Green subsidies with credit constraints

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Incentivizing green technology adoption

- *Example: buying an electric vehicle and driving the EV instead of a gas car*
  Buying a heat pump and using it instead of a gas furnace system;
  buying an induction stove and using it instead of a charcoal stove
- Using a dirty technology generates a negative externality
- Green technologies require initial purchase and subsequent usage
- Buyers continue to own the dirty technology

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1) First-best: Pigouvian tax

Example: tax gasoline

✓ Incentivizes increased purchasing ('extensive margin')
✓ Incentivizes purchasing by high emitters ('intensive margin')
✓ Incentivizes usage of the green tech ('intensive margin')
✓ Disincentivizes usage of the dirty tech ('intensive margin')

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Downsides: Often infeasible due to informality, regressivity, political constraints, or jurisdictional limitations

Green technology subsidies: US, EU

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Marginal cost subsidies

Menu PG&E

Electric Vehicle (EV) rate plans

Making sense of EV rate plans

Residential EV rates

You can lower your energy costs by enrolling in one of our EV rate plans:

- Home Charging EV2-A
- Electric Vehicle Rate Plan EV-B

Volvo Offers Swedish Buyers A Year Of Free Charging To Spark EV Sales

The pilot program will serve as a test for broader rollout across Europe and beyond.

BY NATALIE NEFF
PUBLISHED: OCT 22, 2025 9:00 AM EDT

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Fixed cost subsidies

UP TO
$2,000
IN TAX CREDITS FOR HEAT PUMP[1] INSTALLATIONS

OR UP TO
$2,600
IF INSTALLING A QUALIFYING HEAT PUMP AND GAS FURNACE SYSTEM

Heat pump grant increased to £7,500 by government in efforts to lower pollution and bills

Heat pumps emit far less pollution than gas boilers and can lower bills, but are expensive upfront. The government hopes the scheme will bring the cost of installing a new heat pump in line with that of a gas boiler.

Victoria Seabrook
Climate reporter @SeabrookClimate

Monday 23 October 2023 11:33, UK

electrek

Here are the cars eligible for the $7,500 EV tax credit in the Inflation Reduction Act in 2023

Jameson Dow | Dec 2 2022 - 10:52 am PT

Green technology subsidies: East Africa

Marginal cost subsidy

Business Daily

How new special power tariff has spurred electric vehicle uptake

THURSDAY, DECEMBER 26, 2024 — UPDATED ON MAY 28, 2025 - 5

UMEME Customers Enjoy Cheaper Cooking Tariff Set By ERA

Christopher Kiiza • November 14, 2022 3 minutes read

eCooking Tariff Development

- Test the viability and impact of a specialized eCooking tariff for Tier 3+ connected households in Kenya

Cost: USD 450,000 (KES 57 million)

Fixed cost subsidy

Tax waivers on eCooking

- A dedicated study to define a suitable tax waiver regime to reduce upfront appliances costs to locally manufactured appliances, components and/or accessories, which will increase demand.
- Determine the economic and financial impact of these waivers on government revenues and household affordability.

Cost: USD 125,000 (KES 16 Million)

Green technology subsidies: Carbon credits

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Figure 2. Voluntary Carbon Market Size, by Volume of Traded Carbon Credits, pre-2005 to 2023

Green technology subsidies: Carbon credits

Figure 1. Voluntary Carbon Market Size, by Value of Traded Carbon Credits, pre-2005 to 2023

Second-best policies: Subsidize the green technology

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Example: subsidize EV charging

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- × Does not disincentivize usage of the dirty tech holding fixed adoption

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3) Fixed cost subsidies

Example: EV tax credit

- ✓ Incentivizes increased purchasing
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- × No intensive margin usage incentive
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Intensive and extensive margin subsidies also differ in their intertemporal distribution of financial transfers

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Intensive and extensive margin subsidies also differ in their intertemporal distribution of financial transfers ⇒ access to credit might matter

Credit market failures are pervasive and persistent

Moral hazard and adverse selection undermine credit markets Bernanke, 2023

- **Institutional constraints** ⇒ lack of nationwide credit bureaus (e.g. FICO), asymmetric information about borrower quality
- **Institutional constraints** ⇒ lack of insurance (e.g. FDIC), riskier savings
- **Informality** ⇒ 1.7 billion people lack a bank or mobile money account
- **Relational economies** ⇒ non-credible threat of punishment
- **Imperfect property rights** ⇒ difficulty using or recovering collateral
- **Frictions in legal systems** ⇒ poor debt recovery in case of default

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- Banks respond by increasing the pecuniary and non-pecuniary costs of credit ⇒ higher interest rates, shorter repayment periods, shorter grace periods, other-asset collateral, strict eligibility requirements Quinn & Woodruff 2019; Banerjee & Duflo 2005, 2014; Field et al. 2013; Kaboski & Townsend 2012; Gertler, Green, Wolfram 2024; Jack et al. 2023; Fafchamps et al. 2014; Itskhoki & Moll 2019

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First best solution—fixing credit market failures—is infeasible in the short run

This paper: How do credit constraints affect subsidy optimality?

