Online Appendix to
Environmental externalities and free-riding in the household

A.1 Model proofs

Set up

We follow the set up from the main text, which gives the following.

1. Individual water consumption: $w_i = \bar{w}(1-e_i)$, where $\bar{w}$ is the individual satiation level of water use and $e_i \in [0,1]$ is the individual's water conservation effort.
2. Household water consumption: $W = \bar{w}(1-e_i) + \bar{w}(1-e_{-i}) = 2\bar{w}(1 - \frac{(e_i+e_{-i})}{2})$.
3. Individual water conservation cost: $C(e_i, \mu) = ce_i^{\mu}$, with $\mu > 2$.
4. Water prices: Household price of water: $p > 0$. Individual-specific price of water: $P_i > 0$.
5. Household income: Y, with $Y > 2p\bar{w}$.
6. Sharing rule, ex-post division of residual income from water bill: $\lambda_i \in [0,1]$ and $\lambda_i + \lambda_{-i} = 1$.
7. Individuals derive utility from residual income after the water bill is paid, minus the cost of having conserved water: $U = (Y - pW) - ce_i^{\mu}$. In the presence of an individual price for water, this becomes $U = (Y - pW) - ce_i^{\mu} - P_i W$.

Prediction 1

Prediction: $\frac{\partial^2 W^*}{\partial \lambda_i \partial P_i} > 0$, or equivalently, $\left|\frac{\partial W^*}{\partial P_i}\right|$ is decreasing in λ_i. In words, the individual who is not the primary residual claimant (lower λ in the household) is more responsive to changes in the individual-level price.

Proof. Each individual chooses water consumption to maximize individual utility U_i. Individual i takes the effort (best-response function) of her spouse e_{-i} as given so that, after substituting in the effort of her spouse, U_i becomes:

$$\max_{e_i|e_{-i}} \left\{ \lambda_i \left(Y - p \left(2\bar{w} \left(1 - \frac{(e_i + e_{-i})}{2} \right) \right) \right) - ce_i^{\mu} - P_i \left(2\bar{w} \left(1 - \frac{(e_i + e_{-i})}{2} \right) \right) \right\} \quad \text{(A.1)}$$

With U_i twice-differentiable and strictly concave in e_i when $\mu > 1$, the maximization problem (A.1) is concave in e_i and the optimal effort level e_i^* satisfies the FOC

$$\lambda_i p\bar{w} - c\mu(e_i^*)^{\mu-1} + P_i\bar{w} = 0$$

and is given by

$$e_i^* = \left(\frac{\bar{w}}{c\mu}\right)^{\frac{1}{\mu-1}}\Big(\lambda_i p + P_i\Big)^{\frac{1}{\mu-1}} \tag{A.2}$$

which yields optimal water use for individual i:

$$\boxed{w_i^* = \bar{w}\Big(1 - \left(\frac{\bar{w}}{c\mu}\right)^{\frac{1}{\mu-1}}\Big(\lambda_i p + P_i\Big)^{\frac{1}{\mu-1}}\Big)} \tag{A.3}$$

Note that (A.3) gives that individual i's water use does not depend on her spouse's effort level e_{-i}. Since w_{-i} is unaffected by a change in P_i, the response of household aggregate water use W to a change in P_i is the same as the change in w_i.[1] In other words:

$$\frac{\partial W^*}{\partial P_i \partial \lambda_i} = \frac{\partial w_i^*}{\partial P_i \partial \lambda_i} + \frac{\partial w_{-i}^*}{\partial P_i \partial \lambda_i} = \frac{\partial w_i^*}{\partial P_i \partial \lambda_i}. \tag{A.4}$$

Individual i's response to a change in P_i is given by:

$$\frac{\partial w_i^*}{\partial P_i} = \frac{-\bar{w}}{\mu - 1}\left(\frac{\bar{w}}{c\mu}\right)^{\frac{1}{\mu-1}}\Big(\lambda_i p + P_i\Big)^{\frac{2-\mu}{\mu-1}} < 0. \tag{A.5}$$

The effect of λ_i is then obtained by differentiating $\frac{\partial w_i^*}{\partial P_i}$ with respect to λ_i:

$$\frac{\partial^2 w_i^*}{\partial P_i \partial \lambda_i} = \frac{-\bar{w}(2-\mu)p}{(\mu-1)^2}\left(\frac{\bar{w}}{c\mu}\right)^{\frac{1}{\mu-1}}\Big(\lambda_i p + P_i\Big)^{\frac{3-2\mu}{\mu-1}} > 0, \quad \forall\ \mu > 2 \tag{A.6}$$

When $\mu > 2$, as $\lambda_i p + P_i > 0$ the first term is positive, making the cross partial derivative positive. Individual i's price sensitivity decreases (change in consumption is less negative) as her residual claim increases.

□

Prediction 2

Prediction: $\frac{\partial^2 W^*}{\partial|\lambda_i - \lambda_{-i}|\partial p} > 0$, or equivalently, $\left|\frac{\partial W^*}{\partial p}\right|$ is decreasing in $|\lambda_i - \lambda_{-i}|$. In words, households with a smaller difference in λs are more responsive to changes in the household-level price.

[1] We follow the notation in the main text with $W^* = W = w_i^* + w_{-i}^*$.

Proof. From the optimal consumption result in (A.1) and setting $P_i = 0$, individual i's response to a change in p is given by

$$\frac{\partial w_i^*}{\partial p} \leq 0 \tag{A.7}$$

with strict inequality whenever $\lambda_i \in (0, 1)$. By definition, for any $\lambda_i \in [0, 1]$, we have $\lambda_{-i} = 1 - \lambda_i$. So in each household, individual $-i$'s response to a change in p can be expressed as a function of her spouse's residual claim, λ_i:

$$\begin{aligned} \frac{\partial w_{-i}^*}{\partial p} &= \lambda_{-i}^{\frac{1}{\mu-1}} \frac{-\bar{w}^2}{c\mu(\mu-1)} \left(\frac{p\bar{w}}{c\mu}\right)^{\frac{2-\mu}{\mu-1}} \\ &= (1-\lambda_i)^{\frac{1}{\mu-1}} \frac{-\bar{w}^2}{c\mu(\mu-1)} \left(\frac{p\bar{w}}{c\mu}\right)^{\frac{2-\mu}{\mu-1}} \leq 0 \end{aligned} \tag{A.8}$$

