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Keywords: game theory, utility bill payment, water finance, utility policy

JEL Codes: C72 , Q25 , L97

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1 Introduction

Public and private utilities in high-income countries rely substantially, or solely, on tariffs (i.e., user fees) to maintain and expand high-quality services, such as reliable electricity and piped water and sanitation services. When customers pay bills late, accrue debts, or refuse to pay, utilities face a complex challenge. They rely on revenue to service debt and meet ongoing operational expenses, but disconnecting (and reconnecting) customers is financially costly as well as politically and morally fraught. Utility services are widely considered merit goods, and the Sustainable Development Goals include the provision of universal and affordable services in both energy (7.1) and water (6.1) by 2030. The UN has gone further with regard to water access, recognizing access to water as a human right in 2010.[1] Many governments are also wrestling with whether and how to phase out programs implemented during the COVID-19 pandemic to forgive or forbear utility bills, and whether to continue disconnection moratoria.

The experience in many low- and middle-income countries suggests that tolerating high water debts and nonpayment can contribute to a vicious 'low-equilibrium trap': a cycle of insufficient cost recovery resulting in a decrease in the quality of water services, which further diminishes households' incentives to pay their water bills (Singh et al., 1993). Indeed, several studies have found that a major determinant of nonpayment behavior of water and electricity bills in low- and middle-income countries is customer dissatisfaction with the quality of these services (Ben Zaied, Kertous, Ben Cheikh, & Ben Lahouel, 2020; Kayaga, Franceys, & Sansom, 2004; Sualihu & Rahman, 2014; Sualihu, Rahman, & Tofik-Abu, 2017; Vásquez, 2015; Vásquez & Alicea-Planas, 2017). Burgess, Greenstone, Ryan, and Sudarshan (2020) also strike a skeptical note about considering electricity as a right where service is independent of payment, arguing that this has caused widespread nonpayment of electricity bills and service deterioration in developing countries.

Therefore, whether the threat of disconnection is needed to compel on-time payment remains an important and unanswered question. In the literature Coville, Galiani, Gertler, and Yoshida (2020) found that a randomized threat of disconnection was effective in spurring payment among landlords in Nairobi, Kenya. However, disconnection is banned in France, Ireland, and Estonia and can be a lengthy and difficult process in other European countries (WAREG, 2017), yet service levels have not spiraled downwards. Customers in these settings may perceive a moral obligation to pay their utility bills, such that non-payment is akin to a moral tax.

Surprisingly, however, we know of no theoretical models describing the interaction between a utility and its customers.[2] In this paper, we develop a game-theoretic model based on a two-period sequential move game with a representative household and a utility. We use the context of piped water services, but our model is also generalizable to electricity service provision. For simplicity, we leave aside the possibility of prepaid meters (Jack & Smith, 2015) or flow restrictors (Beckett, 2022) and focus on the most

[1] https://www.un.org/waterforlifedecade/human_right_to_water.shtml

[2] Spink (2022) develops a theoretical framework of household water payment decisions set up as an infinite-horizon dynamic optimization problem; however, water disconnection is decided by nature. Murphy, Dinar, Howitt, Rassenti, and Smith (2000) experimentally study the water market in California and Saleth and Dinar (2005) examine different institutional arrangements in the water market. Nonetheless, these papers do not examine the strategic interactions between the utility and the household.

common billing scheme for customers with networked connections around the world: monthly bills paid after consumption has occurred.

Given that many utilities do not disconnect all customers with arrears, the utility's key choice is whether or not to disconnect in expectation since the utility does not know if the household will pay.[3] The household chooses whether or not to pay their bill considering the moral cost of non-payment and the financial cost to reconnect to services. Because alternative public sources of water are common in many cities in the Global South, we also examine changes in the price of these alternative sources in the model. To keep the model tractable, we do not incorporate tariff structure, assuming that the utility charges a single volumetric price. We similarly ignore the role of targeted customer assistance programs and the quality of service.

We show that a decrease in the reconnection levy or moral cost increases the probability of nonpayment, in turn requiring an increased probability of disconnection to induce payment. In contrast, a high moral cost makes a household's payment more likely even when the probability of disconnection is low. Likewise, a large financial or political cost to disconnect the non-paying household decreases the disconnection probability and increases non-payment. Therefore, intense political pressure makes non-payment behavior and non-disconnection more likely. Finally, we show that when the relative price of alternative water sources is high, the household is more likely to pay a bill and the utility is, therefore, able to reduce the threat of disconnection. Hence, contexts in which alternative water sources are too scarce or very difficult to access should induce a higher likelihood of payment. Our model speaks to the broader question of whether utilities need to disconnect non-paying customers at all. The moral tax component of our model might be used to explain situations in countries where disconnections are rare yet most customers do in fact pay their water bills. Utilities may also leverage this moral tax by using low-cost information treatments to "nudge" non-paying customers by making the community's payment norms or behaviors more salient.

The remainder of the paper proceeds as follows. Section 2 develops the theoretical model. Section 3 presents numerical simulations exploring the effect of changes in key variables, such as the price of water sources (municipal and alternative sources), the reconnection fee, and the discount factor. Section 4 concludes with a discussion of the results.

2 Theoretical Framework

We model the interaction between a household and a water utility in a two-stage game. The representative household must decide whether to pay the household's water bill. The utility decides whether to disconnect the service if no payment is received. Because utilities may not disconnect a non-paying household, both agents face uncertainty related to the threat of disconnection and payment. We consider a representative individual consuming water, w, and a numeraire good, x. The utility that a household

[3] Alternatively, some utilities only disconnect households with arrears over a certain threshold, but we are abstracting away from this distinction in the model.

receives from w and x is represented by a quasilinear utility function:

$$u(x, w) = x + \sqrt{w} \tag{1}$$

where $\frac{\partial u}{\partial w} > 0$ and $\frac{\partial^2 u}{\partial w^2} < 0$, thus consumption of water displays diminishing marginal utility. The average price of water is p_w, the price of the numeraire good is normalized to one, and the household's income is M. The water utility has an average total cost of water per cubic meter, c, which is strictly positive. This average total cost would include amortized capital costs and depreciation. Most utilities will face cost-of-service regulation that would limit p_w to near c, perhaps with a rate-of-return of $p_w = 1.07c$ so that the utility only recovers its costs.[4] In this sense, utilities are not maximizing profits but maximizing water deliveries, which can be conceptualized as trying to serve as many customers as possible. When the household pays their bill in full, the utility receives revenue $p_w w$. If the household does not pay their bill, the utility has the option to disconnect and stop providing water. The utility's operational cost of disconnecting a household (for instance, by sending a staff person to the home) is D.