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1. In a standard model, the optimal $s_f^* = 0$, $s_m^* = \phi$

2. What context features might make a principal indifferent between marginal cost subsidies and fixed cost subsidies?
   - Inelastic intensive margin $\Rightarrow$ usage incentive has less bite
   - Positively correlated private and social benefits $\Rightarrow$ selection incentive has less bite

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3. Credit market failures can mean $s_f^* > 0$, $s_m^* < \phi$. Why?
   - Marginal adopter has a higher negative externality
   - More elastic demand $\Rightarrow$ more marginal, fewer inframarginal payments
   - Marginal cost reductions only increase WTP by a factor 1/(1+r)

This paper: Induction stoves in Kenya

Kenyan charcoal Jiko

Induction stove

This paper: Randomized Controlled Trial

We implement an RCT in urban and peri-urban Nakuru County

1. 2,100 households who cook primarily with charcoal and who have an electricity connection at home 63% of Kenyans cook primarily with biomass
2. Elicit WTP for an induction stove using incentive-compatible BDM auctions

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6. High-frequency monitoring of charcoal stove usage and induction stove usage and an in-person follow up survey

Results I: Impacts

1. Induction stoves:
   - Reduce monthly charcoal spending by \$9.9 (61%)
   - Reduce monthly LPG spending by \$0.70 (13%)
   - Increase monthly electricity spending by \$1.7 (55%)
2. Aggregate energy spending down \$9.4 per month (37%); 134% annual IRR
3. Induction stoves abate 2.5 tCO_2e per year
   (Factoring in decreases in charcoal and LPG, increases in electricity consumption)
4. \$82 cost corresponds to a **resource abatement cost** of \$9.3 per tCO_2e
5. **Credit constraints** decrease average willingness-to-pay from \$34.4 to \$19.5

Results II: Subsidy efficacy

- **Model assumptions:**
  - Inelastic intensive margin response to MC subsidies: $\mathcal{E}_d = -0.18$
  - Positively correlated private and social benefits: $r = 0.76$

    Accounts for charcoal, electricity, LPG consumption

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    Accounts for charcoal, electricity, LPG consumption
- In terms of **marginal cost subsidy**, every \$1 of expenditure increases WTP:
  - By 0.02 [-0.15, 0.19] in the credit treatment group
  - By -0.08 [-0.19, 0.02] in the credit control group

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- **In terms of fixed cost subsidy:**

	Credit treatment	**Credit control**
Annual tCO_2e abated per marginal adopter	1.5	2.5
Extensive margin elasticity to fixed subsidy	$\mathcal{E}_d = -2.5$	$\mathcal{E}_d = -30.8$
Fraction of fixed cost subsidies to inframarginal adopters	32%	3.7%
Fixed cost subsidy expenditure per marginal adoption	\$99	\$63

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Fixed cost subsidy expenditure per marginal adoption	\$99	\$63
Abatement cost per tCO_2e after 3 years	**\$22**	**\$6**

Applications

In what other settings might fixed cost subsidies be effective?

- Pervasive credit constraints
- Positively correlated private and social benefits
- Inelastic intensive margin usage
- Homogenous baseline and substitute technologies

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Examples:

- 1.3 billion people connected to electricity cook with biomass
  $\Rightarrow$ **Induction stoves:** abate 2.2 tCO_2e per year at \$6 per tCO_2e
- 700 million unconnected people cook with biomass
  $\Rightarrow$ **Improved charcoal stoves:** abate 1.8 tCO_2e per year at \$8 per tCO_2e
- 700 million unconnected people primarily use kerosene
  $\Rightarrow$ **Solar lamps** abate 0.8 tCO_2e per year at \$10 per tCO_2e

EVs abate around 1-2 tCO_2e per year at $>$ \$1,000 per tCO_2e

Today

Background

Theory

RCT Design

CO_2 Abatement

Extensive margin: Inframarginal and marginal subsidy expenditures

Intensive margin: Usage among marginal adopters

Aggregate subsidy efficacy

Implications for global abatement policy

Energy efficiency adoption

Building on Allcott, Mullainathan, Taubinsky (2012, 2014)

- Agent i earns income Y_i and derives linear utility from a numeraire good
- They consume perfectly inelastic energy services θ_i
- At $t = 1$ they decide whether to buy the green technology, $d_{1i} = \{0, 1\}$
- At $t = 2$ they choose what fraction $d_{2i} \in [0, 1]$ of θ_i to consume using the green substitute
- Assume no discounting, no myopia, no non-financial utility impacts

