Curbing Energy Consumption through Voluntary Quotas

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Three definitions

Best response

In game theory, it is the strategy that will give a player the highest reward, given the strategies that the other players choose.

Nash equilibrium

A set of strategies, one for each player in a strategic interaction, such that each player's strategy is a best response to the strategies chosen by everyone else.

Tragedy of the commons

A social dilemma in which self-interested individuals acting independently deplete a common resource, thereby reducing the well-being of all.

BBC NEWS

Texas weather: Deaths mount as winter storm leaves millions without power

17 February 2021

Texas power outage

European Commission

Home > Press corner > Save Gas for a Safe Winter

Available languages: English

Press release | 20 July 2022 | Brussels

Save Energy for a Safe Winter: Commission proposes gas demand reduction plan to prepare EU for supply cuts

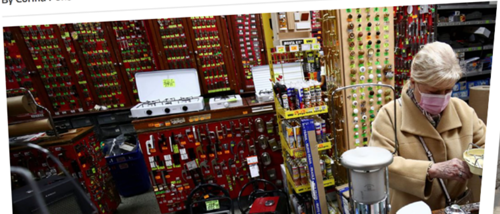
REUTERS®

Energy

November 11, 2021 12:48 PM GMT+1

Blackout fears amid energy crunch boosts gas cookers, lantern sales in Spain

By Corina Pons



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News | Energy

'Unprecedented' power cuts in China hit homes, factories

Northeastern China is experiencing power cuts because of coal shortages and the tightening of emissions standards.

28 Sep 2021

Getting started

- Short-term interventions to deal with energy shortages typically involve:
  - Capping heating and cooling.
  - Cutting power at times of grid stress.
- Outages and mandatory power cuts disrupt daily lives and businesses, sparking public discontent.
- Some policymakers remain reluctant to introduce rationing measures, possibly due to concerns for their libertarian image.

The Guardian

Don't mention rationing: why energy crisis may need another Truss U-turn

National Grid is taking blackout risk seriously, yet PM remains reluctant to take action to limit energy usage

Fri 9 Sep 2022 14.58 BST

so far, the new prime minister has refused to either introduce mandatory rationing for households and businesses, or urge the public to cut back. The decision is deeply political.

there appears to be a deep reluctance to tell the public how many times they should use the kettle a day or when to put the dishwasher on, amid fears it would further erode the principles of libertarian Tories.

The government is preparing for blackouts and energy shortages this winter due to the supply crisis. Photograph: Andy Rain/EPA

This paper

- We examine voluntary quotas (VQs) that trade-off energy consumption for energy security.
  - Contracts by which users willingly limit their maximum possible consumption of energy...
  - ...in exchange for the guarantee that they will not suffer, or suffer as little as possible, from outages.
- Pros of VQs:
  - Not imposed without consent.
  - Allow users to sort themselves into different consumption schemes.

This paper (cont'd)

- We study VQs in the simplified framework of an incentivized experiment.
  - 800 UK residents recruited through Prolific.
  - Captures aspects of strategic behaviour that are relevant to situations where agents face sudden reductions in resource supply and do not have the time to learn how to coordinate with others.
- Impact of VQs on overall consumption not obvious a priori:
  - A quota that restricts demand by a great extent may fail to meet its objectives because it is not appealing to users.
  - A quota that restricts demand by a small extent may be welcomed by the public but be of little help in reducing consumption.

Baseline game: setup

- A group of 10 players consume a limited shared resource of size C.
- Each player i can demand any whole amount $d_i \in [0, 20]$ of the resource.
- Players choose how much they would like to consume in each of two rounds. Choices are made independently and simultaneously.
- If the demands sum to C or less, then players receive what they demanded; otherwise they get nothing.
- Player i's payoff in Round $t = 1, 2$:

$$\pi_{i,t} = \begin{cases} d_{i,t} & \text{if} \quad \sum_{j=1}^{10} d_{j,t} \leq C_t \\ 0 & \text{otherwise} \end{cases}$$

Baseline game: setup (cont'd)

- In Round 1 the pool size is 100:

$$C_1 = 100$$

- In Round 2, there is a 50% probability that the pool size remains 100 and a 50% probability that it drops to 50:

$$C_2 = \begin{cases} 100 & \text{with probability } 1/2 \\ 50 & \text{with probability } 1/2 \end{cases}$$

- This information is given to each subject at the beginning of Round 1. At the beginning of Round 2, players are then informed about the actual realized pool size (i.e. either 50 or 100).

Baseline game: framing

You are a tailor making shirts.

You use an electric sewing machine, the energy consumption of which is measured in ‘Energy Units’. To produce one shirt you must use 1 Energy Unit. The more Energy Units you use, the more shirts you produce.