where the inequality is again strict when $\lambda_i \neq 1$. Equations (A.7) and (A.8) lead to the following cross-partial derivatives with respect to λ_i and p:

$$\frac{\partial^2 w_i^*}{\partial p \partial \lambda_i} = \lambda_i^{\frac{2-\mu}{\mu-1}} \frac{-\bar{w}^2}{c\mu(\mu-1)^2} \left(\frac{p\bar{w}}{c\mu}\right)^{\frac{2-\mu}{\mu-1}} < 0, \quad \forall\ \lambda_i \in [0, 1],\ \mu > 2 \tag{A.9}$$

$$\frac{\partial^2 w_{-i}^*}{\partial p \partial \lambda_i} = (1-\lambda_i)^{\frac{2-\mu}{\mu-1}} \frac{\bar{w}^2}{c\mu(\mu-1)^2} \left(\frac{p\bar{w}}{c\mu}\right)^{\frac{2-\mu}{\mu-1}} > 0, \quad \forall\ \lambda_i \in [0, 1],\ \mu > 2 \tag{A.10}$$

Notice that (A.9) and (A.10) have opposite signs. This is because when the residual claim of one spouse increases, the other's must decrease; when λ_i rises, λ_{-i} must fall by the same amount.

The household's *aggregate* price sensitivity is the sum of both individuals' price sensitivities. Thus, the effect of a change in λ_i on the household's price sensitivity is given by:

$$\begin{aligned} \frac{\partial^2 W^*}{\partial p \partial \lambda_i} &= \frac{\partial^2 w_i^*}{\partial p \partial \lambda_i} + \frac{\partial^2 w_{-i}^*}{\partial p \partial \lambda_i} \\ &= (A.9) + (A.10) = \frac{\bar{w}^2}{c\mu(\mu-1)^2} \left(\frac{p\bar{w}}{c\mu}\right)^{\frac{2-\mu}{\mu-1}} \left((1-\lambda_i)^{\frac{2-\mu}{\mu-1}} - \lambda_i^{\frac{2-\mu}{\mu-1}} \right) \\ &> 0, \quad \forall\ \lambda_i \in (1/2, 1],\ \mu > 2 \end{aligned} \tag{A.11}$$

□

Intuition. For $\lambda_i > 1/2$, an increase in λ_i reflects an increase in the absolute value of the difference between λ_i and λ_{-i}. When the spouse with a higher residual claim increases her λ_i, the household's residual claim shares become less equal, and aggregate price sensitivity declines (becomes less negative).

Comparison of individual-level to household-level price changes

Corollary: $\left|\frac{\partial W^*}{\partial P_i}\right|_{\lambda_i \in (\frac{1}{2},1)} < \left|\frac{\partial W^*}{\partial p}\right| < \left|\frac{\partial W^*}{\partial P_i}\right|_{\lambda_i \in (0,\frac{1}{2})}$. In words, the effect of a change in the household-level price falls between the effect of the individual-level price directed to the individual with the smaller claim and the individual with the larger claim on savings on the household water bill. This holds for all $0 \le P_i < p$.

To compare the effects of a change in the household-level price to a change in the individual-level price, we calculate the difference (in levels) in total household water consumption after (i) a marginal increase in the household-level price p experienced by both spouses and (ii) a marginal increase in P_i experienced by either the high residual claimant (High-RC, $\lambda_i > 1/2$) or low residual claimant (Low-RC, $\lambda_i < 1/2$) spouse.

For a marginal change in the household or individual price, a bigger change in levels implies greater price sensitivity.

The household's aggregate response to a change in the price faced by both spouses, p, is given by:

$$\frac{\partial W^*}{\partial p} = \frac{\partial w_i^*}{\partial p} + \frac{\partial w_{-i}^*}{\partial p} = \frac{-\bar{w}}{(\mu-1)}\left(\frac{\bar{w}}{c\mu}\right)^{\frac{1}{\mu-1}} p^{\frac{2-\mu}{\mu-1}}\left(\lambda_i^{\frac{1}{\mu-1}} + (1-\lambda_i)^{\frac{1}{\mu-1}}\right). \tag{A.12}$$

The household's aggregate response to a change in the individual price, $\frac{\partial W^*}{\partial P_i}$, is given by (A.5).

We compare consumption levels as the difference between the aggregate use after a marginal change in the household price, W^{*p}, and the aggregate use after a marginal change in the individual price, W^{*P_i}.

$$\begin{aligned}
W^{*p} - W^{*P_i} &= \Big(w_i^* + w_{-i}^* + \frac{\partial w_i^*}{\partial p} + \frac{\partial w_{-i}^*}{\partial p}\Big) - \Big(w_i^* + w_{-i}^* + \frac{\partial w_i^*}{\partial P_i}\Big) \\
&= \Big(\frac{\partial w_i^*}{\partial p} + \frac{\partial w_{-i}^*}{\partial p}\Big) - \frac{\partial w_i^{'*}}{\partial P_i} = \text{(A.12) - (A.5)} \\
&= \frac{-\bar{w}}{\mu - 1}\Big(\frac{\bar{w}}{c\mu}\Big)^{\frac{1}{\mu-1}} \Bigg(\underbrace{p^{\frac{2-\mu}{\mu-1}}\Big(\lambda_i^{\frac{1}{\mu-1}} + \big(1-\lambda_i\big)^{\frac{1}{\mu-1}}\Big)}_{\text{Household}} - \underbrace{\big(\lambda_i p + P_i\big)^{\frac{2-\mu}{\mu-1}}}_{\text{Individual}}\Bigg)
\end{aligned} \tag{A.13}$$

We evaluate this expression both at $P_i = 0$ and $P_i > 0$ for λ_i above and below 1/2.

Household vs. high residual claimant We start by comparing the effect of a marginal change in the household price to a marginal change in the individual price delivered to the high residual claimant ($\lambda_i \in (1/2, 1)$).

Evaluate at $P_i = 0$.