The water utility observes the household's payment decision in the first stage and, if the household chooses not to pay, must decide whether to disconnect the household (Figure 1). This is a simplification: utilities may respond in multiple ways to delinquent households, including reminders, visits, or offers to put households on payment plans. The utility then faces uncertainty about payment in the second period, assigning a probability q to payment and $(1 - q)$ to non-payment, where $q \in [0, 1]$.

The non-paying household knows they is at risk of disconnection but faces uncertainty about whether the utility will implement its disconnection policy. The household e assigns a probability p to disconnection and $(1 - p)$ to the utility keeping them connected, where $p \in [0, 1]$. Disconnection probabilities might be close to one in high-income countries with well-resourced water utilities and relatively few non-paying customers. However, even in these settings, utilities may be constrained by politics (discussed further below). Furthermore, utilities in low- and middle-income countries are likely to face a far higher share of non-paying customers and may lack the resources to promptly disconnect all of them. Based on an analysis of billing data in Nairobi, Kenya for example, roughly half of customers do not pay their water bills in full each month.

In the first stage of Figure 1, a household that pays their bill[5] receives the payoff

$$\pi_h = x + \sqrt{w} - p_w w. \tag{2}$$

The utility receives

$$\pi_u = (p_w - c)w \tag{3}$$

, and the game ends. However, if the household skips payment, the game continues.

[4] In Kenya, for example, the Water Services Regulatory Board (WASREB) regulates water tariffs. They seek to ensure that private water providers' tariff structures balance the competing objectives of access, simplicity, efficiency, conservation, and financial sustainability. The latter includes changes in 'justified costs'. See https://wasreb.go.ke/tariff-guidelines/.

[5] For simplicity, we assume that payments equate to the full amount of the bill without any possibility of making partial payments or carrying a credit forward as a result of over-payment.

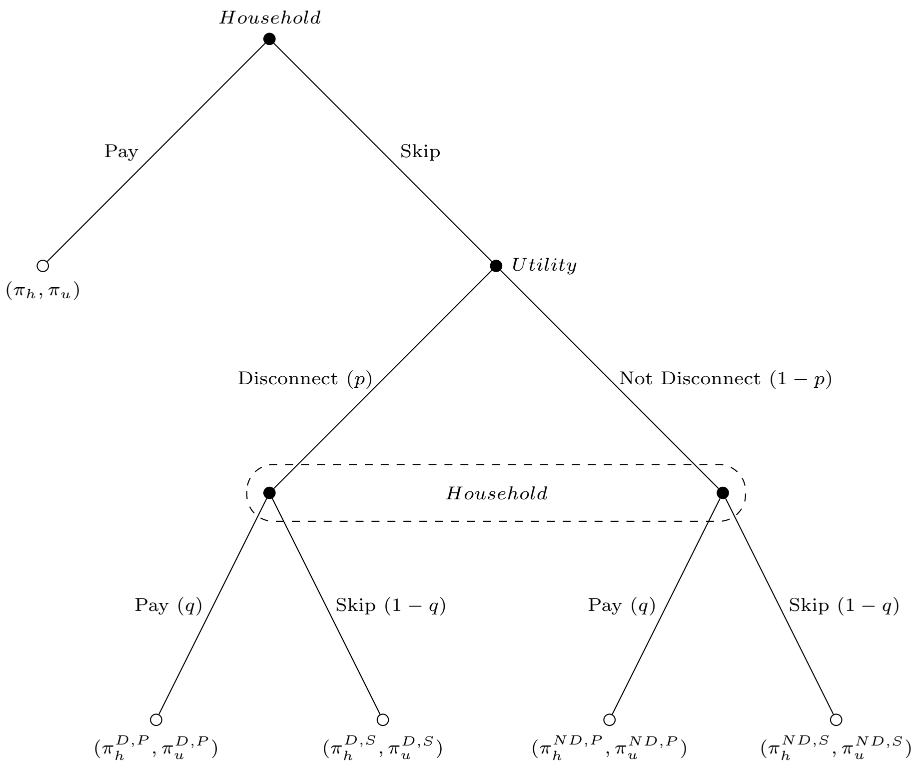


Fig. 1: Bill payment decision tree

The utility now has to decide whether to disconnect the household. If the utility disconnects and the household decides to pay, the household receives a payoff of $\pi_h^{D,P}$ and the utility receives payoff $\pi_u^{D,P}$. If the utility disconnects and the household continues to skip payment, the household and utility receive $\pi_h^{D,S}$ and $\pi_u^{D,S}$, respectively. The payoff notation for the right branch of the tree where the utility chooses not to disconnect simply replaces the D with ND (e.g. $\pi_h^{ND,P}$ is the household's payoff if the utility does not disconnect but the household chooses to pay their bill in the second round).

We consider several costs that arise when the household decides not to pay.[6] First, if the utility disconnects, the household has to procure water z from other sources like public wells, surface sources, or water vendors. We focus on the case where the volumetric price of these alternative water sources is higher, or $p_z > p_w$. The total cost of acquiring water from alternative sources would include the financial volumetric cost of the alternative water, the time and travel costs, and the inconvenience of

[6]One set of costs that we omit for simplicity are interest payments or fees that utilities might charge on late payments. We also do not account for any impact on an individual's creditworthiness resulting from carrying large water debts. This effect is likely minimal for households in developing countries but may be severe in rich countries, where an individual's credit score is essential for any loan application. If utility bills are included in credit scores, non-paying individuals would risk significant damage to their scores.

getting water from outside the house. In most cities in the Global South, the full economic cost of water from the piped system is lower than alternative sources like kiosks and vendors (Thompson et al., 2000; Whittington, Lauria, & Mu, 1991; Zuin et al., 2011).[7] Moreover, in high-income countries, alternative sources of water, like water kiosks or wells, are practically non-existent, so p_z (the price of using bottled water, or collecting water in large tanks and transporting it home) would be much higher than p_w. In addition, the quality of delivered or sourced water would also differ from municipal water, which is typically of a superior quality than alternative sources. If households perceive differences in quality and take action, such as boiling the water before consumption, this would further add to the time cost and inconvenience of using alternative water sources. We ignore quality differences for simplicity. Finally, economic theory suggests that if the price of alternative water is higher than the utility water, the quantity consumed would fall since water is not perfectly inelastic. Nonetheless, for simplification, we assume that the household would consume the same amount of water, w, regardless of its source or price.

We define λ as the moral cost of not paying a bill, where $\lambda \geq 0$. High values represent a setting where there is a high aversion to debt, or where it is considered socially unacceptable for one to fail to pay a bill. Low values would describe a context where non-payment is widespread or where bill non-payment is considered socially acceptable, perhaps because of a perceived right to receive "free" services (Burgess et al., 2020). In some cases, a household may choose to skip their bill in protest, without feeling any shame or moral conflict, implying a $\lambda = 0$.

