j > U_i$ for this value of η, then $U(\overline{w}_i) \leq V(P_j, Y_j^0)$.

2. Establish the feasibility conditions for each segment and kink as described in (2.5.9) using θ_{jk} calculated in 1(a).

3. Combine the feasibility and optimality conditions for each segment and kink, as described in Section 2.5.1, by taking the maximum of the lower bounds and the minimum of the upper bounds. Denote these values (L_k, H_k) and (l_k, h_k) for segments and kinks, respectively.

4. Substitute in the likelihood function as described in Appendix 4.1.2.

5. Choose δ, α, γ σ_η and σ_ε to minimize the objective function. Iterate.

4.1.5 Consistency of the MLE

Let $W = (W_1, ..., W_N) \in \Theta$ denote the sequence of observations on the data and let G_N bet the empirical distribution of W. Let $L(b, W)$ denote the the log likelihood function derived in Section 4.1.2, where $b = (\delta, \alpha, \gamma, \sigma_\eta, \sigma_\varepsilon) \in B$ denotes the vector of parameters to be estimated.

Manski (1988, Theorem 2') shows that the maximum likelihood estimator of b is consistent provided the following conditions hold:

Condition 4.1.1 *There is a unique* $b \in B$ *for which* $b = \arg\max_{c \in B} {}_\Theta L(c, W) dG$.

Condition 4.1.2 $L(\cdot, W)$ *is continuous on* B *for all* $W \in \Theta$.

Condition 4.1.3 *There exists an integrable function* $D : \Theta \to [0, \infty)$ *for which* $|L(c, W)| \leq D(W)$ *for all* $(c, W) \in B \times \Theta$.

Condition 4.1.4 B *is compact.*

Condition 4.1.5 *The observations* W_i*,* $i = 1, ..., \infty$ *are independent realizations from* G.

Condition 1 states that the parameters $(\delta, \sigma_\varepsilon, \sigma_\eta)$ are identified. This requires the assumption that the model (hence the conditional densities in the likelihood function) is well-specified. If this holds, as explained in the text σ_ε and σ_η are identified from variation in consumption within and across segments (or kinks). Note that if the distribution of η is well-specified, it contains household-level heterogeneity without incurring an incidental parameters problem. In particular, household-level fixed effects are not estimated.

Condition 2 states that the likelihood function is continuous. In fact, as Manski (1988, Chapter 7.3) shows, this assumption can be relaxed to requiring that points of discontinuity have zero probability. Inspection of (4.1.8) shows that continuity of the likelihood function is satisfied.

Condition 3 is the condition for the Lebesgue dominated convergence theorem. In the standard case when the likelihood function is differentiable, this theorem guarantees that integration and differentiation of the likelihood function can be interchanged, which is used to show that the expected score is zero under the true parameters (e.g., Greene, 2000, p475) An important class of problems for which this condition fails is when the support of the dependent variable depends on the parameters. In my case, this might appear to be a problem because the support of η depends on the parameters due to the assumed truncation. However, note that the dependent variable also contains the optimization error ε which is distributed normally. Thus, the support of W is $(-\infty, +\infty)$ regardless of the parameters.

Finally, Conditions 4 and 5 are conditions on the parameter space and the sample which we assume to hold. Note that this theorem does not require the differentiability of the likelihood function.

4.1.6 Uniqueness of the demanded quantity for any η

As long as preferences are convex, we know that demand exits and is unique for any kinked budget. (More precisely, uniqueness is true 'almost surely', ignoring the case when a convex indifference curve has two tangency points with a non-convex part of the budget. Not to deal with this situation is standard.). This means that demand is unique for any η, and it is either w_1^0, $\overline{w}_1, w_2^0$, or w_3^0, since these are all the possibilities under the specific 3-part budget considered here. The conditions given in (4.1.9) are necessary for each of these cases to obtain.

