Selection on Welfare Gains:

Experimental Evidence from Electricity Plan Choice

Koichiro Ito[1] Takanori Ida[2] Makoto Tanaka[3]

[1]University of Chicago and NBER (ito@uchicago.edu)

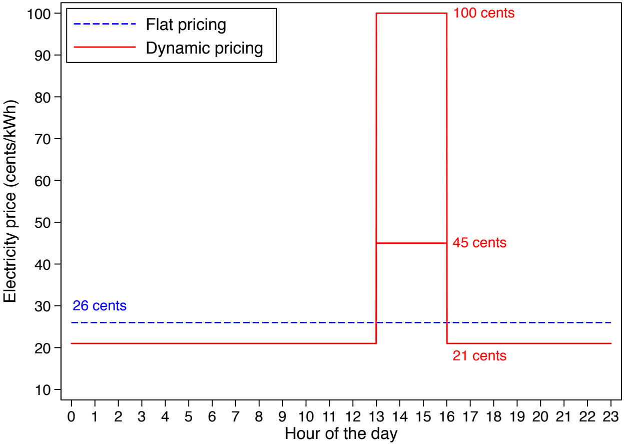
[2]Kyoto University (ida@econ.kyoto-u.ac.jp)

[3]GRIPS (mtanaka@grips.ac.jp)

Voluntary take-up plays a key role in economic policies

- Examples:
  - Food stamp (Finkelstein and Notowidigdo, 2018)
  - Disability benefits (Deshpande and Li, 2019)
  - Energy efficiency rebates (Allcott and Greenstone, 2017)
  - Electricity/natural gas/water tariffs (Hortacsu, et al., 2017, Fowlie et al., 2018)
- Self-selection: Individuals select into a program
- Welfare gains from these policies depend on two factors:
  1. Size of enrollment: "How many people select into?"
  2. Types of enrollees: "What types of people select into?"

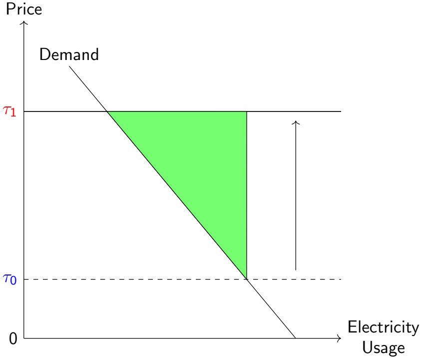
Example: Electricity pricing in many countries



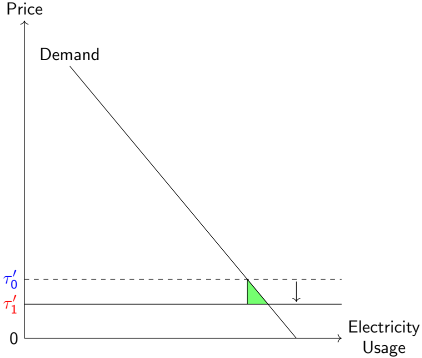
- Default: A flat price is inefficient b/c MC of electricity is time-varying
- Optional: Dynamic pricing makes P $=$ MC $\rightarrow$ improves social welfare

Example: ComEd in Illinois offers opt-in hourly pricing

Social welfare gain comes from ΔDWL

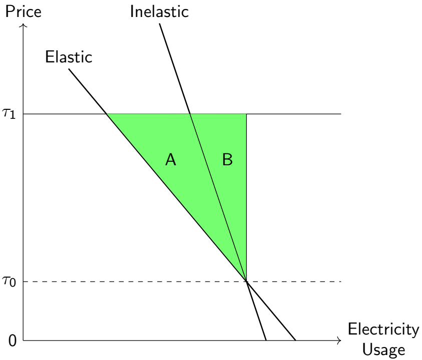


Peak hours ($\tau_0 \to \tau_1$)



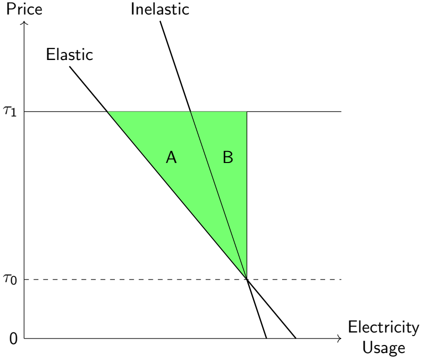
Off-peak hours ($\tau_0' \to \tau_1'$)

Social welfare gain depends on two factors



1. "How many consumers select into dynamic pricing?"
2. "What types of consumers (e.g. price elasticity) select into?"

Social welfare gain depends on two factors



1. "How many consumers select into dynamic pricing?"
2. "What types of consumers (e.g. price elasticity) select into?"

→ Key question: How is selection related to heterogeneity in welfare gains?

In this paper, we explore this question by three steps

1. A framework based on the Roy model and Marschak (1953)
   - Connect selection to heterogeneity in social welfare gains
   - Marginal treatment effects (MTE) (Eisenhauer, Heckman, and Vytlacil 2015)
   - Sufficient statistics (Chetty 2009, Kleven 2018)

In this paper, we explore this question by three steps

1. A framework based on the Roy model and Marschak (1953)
   - Connect selection to heterogeneity in social welfare gains
   - Marginal treatment effects (MTE) (Eisenhauer, Heckman, and Vytlacil 2015)
   - Sufficient statistics (Chetty 2009, Kleven 2018)
2. A randomized field experiment on electricity tariff choice
   - Generate randomized variation in a take-up incentive for dynamic pricing
   - Estimate MTE by a method from Brinch, Mogstad, and Wiswall (2017)

In this paper, we explore this question by three steps

1. A framework based on the Roy model and Marschak (1953)
   - Connect selection to heterogeneity in social welfare gains
   - Marginal treatment effects (MTE) (Eisenhauer, Heckman, and Vytlacil 2015)
   - Sufficient statistics (Chetty 2009, Kleven 2018)

2. A randomized field experiment on electricity tariff choice
   - Generate randomized variation in a take-up incentive for dynamic pricing
   - Estimate MTE by a method from Brinch, Mogstad, and Wiswall (2017)

3. Welfare analysis of existing and counterfactual policies
   - Is the current level of take-up socially optimal?
   - What policy can achieve the socially optimal take-up?