Next, we assume that if the utility disconnects the household, the household must pay a reconnection fee of f in addition to the arrears A. However, the utility may face a backlash after disconnecting a household which leads to sabotage of infrastructure or weakened political support from regulators who do not wish to see a household disconnected. By allowing a non-paying household to remain connected, the utility prevents this backlash[8] and we therefore model this as a benefit b to keeping a delinquent household connected.

When the household does not pay in the first stage and the utility responds with disconnecting or not, the household has to decide again whether to pay to reconnect and clear their period 1 debt or skip payment and continue to rely on alternative sources to consume z. Each player i's payoff at the end of period 2 is the discounted sum of payoffs, that is $\pi_i = \pi_{i1} + \delta\pi_{i2}$, where $i = h, u$ and δ is the discount factor and $\delta \in [0, 1]$. Hence, if the household decides to pay in period 2 after getting disconnected, their payoff becomes

[7] In Nairobi, Kenya, for example, the price of non-network water is approximately 2-3 times higher than water from the piped network. Using billing data from 2017-2020, the median residential consumer uses approximately 10 cubic meters. At prevailing tariffs, this implies a total bill of Ksh 251, or an average total price of 200 Ksh/m3. In contrast, delivering vendors charge 10-15 Ksh per 20-liter jerrycan or approximately 500-750 Ksh. Water from tankers is somewhat less expensive but still higher than the average price of piped water.

[8] In 2015, protests emerged outside City Hall in Baltimore in response to the Department of Public Works' plan to disconnect 25,000 delinquent customers (Wenger, 2015). Likewise in Tenkanidiyur Gram Panchayat, India, residents protested in front of the water provider, CMC, in response to the disconnection of 150 households (Udupi, 2012).

$$\pi_h^{D,P} = \overbrace{x + \sqrt{w} - \lambda}^{\text{Period 1}} + \delta \overbrace{(x + \sqrt{w} - p_w w - f - A)}^{\text{Period 2}}. \tag{4}$$

However, if the household does not pay following the disconnection, their payoff is

$$\pi_h^{D,S} = x + \sqrt{w} - \lambda + \delta(x + z - p_z z - \lambda). \tag{5}$$

Meanwhile, if the household pays in period 2 after being disconnected, the utility receives

$$\pi_u^{D,P} = -cw - D + \delta(A + f - b + p_w w - cw) \tag{6}$$

where $-cw$ is the cost of providing water in period 1; D is the financial disconnection cost to the utility and $A + f - b + p_w w - cw$ is the payoff in period 2 with the receipt of the unpaid bill, A, the reconnection fee, f, the revenue from water consumption, $p_w w$, minus the cost of providing water, cw, and the loss of the benefit from avoiding sabotage of infrastructure or of some political support, b. If the household does not pay in period 2, the utility's payoff is

$$\pi_u^{D,S} = -cw - D - \delta b. \tag{7}$$

If the utility's response from nonpayment in period 1 is to keep the household connected and the household decides to pay in period 2, the payoff of the household becomes

$$\pi_h^{ND,P} = (x + \sqrt{w} - \lambda) + \delta(x + \sqrt{w} - p_w w - A) \tag{8}$$

and the utility receives

$$\pi_u^{ND,P} = -cw + \delta(p_w w + A + b - cw). \tag{9}$$

Meanwhile, if the household does not pay in period 2 when they were not disconnected in the previous period, their payoff is

$$\pi_h^{ND,S} = (x + \sqrt{w} - \lambda) + \delta(x + \sqrt{w} - \lambda) \tag{10}$$

and the utility gets

$$\pi_u^{ND,S} = -cw + \delta(b - cw). \tag{11}$$

Using backward induction, we derive the conditions under which the household chooses whether to pay their bill after being disconnected (or kept connected) by the utility. We begin by solving the bottom of the game as a normal-form game (Figure 2). This setting is represented as a simultaneous move game since both agents are uncertain about the other's decisions. Recall from Figure 1 that we only reach this game if the household has skipped paying in period 1.

The household decides to pay in the last period if their expected payoff is greater than that of skipping payment, such that,

$$p\pi_h^{D,P} + (1-p)\pi_h^{ND,P} \geq p\pi_h^{D,S} + (1-p)\pi_h^{ND,S}.$$

Utility		**Household**	
		Pay (q)	Skip (1-q)
	Disconnect (p)	$\pi_u^{D,P}$, $\pi_h^{D,P}$	$\pi_u^{D,S}$, $\pi_h^{D,S}$
	Not Disconnect (1-p)	$\pi_u^{ND,P}$, $\pi_h^{ND,P}$	$\pi_u^{ND,S}$, $\pi_h^{ND,S}$

Fig. 2: Household's payment decision in the last period

Substituting the payoffs in Equations 4, 5, 8, and 10, we next present the expected payoffs of the household from paying and skipping their bill in the last period, respectively,

$$\begin{aligned} E(\pi_{pay}) &= p\pi_h^{D,P} + (1-p)\pi_h^{ND,P} \\ &= x + \sqrt{w} - \lambda + \delta(x + \sqrt{w} - A) - p\delta f - \delta p_w w \end{aligned}$$

and

$$\begin{aligned} E(\pi_{skip}) &= p\pi_h^{D,S} + (1-p)\pi_h^{ND,S} \\ &= x + \sqrt{w} - \lambda + \delta(x - \lambda) + p\delta(\sqrt{z} - p_z z) + (1-p)\delta\sqrt{w}. \end{aligned}$$

Hence, the household always pays if and only if $E(\pi_{pay}) \geq E(\pi_{skip})$, which is satisfied when

$$p \geq \frac{A + p_w w - \lambda}{(\sqrt{w} - \sqrt{z} + p_z z - f)}.$$

Therefore, the household pays their bill if the probability of disconnection is sufficiently high. This condition on p becomes more restrictive as the right-hand side figure increases. Hence, the probability p that supports a household's payment becomes more demanding if their debt, A, increases or the price of water, p_w, increases. In addition, if λ, the moral cost increases, the numerator becomes smaller making it easier for the condition to hold. That is, if the household considers not paying their bill but also considers having utility debt as highly immoral, they would be more likely to pay even if the probability of disconnection is low. Similarly, if the reconnection fee, f, is sufficiently high, the utility requires a lower disconnection probability to induce the household to pay.