Your machine is powered by an electric generator, and so are the machines of nine other tailors. Each tailor’s machine consumes 1 Energy Unit per shirt, just like yours.

You must decide how many shirts to produce, on the basis of the generator’s capacity. You will make this decision twice, once in Round 1 and once in Round 2.

Baseline game: framing (cont'd)

In each round, you can use 0 to 20 Energy Units and produce up to 20 shirts.

In Round 1, the generator's capacity is 100 Energy Units.

In Round 2, there is a 50% probability that the capacity will remain steady at 100 Energy Units, and a 50% probability that it will decrease to 50 Energy Units due to an energy shortage.

The nine participants you are matched with will be faced with the same decisions as yourself. If in a decision round the overall number of Energy Units used by the 10 of you exceeds generator capacity, then there will be a power outage, in which case you will produce nothing in that round.

Enter voluntary quotas

- Before making their first demand decision, each player is offered the choice to either accept or reject a consumption quota.
- If the quota is rejected, then the set of possible demands and the payoff function are as described earlier.
- To accept the quota means to reduce maximum demand to $\underline{d} < 20$ in exchange for the guarantee that demand will be met.
- Player i's demand: $d_{i,t} \in \begin{cases} [0, \underline{d}\,] & \text{if accept} \\ [0, 20] & \text{if reject} \end{cases}$
- Player i's payoff: $\pi_{i,t} = \begin{cases} d_{i,t} & \text{if accept or } \sum_{j=1}^{n} d_{j,t} \leq C_t \\ 0 & \text{otherwise} \end{cases}$

Treatments

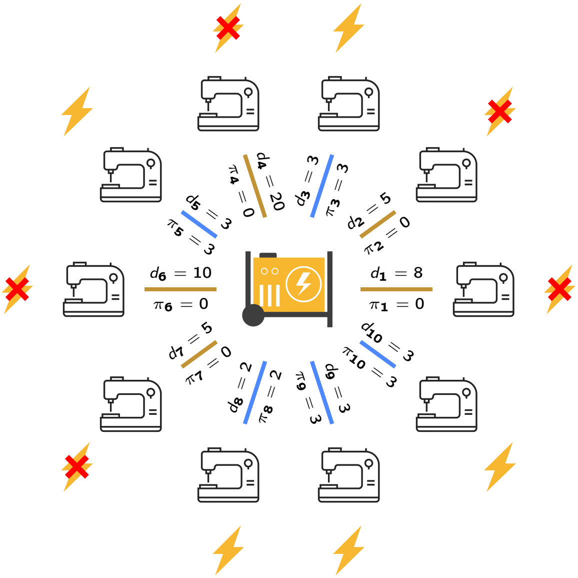
- **Treatment F** (**Fixed quota**)
  Maximum demand = 5 per round:
  $$\underline{d}^{F} = 5$$
- **Treatment HP** (**High Proportional quota**)
  Maximum demand = 10 percent of capacity:
  $$\underline{d}^{HP} = 10 \times \mathbb{1}_{C=100} + 5 \times \mathbb{1}_{C=50}$$
- **Treatment LP** (**Low Proportional quota**)
  Maximum demand = 6 percent of capacity:
  $$\underline{d}^{LP} = 6 \times \mathbb{1}_{C=100} + 3 \times \mathbb{1}_{C=50}$$

Maximum demand by treatment and capacity

	Baseline	F		HP		LP	
		Quota accepted	Quota rejected	Quota accepted	Quota rejected	Quota accepted	Quota rejected
$C = 100$	20	5	20	10	20	6	20
$C = 50$	20	5	20	5	20	3	20

- 4×2 design to assess and compare...
  - The effects of a high and a low quota (**HP** vs. **LP**).
  - The effects of a fixed quota and a quota that varies with capacity (**F** vs. **LP**).

Example: Treatment LP, $C = 50$, capacity exceeded



Blue line:
quota accepted

Brown line:
quota rejected

Quota acceptance rate:
50%

Group demand:
62/50

Outage:
yes

Group payoff:
14/50

Optimal behaviour: baseline example 1

- Suppose that:
  - Capacity is 100
  - Players 1 to 9 demand 9 Energy Units each: $d_1 = d_2 = \cdots = d_9 = 9$
  - Overall, their demand is $9 \times 9 = 81$
  - The resulting spare capacity is $100 - 81 = 19$
- What is player 10's optimal strategy?
  - It is to demand 19 Energy Unit for herself, in which case capacity is exhausted
  - Demanding less than 19 Energy Units is not optimal, as player 10 could do better
  - Demanding 20 Energy Units is not optimal, because it would cause an outage, in which case player 10 (and all other players) would receive nothing

Optimal behaviour: baseline example 2

- Suppose that:
  - Capacity is 100
  - Players 1 to 5 demand 10 Energy Units each: $d_1 = d_2 = \cdots = d_5 = 10$
  - Players 6 to 9 demand 15 Energy Units each: $d_6 = d_7 = d_7 = d_8 = 15$
  - Overall, their demand is $5 \times 10 + 4 \times 15 = 50 + 60 = 110$
  - Capacity is exceeded regardless of player 10's choice
- What is player 10's optimal strategy?
  - Any demand between 0 and 20 is optimal. Why?
  - No matter what player 10 does, all players will experience an outage and receive nothing.