Factor out common terms to arrive at

$$\begin{aligned}
W^{*p} - W^{*P_i} = \frac{-\bar{w}}{\mu-1}\Big(\frac{\bar{w}}{c\mu}\Big)^{\frac{1}{\mu-1}} p^{\frac{2-\mu}{\mu-1}} \Bigg(\underbrace{\lambda_i^{\frac{1}{\mu-1}} + \big(1-\lambda_i\big)^{\frac{1}{\mu-1}}}_{\text{Household}} - \underbrace{\lambda_i^{\frac{2-\mu}{\mu-1}}}_{\text{High RC}}\Bigg) < 0,\ \forall\ \lambda_i \in (1/2, 1),\ \mu > 2 \\
\implies \frac{\partial W}{\partial P_i}\bigg|_{\lambda_i \in (1/2,1)} < \frac{\partial W}{\partial p}
\end{aligned} \tag{A.14}$$

Evaluate at $P_i > 0$.

When the two terms inside the parentheses labeled "Household" and "High RC" are equal, the household and individual price changes have equal effects. To find the values of (p, P_i) that lead to this result, let $\widehat{P}_i$ be the level of the individual price at which a marginal change leads to the same effect on aggregate water use as a marginal change in the household price.

$$\begin{aligned}
\underbrace{p^{\frac{2-\mu}{\mu-1}}\Big(\lambda_i^{\frac{1}{\mu-1}} + \big(1-\lambda_i\big)^{\frac{1}{\mu-1}}\Big)}_{\text{Household}} = \underbrace{\big(\lambda_i p + \widehat{P}_i\big)^{\frac{2-\mu}{\mu-1}}}_{\text{High RC}} \\
\iff \frac{\widehat{P}_i}{p} = \Big(\lambda_i^{\frac{1}{\mu-1}} + \big(1-\lambda_i\big)^{\frac{1}{\mu-1}}\Big)^{\frac{\mu-1}{2-\mu}} - \lambda_i\ \in\ [-1, 0],\ \forall\ \lambda_i \in (0.5, 1).
\end{aligned} \tag{A.15}$$

Intuition. The individual price level that satisfies this equation, $\widehat{P}_i(p, \lambda_i, \mu)$, is a function of three parameters: household-level price, residual claim distribution, and cost of conservation. Increasing P_i above $\widehat{P}_i$ makes the individual price *less effective* than the household price. Equality only happens with $P_i^*/p \in [-1, 0]$, implying $P_i^* < 0$. This means that there are no possible combinations of household characteristics (λ_i, μ) and *positive* individual price P_i where the household as a whole would be more price-responsive to a change in the individual price delivered to the individual with $\lambda_i > 0.5$ than to a change in the household price (as long as $P_i \geq 0$).

Household vs. low residual claimant The setup for this comparison is the same as the one laid out above, except that now we evaluate the results with the individual price to the low residual claimant ($\lambda_i \in (0, 1/2)$).

$$\begin{aligned} W^{*p} - W^{*P_i} &= \left(w_i^* + w_{-i}^* + \frac{\partial w_i^*}{\partial p} + \frac{\partial w_{-i}^*}{\partial p}\right) - \left(w_i^* + w_{-i}^* + \frac{\partial w_i^*}{\partial P_i}\right) \\ &= \left(\frac{\partial w_i^*}{\partial p} + \frac{\partial w_{-i}^*}{\partial p}\right) - \frac{\partial w_i^*}{\partial P_i} = \text{(A.12) - (A.5)} \\ &= \frac{-\bar{w}}{\mu - 1}\left(\frac{\bar{w}}{c\mu}\right)^{\frac{1}{\mu-1}}\left(\underbrace{p^{\frac{2-\mu}{\mu-1}}\left(\lambda_i^{\frac{1}{\mu-1}} + (1-\lambda_i)^{\frac{1}{\mu-1}}\right)}_{\text{Household}} - \underbrace{(\lambda_i p + P_i)^{\frac{2-\mu}{\mu-1}}}_{\text{Low RC}}\right) \end{aligned} \tag{A.16}$$

Evaluate at $P_i = 0$.

Factor out common terms to arrive at

$$\begin{aligned} W^{*c} - W^{*h} = \frac{-\bar{w}}{\mu - 1}\left(\frac{\bar{w}}{c\mu}\right)^{\frac{1}{\mu-1}} p^{\frac{2-\mu}{\mu-1}}\left(\underbrace{\lambda_i^{\frac{1}{\mu-1}} + (1-\lambda_i)^{\frac{1}{\mu-1}}}_{\text{Household}} - \underbrace{\lambda_i^{\frac{2-\mu}{\mu-1}}}_{\text{Low RC}}\right) > 0,\ \forall\ \lambda_i \in (0, 1/2),\ \mu > 2 \\ \implies \frac{\partial W}{\partial p} < \left.\frac{\partial W}{\partial P_i}\right|_{\lambda_i \in (0,1/2)} \end{aligned} \tag{A.17}$$

Evaluate at $P_i > 0$

In the case where the two terms inside the parentheses are equal, and the individual and household price changes have the same impact on aggregate water use, which depends on

p, P_i as follows.

$$\underbrace{p^{\frac{2-\mu}{\mu-1}}\Big(\lambda_i^{\frac{1}{\mu-1}}+\big(1-\lambda_i\big)^{\frac{1}{\mu-1}}\Big)}_{\text{Couple}}=\underbrace{\big(\lambda_i p+\widehat{P}_i\big)^{\frac{2-\mu}{\mu-1}}}_{\text{Low RC}}$$
$$\iff \frac{\widehat{P}_i}{p}=\Big(\lambda_i^{\frac{1}{\mu-1}}+\big(1-\lambda_i\big)^{\frac{1}{\mu-1}}\Big)^{\frac{\mu-1}{2-\mu}}-\lambda_i \;\in\; (0,1],\ \forall\,\lambda_i\in(0,0.5). \tag{A.18}$$

Intuition. Equality in the effect of a price change occurs with with $\widehat{P}_i/p \in (0,1]$, implying $0 < \widehat{P}_i \leq p$. This means that there are possible combinations of household characteristics (λ_i, μ) and *positive* individual prices P_i where the household would respond more to a marginal change in the household price than to a change in the individual price directed to the individual with $\lambda < 0.5$. This individual price change will only have a larger impact if the level of the individual price is $P_i < \widehat{P}_i(p, \lambda_i, \mu) \leq p$. In other words, a marginal change in the individual price to the low residual claimant will be more effective than a marginal change in the household price when the individual price lies below the household price.