Using equations 6, 7, 9, and 11, we obtain the following expected payoffs for the water utility from disconnecting and not disconnecting a household, respectively,

$$\begin{aligned} E(\pi_{Disconnect}) &= q\pi_u^{DP} + (1-q)\pi_u^{DS} \\ &= q\delta(A + f + p_w w - cw) - cw - D - \delta b \end{aligned}$$

and

$$E(\pi_{Not\ Disconnect}) = q\pi_u^{NDP} + (1-q)\pi_u^{NDS}$$
$$= q\delta(p_w w + A) - cw + \delta(b - cw).$$

The water utility does not disconnect if and only if $E(\pi_{NotDisconnect}) \geq E(\pi_{Disconnect})$ and solving for q, we obtain,

$$q \geq \frac{\delta(cw - 2b) - D}{\delta(cw - f)}.$$

We summarize the previous results in the following lemma.

Lemma 1. *The mixed strategy Nash Equilibrium (msNE) in the second stage is: the household (utility) randomizes between paying or not paying (disconnecting or not, respectively) if* $p = \frac{A + p_w w - \lambda}{H}$ *and* $q = \frac{\delta(cw-2b)-D}{\delta(cw-f)}$*, which are positive if* $\lambda \in [p_w w + A - H, p_w w + A]$*,* $D \in [\delta(f - 2b), \delta(cw - 2b)]$ *and* $f < cw$*. In addition,* $H = [(\sqrt{w} - f) - (\sqrt{z} - p_z z)]$ *is positive if* $f < p_z z$ *and* p*,* $q \in [0, 1]$*.*

First, H can be interpreted as the household loss in utility from disconnection since it represents the difference in utility from consuming municipal water less the reconnection fee $(\sqrt{w} - f)$ and the utility from consuming alternative water $(\sqrt{z} - p_z z)$. For H to be strictly positive, it requires that $(\sqrt{w} - f) > (\sqrt{z} - p_z z)$. Intuitively, the household values access to the municipal water more than access to the alternative sources. The condition on H being strictly positive is more likely when the reconnection fee, f, is low and the cost of alternative water, p_z, is sufficiently high.

The condition for the household in Lemma 1 requires a certain range of λ and D to guarantee positive probabilities. The acceptable values of the moral cost, λ, depend on the magnitude of H. If H is large, the range of values of λ that satisfies the condition expands. hHowever, if H is small, the acceptable range of λ shrinks, for instance, when $H = 0$, $\lambda = p_w w + A$. Thus, the larger the household loss in utility from disconnection, the more likely it is to reach the msNE of the second stage of the game. Additionally, an increase in the moral cost, λ, reduces the likelihood of the household randomizing between paying or not paying their bill. Hence, in settings where people consider not paying their bills as immoral, the household is more likely to pay. For the utility, the acceptable range of D depends on the cost of water, cw, and the reconnection fee, f. The smaller the reconnection fee, and/or the more costly it is to produce water, the larger the range of values of D that satisfies the condition. However, if providing water is relatively cheap, the reconnection fee has to be very small and as a result, the number of acceptable values of D decreases. If $f = cw$, D is reduced to $D = \delta(cw - 2b)$. Additionally, if the cost of disconnecting households increases, the utility is more likely to keep households connected. Hence, a setting in which it is very difficult to disconnect a household, for instance, due to its geographical location, decreases the probability of disconnection.

Lastly, we examine when the household decides to skip payment in the first period given the responses of the utility and the household in the last period. Hence, we compare the payoffs π_h with the expected payoff $p\pi_h^{D,P} + (1-p)\pi_h^{ND,P}$ evaluated in equilibrium (Lemma 1). We discuss our results in Proposition 1.

Proposition 1. *In the household-water utility game, the household skips payment in the first period if*

$$\lambda < p_w w \quad \text{and} \quad \delta \leq \frac{(p_w w - \lambda)H}{H(A - \sqrt{w} - x + p_w w) + (A + p_w w - \lambda)f}.$$

In the second period, the household and water utility randomize as discussed in Lemma 1.

In the first period, the household skips payment if the discount factor is sufficiently low, meaning that future payoffs are less valued, and the moral cost of having debts is also relatively low. Alternatively, a household would be more likely to pay their bill if they have a high discount factor and see debt as immoral. In the second period, the water utility and the household will randomize between not disconnecting and paying, respectively, if the disconnection cost is relatively high and the household values the municipal water connection and the reconnection fee is sufficiently low.

We next explore four cases based on the level of moral cost to the household from non-payment, λ, and the benefit to the utility from not disconnecting a household, b:

Case I: (λ, b) = (low, low). The equilibrium results are more difficult to reach since the conditions on the probabilities of payment and disconnection become more demanding. Both λ and b, respectively, enter negatively in the conditions on p and q that support Lemma 1. Hence, if the moral cost of not paying and the utility's political benefit from not disconnecting a household are very low, the right-hand sides of the conditions on q and p go up. As a consequence, it becomes less likely that the household pays (utility keeps connection).

Case II: (λ, b) = (low, high). The condition on p that supports household payment becomes more demanding. However, the condition on q that supports connection becomes less demanding. That is, it is less likely to observe payment when the moral cost decreases. However, the utility is more likely to keep households connected since benefits from keeping connection are sufficiently high, making the condition on q less demanding.

Case III: (λ, b) = (high, low). This setting is the opposite of case II. When the moral cost is very high, it becomes more likely that households pay. Meanwhile, the utility is more likely to disconnect with a low benefit.

Case IV: (λ, b) = (high, high). This case indicates that the equilibrium result prescribed in Proposition 1 is very likely to be observed. That is, a high moral cost is more likely to induce payment since the condition on p becomes less demanding. Similarly, a high benefit from not disconnecting induces the utility to keep the household connected since the condition that supports this behavior becomes less demanding (condition on q).

A special case of Proposition 1 arises when the household arrears, A, is defined as just the previous period's water bill, i.e., $A = p_w w$. Hence, in the first stage, the household skips payment if

$$\lambda < p_w w \quad and \quad \delta \leq \frac{(p_w w - \lambda)H}{H(2p_w w - \sqrt{w} - x) + (2p_w w - \lambda)f}.$$

If we consider a positive H, the derivative of the cutoff on δ with respect to p_w is positive if $f > \frac{H(x+\sqrt{w}-2\lambda}{\lambda}$ (see Appendix) indicating that when the reconnection fee is sufficiently high, an increase in the price of water increases the range of values of δ that supports no payment in the first period. In the second period, the household (utility) randomizes between paying or not paying (disconnecting or not) respectively if $p = \frac{2p_w w - \lambda}{H}$ and $q = \frac{\delta(cw-2b)-D}{\delta(cw-f)}$. The condition on q does not change from Lemma 1; however, a positive p requires that $\lambda \in [2p_w w - H, 2p_w w]$ where higher values of H expand the range of λ. Additionally, H is positive if $f < p_z z$, thus the condition now becomes dependent on the price of the water from alternative sources as opposed to the cost of providing the municipal water in the general case. Finally, for both cases, a low reconnection fee increases the likelihood of the household skipping payment in the first stage.

