Relief, Stimulus, and Welfare:

Modeling a Cross-sector Scarce Resource Supply Chain Network under Fiscal and Monetary Policies

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Motivations

A farmer kneeling on his cracked land, Los Angeles, 2014

Congolese soldiers guarding suspected rebel fighters over the conflict of rare earth elements (cobalt, copper, and coltan) near the eastern town of Goma, 2013

Yemenis presenting documents in order to receive food rations provided by a local charity, in Sanaa, Yemmen, 2017

Some empty shelves in a grocery store in the US during COVID-19 pandemic, 2020

A notice covering an empty shelf at an Oakland CVS store in February, 2020

How climate change may impact energy usage: 2080-2099

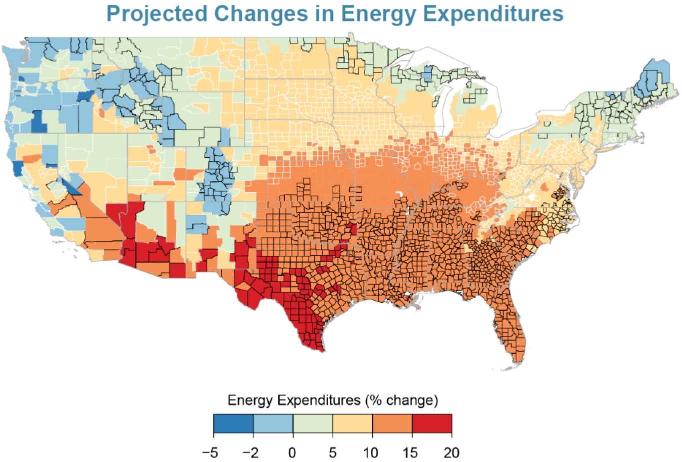


Figure 4.2: This figure shows county-level median projected increases in energy expenditures for average 2080–2099 impacts under the higher scenario (RCP8.5). Impacts are changes relative to no additional change in climate. Color indicates the magnitude of increases in energy expenditures in median projection; outline color indicates level of agreement across model projections (thin white outline, inner 66% of projections disagree in sign; no outline, more than 83% of projections agree in sign; black outline, more than 95% agree in sign; thick gray outline, state borders). Data were unavailable for Alaska, Hawai'i and the U.S.-Affiliated Pacific Islands, and the U.S. Caribbean regions. Source: Hsiang et al. 2017.[14]

Background

Scarce Resource

What are considered scarce resources?
(Rosenberg, 1973; Krautkraemer, 2005)

- Natural resources: agricultural crops, fisheries, wildlife, forests, petroleum, metals, minerals, even air, soil, water, etc
- Non-renewable resources: rare earth elements, fossil fuels
- Commodities in high demand during a short period of time: PPE during COVID-19 pandemic.



Resource scarcity: characters and causes

Characters of scarce resource
(Pfeffer and Salancik, 1978; Cannon and Perreault, 1999; Pfeffer and Salancik, 2003; Caniëls and Gelderman, 2007; Hunt, 2000)

- Abundance means power
- Heterogeneous demand
- Interdependent with one another

Some causes of resource scarcity or stress

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

Laws in resource usage, ownership, and enforcement

Often, the conflicts over scarce resources have been taken to the courts of law.

Some famous resource related supreme court cases

- WYOMING HEREFORD RANCH v. HAMMOND PACKING CO., Supreme court of Wyoming, 1952. (PRIOR APPROPRIATION)
- HARRIS v. BROOKS, Supreme Court of Arkansas 1955. (RIPARIAN RIGHTS)
- COMMONWEALTH OF MASSACHUSETTS et al. v. ENVIRONMENTAL PROTECTION AGENCY, the U.S. Supreme Court, 2007. (EPA's authority on CAA of 1963)

Research Questions

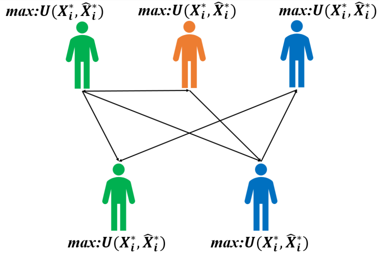
1. How can a scarce resource supply chain be represented by a general network?
2. For resource producing firms, how do they benefit from an incentive scheme? How does a specific incentive impact demands, prices, and profits? Under a certain environmental policy, how should firms adjust their business strategies in order to be more profitable and competitive?
3. For consumers at different demand markets, how do they benefit from a producer "stimulus package"?
4. For resources owners, what happens when conflict emerges? What could alleviate it?
5. For policy makers, how does social welfare respond to policy instruments? Who is the winner? During supply chain overload, who should get the stimulus when budget is limited? To relieve a critical resource shortage crisis, what might be a better incentive structure?