High residual claimant vs. low residual claimant. The comparison between a marginal change in the individual price targeted to the high versus low residual claimant is given in Prediction 1.[2]

A note on discrete versus marginal changes in P_i and p.

The predictions in the main text and proofs above pertain to marginal changes in prices P_i and p. The treatments in the experiments instead deliver discrete changes in P_i and p. Here we show that the comparative statics regarding the price sensitivity of water consumption also hold for discrete price changes.

Prediction 1

Proof. From (A.3) individual i's optimal water consumption is given by

$$w_i^* = \bar{w}\Big(1-\Big(\frac{\bar{w}}{c\mu}\Big)^{\frac{1}{\mu-1}}\Big(\lambda_i p + P_i\Big)^{\frac{1}{\mu-1}}\Big). \tag{A.19}$$

Define the function $F(P|\lambda_i)$

[2]Using a similar approach to evaluating the individual prices that lead to equality in the effect of a marginal change in prices when $P_i > 0$, we find that equality occurs at $P_l = P_h + p(2\lambda_i - 1) \geq 0$, where P_l denotes the price to the low RC and P_h denotes the price to the high RC. That is, the only condition in which a change to the high RC's individual price has a larger effect is one in which the low RC already faces a (much) higher individual price.

$$F(P|\lambda_i) := \frac{\partial w_i^*}{\partial \lambda_i} = -p\bar{w} \left(\frac{\bar{w}}{c\mu}\right)^{\frac{1}{\mu-1}} \left(\frac{1}{\mu-1}\right) (\lambda_i p + P_i)^{\frac{2-\mu}{\mu-1}} \tag{A.20}$$

as the derivative of (A.19), household i's water demand, with respect to λ_i. For $\mu > 2$, Equation (A.20) is continuous and differentiable in both P_i and λ_i as $\lambda_i p + P_i > 0$. Let $P'' > P' \geq 0$. By the fundamental theorem of calculus (FTC), we then have

$$F(P''|\lambda_i) = F(P'|\lambda_i) + \int_{P'}^{P''} f(p|\lambda_i)dp \tag{A.21}$$

where $F(P|\lambda_i)$ is the antiderivative of $f(P|\lambda_i)$

$$\begin{gathered} f(P|\lambda_i) := F'(P|\lambda_i) \equiv \frac{\partial}{\partial P}\left(\frac{\partial w_i^*}{\partial \lambda_i}\right) = \\ \frac{-\bar{w}(2-\mu)p}{(\mu-1)^2}\left(\frac{\bar{w}}{c\mu}\right)^{\frac{1}{\mu-1}}\left(\lambda_i p + P_i\right)^{\frac{3-2\mu}{\mu-1}} > 0 \end{gathered} \tag{A.22}$$

which is strictly greater than zero when $\mu > 2$ as shown in (A.6). Note that $f(P|\lambda_i)$ in (A.22) is also continuous in P_i and λ as $\mu > 2$. Combining (A.21) and (A.22) gives

$$F(P''|\lambda_i) - F(P'|\lambda_i) = \int_{P'}^{P''} f(p|\lambda_i)dp > 0 \tag{A.23}$$

which implies that

$$\left.\frac{\partial w_i^*}{\partial \lambda_i}\right|_{P_i=P''} - \left.\frac{\partial w_i^*}{\partial \lambda_i}\right|_{P_i=P'} > 0. \tag{A.24}$$

or in terms of discrete differences, for $\lambda'' > \lambda'$ and $P'' > P'$ we have that optimal water consumption w^* satisfies

$$w^*(\lambda'', P'') - w^*(\lambda'', P') - [w^*(\lambda', P'') - w^*(\lambda', P')] > 0 \tag{A.25}$$

The inequality in (A.25) is the discretized version of (A.24). It states that optimal water consumption displays increasing differences in λ_i and P_i. Note from (A.20) as we have $\frac{\partial w_i^*}{\partial \lambda_i} < 0$, the discrete differences comparing demand between λ'' and λ' are also negative. In turn, (A.25) gives that these differences are increasing (decreasing in magnitude) as P_i rises. This implies the lower-λ agent is more responsive to a discrete change in P_i.

$\square$

Prediction 2

Proof. Following the main text, aggregate demand W is given by

$$W^* \equiv w_i^* + w_{-i}^* = 2\bar{w} - \bar{w}\Big(\frac{\bar{w}}{c\mu}\Big)^{\frac{1}{\mu-1}} \left(\Big(\lambda_i p + P_i\Big)^{\frac{1}{\mu-1}} + \Big((1-\lambda_i)p + P_{-i}\Big)^{\frac{1}{\mu-1}} \right).$$

Define the function $G(p|\lambda_i)$ as

$$G(p|\lambda_i) := \frac{\partial W^*}{\partial \lambda_i} = \bar{w}\Big(\frac{\bar{w}}{c\mu}\Big)^{\frac{1}{\mu-1}} \left(\frac{p}{\mu-1}\Big(\lambda_i p + P_i\Big)^{\frac{2-\mu}{\mu-1}} - \frac{p}{\mu-1}\Big((1-\lambda_i)p + P_{-i}\Big)^{\frac{2-\mu}{\mu-1}} \right) \tag{A.26}$$

which is continuous and differentiable in λ_i and p when $\mu > 2$. Suppose $\lambda_i > 0.5$. Take two prices $p'' > p' > 0$ and apply the FTC,

$$G(p''|\lambda') = G(p'|\lambda') + \int_{p'}^{p''} g(x|\lambda)dx \tag{A.27}$$

where, like above, $G(p|\lambda)$ is the antiderivative of $g(p|\lambda)$ which satisfies

$$g(p|\lambda) := G'(p|\lambda) \equiv \frac{\partial}{\partial p}\left(\frac{\partial W^*}{\partial \lambda_i}\right) = \tag{A.28}$$
$$\frac{\bar{w}^2}{c\mu(\mu-1)^2}\Big(\frac{p\bar{w}}{c\mu}\Big)^{\frac{2-\mu}{\mu-1}} \left((1-\lambda_i)^{\frac{2-\mu}{\mu-1}} - \lambda_i^{\frac{2-\mu}{\mu-1}}\right) > 0$$

when $\lambda > 0.5$ and $\mu > 2$ as shown in (A.11). Note $g(\lambda|p)$ is also continuous as $p > 0$ and $\mu > 2$.[3] Then

$$G(p''|\lambda) - G(p'|\lambda) = \int_{p'}^{p''} g(x|\lambda)dx > 0 \tag{A.29}$$

which implies that

$$\left.\frac{\partial W_i^*}{\partial \lambda_i}\right|_{p=p''} - \left.\frac{\partial W^*}{\partial \lambda_i}\right|_{p=p'} > 0 \tag{A.30}$$