Lemma 2 examines how the results in Proposition 1 are affected by considering optimal consumption of water, $w^* = \frac{1}{4p_w^2}$, and other goods, $x^* = M - \frac{1}{4p_w}$. Similarly, if the household is consuming water from alternative sources, their optimal consumption of water would be $z^* = \frac{1}{4p_z^2}$ and good $x^* = M - \frac{1}{4p_z}$.

Lemma 2. *If the household chooses an optimal consumption of water and other inputs, the household skips payment in the first period if*

$$\delta \leq \frac{(\frac{1}{4}p_w - \lambda)H^*}{H^*(A - M) + (A + \frac{1}{4p_w} - \lambda)f} \tag{12}$$

where $\delta \in [0, 1]$ *and* $H^* = \frac{2p_z - p_w - 4fp_w p_z}{4p_w p_z}$. *In the second period, the household and utility randomize with probabilities*

$$p = \frac{4A + p_w - 4\lambda}{4H^*} \quad and \quad q = \frac{\delta(c - 8bp_w^2) - 4p_w^2 D}{\delta(c - 4p_w^2 f)}$$

where p, $q \in [0, 1]$.

The discount factor δ is positive if $\lambda < \frac{1}{4}p_w$, $f < \frac{2p_z - p_w}{4p_w p_z}$, and $A > M$[9]. Hence, the household skips payment in the first period if the reconnection fee and the moral cost are sufficiently low and the household debt is higher than the household's income. In addition, p is strictly positive if $\lambda < \frac{4A+p_w}{4}$ and $f < \frac{2p_z - p_w}{4p_w p_z}$ and q is positive if $D \in [\delta(f - 2b), \frac{C}{4P_w^2} - 2b]$.

In the next section, we present several numerical simulations considering the case previously discussed in which $A = p_w w$. The condition for the household to skip

[9]The numerator is positive if $\lambda < \frac{1}{4}P_w$ and $f < \frac{2p_z - p_w}{4p_w p_z}$ while the denominator requires that $\lambda < \frac{4A+p_w}{4}$ and $A > M$. Since $A \geq 0$, the more demanding condition is $\lambda < \frac{1}{4}p_w$

payment in the first period becomes

$$\delta \leq \frac{(\frac{1}{4}p_w - \lambda)H^*}{H^*(\frac{1}{4p_w} - M) + (\frac{1}{2p_w} - \lambda)f}. \tag{13}$$

In the second period, the household and utility randomize with probabilities:

$$p = \frac{p_w - 2\lambda}{2H^*} \quad and \quad q = \frac{\delta(c - 8bp_w^2) - 4Dp_w^2}{\delta(c - 4fp_w^2)}$$

where p, $q \in [0, 1]$. The assumption on the arrears, A, only affects the condition on p where positive probability requires that $\lambda < \frac{1}{2}p_w$ and $f < \frac{2p_z - p_w}{4p_w p_z}$.

3 Numerical Simulations

3.1 Effect of changes in the ratio of water prices on household payment behavior

We begin by studying the conditions on p from Lemma 2. As a benchmark, we consider $p_w = 0.5$ and $p_z = 0.75$ or a price ratio of $\frac{p_z}{p_w} = 1.5$, which could be interpreted as the case in which the price of alternative resources is considerably higher than water. Hence, the household skips payment if the reconnection fee is sufficiently low, i.e., $f < 0.67$. Let us consider a reconnection fee of $f = 0.3$. In this case, the probability that supports disconnection in the second period becomes,

$$p = -1.3636(-0.5 + 2\lambda).$$

Figure 3 represents the probability that the utility disconnects, p, on the y-axis and the moral cost, λ, on the x-axis. The area above the line represents the cases in which the expected payoff of the household from paying their bill, $E(\pi_{pay})$, is greater than that from not paying, $E(\pi_{skip})$ (or in other words, this is the case in which the household decides to pay.) We examine how a change in the price ratio impacts household payment , all else being equal. Figure 3 portrays three cases stemming from a range of price ratios. A ratio of $\frac{p_z}{p_w} = 1.04$ ($p_w = 0.5$ and $p_z = 0.52$) representing a case where the price of water from alternative sources is almost the same as the price of municipal water. As the ratio increases to $\frac{p_z}{p_w} = 1.5$ then to $\frac{p_z}{p_w} = 2$ ($p_w = 0.5$ and $p_z = 1$), the alternative water becomes considerably more expensive and/or less accessible. We observe that an increase in the ratio of prices makes payment more likely, as illustrated by the area above the red (for a price ratio of 1.5) or green (for a price ratio of 2) line expanding. When alternative water sources are more expensive and harder to access, the utility can set a lower probability of disconnection without jeopardizing bill payment.

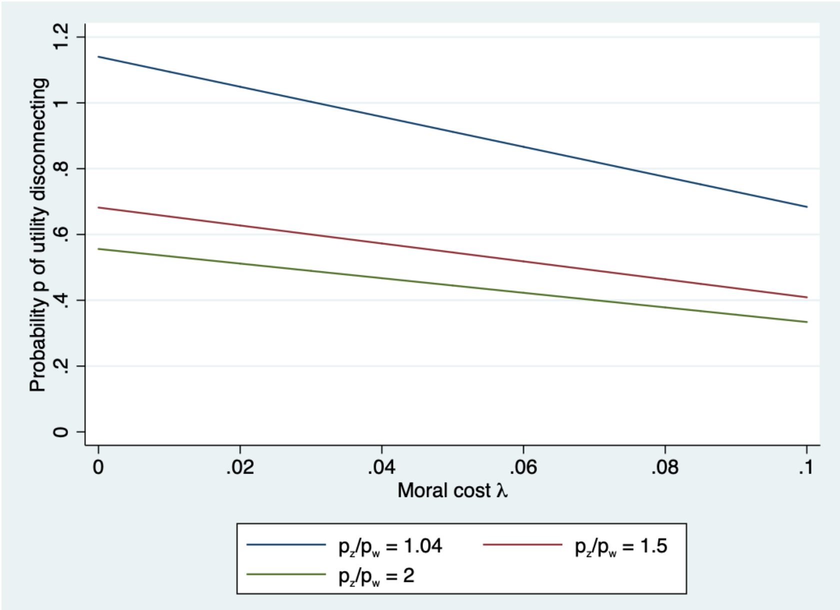


Fig. 3: Household payment behavior with changes in the price ratio

3.2 Changes in the utility's behavior

Following the four cases explored with Proposition 1, we study the effect of changes in the discount factor, water price, and reconnection fee while varying the values of the political benefit b to the utility from keeping a non-paying household connected. We consider a low and a high value of b, $(b^L, b^H) = (0.05, 0.2)$.[10] We examine the conditions on q for the utility that supports keeping the household connected.