$$w = \begin{cases} w_1^0 \quad if & \begin{cases} \text{(i) } w_1^0 < \overline{w}_1 \text{ and} \\ \text{(ii) } V(P_1, Y) \geq V(P_3, Y_3^0) \text{ if } w_3^0 > \overline{w}_2. \end{cases} \\ \overline{w}_1 \quad if & \begin{cases} \text{(i) } w_2^0 < \overline{w}_1 < w_1^0 \text{ and} \\ \text{(ii) } U(\overline{w}_1) \geq V(P_3, Y_3^0) \text{ if } w_3^0 > \overline{w}_2. \end{cases} \\ w_2^0 \quad if & \begin{cases} \text{(i) } w_2^0 \in [\overline{w}_1, \overline{w}_2] \text{ and} \\ \text{(ii) } V(P_2, Y_2^0) \geq V(P_3, Y_3^0) \text{ if } w_3^0 > \overline{w}_2. \end{cases} \\ w_3^0 \quad if & \begin{cases} \text{(i) } w_3^0 > \overline{w}_2 \text{ and} \\ \text{(ii) } V(P_1, Y) < V(P_3, Y_3^0) \text{ if } w_1^0 < \overline{w}_1 \text{ and} \\ \text{(ii') } V(P_2, Y_2^0) < V(P_3, Y_3^0) \text{ if } w_2^0 \in [\overline{w}_1, \overline{w}_2] \text{ and} \\ \text{(ii'') } U(\overline{w}_1) < V(P_3, Y_3^0) \text{ if } w_2^0 < \overline{w}_1 < w_1^0. \end{cases} \end{cases} \tag{4.1.9}$$

Each condition has two parts: (i) feasibility (consumption on the budget), and (ii) optimality (higher utility than the 3 other possibilities if they are feasible). In most cases, (ii) can be simplified, as done in (4.1.9). For example, w_1^0 is demanded iff it is feasible and yields higher utility than $\overline{w}_1, w_2^0$ and w_3^0. In this case, feasibility of w_1^0 implies that neither $\overline{w}_1$ nor w_2^0

is feasible, so optimality simplifies to $V(P_1, Y) \geq V(P_3, Y_3^0)$. Clearly, these conditions are mutually exclusive (because of the optimality conditions). Therefore they are also sufficient for each case to obtain.

I now illustrate this with the specific functional forms resulting in (2.5.9). That is, I show that, for any η, (2.5.9) uniquely defines a demanded quantity (without gaps or overlaps). Under convexity, we know that

$$\theta_{11} < \theta_{12} < \theta_{22},$$

where the second inequality follows from $\overline{w}_1 < \overline{w}_2$, and the first from the fact that $w_2^0 - w_1^0 = (P_2 - P_1)(\alpha + \gamma \overline{w}_1) < 0$ since $P_2 > P_1$ and $\alpha + \gamma \overline{w}_1 < 0$ from convexity. We don't know anything about θ_{23}, since w_3^0 can be anywhere on the extended budget constraint with P_3. Thus, there are 4 possible scenarios:

$$\begin{aligned}
\theta_{23} &< \theta_{11} < \theta_{12} < \theta_{22} \\
\theta_{11} &< \theta_{23} < \theta_{12} < \theta_{22} \\
\theta_{11} &< \theta_{23} < \theta_{12} < \theta_{22} \\
\theta_{11} &< \theta_{12} < \theta_{22} < \theta_{23}.
\end{aligned}$$

Consider the first one, and check that, for each possible η (2.5.9) gives exactly one solution (and we can do the same for the other three scenarios). Denote the conditions in (2.5.9) for demand to be on the first segment, the kink, or the two other segments S1, K1, S2 and S3.

When $\theta_{23} < \theta_{11} < \theta_{12} < \theta_{22}$, we have the following possibilities (summarized in Figure 4.1).

If $\eta < \theta_{23}$: Only S1 holds (and since $\theta_{23} < \eta$ does not hold the value of η_{13} is irrelevant). Observed consumption is predicted to be $w_1^0 + \eta + \varepsilon$.

If $\theta_{23} < \eta < \theta_{11}$: First part of S1 and S3 holds. If $\eta < \eta_{13}$, observed consumption is $w_1^0 + \eta + \varepsilon$. If $\eta > \eta_{13}$,observed consumption is $w_3^0 + \eta + \varepsilon$. Note that the second and third "and" in S3 are irrelevant since $\eta < \theta_{11}$.