Again expressing these derivatives in discrete differences, for $\lambda'' > \lambda'$ and $p'' > p'$ we have that optimal water consumption W^* satisfies

[3] Technically it is only left-continuous at the boundary $\lambda_i = 1$, but in that case this weaker condition is sufficient as it cannot increase beyond one.

$$W^*(\lambda'', p'') - W^*(\lambda'', p') - [W^*(\lambda', p'') - W^*(\lambda', p')] > 0 \tag{A.31}$$

when $\lambda_i > 0.5$, which is without loss of generality since $\lambda_i = (1 - \lambda_{-i})$. The inequality in (A.31) again discretizes (A.30) for clarity. It states that total household water consumption displays increasing differences in λ_i and p. Note from (A.26) as we have $\frac{\partial W_i^*}{\partial \lambda_i} < 0$, the discrete differences comparing λ'' and λ' are also negative. Like in Prediction 1, (A.31) gives that these differences are decreasing in magnitude as λ_i rises. This implies the households where the shares λ are closer to equal are more responsive to discrete changes in p.

□

A.2 Appendix figures and tables

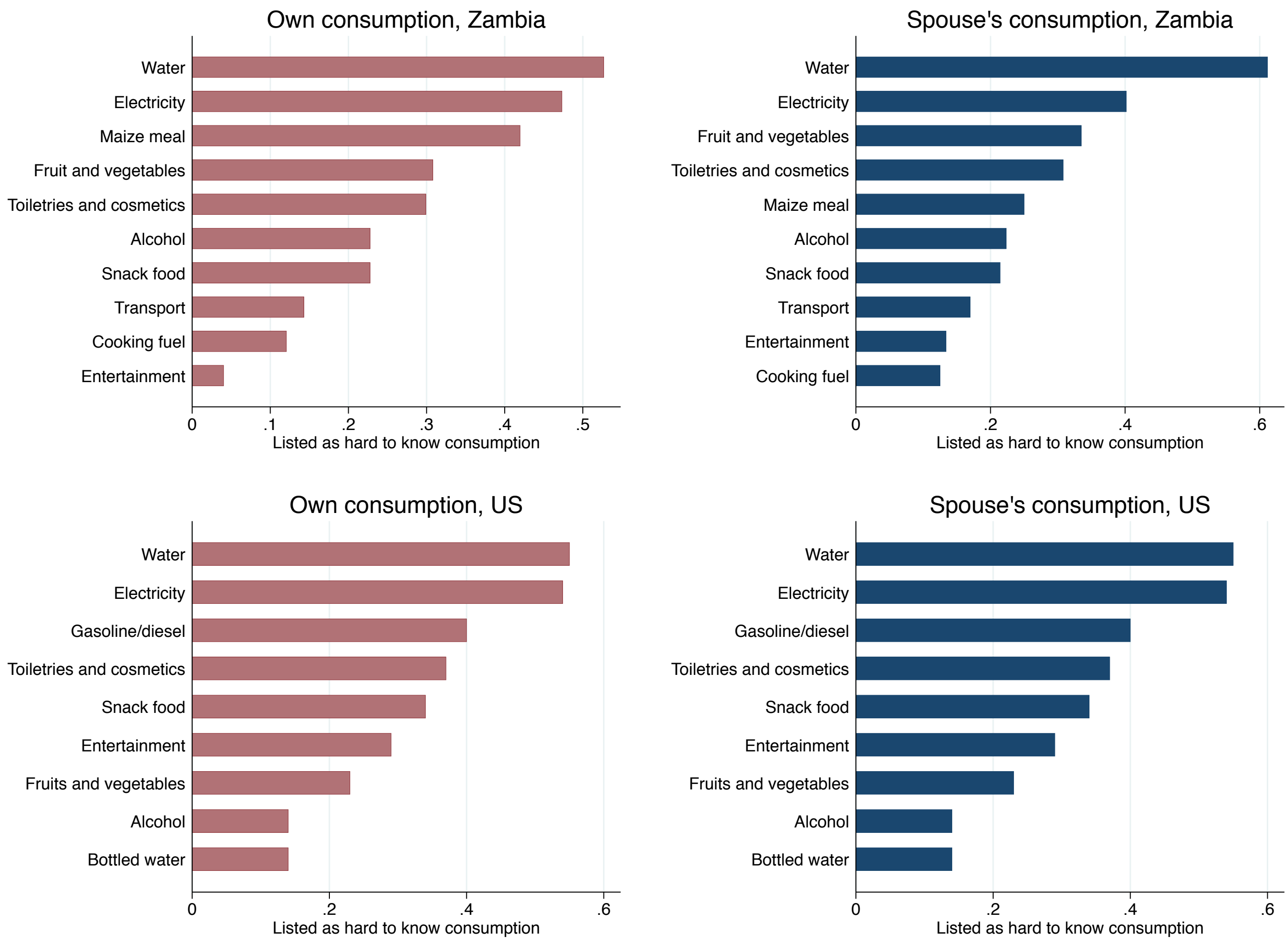

Figure A.1: Observability of consumption

Notes: Share of respondents reporting that a consumption category was among the top three most difficult to observe own (left) and spouse's (right) consumption. Respondents in the top panel are a convenience sample of market-goers in Lusaka (N=96). Respondents in the bottom panel are a sample of Mechanical Turk users in the United States (N=116).