Case with $\mathbf{b^L = 0.05}$. The condition on q becomes

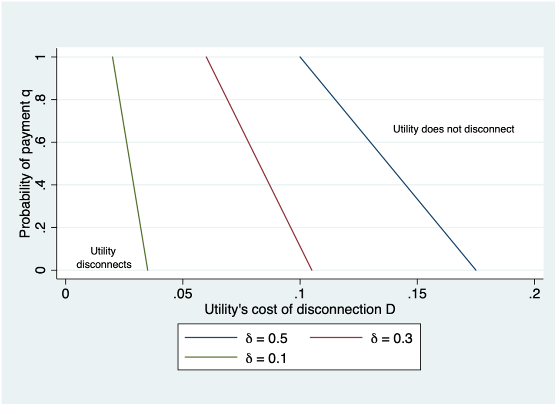
$$q = 2.3333 - 13.3333D.$$

Figure 4a plots the probability q that the household pays their bill on the y-axis and the operational cost of disconnecting D on the x-axis. First, note that the line has a negative slope, indicating that as the cost of disconnection increases, the probability of payment decreases. In addition, a decrease in the discount factor, from 0.5 to 0.3 and 0.1, shifts the line inward and increases the slope of the line. Since the condition on q stems from comparing the utility's payoff from disconnecting and not disconnecting, all pairs of combinations above the line induce the utility to keep the household connected. Thus, at the lowest discount rate of $\delta = 0.1$, incremental

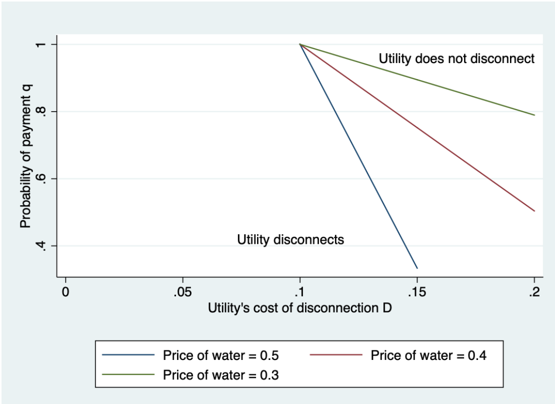
[10] There is an upper bound for b that guarantees a positive probability q, that is $b < \frac{\delta c - 4Dp_w^2}{8\delta p_w^2}$. Considering the following parameter values, $p_w = 0.5$, $f = 0.3$, $p_z = 0.75$, $c = 0.45$, and $\delta = 0.5$, we have that $b < 0.22$ when $D = 0$. If D increases, this upper bound decreases.

increases in the cost of disconnection reduce the probability of payment required for the utility to keep the household connected.

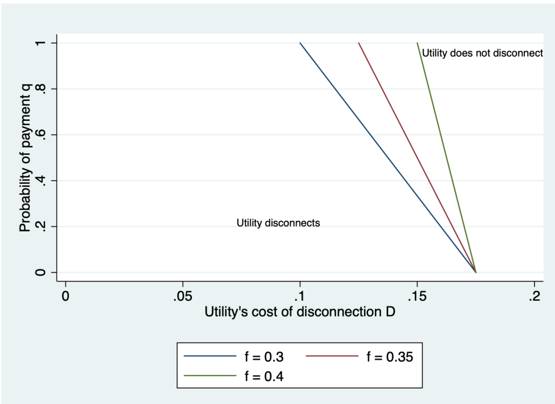
Figure 4b explores the effect of a decrease in the price of water from 0.5 to 0.4 and 0.3 on the utility's behavior. Figure 4c considers an increase in the reconnection fee from 0.3 to 0.35 and 0.4. The effects of the two changes are similar. In both figures, we observe the area that supports the utility not disconnecting the household shrinks as the area above the blue line is larger than the areas above the red and green lines. For the same cost of disconnection D, a decrease in the price of water implies that the utility will disconnect unless the probability of payment is sufficiently high (Figure 4b). Similarly, for the same cost of disconnection, when the reconnection fee increases, the utility will only keep the household connected if the probability of payment is also high.



(a) Decrease in δ



(b) Decrease in p_w



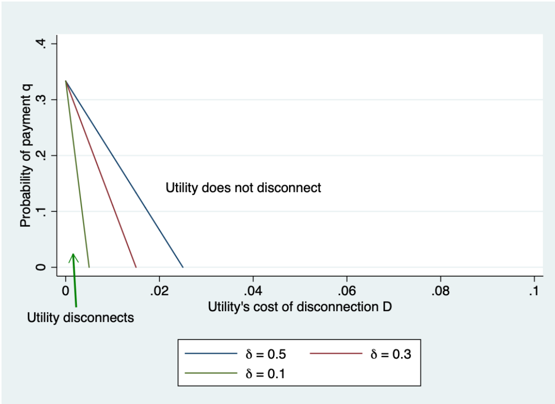
(c) Increase in f

Fig. 4: Effect of changes in δ, p_w, and f on utility with a low b

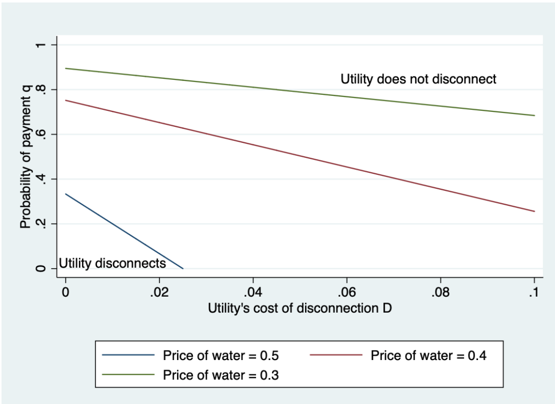
Case with $\mathbf{b^H = 0.20}$. The condition on q becomes

$$q = 0.3333 - 13.3333D.$$

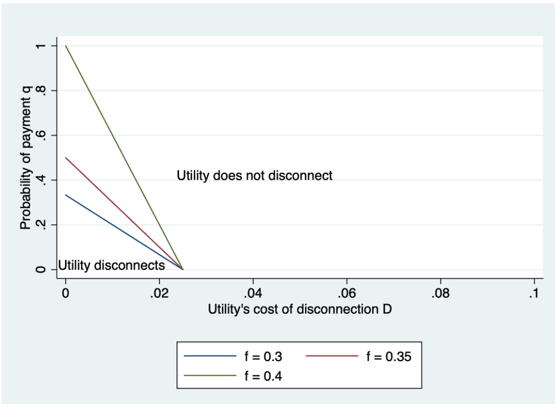
Figure 5a plots the decrease in the discount factor δ to 0.3 and 0.1 for a utility with a high expected benefit from not disconnecting households. A decrease in the discount factor still shifts the line downward, increasing the combinations of values supporting the utility keeping households connected. However, in this scenario, the area supporting not disconnecting households is expanded compared to Figure 4a. As in the previous case, the effects of a price decrease (Figure 5b) and an increase in the reconnection fee (Figure 5c) are similar in reducing the area supporting the utility keeping households connected. Nonetheless, the greater benefit from not disconnecting households increases the pairs of values satisfying the condition for the utility to keep connection as shown in Figures 5b and 5c where lines shifted to the left compared to those with a low benefit.