Relations to energy policy & the literature

1. Economists have advocated dynamic electricity pricing for long time
   - Smart meters solved the infrastructure problem (Joskow and Wolfram 2012)
   - Several RCTs show the effectiveness of dynamic pricing
     (Wolak 2011, Jessoe and Rapson 2014, Ito, Ida, Tanaka 2018)

Relations to energy policy & the literature

1. Economists have advocated dynamic electricity pricing for long time
   - Smart meters solved the infrastructure problem (Joskow and Wolfram 2012)
   - Several RCTs show the effectiveness of dynamic pricing
     (Wolak 2011, Jessoe and Rapson 2014, Ito, Ida, Tanaka 2018)

2. However, mandatory dynamic pricing is politically infeasible in practice
   - Many countries (US, Japan, Chile, etc.) rely on voluntary take-up

Relations to energy policy & the literature

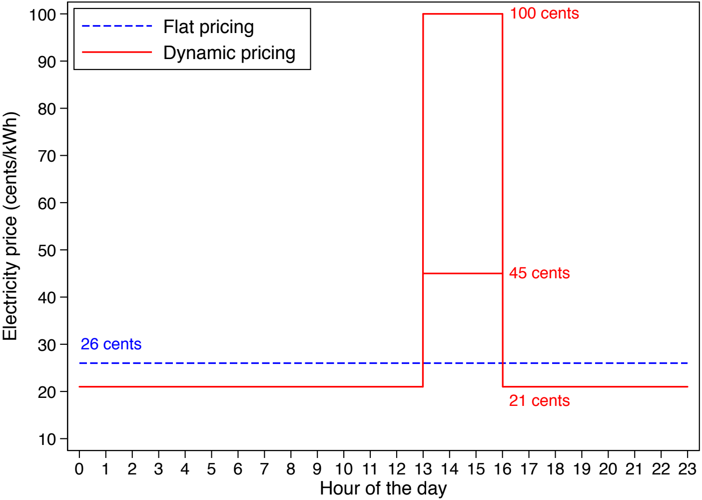
1. Economists have advocated dynamic electricity pricing for long time
   - Smart meters solved the infrastructure problem (Joskow and Wolfram 2012)
   - Several RCTs show the effectiveness of dynamic pricing (Wolak 2011, Jessoe and Rapson 2014, Ito, Ida, Tanaka 2018)
2. However, mandatory dynamic pricing is politically infeasible in practice
   - Many countries (US, Japan, Chile, etc.) rely on voluntary take-up
3. Important to study policy design for non-mandatory policies
   - Default bias (Fowlie et al., 2018)
   - Information friction (Ito, Ida, Tanaka, 2017)
   - Selection and welfare (This study)

Roadmap of the talk

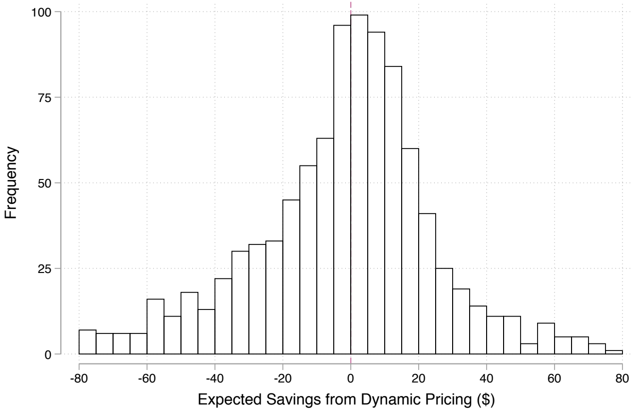
1. Introduction and Background
2. Conceptual Framework
3. Experimental Design and Data
4. Empirical Analysis: Selection Equation
5. Empirical Analysis: MTE
6. Welfare Analysis
7. Conclusion

Conceptual Framework

What affects consumers' selection decisions?

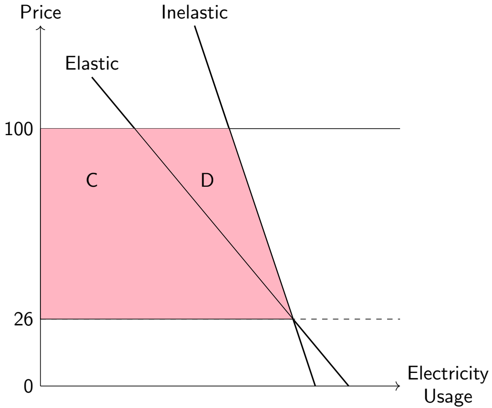


Prediction 1: Selection on expected savings (level)



- Expected savings from dynamic pricing, with zero elasticity assumption
- Prediction 1: "Structural winners" are more likely to select
    - Similar to "selection on the level" in Einav et al (2013)

Prediction 2: Selection on behavioral responses (slope)



- Example (peak-hour): Loss in consumer surplus is smaller for elastic
- Prediction 2: Price-elastic customers are more likely to select
  - Similar to "selection on the slope" in Einav et al (2013)
  - This is Advantageous Selection to social planner

- We use the Roy model to characterize these two selection mechanisms
  - Our framework builds on Eisenhauer, Heckman, and Vytlacil (2015)

- We use the Roy model to characterize these two selection mechanisms
  - Our framework builds on Eisenhauer, Heckman, and Vytlacil (2015)

Consumer

Selection Equation

$D = 1$ if

$S = \nu(x, z) - V > 0$

Social Planner

Incentive for Switching

Z

Consumer's problem: Selection equation and MTE

- Consumer selects into treatment $(D = 1)$ if the net surplus $S_1 - S_0 > 0$

$$S_1 - S_0 = \nu(X, Z) - V$$

  - S_1 and S_0: the consumer's indirect utility for $D = 1$ and $D = 0$
  - X: observables (e.g. expected savings , demographics)
  - Z: a financial take-up incentive
  - $\nu(.)$: a flexible function of observables
  - V: unobserved disutility for treatment, with distribution $F_V(\cdot)$

Consumer's problem: Selection equation and MTE

- Consumer selects into treatment ($D = 1$) if the net surplus $S_1 - S_0 > 0$

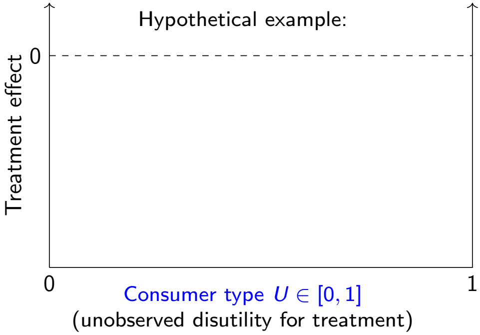
$$S_1 - S_0 = \nu(X, Z) - V$$

  - S_1 and S_0: the consumer's indirect utility for $D = 1$ and $D = 0$
  - X: observables (e.g. expected savings , demographics)
  - Z: a financial take-up incentive
  - $\nu(.)$: a flexible function of observables
  - V: unobserved disutility for treatment, with distribution $F_V(\cdot)$