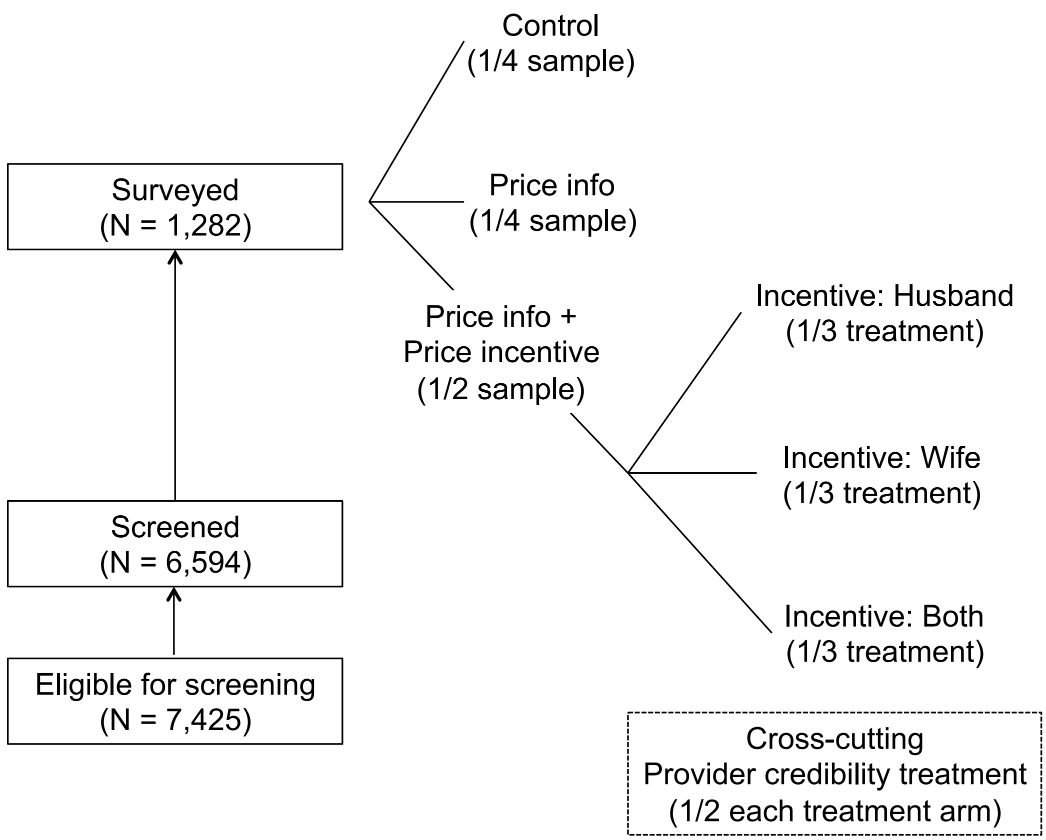

Figure A.2: Experimental design

Notes: Experimental design and sampling flow.

Table A.1: Residual claimant definitions, by spouse

Using payer variable			
	Husband's definition		
Wife's definition	Husband	Wife	Both/other
Husband	625	38	39
Wife	189	206	56
Both/other	73	25	31
Using income variable			
	Husband's definition		
Wife's definition	Husband	Wife	Both/other
Husband	621	1	111
Wife	17	30	46
Both/other	225	15	216

Notes: Residual claimant definitions, by spouse. The version shown in the top panel, which gives precedence to who physically pays the bill if that variable disagrees with whose income is used to pay the bill, is used in the main analysis.

Table A.2: Heterogeneous effects of price information and provider credibility treatments

	log (Quantity) (1)	log (Quantity) (2)
Price information treatment	-0.006	
	[0.048]	
Info x Underestimated price	-0.011	
	[0.060]	
Provider credibility treatment		0.018
		[0.034]
Provider credibility x Distrust billing		0.024
		[0.048]
Observations (HH)	1,282	1,282
Observations (HH-months)	25,506	25,506

Notes: *Underestimated price* equals one if either spouse underestimated the marginal price of water. *Distrust billing* equals one if both spouses blame a high water bill on the provider. Regressions include the post-survey indicator interacted with the heterogeneity variables. The incentive treatment indicator is excluded. The panel begins in March 2014 and ends in February 2016. Standard errors are clustered at the household level, and all columns control for household and month-year fixed effects, an indicator for months following a missing quantity observation, and a continuous month-year variable interacted with sampling wave. Price beliefs are imputed for 257 households.

Table A.3: Robustness to controlling for individual characteristics

	log (Quantity) (1)	log (Quantity) (2)
Indiv incentive x Non-RC	-0.111**	-0.121**
	(0.047)	(0.056)
Indiv incentive x Over 50	0.086**	0.090
	(0.043)	(0.058)
Indiv incentive x Has regular employment	0.017	0.059
	(0.050)	(0.053)
Indiv incentive x Fluent in English	-0.015	-0.022
	(0.082)	(0.092)
Indiv incentive x Low education	-0.011	-0.031
	(0.048)	(0.059)
Indiv incentive x Uses more water	0.005	0.077
	(0.045)	(0.058)
Indiv incentive x Distrust billing	0.037	0.013
	(0.051)	(0.062)
Indiv incentive x Knows bill quantity	0.008	-0.024
	(0.047)	(0.058)
Indiv incentive x Knows bill price	-0.001	0.003
	(0.049)	(0.063)
Indiv incentive x High NGO sharing	-0.064	-0.066
	(0.047)	(0.046)
Observations (HH)	1,024	1,024
Observations (HH-months)	20,365	20,365

Notes: Robustness check on the results reported in column 1 of Table 3. *Indiv incentive* refers to the individual incentive arm. Each coefficient is an interaction between *Indiv incentive* and a characteristic of the recipient. Column 1 shows separate regressions in each cell. Column 2 reports results of a single regression. Regressions include the post-survey indicator interacted with the heterogeneity variables. Households with no within-couple variation in residual claimant status are excluded. The panel begins in March 2014 and ends in February 2016. Standard errors are clustered at the household level, and all columns control for household and month-year fixed effects, an indicator for months following a missing quantity observation, and a continuous month-year variable interacted with sampling wave.