(a) Decrease in δ



(b) Decrease in p_w



(c) Increase in f

Fig. 5: Effect of changes in δ, p_w, and f on utility with a high b

4 Discussion

We examine a two-stage game that describes the interaction between a utility and a household in the common setting where bills are paid after the utility's services are consumed. In the first stage, the household decides whether to pay their bill. In the second stage, if payment does not ensue, the utility (household) has to decide whether to disconnect (pay, respectively). Our model incorporates several important features of this problem, including the possibility of the household feeling a moral aversion to skipping a bill and the possibility that the utility feels political or moral pressure - given that water is considered a merit good - to keep non-paying customers connected. We simulate various settings changing these two parameters, as well as the relative price of piped water (compared to alternative water sources) and other conventional parameters like the financial cost of disconnecting a household, the reconnection fine levied on the household, and the discount rate.

We show how decreasing the reconnection levy or a lower moral cost of nonpayment increases the probability that the household will not pay, which in turn increases the probability of disconnection to induce payment. Likewise, a higher financial or political cost to disconnect decreases the probability of disconnection, making the settings in which the household chooses non-payment more likely. Finally, we show that when the relative price of alternative water sources is high, the household is more likely to pay a bill and the utility is therefore less likely to disconnect.

Our model could be extended and applied to utility policy in a number of ways. First, our model treats the utility's disconnection probability as an objective parameter that is perfectly observed by all agents. But what matters to the customer is the *perceived* threat of disconnection. Utilities may also be able to convince customers that an increase in the disconnection probability is larger than any actual objective increase by using media and messaging. As described above, Coville et al. (2020) use an information treatment targeting Nairobi landlords that emphasized a real and credible increase in this probability and found that it increased payment substantially.

The perceived disconnection probability can also be affected by the number of disconnections that households actually observe in their social networks. Our model uses only a single representative household in a two-stage game, but a dynamic extension could model how changes in the actual number of disconnections in a neighborhood or social network ripple through to perceived disconnection probabilities over time. This could lead to a "contagion" of nonpayment that would then require a very large and credible increase in disconnection probabilities to reverse. Our model could also be informed by empirical surveys (like Burgess et al. (2020) in electricity) that collect data on households' perceptions of the likelihood that they will be disconnected for nonpayment.

Our model also highlights a possible tension for utilities in the Global South who are trying to protect access for the unconnected poor while extending and improving piped services for connected customers. A common policy recommendation to help the poor is for utilities to provide high-quality network water through a series of public standpipes and kiosks. The volumetric price is often low or even free, though as noted we believe the full economic costs to customers using these kiosks (including the burden of collection time) is still nearly always higher than the volumetric price charged to connected customers. But if the utility makes this network of public sources more widespread and lower cost, this may weaken the relative value for connected customers to pay their bills and maintain their connection.

The model can be generalized to electricity service provision although the effect of certain variables might not be as pronounced due to the inherent differences between water and energy. Since electric supply companies can switch off customers remotely, the cost of disconnecting customers is lower than with water. Given that electric utilities are also more likely to be private companies, they are more likely to disconnect non-paying customers in order to maximize profit. Thus, people would be more likely to pay their electricity bills before their water bills because of the perception of a higher likelihood of disconnection. Similar to the case of water, alternative sources of electricity may not be available or very expensive, increasing the costs to customers if they are disconnected and this would thus promote payment, as illustrated in Figure 3.

Finally, our model speaks to the broader question of whether utilities need to disconnect non-paying customers at all. The moral tax component of our model might be used to explain situations in countries where disconnections are objectively rare yet most customers do in fact pay their water bills. Utilities may also leverage this moral tax by using low-cost information treatments to "nudge" non-paying customers by making the community's payment norms or behaviors more salient.

Expanding access to "safe and affordable" water and sanitation services to meet the Sustainable Development Goals, as well as responding to a changing climate and hydrology, will require massive infrastructure investments in the coming decades. The question of how to finance these investments, including how much to rely on customer-generated tariff revenue, will continue to be a critical policy question. Our model is one step towards a structural understanding of the problem that we hope can inform future empirical efforts.

Statements and Declarations.

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- Competing interests
  The authors declare that they have no financial or non-financial interests directly or indirectly related to this research.
- Ethics approval
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- Consent to participate
  Not applicable.
- Consent for publication
  Not applicable.
- Availability of data and materials
  Not applicable.
- Code availability
  Not applicable.
- Authors' contributions

All authors were involved in the conceptualization of the research. Mary Tiana Randriamaro and Ana Espinola-Arredondo developed the main theory model and all contributed to the writing.

Appendix A Proof of Lemma 1

Let us consider the expected payoffs from payment and no payment as follows. For the household,

$$\begin{aligned} E(\pi_{pay}) &= p\pi_h^{D,P} + (1-p)\pi_h^{ND,P} \\ &= x + \sqrt{w} - \lambda + \delta(x + \sqrt{w} - A) - p\delta f - \delta p_w w \end{aligned}$$

and

$$\begin{aligned} E(\pi_{skip}) &= p\pi_h^{D,S} + (1-p)\pi_h^{ND,S} \\ &= x + \sqrt{w} - \lambda + \delta(x - \lambda) + p\delta(\sqrt{z} - p_z z) + (1-p)\delta\sqrt{w}. \end{aligned}$$

The household always pays if and only if $E(\pi_{pay}) \geq E(\pi_{skip})$:

$$x+\sqrt{w}-\lambda+\delta(x+\sqrt{w}-A)-p\delta f-\delta p_w w \geq x+\sqrt{w}-\lambda+\delta(x-\lambda)+p\delta(\sqrt{z}-p_z z)+(1-p)\delta\sqrt{w}.$$

Solving for p, we obtain

$$\begin{aligned} p &\geq \frac{A + p_w w - \lambda}{(\sqrt{w} - \sqrt{z} + p_z z - f)} \\ p &\geq \frac{A + p_w w - \lambda}{H} \end{aligned}$$

where $H = (\sqrt{w} - f) - (\sqrt{z} - p_z z)$ and $p \in [0,1]$ if $\frac{A+p_w w-\lambda}{H} \geq 0$, which implies that $\lambda \leq A + p_w w$. In addition $\frac{A+p_w w-\lambda}{H} \leq 1$, which implies that $\lambda \geq A + p_w w - H$. Hence, $\lambda \in [A + p_w w - H, A + p_w w]$ and $H > 0$.