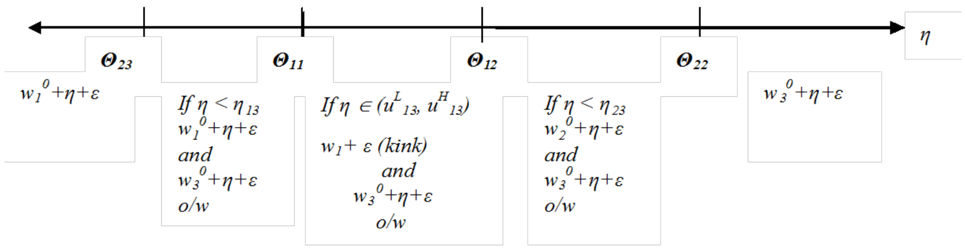
If $\theta_{11} < \eta < \theta_{12}$: First part of K1 and S3 holds. Observed consumption is $\overline{w}_1 + \varepsilon$ if $\eta \in (u_{13}^L, u_{13}^U)$ and $w_3^0 + \eta + \varepsilon$ otherwise. The first and third "and" in S3 are irrelevant.

If $\theta_{12} < \eta < \theta_{22}$: First part of S2 and S3 holds. Observed consumption is $w_2^0 + \eta + \varepsilon$ if $\eta < \eta_{23}$ and $w_3^0 + \eta + \varepsilon$ otherwise. The first and second "and" in S3 are irrelevant.

If $\eta > \theta_{22}$: Only the first part of S3 holds, i.e. $\theta_{23} < \eta$. The other parts of S3 are irrelevant. Observed consumption is $w_3^0 + \eta + \varepsilon$.

Figure 4.1 summarizes the consumer's observed consumption as a function of η for this scenario. The other 3 scenarios can easily be checked in the same way.

Figure 4.1: Uniqueness of the demanded quantity for any η



4.1.7 Reduced form estimates

4.1.8 Data

Table 4.1: Reduced form estimates

	OLS		Fixed effects	
Variable	Parameters	t-value	Parameters	t-value
Indigent	2.281	162.87	3.118	61.02
Restricted	0.68	59.82	-0.819	-57.46
Sanitation	-1.863	-126.95	-5.547	-40.29
Area 2	0.468	32.87	0.501	0.92
Area 3	1.35	137.07	-4.025	-7.26
Avg. max. daily temp.	0.079	115.38	0.081	141.49
Price	3.077	1464.09	2.262	1041.84
N	2,904,366		2,904,366	

	Random effects		IV	
Variable	Parameters	z-value	Parameters	t-value
Indigent	3.069	71.6	-2.68	-123.7
Restricted	-0.661	-47.04	0.919	54.74
Sanitation	-1.773	-33.51	3.912	170.54
Area 2	1.553	26.3	-1.489	-66.95
Area 3	2.737	57.14	1.895	129.56
Avg. max. daily temp.	0.082	142.05	0.099	97.42
Price	2.287	1060.34	-0.807	-135.29
N	2,904,366		2,904,366	

*Note: The dependent variable is monthly consumption in kl.

Table 4.2: Sanitation multiplier, 2002-2008

Water consumption in kl	Sanitation multiplier
0-6	0.98
7-12	0.9
13-18	0.75
19-24	0.6
25-30	0.52
31-42	0.1
42 >	0.01

Figure 4.2: Housing for a typical household in the data

Figure 4.3: Water-using sanitation for a typical household in the data

Table 4.3: Summary statistics, Tariff structure, 2002-2008, 2002 Rand

Variable	Units	Mean	Std. dev.	Min	Max
Marginal price in block 1	kl/R	1.8	3.06	0	7.37
Marginal price in block 2	kl/R	9.35	1.06	3.53	10.1
Marginal price in block 3	kl/R	9.89	1.1	8.55	12.17
Marginal price in block 4	kl/R	9.71	1.48	8.05	12.62
Marginal price in block 5	kl/R	9.62	1.84	7.82	13.5
Marginal price in block 6	kl/R	8.26	2.04	6.34	12.09
Marginal price in block 7	kl/R	8.47	2.19	6.06	12.4
Marginal price in block 8	kl/R	10.06	1.96	7.38	13.26
Water quantity at kink 1	kl	6	0	6	6
Water quantity at kink 2	kl	12	0	12	12
Water quantity at kink 3	kl	18	0	18	18
Water quantity at kink 4	kl	24	0	24	24
Water quantity at kink 5	kl	30	0	30	30
Water quantity at kink 6	kl	42	0	42	42
Water quantity at kink 7	kl	75.72	7.29	72	90

Figure 4.4: Typical sanitation facilities in the sample for households who do not have water using sanitation on their porperties