Table A.4: Robustness to different ways of defining non-residual claimant variable

	log(Quantity)					
	(1)	(2)	(3)	(4)	(5)	(6)
Individual incentive	-0.020	-0.025	-0.043	-0.019	-0.026	-0.027
	[0.038]	[0.036]	[0.039]	[0.037]	[0.037]	[0.041]
Indiv incentive x Non-RC	-0.111**	-0.080	-0.106**	-0.111**	-0.101**	-0.098
	[0.047]	[0.051]	[0.048]	[0.046]	[0.047]	[0.060]
Couple incentive						
Total effect, incentive to non-RC	-0.131***	-0.105***	-0.149***	-0.129***	-0.127***	-0.125***
	[0.037]	[0.041]	[0.040]	[0.036]	[0.037]	[0.042]
RC definition	Main spec	Income variable	Drop interme-diate RC	Husband definition	Wife definition	Equal definition
Observations (HH)	1,024	1,048	831	1,024	1,024	1,024
Observations (HH-months)	20,365	20,814	16,466	20,365	20,365	20,365

Notes: *Incentive* × *Non-RC* is the product of someone in the household having received the individual lottery and (1 minus) the RC status of the individual. Columns vary how the residual claimant variable is constructed relative to our main specification, which is shown in column 1. Column 2 uses the income variable if income and payer disagree. Column 3 drops cases where either income or payer are both/other for at least one of the individual. Column 4 uses the husband's definition of residual claimant. Column 5 uses the wife's definition of residual claimant. Column 6 uses coding to match the intrahousehold billing equality used in Table 4. Households with no within-couple variation in residual claimant status are omitted in all columns. The panel begins in March 2014 and ends in February 2016. Standard errors are clustered at the household level, and all columns control for household and month-year fixed effects, an indicator for months following a missing quantity observation, and a continuous month-year variable interacted with sampling wave.

Table A.5: Robustness check: Panel length

Panel start	Jan 2014	Mar 2014	May 2014	Jan 2014	Mar 2014	May 2014	14 mo pre
Panel end	Feb 2016	Feb 2016	Feb 2016	2 mo post	2 mo post	2 mo post	2 mo post
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Individual incentive	-0.018	-0.020	-0.010	-0.017	-0.017	-0.008	-0.015
	[0.038]	[0.038]	[0.037]	[0.042]	[0.042]	[0.042]	[0.041]
Indiv incentive x Non-RC	-0.120**	-0.111**	-0.103**	-0.134***	-0.127***	-0.119**	-0.100**
	[0.048]	[0.047]	[0.046]	[0.049]	[0.048]	[0.048]	[0.047]
Total effect, incentive to non-RC	-0.138***	-0.131***	-0.113***	-0.151***	-0.145***	-0.128***	-0.115***
	[0.037]	[0.037]	[0.035]	[0.036]	[0.036]	[0.035]	[0.035]
Observations (HH)	1,024	1,024	1,024	1,024	1,024	1,024	1,024
Observations (HH-months)	21,897	20,365	18,786	18,780	17,248	15,669	14,344

Notes: Robustness check on the results reported in column 1 of Table 3 (which is reproduced in column 2 here). The specification shown in column 7 is balanced in event-time; the sample is restricted to the event-time months that are available for all households, those denoted with dark markers in Figure 2. Standard errors are clustered at the household level, and all columns control for household and month-year fixed effects, an indicator for months following a missing quantity observation, and a continuous month-year variable interacted with sampling wave.

A.3 Data appendix

A.3.1 Sample selection

Using the panel of billing data for metered residential customers as of February 2015 (N=9,868),[4] we eliminate households that did not have a working meter for at least 3 out of the 4 preceding months. We also exclude households that use no water (i.e., are billed for zero cubic meters) in more than half of the preceding 4 months. Households with very low variation in usage over the preceding four months are considered to have possibly tampered with the meter or have a delinquent meter reader.[5] Households with consistently low usage are also excluded since they would be least able to adjust their water consumption in response to a price shock, and, moreover, reducing water use from a low base could be harmful, e.g., in terms of hygiene; we drop households if their usage was on the lowest price tier (less than 6 cubic meters) for more than 2 of the preceding 4 months. Households whose median water usage in the preceding four months was above the 99th percentile are also dropped. Finally we drop households with an extremely high outstanding balance with SWSC, or households that are owed a significant amount of money by SWSC, defined as 6 times or 4 times their median bill in the preceding four months, respectively. This yields a total of 7,425 households that we target for an in-person screening.

Households were visited by a surveyor to collect data on characteristics not observed in the billing data that were important for sampling. Specifically, we require that the water meter not be shared with other households, that the primary residual claimant be married (or cohabiting) and that both spouses live at that address, and that the household was in residence for at least the 4-month period prior to April 2015. We also exclude households who say they are planning to move in the following 6 months.

Our surveyors made up to 3 attempts to screen each households; any adult member of the household could be given the screening questionnaire. In total, 6,594 households were screened, of which 31 percent (2,051) met all our screening criteria.[6]

Households that met the screening criteria were informed about the survey. We scheduled a follow-up visit with the primary residual claimant and his/her spouse, emphasizing that we needed both of them to be present for the full survey. We also informed respondents they would be compensated 40 Kwacha (4 USD) for participating in the survey.

We scheduled survey appointments with 1,817 households from our eligible sample. Of

[4] This number excludes roughly 300 households we included in a pilot, who were deemed ineligible for the full study.

[5] They were excluded based on the following criteria: if the coefficient of variation in this period was less than 0.05, or if the quantity reported was identical for 3 or more months.

[6] Reasons for not screening a household include that the home was vacant or under construction, that it was occupied by a business, or that no one was home for three consecutive attempts.

these, we completed surveys with 1,282 households. This high "attrition" rate is due largely to stopping our attempt to survey households at the end of December 2015.

For the full survey, at the scheduled time and date, a pair of surveyors (always a woman and a man) visited the screened-in household. After a few preliminary demographic questions, husbands and wives were separated and surveyed individually in different rooms of the house. Enumerators elicited water price beliefs, asked for perceptions of own and family members' water usage, and conducted the modified dictator game. After finishing their individual questionnaires, both surveyors and respondents met back together in a common room for the last survey questions, and to receive the price information treatment (if applicable).

A.3.2 Calculating price elasticities

To illustrate magnitudes, we use the estimates of β_1 associated with our incentive treatment in equation (4) to calculate short-run price elasticities as follows.[7] First, with y_{it} equal to log of monthly water quantity, we can interpret the coefficient on $IndivTreat_{it}$ as ${}^{\partial ln(q)}/_{\partial treat}$, which we divide by the impact of the treatment on price, ${}^{\partial p}/_{\partial treat}$. This results in ${}^{\partial q}/_{q} \times {}^{1}/_{\partial p}$, which we multiply by the pre-intervention average price to deliver a short run elasticity. We calculate customer-specific average prices, accounting for the increasing block schedule and for inflation (Zambian consumer price index), prior to the intervention and use that as the basis for our subgroup-specific average marginal prices.