Optimal behaviour: treatment example 1

- Suppose that:
  - Capacity is 100 and players are offered the **F quota**
  - Players 1 to 9 reject the quota and demand 15 Energy Units each: $d_1 = d_2 = \cdots = d_9 = 15$
  - Overall, their demand is $9 \times 15 = 135$
  - Capacity is exceeded regardless of player 10's choice
- What is player 10's optimal strategy?
  - It is to accept the quota and demand 5 Energy Units, in which case she is sure to receive her demand (whereas other players will experience an outage and receive nothing)
  - Conversely, if she rejected the quota, she would suffer from the outage just like others

Optimal behaviour: treatment example 2

- Suppose that:
  - Capacity is 100 and players are offered the **F quota**
  - Players 1 to 9 accept the quota and demand 5 Energy Units each: $d_1 = d_2 = \cdots = d_9 = 5$
  - Overall, their demand is $9 \times 5 = 45$
  - The resulting spare capacity is $100 - 45 = 55$
- What is player 10's optimal strategy?
  - It is to reject the quota and demand 20 Energy Units
  - Conversely, if she accepted the quota, she could use at most 5 Energy Units. Accepting the quota is therefore not optimal in this case

Nash equilibria: baseline

- The baseline game has two classes of Nash Equilibria.

  (1) The first class consists of all strategy profiles that satisfy:

  $$\sum_{i=1}^{10} d_{i,t} = C_t$$

  in which case total demand equals total supply and a positive number of players receive a positive payoff.

  (2) The second class satisfies:

  $$\sum_{i=1}^{10} d_{i,t} \geq C_t + \max\{d_{1,t}, \ldots, d_{10,t}\}$$

  in which case a tragedy of the commons-like situation occurs and all players receive a payoff of zero.

Nash equilibria: treatments

- Once a voluntary quota scheme is introduced:
  - Each strategy profile resulting in a tragedy of the commons can no longer be Nash.
  - That is, some if not all players receive a payoff in equilibrium.
  - Intuition: quotas establish a fallback position which allows players to earn a positive payoff with certainty.

- Maximum number of acceptors in a Nash equilibrium:
  - **6 in Treatment F**
  - **7 in Treatment LP**
  - **10 in Treatment HP**

Quota acceptance rates

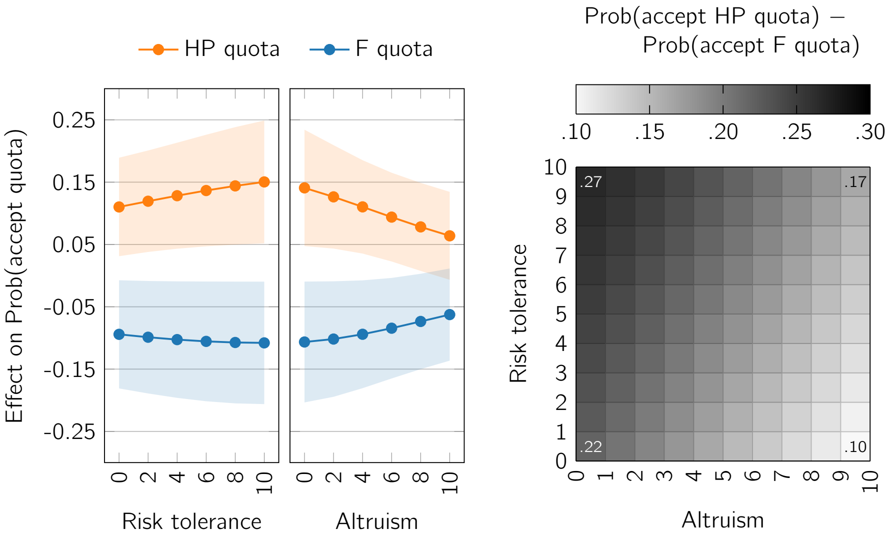
Treatment F	Treatment HP	Treatment LP
53%	77%	64%

- The probability of accepting a quota decreases with risk tolerance and increases with altruism.
  - Intuition: the decision to take the quota leaves more energy for others to use, and may therefore be intended as an altruistic act.

- Highly risk-averse altruists are more likely to accept any quota, whereas risk-tolerant and self-interested individuals are more sensitive to what kind of quota they are offered.