Adding the externality and the principal's subsidies

- The green tech emits less fuel per unit of usage: $\bar{\phi} = \phi_D - \phi_G$
- Substituting with the green tech generates a positive externality, $\phi_i = d_{2i}\theta_i\bar{\phi}$
- The principal can subsidize the fixed cost (s_1) and/or the usage cost (s_2)
- Assuming competitive supply, normalize the market price of the green tech relative to the dirty tech as $p_m - s_1 = (p_G - p_D) - s_1$
- The green tech costs less per unit of usage by some amount $\bar{b} + s_2$ such that substituting with the green tech generates private savings, $b_i = d_{2i}\theta_i(\bar{b} + s_2)$
- Normalize principal's $r = 0$
- An agent facing an implied interest rate of r has maximum willingness to pay:

$$wtp_i = \frac{1}{1+r} \cdot b_i$$

- Market demand is given by:

$$P(Q) = \arg\max \sum_i wtp_i \leq P$$

Planner's problem: Maximize social welfare

$$\mathbf{s}^* = \arg\max \int_{\theta^\dagger}^{\infty} \underbrace{d_{2i}\theta_i\bar{\phi}}_{\text{positive externality}} + \underbrace{d_{2i}\theta_i\bar{b}}_{\text{fuel savings}} - \underbrace{p_j}_{\text{fixed cost}} \; h(\theta)d\theta$$

Model results:

- If $r = 0$ then $s_1^* = 0$ and $s_2^* = \bar{\phi}$ (classic case)

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- If $r > 0$ then
  - $0 < s_1^*$
  - $0 < s_2^* < \bar{\phi}$

Environmentally-minded principal

- Many principals don't value or under-value inframarginal transfers
- Consider a principal focused who places no weight on agent welfare other than through the positive externality EPA, UNFCCC, CORSIA, Article 6.4, etc.

$$\mathbf{s}^* = \arg\max \int_{\theta^\dagger}^{\infty} \underbrace{d_{2i}\theta_i\bar{\phi}}_{\substack{\text{positive}\\ \text{externality}}} - \underbrace{s_1}_{\substack{\text{fixed}\\ \text{subsidy cost}}} - \underbrace{d_{2i}\theta_i s_2}_{\substack{\text{marginal}\\ \text{subsidy cost}}} \; h(\theta)d\theta$$

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For fixed cost subsidy s_1:

1. Higher r increases the marginal positive externality
2. Higher $\mathcal{E}_D$ decreases marginal cost per adoption

Graphical intuition: Marginal externality

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- Higher r increases positive externality of the marginal adopter

Graphical intuition: Cost per marginal adopter

- Credit constraints increase demand elasticity

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Subsidy efficiency: tCO_2e per dollar

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CO_2 Abatement

Extensive margin: Inframarginal and marginal subsidy expenditures

Intensive margin: Usage among marginal adopters

Aggregate subsidy efficacy

Implications for global abatement policy

RCT in Nakuru county

- Peri-urban regions around Naivasha, Nakuru, Gilgil
- 65% of households have a grid electricity connection (Kenya: 50%)
- 15% have solar panels (Kenya: 18%)
- 69% of households cook with charcoal or firewood (Kenya: 63%)

We study the ECOA induction stove

Kenyan Jiko
(instrumented with a SUM)

ECOA

2,100 study participants

- Use traditional charcoal cookstove as primary cooking technology
- Spend at least $3 per week on charcoal
- Have a pre-pay electricity meter
- Enrolled at their homes by Busara enumerators

	Mean	25th	50th	75th	N
Number of residents	5.0	4	5	6	2127
Age	35.8	28	35	42	2127
Male (=1)	0.1	0	0	0	2127
Charcoal cooking time (minutes/day)	186.0	140	180	220	2127
Charcoal spending (USD/month)	19.4	14	16	23	2127
LPG/ethanol spending (USD/month)	5.2	0	7	8	2121
Respondent income (USD/month)	101.6	46	69	116	2120
Household income (USD/month)	247.0	116	196	300	1810
Hours of power outage (30d)	13.9	1	4	12	2127
Hours of voltage fluctuation (30d)	2.0	0	0	1	2127

Randomly assigned credit, FC subsidies, MC subsidies

- **Fixed cost subsidies**, down from store price of \$82:
  - 46% assigned a price of \$20 (86% subsidy)
  - 49% assigned a price of \$73 (10% subsidy)

Full sample:
Random fixed cost subsidy between 10% - 86% of the stove price

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- **Credit:** \$15 down downpayment, three deadlines 1, 2, 3 months later

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Random fixed cost subsidy between 10% - 86% of the stove price

Credit (1/2)	No credit (1/2)