For example, in the main text, we interpret the impact of the effect of delivering the incentive to the non-residual claimant as a short run price elasticity. We observe a statistically significant 0.14 log point decrease in monthly consumption in response to treatment. For this sub-group, the average pre-intervention price is 4.89 Kwacha per cubic meter and the reduction in consumption required to qualify for the lottery (which pays 15 Kwacha in expectation based on a one in twenty chance of being drawn) is 5.74 cubic meters. The implied short run price elasticity is therefore -0.26.[8]

[7]We convert our treatment effects into elasticies to aid interpretation of the magnitudes. However, we note a number of caveats to this transformation. Specifically, the elasticity calculation requires a number of assumptions: (1) that households respond similarly to a discrete price change as to a continuous price change, (2) that households respond similarly to a quantity target as to a continuous price change, and (3) that households respond similarly to a probabilistic payout as to a certain payout from conservation with the same expected value.

[8]Our calculated short-run price elasticity of demand is within the ranges described by Dalhuisen et al. (2003) and Worthington and Hoffman (2008).

A.4 Scripts

A.4.1 Price incentive treatment

[*Private – to be read to husband/wife before they are brought back together*]

Thank you for answering these questions. Before I go to check with my colleague, I have good news: We are running a program that gives prizes to people who cut down their water bill.

We will run a raffle, which has a K. 300 cash prize, and you will be entered into the raffle if your household reduces your water use by 30% next month. Since we are now in [current month]'s billing cycle, we will not consider this month's water use, but use [next month's] water use instead. This shows up on the [next month + 1's] bill.

If your water use in [next month] is below X cubic meters, then you will be entered for the draw. You can check the actual [next month] usage on the bill in [next month + 1] to see if it is X or lower. [*Point out where to locate the water quantity on the bill.*]

The lottery winner will be picked on the 15th of [next month + 2].

If you make the required reduction, you will have a 1 in 20 chance of winning the prize. In other words, for every 20 people who qualify for the raffle based on their bills in [next month + 1], we will draw one winner.

If you are the winner, we will call you on the number you gave us previously to convey the good news.

You will be requested to come to our office in Mosi-oa-Tunya House to collect the prize money, and you will also be compensated K.20 for your transportation.

We will continue to run a raffle every month at least until the end of the year and maybe longer, so if you also reduce water use to X in the months after [next month], you will be entered into that month's raffle too, so if you don't win in one month, you could still win the next month as long as the usage on your bill for that month is less than X cubic meters. You could even be a winner in multiple months!

How do we figure out how much you have to cut back to qualify for the raffle? We look at how much your household used in this year's March and April bills. In these bills (March and April) your average use was for Y cubic meters. So you need to cut your household usage by Y-X cubic meters in order to achieve X cubic meters or lower and qualify to our draw. For every household in this program, the target water usage is based on their own past usage during those two months.

[*If only the husband/only the wife is receiving the treatment*]: Not all individuals or all households are getting the opportunity to try for the raffle. In particular, you have been selected, so I am only informing you of this, and not your husband/wife.

My colleague is not informing your husband/wife about this either, because for your household, only you have been selected to participate. It is entirely up to you if you want to inform him/her or not.

If you would like to check whether your household cut back usage enough to qualify for the raffle, you may call 096-934-3167 after the 15th of [next month + 2]. You will not be charged any airtime to call this number.

When you call, the line will be cut immediately and you will automatically be called back from a different number. When you pick up the phone, you will hear a recorded message that tells you if you qualified for the raffle or not. The message is linked to the number you gave us, so please use the same sim card when you call.

You can also call that number after the 15th of each month following [next month + 2] to see if you qualified for that month's raffle.

You can also use that number to check if the raffle program is still going on.

If you win, we will ensure that we are speaking only with you when we call to inform you. Nobody else will know that you have won, unless you share the news.

[*If both are receiving the treatment*]: Not all individuals or all households are getting the opportunity to try for the raffle. In particular, your household has been selected. Just as I am informing you of this raffle, my colleague in the other room is informing your spouse about it as well.

If your household wins, we will inform both of you, and we would appreciate it if you both came to collect the prize. If you would like to check whether your household cut back usage enough to qualify for the raffle, you may call 096-934-3167 after the 15th of [next month + 2]. You will not be charged any airtime to call this number.

When you call, the line will be cut immediately and you will automatically be called back from a different number. When you pick up the phone, you will hear a recorded message that tells you if you qualified for the raffle or not. The message is linked to the number you gave us, so please use the same sim card when you call.

You can also call that number after the 15th of each month following [next month + 2] to see if you qualified for that month's raffle. You can also use that number to check if the raffle program is still going on.

If you win, we will ensure that we are speaking with you or your spouse when we call to inform you. Nobody else, other than your spouse, will know that you have won, unless you share the news.

[*For everyone*]: Only people in some of the households we are surveying are eligible for this raffle, so others that you speak to may not have been given this opportunity. The raffle is sponsored by our research project, not SWSC – they will not be aware if you are eligible or not, or if you won or not.

A.4.2 Provider credibility treatment

We have collected this information purely for research and will not share any details with SWSC. However, we want to provide you with a little bit of extra information about how SWSC calculates your bill. SWSC tries to ensure that bills are accurate by reading your meter monthly and using the amount of water consumption shown on your meter to calculate your bill. That is, the amount that you are charged is based on the amount of water you use. The meter readings taken this month measure your usage since the time when last month's reading was taken. Once SWSC has collected all the readings for this month, this is used to calculate the bill that will be given to you next month. For example, when you received your water bill in March you were charged for the water your household used between the 21st of January and the 20th of February, roughly speaking. When you received your water bill in April, you were charged for the water your household used between the 21st of February and the 20th of March, and so on. If there are some months that they cannot get a meter reading, then you are charged an estimate based on your previous consumption, and they try to get meter readings again as soon as possible. Then the next time they read your meter, they adjust your bill for any over- or under- charges from the months when they were not able to do the reading. SWSC is taking measures to make sure that bills are fair and based on actual water usage. They are committed to honest billing practices.