- Define the CDF of V by $U = F_V(V)$
  - $U \in [0, 1]$ tells us the quantiles of unobserved disutility for treatment
  - Propensity score: $P(x, z) = \Pr[D = 1|x, z] = F_V(\nu(x, z))$

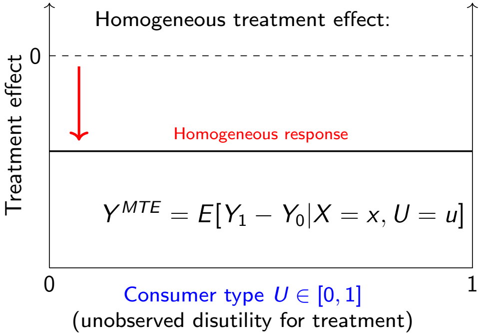
- Marginal Treatment Effect (MTE) $\equiv$ ATE for consumer type U:

$$Y^{MTE}(x,u) = E[Y_1 - Y_0 | X = x, U = p]$$



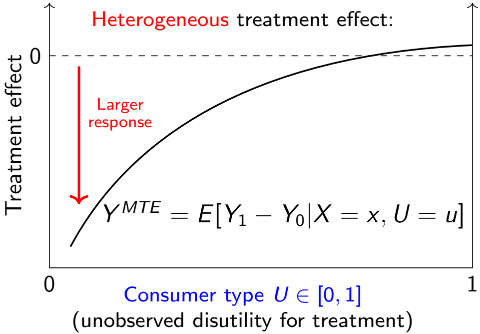
- Marginal Treatment Effect (MTE) $\equiv$ ATE for consumer type U:

$$Y^{MTE}(x,u) = E[Y_1 - Y_0 | X = x, U = p]$$



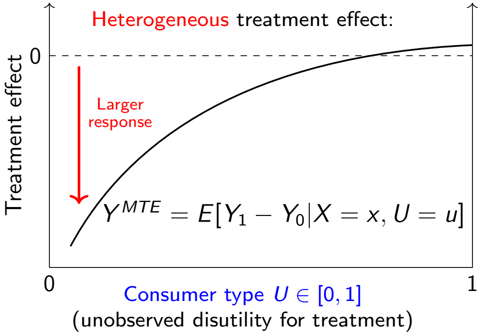
- Marginal Treatment Effect (MTE) $\equiv$ ATE for consumer type U:

$$Y^{MTE}(x,u) = E[Y_1 - Y_0 | X = x, U = p]$$



- Marginal Treatment Effect (MTE) $\equiv$ ATE for consumer type U:

$$Y^{MTE}(x, u) = E[Y_1 - Y_0 | X = x, U = p]$$



- Marginal Treatment Responses (MTR): Mogstad, Santos, Torgovitsky (2018)

$$m_0(x, u) = E[Y_0 | X = x, U = p]$$
$$m_1(x, u) = E[Y_1 | X = x, U = p]$$

Consumer

Social Planner

Selection Equation

$D = 1$ if

$S = \nu(x, z) - V > 0$

Incentive for Switching

Z

$MTE = m_1 - m_0$

$m_0 = E[Y_0|X, U]$

$m_1 = E[Y_1|X, U]$

(U= CDF of V)

Consumer | **Social Planner**

Selection Equation

$D = 1$ if
$S = \nu(x, z) - V > 0$

Incentive for Switching

Z

$P(x,z) = Pr(D = 1|X, Z)$
$= \text{Propensity Score}$

$MTE = m_1 - m_0$

$m_0 = E[Y_0|X, U]$
$m_1 = E[Y_1|X, U]$

(U= CDF of V)

m_0, m_1

Marginal Welfare Gain

$$\frac{dW^{ITT}}{dz} = f\big(P(x,z), m_0, m_1\big)$$

Social planner's problem: Social welfare gain $W_1 - W_0$

- Social planner uses a financial take-up incentive (z)
- If a consumer selects into dynamic pricing, the social welfare gain is:

$$W_1 - W_0 = (S_1 - S_0) + (PS_1 - PS_0)$$

  - S: Consumer's indirect utility
  - PS: Producer surplus

Social planner's problem: Social welfare gain $W_1 - W_0$

- Social planner uses a financial take-up incentive (z)
- If a consumer selects into dynamic pricing, the social welfare gain is:

$$W_1 - W_0 = (S_1 - S_0) + (PS_1 - PS_0)$$

  - S: Consumer's indirect utility
  - PS: Producer surplus

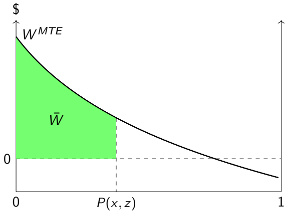
- The MTE of the social welfare gain can be written by:

$$\begin{aligned} W^{MTE}(x, z, u) &= E[W_1 - W_0 | X = x, Z = z, U = p] \\ &= S^{MTE}(x, z, p) + PS^{MTE}(x, z, p) \end{aligned}$$

Social planner's problem: Welfare gain per capita W^{ITT}

- A utilitarian social planner maximizes the per-capita welfare gain:

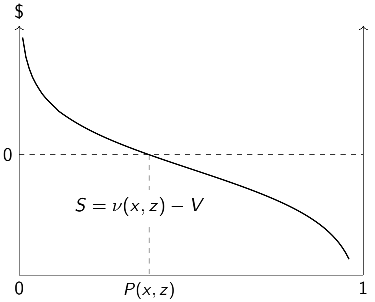
$$W^{ITT}(x,z) = \int_0^{P(x,z)} W^{MTE}(x,z,p)dp$$



Consumer type $U \in [0,1]$
(unobserved disutility for treatment)