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  - 49% assigned a price of $73 (10% subsidy)
- **Credit:** $15 down downpayment, three deadlines 1, 2, 3 months later
- **Marginal cost subsidies:** one-third each to 0%, 25%, 75%

Randomized information about marginal costs

No information (15%)

Randomized information about marginal costs

Information (85%)

Randomized information about marginal costs

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Implementation Timeline

- Visit 1: August 12 - September 19
- Visit 2: September 23 - November 19
- Visit 3: November 10 - December 5 ish [564 out of 2100]

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Main visit timeline

1. Collect Kenya Power meter number
2. Inform about electricity subsidy (if relevant)
3. Inform how credit works (if relevant)
4. Practice TIOLI and BDM with soap and moisturizer Practice
5. Implement Becker-DeGroot-Marschak (BDM) mechanism:
   1) Elicit WTP_i using binary search
   2) Reveal random price P_i; either \$20 or \$73
   3) WTP is binding: adopt *iff* $WTP_i \geq P_i$
      - Pay P_i: incentive compatible
      - 98.2% of respondents complied

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      - Pay P_i: incentive compatible
      - 98.2% of respondents complied
6. For buyers:
   - Show how to boil water and adjust power buttons
   - Add to customer service WhatsApp group
   - Show how child lock and timer buttons work

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Induction stove adopters use charcoal stoves less

- Data collected using high-frequency temperature monitors on charcoal stoves
- Cooking events identified using simple temperature algorithm

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Induction stove adoption causes less charcoal usage

Table: IV estimate of induction stove purchase on daily jiko stove usage (hours)

	Hours			Log		
	(1)	(2)	(3)	(4)	(5)	(6)
Bought induction stove (=1)	-0.61	-0.58**	-0.55**	-0.06	-0.12	-0.09
	(0.61)	(0.24)	(0.24)	(0.25)	(0.11)	(0.09)
Observations	11976	11976	11976	6576	6576	6576
Respondents	304	304	304	290	290	290
Control Mean	2.55	2.55	2.55	1.24	1.24	1.24
WTP control?	Yes	Yes	Yes	Yes	Yes	Yes
Date control?	No	Yes	Yes	No	Yes	Yes
SES control?	No	No	Yes	No	No	Yes
F-Stat	18.49	6.90	9.59	15.23	3.81	52.39

Induction stove adoption causes less energy usage

Table: IV estimate of induction stove purchase on monthly energy spending (USD)

	Charcoal	LPG	Wood	Electricity	Total
Bought ECOA (=1)	-9.9***	-0.7	-0.4	1.7**	-9.4***
	(2.0)	(1.4)	(0.4)	(0.8)	(2.4)
WTP (USD)	0.0	-0.0	0.0	0.0**	0.1*
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Observations	564	564	564	564	564
Control Mean	16.3	5.5	0.4	3.1	25.4
F-Stat	16.68	10.19	0.71	23.39	12.12

- Instrumental variable: Subsidy instruments for stove adoption
- Compliers (marginal adopters): $WTP \in [12, 73]$
- Savings of \$9.4 per month, \$113 per year
- With an \$82 price and 3 years of usage, IRR= 11% per month (134% p.y.)

Effect of induction stoves on CO_2e emissions

Table: IV estimate of induction stove purchase on annual emissions (tCO_2e)

	Charcoal	LPG	Electricity	Total
Bought ECOA (=1)	-3.00***	-0.02	0.01*	-2.95***
	(0.61)	(0.04)	(0.01)	(0.60)
WTP (USD)	0.01	-0.00	0.00**	0.01
	(0.01)	(0.00)	(0.00)	(0.01)
Observations	564	561	564	564
Control Mean	4.9	0.2	0.0	5.1
F-Stat	16.68	10.18	22.72	16.05

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Observations	564	561	564	564
Control Mean	4.9	0.2	0.0	5.1
F-Stat	16.68	10.18	22.72	16.05

- Average abatement across all study participants: 3.0 tCO_2e per year
- Assume 3-year lifetime of the induction stove: 8.9 tCO_2e per stove
- Marginal cost of producing one stove is \$82
- **Resource cost of abatement:** \$9.3

Access to a 3-month loan increases WTP by 76%

- Average WTP in credit control: \$19.5
- Average WTP in credit treatment: \$34.4

Today

Background

Theory

RCT Design

CO_2 Abatement

Extensive margin: Inframarginal and marginal subsidy expenditures

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Aggregate subsidy efficacy

Implications for global abatement policy

Marginal cost subsidies have no impact on WTP

- Can rule out that the subsidy increases WTP by more than $5
- Average subsidy value is $25 (undiscounted)
- Each $1 of marginal cost subsidy increases WTP by no more than $0.20

Credit constraints and demand elasticity

- We evaluate efficacy over our two subsidy points: $p_h = \$73$ and $p_l = \$20$