4.2 Appendix to Chapter 2

4.2.1 Data

Table 4.4: Definition of the variables

All monetary values are included in 1991 Cedis

INVESTMENT	Investment in plant and equipment. It does not include investment in land and buildings.
CAPTIAL STOCK	Imputed replacement value of capital stock of plant and equipment.
INTEREST	Interest rate on the firm's portfolio, which includes loans from formal and informal sources. Created variable, described in part 4. Used for the L-P production function estimation.
r_{Family}	Interest rate on loans from the family. Used in the dynamic estimation. Currently r_{Family}=2.07 which is the sample mean.
r_{Bank}	Interest rate on loans from formal financial institutions. Used in the dynamic estimation. Described in part 5.
$r_{Portfolio}$	Interest rate on the firm's portfolio. Used in the dynamic estimation. Described in part 5.
LABOR	It contains all occupational groups: management, production and support workers and apprentices.
INTERMEDIATE INPUT	Firm's raw material costs plus indirect costs, including rent, utilities and other overheads.
INPUT PRICE	The price of the intermediate inputs. Created variable, described in part 4.
OUTPUT	Value of firm's total production during previous year. Note that where there is a missing observation, output is set as the value of firm's total sales in the previous year. (Following the survey team's suggestion.)
VAD	Value added. Calculated by taking firm output less intermediate inputs and indirect costs.

Table 4.5: Labor constained firms

	Constrained firms %	**N**
Sector		
Food/Bakery	37.0	138
Garment/ Textil	3.1	190
Wood/Furniture	15.1	159
Metal/Machinery	19.9	166
Source of financing		
Informal	9.0	118
Formal	20.0	429
Employment size		
$<$ 10 employees	14.6	314
10 - 20 employees	18.5	211
$>$ 20 employees	23.0	139
Value added		
1 st quartile	0.0	166
2 nd quartile	2.4	168
3 rd quartile	13.9	166
4 th quartile	52.7	169

Table 4.6: Excess labor - Ratio of the current and optimal employment

	Mean	**Std. dev.**	**N**
Sector			
Food/Bakery	0.775	0.987	132
Garment/ Textil	0.299	0.364	190
Wood/Furniture	0.567	0.681	159
Metal/Machinery	0.818	1.016	154
Source of financing			
Informal	0.162	0.513	131
Formal/No financing	0.708	0.854	515
Employment size			
$<$ 10 employees	0.460	0.696	314
10 - 20 employees	0.590	0.801	211
$>$ 20 employees	0.964	1.050	121
Value added			
1 st quartile	0.301	0.535	166
2 nd quartile	0.466	0.743	167
3 rd quartile	0.590	0.748	165
4 th quartile	1.077	1.003	153

Table 4.7: Missing capital - Ratio of the optimal and the current capital stock

	Mean	**Std. dev.**	**N**
Sector			
Food/Bakery	2.876	1.344	40
Garment/ Textil	5.480	2.786	50
Wood/Furniture	3.891	1.903	49
Metal/Machinery	3.429	1.597	39
Source of financing			
Informal and r > 0	5.616	2.657	11
Formal	3.943	1.897	169
Employment size			
< 10 employees	3.608	1.998	90
10 - 20 employees	4.228	2.003	69
> 20 employees	5.085	3.590	21
Value added			
1 st quartile	6.287	2.992	25
2 nd quartile	4.927	2.440	46
3 rd quartile	3.620	1.627	65
4 th quartile	2.641	1.158	46

4.2.2 Notes on interest rates data

The source of all data, including the interest rate data, is the Ghanaian Manufacturing Survey from 1991-1998. The survey was conducted by the World Bank and the Centre for the Study of African Economies at Oxford University in five waves. Teal (2002) describes the construction of the dataset. In the survey, several questions ask about interest rates, Table 4.8 lists all sources used. In general, there are three sources of loans: loans from overdraft facilities, loans from informal borrowing, and loans from informal sources, such as friends and family. In this analysis, I categorize loans from overdraft facilities as formal loans as well. If the firm has multiple loans of the same type, as described in the paper, I take the highest interest rate when computing the gap for capital under the assumption that the highest rate is the marginal price of capital. In a few cases, informal borrowing took place in kind. In this case, I calculated the sum of the loans in cash and in-kind as well as the value expected to be paid back to obtain the corresponding interest rate.