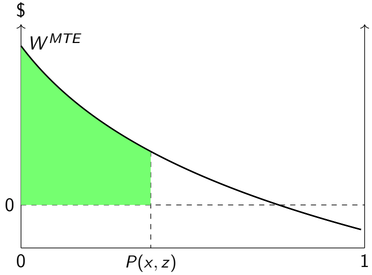
Consumer

- Suppose incentive is $Z = z$
- Consumer switches if $U < P(x, z)$



Social planner

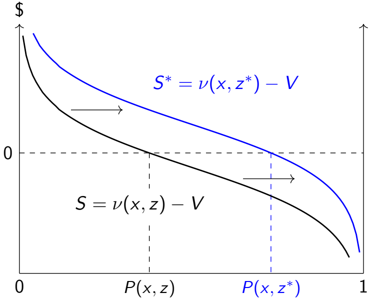
- Social welfare gain is not maximized at $Z = z$



Consumer type $U \in [0, 1]$
(unobserved disutility for treatment)

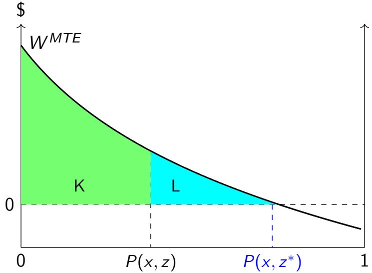
Consumer

- Suppose incentive is $Z = z^*$
- Consumer switches if $U < P(x, z^*)$



Social planner

- Social welfare gain is maximized at $Z = z^*$



Consumer type $U \in [0, 1]$
(unobserved disutility for treatment)

Marginal welfare gain

- Marginal welfare gain with respect to a take-up incentive (z):

$$\begin{aligned}\frac{dW^{ITT}(x,z)}{dz} &= \frac{d}{dz}\int_0^{P(x,z)} W^{MTE}(x,z,p)dp \\ &= \underbrace{\frac{dP(x,z)}{dz}}_{\substack{\text{Size of marginal}\\ \text{consumers}}} \cdot \underbrace{W^{MTE}\left(x,z,P(x,z)\right)}_{\substack{\text{Welfare gain from}\\ \text{marginal consumers}}}.\end{aligned}$$

- The equality comes from Leibniz rule

- The parameters that need to be estimated in empirical analysis:
  1. $W^{MTE}(x,z,p)$
  2. $P(x,z) = \Pr[D=1|x,z]$: Propensity score from selection equation

$W^{MTE}(x, z, p)$ is a function of estimable parameters

- Known parameters:
  - τ_{tj}: electricity price for hour t for plan j
  - c_t: marginal cost of electricity for hour t

$W^{MTE}(x, z, p)$ is a function of estimable parameters

- Known parameters:
  - τ_{tj}: electricity price for hour t for plan j
  - c_t: marginal cost of electricity for hour t
- W^{MTE} can be written by:

$$W^{MTE}(x, z, p) = S^{MTE}(x, p) + PS^{MTE}(x, p)$$
$$= \nu(x) - F_V^{-1}(p) + \sum_{t \in T} \left[(\tau_{t,1} - c_t) \cdot m_{t,1}(x, p) - (\tau_{t,0} - c_t) \cdot m_{t,0}(x, p) \right]$$

$W^{MTE}(x, z, p)$ is a function of estimable parameters

- Known parameters:
  - τ_{tj}: electricity price for hour t for plan j
  - c_t: marginal cost of electricity for hour t

- W^{MTE} can be written by:

$$W^{MTE}(x, z, p) = S^{MTE}(x, p) + PS^{MTE}(x, p)$$
$$= \nu(x) - F_V^{-1}(p) + \sum_{t \in T} \left[(\tau_{t,1} - c_t) \cdot m_{t,1}(x, p) - (\tau_{t,0} - c_t) \cdot m_{t,0}(x, p) \right]$$

- $\nu(x) - F_V^{-1}(p)$ are estimable from the selection equation

$W^{MTE}(x, z, p)$ is a function of estimable parameters

- Known parameters:
  - τ_{tj}: electricity price for hour t for plan j
  - c_t: marginal cost of electricity for hour t
- W^{MTE} can be written by:

$$W^{MTE}(x, z, p) = S^{MTE}(x, p) + PS^{MTE}(x, p)$$

$$= \nu(x) - F_V^{-1}(p) + \sum_{t \in T} \left[(\tau_{t,1} - c_t) \cdot m_{t,1}(x, p) - (\tau_{t,0} - c_t) \cdot m_{t,0}(x, p) \right]$$

- $\nu(x) - F_V^{-1}(p)$ are estimable from the selection equation
- PS^{MTE} is a function of $m_{t,0}$ and $m_{t,1}$ (MTRs)

Consumer | **Social Planner**

Selection Equation

$D = 1$ if
$S = \nu(x, z) - V > 0$

Incentive for Switching

Z

$$P(x,z) = Pr(D=1|X,Z)$$
$$= \text{Propensity Score}$$

$MTE = m_1 - m_0$

$m_0 = E[Y_0|X,U]$
$m_1 = E[Y_1|X,U]$

(U= CDF of V)

m_0, m_1

Marginal Welfare Gain

$$\frac{dW^{ITT}}{dz} = f\big(P(x,z), m_0, m_1\big)$$

Optimal $Z = z^*(x)$ and $Z = z^*$

- The socially optimal Z can be obtained by estimating propensity score $P(x, z)$ and the MTE of the welfare gain $W^{MTE}(x, z, p)$.

- When the social planner can differentiate Z based on observables X, the optimal differentiated take-up incentive $z^*(x)$ is:

$$z^*(x) = \underset{z(x)}{\operatorname{argmax}} \int_0^{P(x,z)} W^{MTE}(x, z, p) dp.$$

- When the planner cannot differentiate Z by X, the planner can find the optimal uniform take-up incentive z^* by

$$z^* = \underset{z}{\operatorname{argmax}} \int_X \int_0^{P(x,z)} W^{MTE}(x, z, p) dp \; dF_X$$

where F_X is the distribution of X.