Credit constraints and demand elasticity

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Credit constraints and demand elasticity

- We evaluate efficacy over our two subsidy points: $p_h = \$73$ and $p_l = \$20$
- Demand elasticity using p_h as the starting point:
  - Credit treatment: $\mathcal{E}_D = -2.5$, credit control: $\mathcal{E}_D = -30.8$
- Demand elasticity from a log-log regression over $[p_l, p_h]$:
  - Credit treatment: $\mathcal{E}_D \in [-0.75, -0.67]$, credit control: $\mathcal{E}_D \in [-2.13, -1.89]$

Credit constraints increase marginality

More marginal payments, fewer inframarginal payments:

Credit constraints increase marginality

	Credit treatment	**Credit control**
Extensive margin elasticity to fixed subsidy	$\mathcal{E}_d = -2.5$	$\mathcal{E}_d = -30.8$
Fraction of population that is marginal	46%	63%
Fraction of subsidies cost to inframarginal adopters	32%	3.7%

Credit constraints increase marginality

	Credit treatment	**Credit control**
Extensive margin elasticity to fixed subsidy	$\mathcal{E}_d = -2.5$	$\mathcal{E}_d = -30.8$
Fraction of population that is marginal	46%	63%
Fraction of subsidies cost to inframarginal adopters	32%	3.7%

Aggregate extensive margin subsidy efficiency:

- Credit treatment group: \$99 in subsidy expenditures per additional adoption
- Credit control group: \$63 in subsidy expenditures per additional adoption

Aggregate WTP impacts

Table: Effect of credit and electricity subsidy on WTP

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Credit treatment	14.1***	14.1***	14.9***	14.7***	15.9***	14.1***	14.1***	14.9***	14.7***	15.9***
	(2.1)	(2.1)	(1.9)	(1.9)	(2.0)	(2.1)	(2.1)	(1.9)	(1.9)	(2.0)
Subsidy	-2.0	-2.0	-1.6	-1.7	-1.4					
	(1.3)	(1.3)	(1.2)	(1.3)	(1.3)					
Subsidy=25						-2.2	-2.3	-1.1	-1.1	-0.4
						(1.5)	(1.5)	(1.4)	(1.4)	(1.5)
Subsidy=75						-1.7	-1.8	-2.0	-2.2	-2.2
						(1.5)	(1.4)	(1.4)	(1.4)	(1.5)
Credit X Subsidy (any)	2.4	2.4	2.2	2.4	1.6					
	(2.6)	(2.5)	(2.4)	(2.4)	(2.4)					
Credit X 25% Subsidy						0.9	1.0	0.5	0.7	-0.4
						(3.0)	(3.0)	(2.8)	(2.8)	(2.9)
Credit X 75% Subsidy						4.0	3.8	3.9	4.1	3.6
						(2.9)	(2.9)	(2.7)	(2.7)	(2.7)
Observations	2127	2127	2127	2127	2127	2127	2127	2127	2127	2127
Control Mean	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5
SES controls	None	Some	Many	Most	All	None	Some	Many	Most	All

Today

Background

Theory

RCT Design

CO_2 Abatement

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Implications for global abatement policy

Fixed cost subsidies: Externality of marginal adopters

- **Theory:** If credit constraints decrease net willingness-to-pay, and private and social benefits are positively correlated, then credit constraints increase the positive externality generated by adopters who are marginal to the fixed cost subsidy

- We test for this with:
  - Electric stove usage
  - Charcoal stove usage
  - Self-reported charcoal expenditures
  - Self-reported LPG expenditures
  - Combined measure of cooking-related CO_2 emissions

- As before, define marginal adopters as having $WTP \in [12, 73]$

Marginal adopters in credit treatment use new stoves less

Marginal adopters in credit treatment use new stoves less

Table: Daily data

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Credit treatment	-198.75**	-206.03**	-224.32**	-0.20*	-0.18*	-0.19*	-0.44*	-0.43*	-0.50**
	(98.20)	(103.61)	(98.33)	(0.11)	(0.11)	(0.11)	(0.24)	(0.23)	(0.22)
Observations	9285	9285	9285	5632	5632	5632	9285	9285	9285
Respondents	347	347	347	320	320	320	347	347	347
Control Mean	758.0	758.0	758.0	6.6	6.6	6.6	3.4	3.4	3.4
SES controls	None	Many	All	None	Many	All	None	Many	All
Units	Wh	Wh	Wh	log	log	log	ihs	ihs	ihs