Table 4.8: Source of interest rate data

Wave	Source of loan	Question number
Wave 1	Overdraft facilities	[R37Q02AA- R37Q02AE]
		[R37Q04A- R37Q04E]
	Formal borrowing	[R39Q06AA- R39Q06AE]
		[R39Q07A- R39Q07E]
	Informal borrowing	R44Q06
		R44Q09
		R44Q07
		R44Q10
Wave 2	Overdraft facilities	Z32Q03
		Z32Q04
	Formal borrowing	[Z34Q09A - Z34Q09D]
		[Z34Q11A - Z34Q11D]
	Informal borrowing	[Z38Q05A- Z38Q05F]
		[Z38Q08A- Z38Q08F]
		[Z38Q06A- Z38Q06F]
		[Z38Q09A- Z38Q09F]
Wave 3	Overdraft facilities	L39Q03
		L39Q04
	Formal borrowing	
	Informal borrowing	[L43Q03A- L43Q03G]
		[L43Q04A- L43Q04G]
		L44Q05
		L44Q05P
Wave 4	Overdraft facilities	S9CQ3
		S9CQ4
	Formal borrowing	[S9CQ8A- S9CQ8E]
		[S9CQ10AA- S9CQ10AE]
	Informal borrowing	[S9DQ3A- S9DQ3H]
		[S9DQ4A- S9DQ4H]
		S9DQ5A
		S9DQ5B
Wave 5	Overdraft facilities	F7DQ5A, F7DQ5B
		F7DQ6
		[F7DQ9AA- F7DQ9AE , F7DQ9BA- F7DQ9BE]
	Formal borrowing	[F7DQ12A- F7DQ12E]
	Informal borrowing	[F7FQ3A- F7FQ3H, F7FQ4A- F7FQ4H]
		F7FQ5B
		F7FQ5A

4.2.3 Inversion of the intermediate input demand function

Consider the following production technology

$$Y = f(K, L, m, \omega).$$

The intermediate demand function is given by

$$m = m(K, p, \omega).$$

Assumptions about the production technology

Condition 4.2.1 *Y is twice continuously differentiable in labor (L) and in the intermediate input (m).*

Condition 4.2.2 *$f_{L\omega}$, $f_{m\omega}$ and f_{mL} exist for all values .*

Condition 4.2.3 $f_{mL} f_{L\omega} > f_{LL} f_{m\omega}$

Condition 4.2.4 *Let $\pi(K, L, m, \omega)$ be the profit function of the firm. $\partial\pi(K, L, m, \omega)/\partial K$, $\partial\pi(K, L, m, \omega)/\partial L$ and $\partial\pi(K, L, m, \omega)/\partial m$ are increasing in ω for all values of $(K, L, m, \omega) \in R^4$.*

The last assumption ensures that $\pi(K, L, m, \omega)$ satisfies increasing differences, therefore the Fundamental Theorem of Calculus applies.

Note that since the only new element in the intermediate input demand is the variable input price, the assumptions stated in Pakes (1991) or in Levinsohn and Petrin (2003) are sufficient. The reason is that the input price does not enter the firm's production technology. One slight addition is that invertability requires that the optimal policy should be unique. That is, for a given pair of (K, p), the associated m could only have been generated by a single value of ω.

If the above assumptions hold, and the firm takes input prices and the output price for the homogeneous good as given, then the intermediate input demand function is strictly increasing in ω, and it is invertable.

Proof. Profit maximization by the firm yields the following equations:

$$f_{LL}\frac{\partial L}{\partial \omega} + f_{Lm}\frac{\partial m}{\partial \omega} + f_{L\omega} = 0$$

$$f_{mL}\frac{\partial L}{\partial \omega} + f_{mm}\frac{\partial m}{\partial \omega} + f_{m\omega} = 0$$

Using Cramer's rule, we get

$$\frac{\partial m}{\partial \omega} = \frac{-f_{LL}f_{m\omega} + f_{L\omega}f_{mL}}{f_{LL}f_{mm} - f_{Lm}f_{mL}}$$

By the second-order condition for profit maximization, the denominator is the determinant of a negative semidefinit matrix, which guarantees that

$$sign\frac{\partial m}{\partial \omega} = sign\left(-f_{LL}f_{m\omega} + f_{L\omega}f_{mL}\right)$$

Note that by assumption 3, the RHS is positive. The assumption about the production technology assures that the Fundamental Theorem of Calculus holds:

$$m(p, K, \omega_2) - m(p, K, \omega_1) = \int_{\omega_1}^{\omega_2} \frac{\partial m}{\partial \omega}(p, K, \omega)$$

The RHS is positive, which means that

$$m(p, K, \omega_2) > m(p, K, \omega_1)$$

if $\omega_2 > \omega_1$.