(Note) Subjective cost of treatment

- Suppose that we want to decompose $S_1 - S_0$ into $(v_1 - v_0) - C$
  - $(v_1 - v_0)$ = change in indirect utility purely from electricity consumption
  - C = subjective cost of treatment (Eisenhauer, Heckman, and Vytlacil (2015))
- C could include:
  - Switching cost
  - Plan preferences that are unrelated to electricity consumption
- Note that this decomposition is not necessary for our analysis
- However, for some other questions, it can be useful to know C

(Note) Two more assumptions are required to estimate C

- Assumption 1: Quasi-linear utility for electricity consumption
- Assumption 2: Demand curve is locally linear

$$\begin{aligned} S_1 - S_0 &= (v_1 - v_0) - C \\ &= \frac{1}{2}\sum_{t \in T}(\tau_{1,t} - \tau_{0,t})(Y_{t,1} + Y_{t,0}) - C \end{aligned}$$

- Then, the MTE of the subjective cost of treatment is:

$$C^{MTE}(x,p) = S^{MTE} - \frac{1}{2}\sum_{t \in T}\left[\Delta\tau_t(m_{t,0} + m_{t,1})\right]$$

Roadmap of the talk

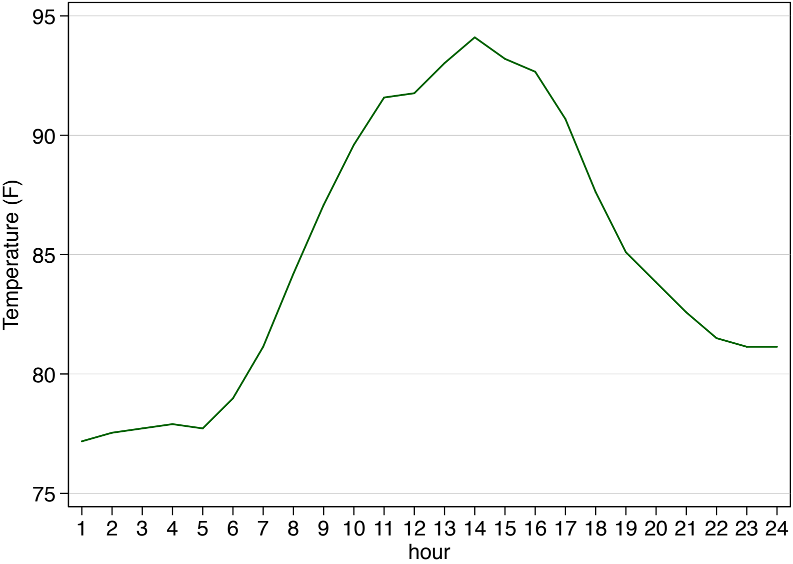
Field Experiment and Results

A field experiment in the city of Yokohama, Japan

- We collaborated with several government agencies and firms
  - Ministry of Economy, Trade, and Industry; City of Yokohama
  - Tokyo Electric Power Company; Toshiba; Panasonic

The city of Yokohama is known for their summer **Pikachu festival**

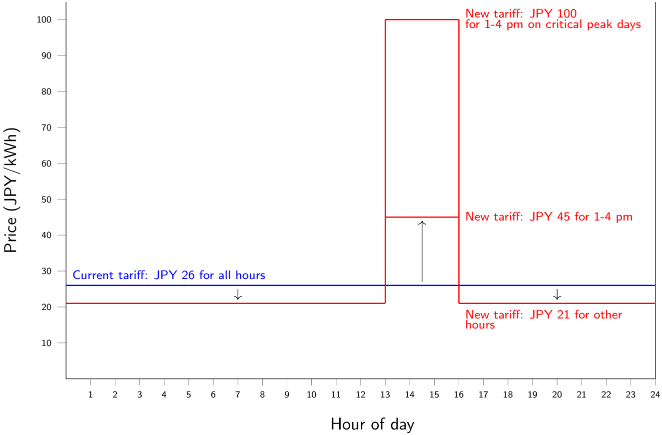
Hourly temperature on a hot summer day in Yokohama



Group	Eligible to switch tariff	Information provision	Incentive for switching	Number of customers
Control	-	-	-	697
Baseline	Yes	-	-	486
Information	Yes	Yes	-	468
Information + Incentive	Yes	Yes	Yes	502

Focus of this study

- Note: Our another paper, Ito, Ida, Tanaka (2017) studies the effect of the information provision on consumer behavior

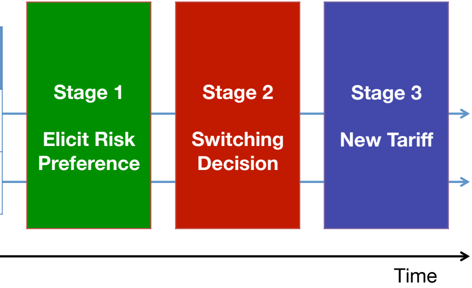


Below is the estimated difference in your payment based on your past consumption data:

You are expected to pay JPY 5,500 less if you switch to the new tariff

Experimental timeline and data:

Group	Information provision	Incentive for switching
Information	Yes	-
Information + Incentive	Yes	Yes



- Main data: Household-level electricity usage for every 30 minutes
- We also elicit risk preferences in the pre-experimental period
  - Use the method by Callen, Isaqzadeh, Long, and Sprenger (2014 AER)

- Summary statistics: Observables are balanced by group b/c of randomization

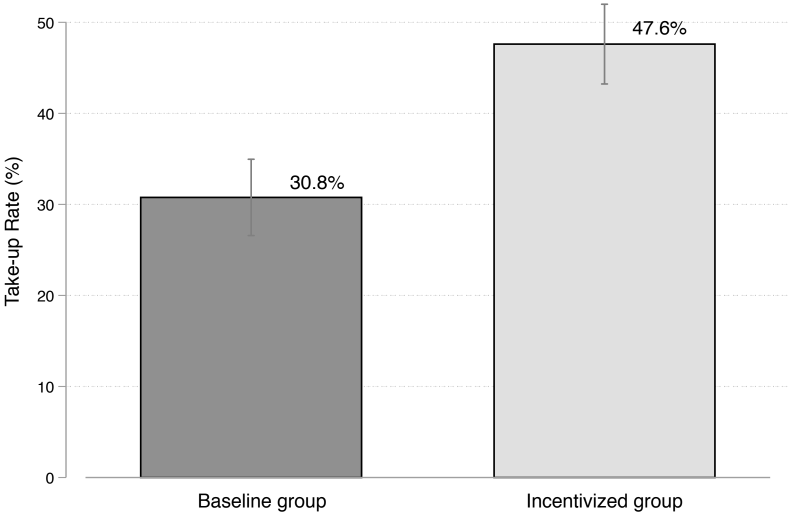
	Baseline group	Incentivized group
Household income (JPY10,000)	742.31	749.80
	(296.29)	(311.25)
Years of schooling	14.84	14.62
	(2.22)	(2.30)
Employed	0.84	0.86
	(0.37)	(0.35)
Risk aversion	0.66	0.63
	(0.28)	(0.30)
Certainty premium	0.04	0.06
	(0.24)	(0.26)
Square meters	99.82	100.91
	(33.20)	(33.43)
Number of bedrooms	3.70	3.81
	(1.10)	(0.99)
Age of building	12.71	11.63
	(12.29)	(11.15)
Number of room AC	3.18	3.13
	(1.25)	(1.25)
Number of TV	2.08	2.05
	(1.02)	(0.94)
Number of refrigerator	1.16	1.12
	(0.41)	(0.38)
Electricity usage (kWh/day) in the pre-experimental period	13.17	13.18
	(5.82)	(6.13)
Expected savings from dynamic pricing (USD/year)	-2.00	-1.86
	(29.73)	(34.96)