Table: Respondent-level data

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Credit treatment	-157.81*	-195.68**	-222.26**	-0.25*	-0.30*	-0.33*	-0.28	-0.35	-0.38*
	(82.89)	(99.31)	(102.75)	(0.15)	(0.17)	(0.17)	(0.19)	(0.22)	(0.23)
Observations	347	347	347	320	320	320	347	347	347
Respondents	347	347	347	320	320	320	347	347	347
Control Mean	692.1	692.1	692.1	6.0	6.0	6.0	4.5	4.5	4.5
SES controls	None	Many	All	None	Many	All	None	Many	All
Units	Wh	Wh	Wh	log	log	log	ihs	ihs	ihs

Marginal adopters in credit treatment abate less

Table: Instrumental variable

	Charcoal (USD)			Total (USD)			Charcoal (CO2)			Total (CO2)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Bought ECOA (=1)	-7.8***	-5.7**	-3.8***	-7.0***	-9.0***	-1.7	-2.4***	-1.7**	-1.1***	-2.4***	-1.8**	-1.1***
	(1.8)	(2.4)	(1.3)	(2.3)	(3.1)	(1.7)	(0.6)	(0.7)	(0.4)	(0.5)	(0.7)	(0.4)
Credit treatment (=1)	-3.0			0.6			-0.9			-0.7		
	(3.2)			(4.1)			(1.0)			(1.0)		
ECOA X Credit	2.7			3.2			0.8			0.9		
	(2.1)			(2.7)			(0.6)			(0.6)		
WTP (USD)	-0.0	0.1	0.0	0.2*	0.2*	0.1	-0.0	0.0	0.0	-0.0	0.0	0.0
	(0.1)	(0.1)	(0.0)	(0.1)	(0.1)	(0.1)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
WTP (USD) X Credit	0.0			-0.1			0.0			0.0		
	(0.1)			(0.1)			(0.0)			(0.0)		
Observations	177	74	103	177	74	103	177	74	103	177	74	103
Control Mean	16.9	16.9	16.9	27.5	27.5	27.5	5.1	5.1	5.1	5.3	5.3	5.3
Controls	Some	Some	Some	Some	Some	Some	Some	Some	Some	Some	Some	Some
Sample	All	C=0	C=1	All	C=0	C=1	All	C=0	C=1	All	C=0	C=1
F-Stat	2.45	2.19	1.69	2.08	1.52	1.42	2.45	2.19	1.69	2.46	2.19	1.69

Marginal adopters in credit treatment abate less

Table: Instrumental variable

	Charcoal (USD)			Total (USD)			Charcoal (CO2)			Total (CO2)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Bought ECOA (=1)	-8.1***	-5.8**	-4.4***	-7.3***	-11.2***	-1.8	-2.4***	-1.8**	-1.3***	-2.5***	-2.1**	-1.3**
	(1.8)	(2.8)	(1.2)	(2.2)	(3.1)	(1.6)	(0.5)	(0.8)	(0.4)	(0.5)	(0.8)	(0.4)
Credit treatment (=1)	-2.3			0.1			-0.7			-0.6		
	(3.3)			(4.0)			(1.0)			(1.0)		
ECOA X Credit	2.9			3.4			0.9			1.0		
	(2.1)			(2.6)			(0.6)			(0.6)		
WTP (USD)	-0.0	-0.1	0.0	0.1*	0.1	0.0	-0.0	-0.0	0.0	-0.0	-0.0	0.0
	(0.1)	(0.1)	(0.0)	(0.1)	(0.1)	(0.1)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
WTP (USD) X Credit	0.0			-0.1			0.0			0.0		
	(0.1)			(0.1)			(0.0)			(0.0)		
Observations	177	74	103	177	74	103	177	74	103	177	74	103
Control Mean	16.9	16.9	16.9	27.5	27.5	27.5	5.1	5.1	5.1	5.3	5.3	5.3
Controls	Some	Some	Some	Some	Some	Some	Some	Some	Some	Some	Some	Some
Sample	All	C=0	C=1	All	C=0	C=1	All	C=0	C=1	All	C=0	C=1
F-Stat	2.20	1.88	1.61	2.15	1.84	1.43	2.20	1.88	1.61	2.22	1.86	1.60

Conversely, intensive margin is very price inelastic

- Cannot distinguish between selection plus direct treatment effect
- Likely an upper bound on intensive margin elasticity
- Lack of response could be due to inattention (running another treatment!)

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- Cannot distinguish between selection plus direct treatment effect
- Likely an upper bound on intensive margin elasticity
- Lack of response could be due to inattention (running another treatment!)

