Public policies, economics, and operations research: a trident for resource scarcity and supply chain disruption

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Introduction

The humanity has been facing an unprecedented challenge of resource scarcity, e.g., lack of water, food, essential medical supply, etc. (as illustrated above)

What are considered scarce resource?

- Natural resources: crops, fisheries, wildlife, petroleum, metals, minerals, water, etc
- Non-renewable resources: fossil fuels, etc
- Short-term high-demand commodities: PPE during COVID-19 pandemic.

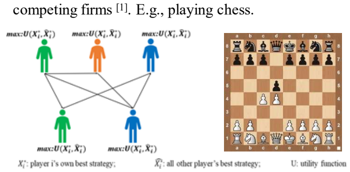
What can cause resource scarcity?

- Growing population and demand
- Climate change
- Geopolitical shift, trade wars
- Rising risk of crises such as pandemics

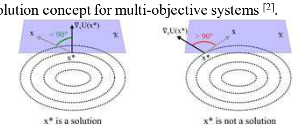
Methods

We adopt a game-theory and convex mathematical optimization approach.

- **Game theory:** provides strategic dynamics between competing firms [1]. E.g., playing chess.

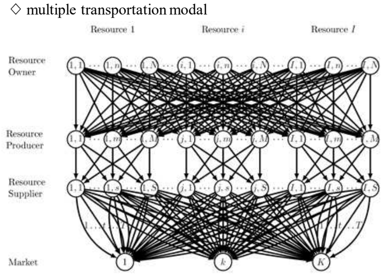


- **Convex optimization and variational inequalities:** a solution concept for multi-objective systems [2].



Results

We develop a general scarce resource supply chain network with policy instruments featuring the following traits:
◇ multi-product; ◇ cross-sector; ◇ competition;
◇ multiple transportation modal



The unified fiscal-monetary policy administered

$$\alpha_0^i(x) + \sum_{g=1}^{G} \alpha_g^i(\delta_g^{in})$$

x: the quantity of a flow; A_g^i: the bracket; $\alpha_0^i(.)$, $\alpha_g^i(.)$: the function of fiscal-monetary; $\delta_g^{in} = \max\{x - A_g^i, 0\}$: the excess of x to bracket A_g^i.

The equilibrium of the supply chain flow pattern satisfies:

$$\langle F(X^*), X - X^* \rangle \geq 0, \quad \forall X^* \in \mathcal{K}$$

Where, X is a collection of flow pattern in the network, X* is the equilibrium, and F is the entry function (see paper [3] for details).

Algorithm: modified projection method [4]

Step 0. Initialization
Set $X^0 \in \mathcal{K}$. Set $\tau =: 1$ and select φ such that $0 < \varphi \leq 1/L$, where L is the Lipschitz constant for function F.
Step 1. Construction and computation
Compute $\bar{X}^{\tau-1} \in \mathcal{K}$ by solving the variational inequality sub-problem

$$\langle \bar{X}^{\tau-1} + \varphi F(X^{\tau-1}) - X^{\tau-1}, X - \bar{X}^{\tau-1} \rangle \geq 0, \quad \forall X \in \mathcal{K}.$$

Step 2. Adaptation
Compute $X^{\tau} \in \mathcal{K}$ by solving the variational inequality sub-problem

$$\langle X^{\tau} + \varphi F(\bar{X}^{\tau-1}) - X^{\tau-1}, X - X^{\tau} \rangle > 0, \quad \forall X \in \mathcal{K}.$$

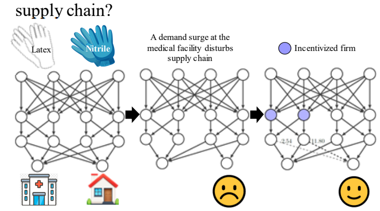
Step 3. Convergence verification
If $|X^{\tau} - X^{\tau-1}| \leq \epsilon$, for $\epsilon > 0$, a pre-specified tolerance, then, stop; otherwise, set $\tau =: \tau + 1$ and go to step 1.

$\nabla_x U$: gradient of utility function; ε: tolerance; φ: step size

Application I:

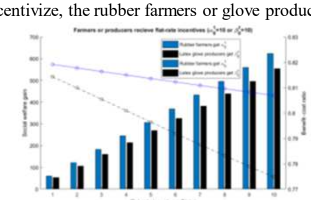
COVID-19 pandemic has caused a demand surge in PPE. Many healthcare facilities have had shortage of medical gloves due to the distressed supply chain.

Question 1: How would a producer-stimulus help the pandemic-induced distress in a medical glove supply chain?



Answer 1: A flat-rate incentive on both latex gloves producers will restore the supply shortage of latex gloves at the residential facilities.

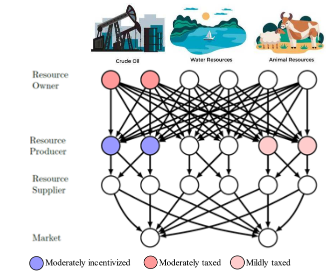
Question 2: Who should the government incentivize, the rubber farmers or glove producers?



Answer 2: Incentivizing the rubber farmers will result a higher welfare efficiency, e.g., a $1 incentive yields a $0.8 welfare gain, comparing to $0.6 gain.

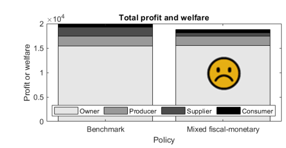
Application II:

Humanity depends on the earth's physical resource and natural system to survive and flourish. We examine a food-energy-water nexus on: the stimulus packages, wealth taxes, and carbon footprint.



Question: With ex ante knowledge, what if we tax the "rich" and incentivize the "poor"?

Answer: The social welfare will be undercut.



Conclusions

- A producer incentive is more beneficial to suppliers; a resource-owner incentive is more beneficial to the society.
- A flat-rate incentives is more effective than the one with brackets.
- producer incentive can be a viable relief for supply chain distress caused by demand surge.
- A mixed fiscal-monetary policy may result in a net loss of welfare.

Literature cited

[1] Nash, J.F.. (1950). Equilibrium points in n-person games. Proceedings of the national academy of sciences, 36(1), pp.48-49.

[2] Gabay, D. and Moulin, H. (1980). On the uniqueness and stability of Nash-equilibria in noncooperative games. In Applied stochastic control in econometrics and management science, pages 271–293. North-Holland Publ. Co., Amsterdam, The Netherlands.

[3] Hu, Xiaowei, Peng Li, and Jaejin Jang. (2021). Relief and Stimulus in A Cross-sector Multi-product Scarce Resource Supply Chain Network. arXiv preprint arXiv:2101.09373.

[4] Korpelevich, G. M. (1976). The extragradient method for finding saddle points and other problems. Ekonomika Matematicheskie Metody, 12:747–756.

[5] 117th Congress. (2021) H.R.1319 - American Rescue Plan Act of 2021.

Acknowledgments

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For further information

See the following paper for more details.
Hu, Xiaowei, Peng Li, and Jaejin Jang. "Relief and Stimulus in A Cross-sector Multi-product Scarce Resource Supply Chain Network." arXiv preprint arXiv:2101.09373 (2021).

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