Roadmap of the talk

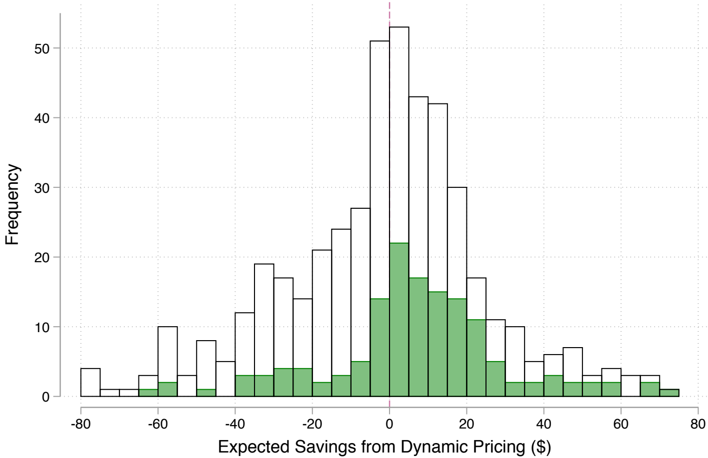
1. Introduction and Background
2. Conceptual Framework
3. Experimental Design and Data
4. Empirical Analysis: Selection Equation
5. Empirical Analysis: MTE
6. Welfare Analysis
7. Conclusion

Empirical Analysis: Selection Equation

Overall switching rate by treatment group

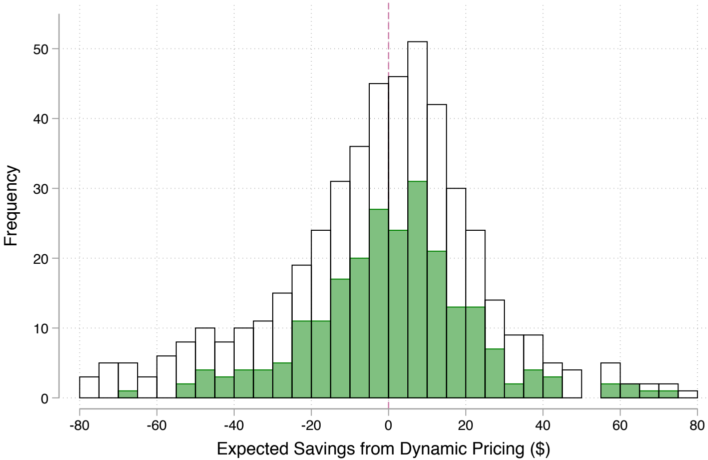


Group 1) Information-only group



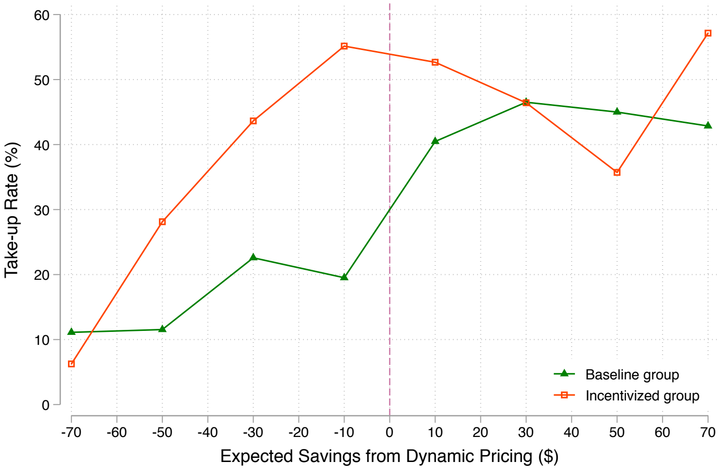
- Switching rate = 31%
- Switching rate is high for structural winners (expected gain > 0)

Group 2) Information + incentive group



- Switching rate = 48%
- The take-up incentive let structural losers also switch

Switching rate by expected savings from switching



- Selection on the level: Structural winners are more likely to switch
- Switching incentive nudged consumers (including structural losers) to switch

Selection equation

$$D = 1\{\nu(X, Z) - V > 0\}$$

- Observables:
  - Randomly assigned \$60 cash incentive (Z)
    $\rightarrow$ We can use its coefficient to scale all estimates into \$
  - expected savings from dynamic pricing (\$)
  - Years of schooling, employment, and other demographics
  - Risk aversion, Certainty premium
- We elicited risk preferences in the pre-experimental period
  - A method by Callen, Isaqzadeh, Long, and Sprenger (2014 AER)

Average marginal effects on $\Pr[D_i = 1(\text{household } i \text{ selected into dynamic pricing})]$

	(1)	(2)	(3)	(4)
Take-up incentive (USD)	0.0029	0.0030	0.0031	0.0033
	(0.0005)	(0.0005)	(0.0006)	(0.0006)
Expected savings (USD)	0.0019	0.0021	0.0026	
	(0.0005)	(0.0005)	(0.0006)	
Risk aversion		-0.2045	-0.2430	-0.2606
		(0.0811)	(0.0862)	(0.0876)
Certainty premium		-0.3130	-0.3355	-0.3432
		(0.0963)	(0.1015)	(0.1027)
Years of schooling		0.0210	0.0160	0.0115
		(0.0075)	(0.0079)	(0.0080)
Employed		-0.1308	-0.0541	-0.0818
		(0.0496)	(0.0638)	(0.0646)
Income (100,000 USD)		0.0527	0.0541	0.0690
		(0.0593)	(0.0645)	(0.0650)
Covariates interacted with each other	No	No	Yes	Yes
Non-parametric controls for expected savings	No	No	No	Yes
Log likelihood	-628.8	-613.1	-592.7	-579.6

