Vickrey-Clarke-Groves (VCG) mechanisms for energy efficiency

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Setup

• Lights have three settings.
  – normal (N), bright (B), and very bright (VB).

• Users are asked which setting they prefer.

• Then they are asked how many points they are willing to pay to change the lights for one hour.
Setup

smartSDH decides the light setting based on people’s answers.

smartSDH gives points to users based on how much they compromised with each other.

Subject to tuning: Every 75000 total points earned among all users, a raffle is held for $150 in Amazon gift cards; each point counts as one raffle ticket.

Every 500 points has an expected value of $1.
Seated in Zone A

What is your desired light setting?

Reset

Current light level is Brightest:

How Many Points would you pay to have the lights Bright instead of Normal for one hour?

As many as it takes.

NOTE: You will not be asked to pay any points for changing the lights. This question is simply to understand how much everyone values the lighting in your shared zone. For more details on the VCG mechanism, you can see the details of our implementation [Link].
User preferences

We make the following assumptions on user preferences:

– Without any points, each user has one (or more) preferred light settings.
– Ceteris paribus, more points are preferred.
– Given enough points (money), users are willing to switch from one light setting to another.
– Preferences are transitive, i.e. if A is preferred over B and B is preferred over C, then A is preferred over C.
Utility functions

• With these assumptions, we can represent the preferences of user $i$ with a utility function:

$$u(x, p; \lambda^i) = p - \lambda^i_x$$

• Here, $x$ is the light setting applied, and $p$ is the payment given.

• A user’s preferences are determined by the parameter $\lambda^i_x$; in economics, this is the user’s type.
Mechanism design desiderata

• We want to find a mechanism of the form:
  – **Input:** User preferences
  – **Output:** light setting, payments.

• Let $\lambda = (\lambda^1, ..., \lambda^n)$ represent the types of all $n$ users.
  – Similarly, let $\lambda^{-i} = (\lambda^1, ..., \lambda^{i-1}, \lambda^{i+1}, ..., \lambda^n)$ represent the types of all users except user $i$.

• We represent the mechanism with functions $f: \lambda \mapsto x$ and $p_i: \lambda \mapsto p$. 
Mechanism design desiderata

We want:

• **Incentive compatibility**, i.e. users do not benefit from misrepresenting their preferences.

• Mathematically: for any types \( \lambda \), user \( i \), and any \( \tilde{\lambda} = (\gamma, \lambda^{-i}) \):

\[
    u(f(\lambda), p_i(\lambda); \lambda^i) \geq u(f(\tilde{\lambda}), p_i(\tilde{\lambda}); \lambda^i)
\]

• Note that \( \tilde{\lambda} \) is the result of user \( i \) changing their reported preference to \( \gamma \), while all other users — \( i \) report their true type.
Mechanism design desiderata

We want:

• **Ex-post individual rationality**, i.e. users are better off when the mechanism exists, for all realizations of preferences.

• Mathematically: for any types $\lambda$:

$$u(f(\lambda), p_i(\lambda); \lambda^i) \geq u(VB, 0; \lambda^i)$$
VCG mechanism

• Given user preferences \( \lambda \), we can define the social welfare:

\[
s(x, \lambda) = \sum_{i=1}^{n} -\lambda^i_x
\]

• This is the total utility from a chosen light setting.

• We define:

\[
f(\lambda) = \arg\max_x s(x, \lambda)
\]
VCG mechanism

• We give rewards:

\[ p_i(\lambda) = \lambda_{max} + \sum_{j \neq i} -\lambda^i_{f(\lambda)} \]

• The payment has two parts:

\( \lambda_{max} \) is a reward given to users for participating.

The \( \sum_{j \neq i} \) part pays user \( i \) according to the utilities of the other users.
A user only experiences their own utility.

The effects of a user’s actions affect the utilities of all other users; these are externalities.

This payment internalizes externalities.

– With the payments, the outcome you desire is the social optimum.
Internalizing energy-efficiency

• Suppose an energy-efficiency program pays $\lambda^0$ for using a normal light setting.

• We can introduce an imaginary user:

$$u(x; \lambda^0) = \lambda_x^0$$

• Our payments **internalize** the energy-efficiency incentives.
  – If the incentive $\lambda^0$ is large enough, the lights change to normal and users are paid accordingly.
  – If the incentive $\lambda^0$ is too small, the light setting does not change.
  – Our mechanism determines when user preferences are **stronger** than the incentives, and vice versa.
User reactions

We plan to:

• Collect data to see how users learn and adapt as the system is deployed in closed-loop.

• Determine if our user preference assumptions valid.

• **Survey** users on their experience using Likert system:
  – Comfort.
  – Satisfaction with the rewards.
  – Productivity.
  – Consciousness of energy-efficient actions.
Closing remarks

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