Intensive margin is very price inelastic

Table: Selection plus treatment effect of electricity subsidy (hourly usage)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Subsidy	1.0	0.6	0.6	-1.3	-2.0					
	(4.4)	(4.4)	(4.4)	(4.5)	(4.5)					
=25						-0.8	-1.5	-1.5	-4.5	-4.6
						(4.7)	(4.6)	(4.6)	(5.1)	(4.6)
=75						2.9	2.7	2.7	1.9	1.2
						(4.8)	(4.8)	(4.8)	(4.5)	(5.3)
Observations	379008	379008	379008	379008	304992	379008	379008	379008	379008	304992
Respondents	587	587	587	587	463	587	587	587	587	463
Control mean	29.7	29.7	29.7	29.7	29.7	29.7	29.7	29.7	29.7	29.7
Controls	None	Some	Many	Most	All	None	Some	Many	Most	All
Units	Wh	Wh	Wh	Wh	Wh	Wh	Wh	Wh	Wh	Wh

Today

Background

Theory

RCT Design

CO_2 Abatement

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Implications for global abatement policy

Aggregate subsidy efficacy by credit treatment

	Credit treatment	**Credit control**
(a) Marginal cost subsidy efficacy		
Intensive margin elasticity to marginal subsidy	<0.3	<0.3
Extensive margin elasticity to marginal subsidy	<0.2	<0.2

Aggregate subsidy efficacy by credit treatment

	Credit treatment	**Credit control**
(a) Marginal cost subsidy efficacy		
Intensive margin elasticity to marginal subsidy	<0.3	<0.3
Extensive margin elasticity to marginal subsidy	<0.2	<0.2
(b) Fixed cost subsidy efficacy		
Annual tCO_2e abated per marginal adopter	1.5	2.5
Extensive margin elasticity to fixed subsidy	$\mathcal{E}_d = -2.5$	$\mathcal{E}_d = -30.8$
Fixed cost subsidy expenditure per marginal adoption	\$99	\$63
Abatement cost per tCO_2e after 3 years	**\$22**	**\$6**

Today

Background

Theory

RCT Design

CO_2 Abatement

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When might we prefer larger marginal cost subsidies?

- Uncorrelated private benefits and externality
- Heterogeneous baseline technologies
- Heterogeneous substitute technologies
- High intensive margin elasticity
- Access to credit
  In U.S., 80% of new cars sold with financing

When might we want larger fixed cost subsidies?

Recall model results:

- If $r = 0$ then $s_1^* = 0$ and $s_2^* = \phi$
- If $r > 0$ then $s_1^* > 0$ and $0 < s_2^* < \phi$

Optimal fixed cost subsidy will be larger in contexts characterized by:

- Larger credit constraints *e.g. many low- and middle-income contexts*
- Positively correlated private and social benefits, *e.g. fuel usage with proportional prices and emissions*
- Inelastic intensive margin *e.g. daily routines*
- Uniform baseline technology
- A single substitute technology

Population in China, India, Africa

Source: UN, World Population Prospects (2024), medium scenario

2.1 billion people lack clean cooking; >1bn in 2030

Source: Joint SDG 7 Report

>700 million people without electricity

Many use kerosene (paraffin) for lighting

Source: World Bank

Potentially effective fixed cost subsidies

- Low SES household energy appliances emit billions of tCO_2e each year
- These CO_2 emissions can be avoided for less than \$10 per tCO_2e

Incumbent technology	**Green technology**	**Annual emissions in tCO_2e**	**Abatement cost per tCO_2e**	**Evidence**
1.3bn people with electricity cook with biomass	Induction stoves	5-10	\$X	Berkouwer, Dean (2025)
700mn unconnected people cook with biomass	Improved charcoal stoves	5-10	\$8	Berkouwer, Dean (2022)
700mn people lack electricity, use kerosene	Solar lights	1-2	\$10	Rom, Gunther, Pomeranz (2023)

Potentially effective fixed cost subsidies

- Low SES household energy appliances emit billions of tCO_2e each year using technologies with abatement costs below \$10 per tCO_2e
  2 billion biomass users, 700 million kerosene users
- For comparison:
  - 100 million tCO_2e voluntary carbon credits sold in 2023
  - 40 million electric vehicles globally abate $\sim$100 million tCO_2e per year at $>$\$1,000 per tCO_2e
    IEA 2024; Muehlegger, Rapson 2023; Hahn, Hendren, Metcalfe, Sprung-Keyser 2025
- Many other technologies likely exist
  - 20 million diesel irrigation pumps in India
  - 25 million ICE motorcycles in Africa

Conclusion

- Credit constraints alter the efficacy of green subsidies
- In some common settings large fixed cost subsidies can be optimal
- We run a randomized trial to study induction stove adoption among 2,100 charcoal-using households in Nakuru County, Kenya
- We generate four main findings:
  - Induction stove adoption abates 2 tCO_2e per year
  - Marginal cost subsidies have minor extensive or intensive margin impacts
  - Fixed cost subsidies are effective: credit constraints increase the marginal adopter's positive externality and decrease the cost per marginal adopter
  - Credit constraints lower abatement costs from \$22 to \$6 per tCO_2e