Roadmap of the talk

1. Introduction and Background
2. Conceptual Framework
3. Experimental Design and Data
4. Empirical Analysis: Selection Equation
5. Empirical Analysis: MTE
6. Welfare Analysis
7. Conclusion

Empirical Analysis: MTE

MTE estimation with a discrete instrument Z

- Brinch, Mogstad, and Wiswall (2017)
  - A linear MTE can be estimated by Z given standard IV assumptions
  - Non-linear MTE can be estimated with the separability assumption:
    - Denote potential outcomes by: $Y_j = \mu_j(X) + U_j, \;\; j = \{0, 1\}$

Assumption: $E[Y_j|U, X] = \mu_j(X) + E[U_j|U], \;\; j = \{0, 1\}$

MTE estimation with a discrete instrument Z

- Brinch, Mogstad, and Wiswall (2017)
  - A linear MTE can be estimated by Z given standard IV assumptions
  - Non-linear MTE can be estimated with the separability assumption:
    - Denote potential outcomes by: $Y_j = \mu_j(X) + U_j, \;\; j = \{0, 1\}$

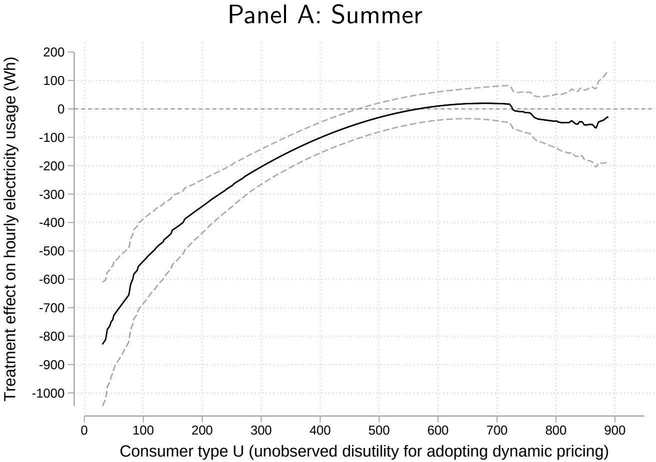
Assumption: $E[Y_j|U, X] = \mu_j(X) + E[U_j|U], \;\; j = \{0, 1\}$

- With this assumption, the MTE can be written as:

$$Y^{MTE}(x, p) = \mu_1(X) - \mu_0(X) + E[U_1 - U_0|U = p], \;\; j = \{0, 1\}$$

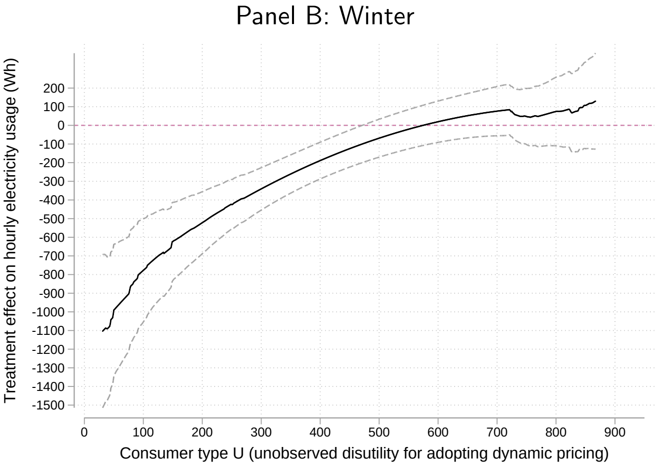
  - This allows the MTE to be non-linear in U
  - This still allows the MTE to vary by X
  - Restriction: $E[U_1 - U_0|U = p]$ does not vary by X

Peak-hour usage Y^{MTE}: Selection on the *Slope*



- This figure shows $Y^{MTE}(x, p)$ for a given set of observables x
- We obtain this figure for each set of $x \in X$

Peak-hour usage Y^{MTE}: Selection on the *Slope*



- This figure shows $Y^{MTE}(x, p)$ for a given set of observables x
- We obtain this figure for each set of $x \in X$

Roadmap of the talk

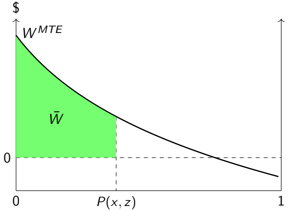
1. Introduction and Background
2. Conceptual Framework
3. Experimental Design and Data
4. Empirical Analysis: Selection Equation
5. Empirical Analysis: MTE
6. Welfare Analysis
7. Conclusion

Welfare Analysis

Social planner's problem: Welfare gain per capita W^{ITT}

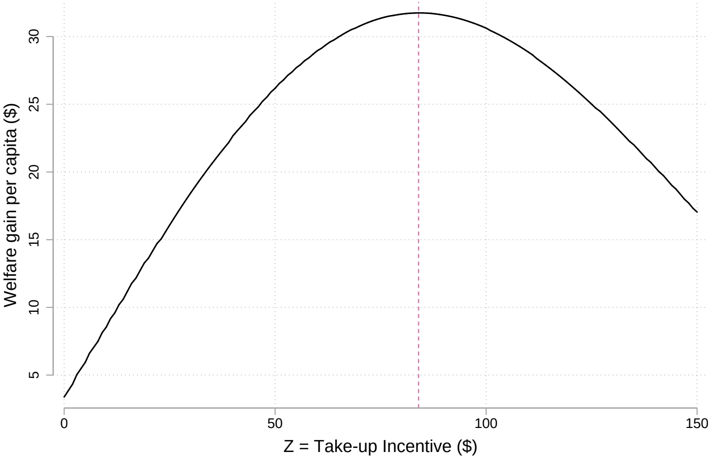
- A utilitarian social planner maximizes the per-capita welfare gain:

$$W^{ITT}(x,z) = \int_0^{P(x,z)} W^{MTE}(x,z,p)dp$$



Consumer type $U \in [0,1]$
(unobserved disutility for treatment)

Empirical results: Per-capita welfare gain $\overline{W}(x, z)$



- This figure shows $\frac{d\overline{W}(x,z)}{dz}$ for a given set of observables x
- We obtain this figure for each set of $x \in X$