For the utility, the expected payoffs are as follows.

$$\begin{aligned} E(\pi_{Disconnect}) &= q\pi_u^{DP} + (1-q)\pi_u^{DS} \\ &= q\delta(A + f + p_w w - cw) - cw - D - \delta b \end{aligned}$$

and

$$\begin{aligned} E(\pi_{Not\ Disconnect}) &= q\pi_u^{NDP} + (1-q)\pi_u^{NDS} \\ &= q\delta(p_w w + A) - cw + \delta(b - cw). \end{aligned}$$

The water utility does not disconnect if and only if $E(\pi_{NotDisconnect}) \geq E(\pi_{Disconnect})$:

$$q\delta(p_w w + A) - cw + \delta(b - cw) \geq q\delta(A + f + p_w w - cw) - cw - D - \delta b.$$

Solving for q, we obtain,

$$q \geq \frac{\delta(cw - 2b) - D}{\delta(cw - f)}.$$

The probability of payment that supports disconnection is $q \geq \frac{\delta(cw-2b)-D}{\delta(cw-f)}$ where $q \in [0, 1]$ if $\frac{\delta(cw-2b)-D}{\delta(cw-f)} \geq 0$, which implies that $D \leq \delta(cw - 2b)$. In addition, $\frac{\delta(cw-2b)-D}{\delta(cw-f)} \leq 1$, which implies that $D \geq \delta(cw - 2b) - \delta(cw - f)$. Hence, $D \in [\delta(cw - 2b) - \delta(cw - f), \delta(cw - 2b)]$ and $f < cw$.

Appendix B Proof of Proposition 1

We next compare the household's payoff in the first stage, π_h, with the expected payoff in the second stage evaluated at $p = \frac{A+p_w w-\lambda}{H}$. That is,

$$\pi_h = x + \sqrt{w} - p_w w$$

and

$$E(\pi_{pay}) = p[x+\sqrt{w}-\lambda+\delta(x+\sqrt{w}-p_w w-f-A)]+(1-p)[x+\sqrt{w}-\lambda+\delta(x+\sqrt{w}-p_w w-A)]$$

Solving for δ, we obtain that $\pi_h \leq E(\pi_{pay})$ if

$$\delta \leq \frac{(p_w w - \lambda)H}{H(A - \sqrt{w} - p_w w) + (A + p_w w - \lambda)f}.$$

Finally, in order to guarantee that the above condition is positive, we have that $\lambda < p_w w$.

When the household arrears, A, is defined as $A = p_w w$, the household skips payment in the first stage if

$$\delta \leq \frac{(p_w w - \lambda)H}{H(p_w w - \sqrt{w} - p_w w) + (p_w w + p_w w - \lambda)f}$$
$$\delta \leq \underbrace{\frac{(p_w w - \lambda)H}{H(2p_w w - \sqrt{w} - x) + (2p_w w - \lambda)f}}_{\text{Cutoff G}}$$

and $\quad \lambda < p_w w$.

Taking the derivative of the cutoff G with respect to p_w, we get

$$\frac{\partial G}{\partial p_w} = \frac{wH(H(2p_w w - \sqrt{w} - x) + (2p_w w - \lambda)f) - (2wH + 2wf)(p_w w - \lambda)H}{[H(2p_w w - \sqrt{w} - x) + (2p_w w - \lambda)f]^2}$$
$$= \frac{wH^2(2\lambda - \sqrt{w} - x) + wHf\lambda}{[H(2p_w w - \sqrt{w} - x) + (2p_w w - \lambda)f]^2}.$$

The denominator is always positive and assuming H is positive, the sign of the derivative depends on $wH^2(2\lambda - \sqrt{w} - x) + wHf\lambda$.

$\frac{\partial G}{\partial p_w} > 0$ if $wH^2(2\lambda - \sqrt{w} - x) + wHf\lambda > 0$, which leads to $f > \frac{H(x+\sqrt{w}-2\lambda)}{\lambda}$. Alternatively, $\frac{\partial G}{\partial p_w} < 0$ if f is sufficiently low, i.e., $f < \frac{H(x+\sqrt{w}-2\lambda)}{\lambda}$.

Appendix C Proof of Lemma 2

Solving the maximization problem of the household given an income, M, and numeraire price of good x, p_x, we get

$$\begin{aligned} \max_{w,\, x} \quad & x + \sqrt{w} \\ \text{s.t.} \quad & p_x x + p_w w \leq M, \\ & x \geq 0, \\ & w \geq 0 \end{aligned} \tag{C1}$$

$$w^* = \frac{1}{4p_w^2} \quad x^* = M - \frac{1}{4p_w}.$$

If the household consumes water from alternative sources, we have

$$\begin{aligned} \max_{z,\, x} \quad & x + \sqrt{z} \\ \text{s.t.} \quad & p_x x + p_z z \leq M, \\ & x \geq 0, \\ & z \geq 0 \end{aligned} \tag{C2}$$

$$z^* = \frac{1}{4p_z^2} \quad x^* = M - \frac{1}{4p_z}.$$

For the household, payment occurs if and only if $E(\pi_{pay}) \geq E(\pi_{skip})$:

$$x{*}+\sqrt{w{*}}-\lambda+\delta(x{*}+\sqrt{w{*}}-A)-p\delta f-\delta p_w w{*} \geq x{*}+\sqrt{w{*}}-\lambda+\delta(x{*}-\lambda)+p\delta(\sqrt{z{*}}-p_z z{*})+(1-p)\delta\sqrt{w{*}}$$

Using the optimal consumption, we obtain

$$M-\frac{1}{4p_w}+\sqrt{\frac{1}{4p_w^2}}-\lambda+\delta(M-\frac{1}{4p_w}+\sqrt{\frac{1}{4p_w^2}}-A)-p\delta f-\delta p_w\sqrt{\frac{1}{4p_w^2}} \geq sqrt\frac{1}{4p_w^2}-\lambda+\delta(M-\frac{1}{4p_w}-\lambda)+$$

$$p\delta(\sqrt{\frac{1}{4p_z^2}} - p_z\frac{1}{4p_z^2} + (1-p)\delta\sqrt{\frac{1}{4p_w^2}}$$

Solving for δ, we obtain

$$\delta \leq \frac{(\frac{1}{4}p_w - \lambda)H^*}{H^*(A-M) + (A + \frac{1}{4p_w} - \lambda)f}$$

where $H^* = [(\sqrt{w^*} - f) - (\sqrt{z^*} - p_z z^*)]$.

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