    200x cheaper than EV abatement cost
- 1.3 billion people connected to electricity cook primarily with biomass

  3x more than annual abatement by EVs and voluntary carbon offsets, combined

Today

Background

Theory

RCT Design

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Energy efficiency adoption

Building on Allcott, Mullainathan, Taubinsky (2012, 2014)

- Agent i earns income Y_i and derives linear utility from a numeraire good
- They consume perfectly inelastic energy services θ_i
- At $t = 1$ they decide whether to buy the green technology, $d_{1i} = \{0, 1\}$
- At $t = 2$ they choose what fraction $d_{2i} \in [0, 1]$ of θ_i to consume using the green substitute
- Usage of the green tech generates convex utility $\mu(d_{2i}\theta_i - \alpha_i)$ so that higher α types have higher optimal green tech usage
- Assume no discounting, myopia

Adding the externality and the principal's subsidies

- The green tech emits less fuel per unit of usage: $\bar{\phi} = \phi_D - \phi_G$
- Substituting with the green tech generates a positive externality, $\phi_i = d_{2i}\theta_i\bar{\phi}$
- The principal can subsidize the fixed cost (s_1) and/or the usage cost (s_2)
- Assuming competitive supply, normalize the market price of the green tech relative to the dirty tech as $p_m - s_1 = (p_G - p_D) - s_1$
- The green tech costs less per unit of usage by some amount $\bar{b} + s_2$ such that substituting with the green tech generates private savings, $b_i = d_{2i}\theta_i(\bar{b} + s_2)$
- Normalize principal's $r = 0$

Agent's adoption decision, with credit constraints

Usage utility consists of a financial benefit and a non-financial utility impact:

$$f(d_{2i}, \bar{b}, \theta_i, \alpha_i) = d_{2i}\theta_i\bar{b} + \mu(d_{2i}\theta_i - \alpha_i)$$

An agent facing an implied interest rate of r has maximum willingness to pay:

$$wtp_i = \frac{1}{1+r} \cdot f(d_{2i}, \bar{b}, \theta_i, \alpha_i)$$

Planner's problem: Maximize social welfare

$$\mathbf{s}^* = \arg\max \int_{-\infty}^{\infty} u_{d_{1i},d_{2i}}$$

$$+ \arg\max \int_{\theta^\dagger}^{\infty} \underbrace{Y - p_j}_{\text{net income}} + \underbrace{d_{2i}\theta_i\bar{\phi}}_{\text{positive externality}} + \underbrace{d_{2i}\theta_i\bar{b}}_{\text{fuel savings}} + \underbrace{\mu(d_{2i}\theta_i - \alpha_i)}_{\text{usage utility}} h(\theta)g(\alpha)d\theta d\alpha$$

Model results:

- If $r = 0$ then $s_1^* = 0$ and $s_2^* = \bar{\phi}$ (classic case)

Planner's problem: Maximize social welfare

$$\mathbf{s}^* = \arg\max \int_{-\infty}^{\infty} u_{d_{1i},d_{2i}}$$

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Model results:

- If $r = 0$ then $s_1^* = 0$ and $s_2^* = \bar{\phi}$ (classic case)
- If $r > 0$ then
  - $0 < s_1^*$
  - $0 < s_2^* < \phi$

Environmentally-minded principal

- Many principals don't value or under-value inframarginal transfers
- Consider a principal focused who places no weight on agent welfare other than through the positive externality EPA, UNFCCC, CORSIA, Article 6.4, etc.

$$\mathbf{s}^* = \arg\max \int_{-\infty}^{\infty}\int_{\theta^\dagger}^{\infty} \underbrace{d_{2i}\theta_i\bar{\phi}}_{\substack{\text{positive}\\ \text{externality}}} - \underbrace{d_{1i}s_1}_{\substack{\text{technology}\\ \text{subsidy cost}}} - \underbrace{d_{2i}\theta_i s_2}_{\substack{\text{electricity}\\ \text{subsidy cost}}} \quad h(\theta)g(\alpha)d\theta d\alpha$$

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Two key model results for fixed cost subsidy s_1:

1. Higher $\mathcal{E}_D$ decreases marginal cost per adoption
2. Higher r increases the marginal positive externality

Graphical intuition: Marginal externality

- Consider the case where $\alpha_i = 0 \ \forall \ i$, such that private and social benefits are perfectly proportional

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- Higher r increases positive externality of the marginal adopter

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Graphical intuition: Cost per marginal adopter

- Credit constraints increase demand elasticity

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- Credit constraints increase demand elasticity
- Elastic demand creates more marginal and fewer inframarginal adopters

Graphical intuition: Cost per marginal adopter

- Credit constraints increase demand elasticity
- Elastic demand creates more marginal and fewer inframarginal adopters

Subsidy efficiency: tCO_2e per dollar