Marginal welfare gain

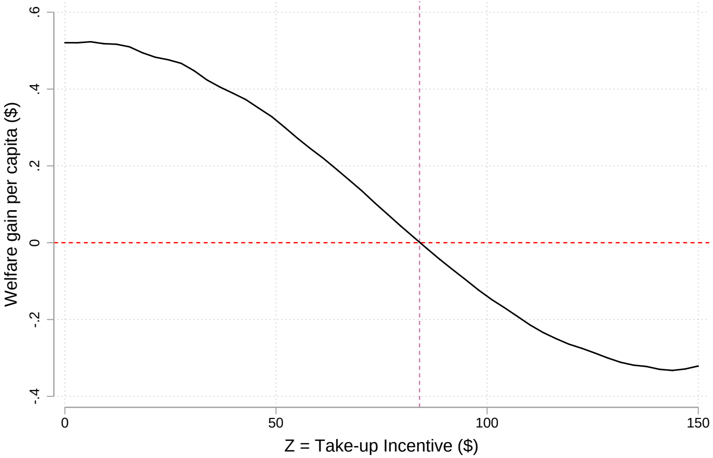
- Marginal welfare gain with respect to a take-up incentive (z):

$$\begin{aligned}\frac{dW^{ITT}(x,z)}{dz} &= \frac{d}{dz}\int_0^{P(x,z)} W^{MTE}(x,z,p)dp \\ &= \underbrace{\frac{dP(x,z)}{dz}}_{\substack{\text{Size of marginal}\\ \text{consumers}}} \cdot \underbrace{W^{MTE}\left(x,z,P(x,z)\right)}_{\substack{\text{Welfare gain from}\\ \text{marginal consumers}}}.\end{aligned}$$

- The equality comes from Leibniz rule

- The parameters that need to be estimated in empirical analysis:
  1. $W^{MTE}(x,z,p)$
  2. $P(x,z) = \Pr[D=1|x,z]$: Propensity score from selection equation

Empirical results: Marginal welfare gain $\frac{d\overline{W}(x,z)}{dz}$



- This figure shows $\frac{d\overline{W}(x,z)}{dz}$ for a given set of observables x
- We obtain this figure for each set of $x \in X$

Optimal $Z = z^*(x)$ and $Z = z^*$

- The socially optimal Z can be obtained by estimating propensity score $P(x, z)$ and the MTE of the welfare gain $W^{MTE}(x, z, p)$.
- When the social planner can differentiate Z based on observables X, the optimal differentiated take-up incentive $z^*(x)$ is:

$$z^*(x) = \underset{z(x)}{\operatorname{argmax}} \int_0^{P(x,z)} W^{MTE}(x, z, p) dp.$$

- When the planner cannot differentiate Z by X, the planner can find the optimal uniform take-up incentive z^* by

$$z^* = \underset{z}{\operatorname{argmax}} \int_X \int_0^{P(x,z)} W^{MTE}(x, z, p) dp \; dF_X$$

where F_X is the distribution of X.

Panel A: Welfare gain from each policy

Policy	Evidence from	Targeting	Take-up	Welfare gain: W^{ATT} (\$/year/consumer)	Welfare gain: W^{ITT} (\$/year/consumer)
$Z = 0$	RCT	No	30.8%	60.2	18.0
$Z = 60$	RCT	No	47.6%	47.9	23.2
$Z = z^*$	Counterfactual	No	43.9%	53.8	23.7
$Z = z^*(x)$	Counterfactual	Based on X	44.1%	75.1	33.1
$Z = z^\dagger(x)$	Counterfactual	Based on a subset of X	42.0%	66.9	28.1

Panel B: Welfare comparison

	Difference in W^{ITT}	Difference in W^{ATT}
$Z = z^*$ vs. $Z = 0$	5.6 (0.89)	-6.3 (5.81)
$Z = z^*(x)$ vs. $Z = 0$	15.1 (1.12)	14.9 (5.18)
$Z = z^*(x)$ vs. $Z = z^*$	9.5 (0.42)	21.3 (0.96)
$Z = z^*(x)$ vs. $Z = z^\dagger(x)$	5.0 (0.40)	8.2 (1.57)

- $Z = z^*(x)$ is based on all observable variables (X)
- $Z = z^\dagger(x)$ is based on a subset of X (pre-experimental electricity usage data only)

(Note: This welfare gain does not include savings from potential reductions in long-run investment costs for generation capacity)

Panel A: Welfare gain from each policy

Policy	Evidence from	Targeting	Take-up	Welfare gain: W^{ATT} (\$/year/consumer)	Welfare gain: W^{ITT} (\$/year/consumer)
$Z = 0$	RCT	No	30.8%	60.2	18.0
$Z = 60$	RCT	No	47.6%	47.9	23.2
$Z = z^*$	Counterfactual	No	43.9%	53.8	23.7
$Z = z^*(x)$	Counterfactual	Based on X	44.1%	75.1	33.1
$Z = z^\dagger(x)$	Counterfactual	Based on a subset of X	42.0%	66.9	28.1

Panel B: Welfare comparison

	Difference in W^{ITT}	Difference in W^{ATT}
$Z = z^*$ vs. $Z = 0$	5.6 (0.89)	-6.3 (5.81)
$Z = z^*(x)$ vs. $Z = 0$	15.1 (1.12)	14.9 (5.18)
$Z = z^*(x)$ vs. $Z = z^*$	9.5 (0.42)	21.3 (0.96)
$Z = z^*(x)$ vs. $Z = z^\dagger(x)$	5.0 (0.40)	8.2 (1.57)

- W^{ITT} can be maximized by $Z = z^*(x)$. $Z = z^\dagger(x)$ & $Z = z^*$ are also useful policies.
- The uniform subsidy ($Z = z^*$) improves W^{ITT}, but W^{ATT} gets lower
- This is because the welfare gain is diminishing in $U = p$
- Differentiated subsidy ($Z = z^*(x)$) improves W^{ITT} and W^{ATT} by optimal targeting

Conclusion

We studied selection on welfare gains and policy design

1. Framework:
   - Connect heterogeneity in selection to heterogeneity in social welfare gains
2. Randomized field experiment on electricity tariff choice:
   - Finding 1: Structural winners were more likely to select (level)
   - Finding 2: Price-elastic consumers were more likely to select (slope)
3. Welfare analysis to compare counterfactual policies:
   - Finding 3: Quantify optimal take-up incentives $z^*(x)$ that exploit heterogeneity in selection and welfare gains