- Climate change skeptics are significantly less likely than others to accept quotas.

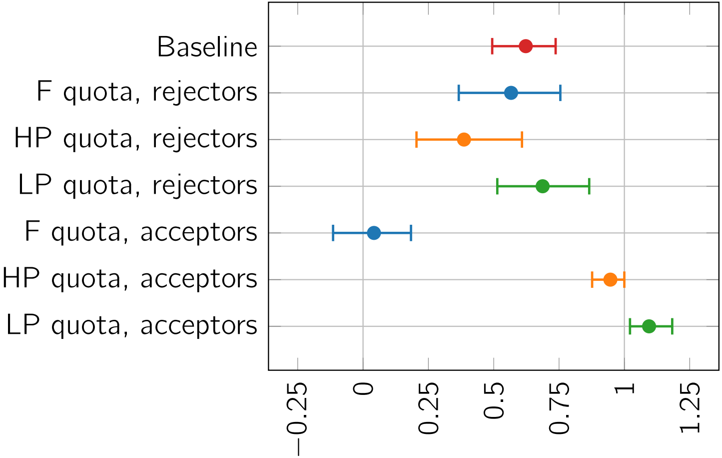
Acceptance predictions



Elasticity

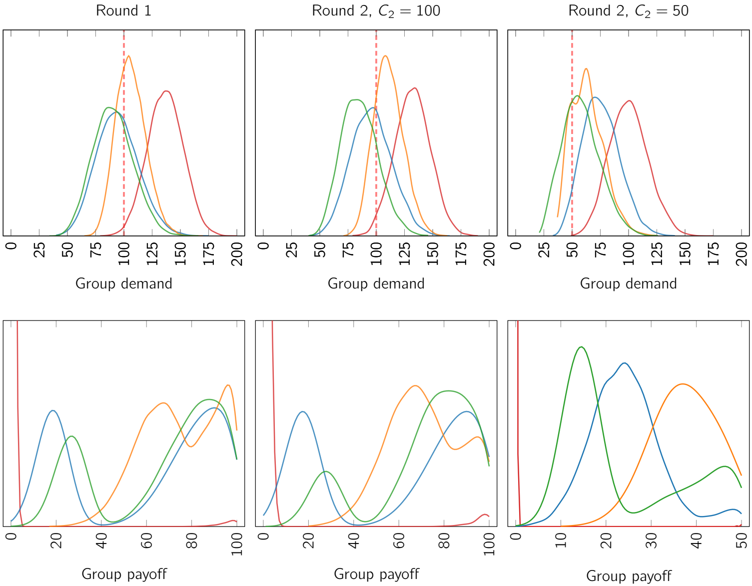
- An elasticity measures the sensitivity of one variable to another.
- Specifically, it is a number that tells us the percentage change that will occur in one variable in response to a 1-percent change in another variable.
- For example, the elasticity of demand with respect of capacity measures the sensitivity of d to changes in C.
  - It tells us what the percentage change in demand will be following a 1-percent change in capacity.
- If the elasticity is greater than 1 in magnitude, we say that demand is elastic because the percentage change in quantity demanded is greater than the percentage change in capacity.
- If the price elasticity is less than 1, demand is said to inelastic.

Elasticity of demand wrt capacity



Group outcomes: kernel density estimates

Baseline · F quota · HP quota · LP quota



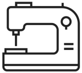
Group outcomes: summary of results

	Acceptance rate	Round	Group demand	Outage rate	Group payoff
Baseline		1	136.6±15.7	98.9	1.0±9.9
		2, $C_2 = 100$	132.0±15.5	97.9	2.0±13.7
		2, $C_2 = 50$	100.1±17.2	99.4	0.1±1.2
F quota	52.9	1	94.5±18.7	35.8	60.0±32.8
		2, $C_2 = 100$	95.9±18.3	38.7	58.3±34.1
		2, $C_2 = 50$	75.7±16.1	95.3	24.4±8.1
HP quota	77.0	1	106.2±13.0	64.9	74.7±16.8
		2, $C_2 = 100$	111.0±12.8	78.3	71.7±16.1
		2, $C_2 = 50$	63.6±14.0	77.8	37.6±6.7
LP quota	64.1	1	90.4±17.6	27.6	66.6±27.2
		2, $C_2 = 100$	85.4±16.1	17.1	71.1±22.9
		2, $C_2 = 50$	57.9±16.7	64.4	23.8±13.6

= best; = second best; = third best

Wrap-up

- People are slow to adjust their demand to sudden changes in capacity.
- Although VQs seem not to be sufficient to prevent outages entirely, they might nevertheless play a role in reducing aggregate consumption.
- The choice of what kind of quota to introduce depends on the resource provider's objective.



Thank you :-)

Questions and suggestions welcome!

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