Related Literature

Related literature I: network game theories

The theoretical study of network game is a new avenue of research. It was revived from the earlier studies that address existence, uniqueness, sensitivity, convergence, and ϵ-approximation, etc.

- Network games theory (existence, uniqueness, sensitivity): Rosen (1965); Jackson and Zenou (2015); Parise and Ozdaglar (2017)
- Emerging trend - scalar quantities (eigenvalues of game Jacobians): Bramoullé et al. (2014); Naghizadeh and Liu (2017); Melo (2018)



Related literature II: applications of network games

- Spatial price equilibrium (SPE) - a transportation network: Enke (1951); Samuelson (1952); Takayama and Judge (1964); Dafermos and Nagurney (1984, 1987)
- General supply chains: Nagurney et al. (2002); Zhang (2006); Nagurney (2006)
- Specialized supply chains: power (Nagurney et al., 2006; Nagurney and Matsypura, 2007; Wu et al., 2006); blood (Nagurney and Dutta, 2019); food (Besik and Nagurney, 2017); drugs (Masoumi et al., 2012).
- Policy intervention: taxation (Wu et al., 2006; Yu et al., 2018); subsidy (Wu et al., 2019)

Related literature III: modeling non-cooperative complex systems

This study is also inherent to the research that aims to understand the interconnected physical resources and their ability to adapt to external stressors in a competitive environment.

- Agriculture and fuels: Wang et al. (2013); Lim and Ouyang (2016); Bai et al. (2016, 2012); Luo and Miller (2013); Bajgiran et al. (2019)
- Energies and water: Zhang and Vesselinov (2016); Hamoud and Jang (2020)
- Water and agriculture: Bakker et al. (2018)

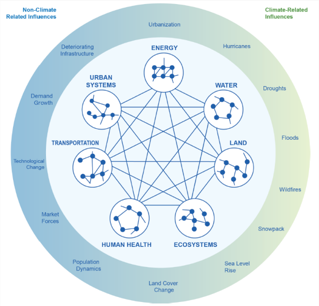


Figure 1: Sources: Pacific Northwest Nat'l Lab, Arizona State, Cornell University

A General Model

The incentivized scarce resource supply chain network

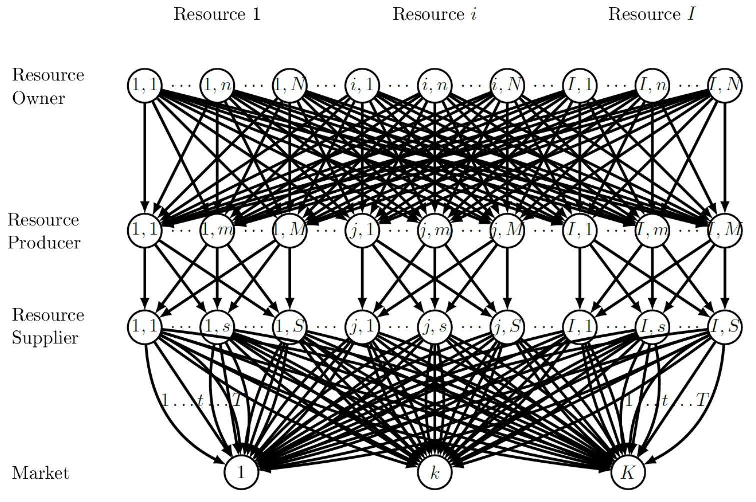


Figure 2: A Scarce Resource Supply Chain Network

The incentive scheme

A_g: cutoff bracket of the incentives, $g = 1, ...G$.
δ_g: the excess of output quantity within bracket A_g. Assume linear.

The general incentive payment function

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

where, $\delta_g = [x - A_g^{in}]_+, \quad g = 1, ..., G.$

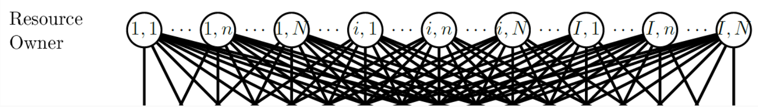
Note: this scheme can also be used as a general taxation scheme.

Example: the US Economic Impact Payments of COVID-19 (aka, the stimulus checks) is:

$$\$1200 - \$0.05(\delta_1), \tag{2}$$

where, $\delta_1 = [x - \$75000]_+$, $\delta_2 = [x - \$99000]_+$.

Resource owner's problem (1 of 2)



$$max: \sum_{j=1}^{I}\sum_{m=1}^{M}\rho_{0jm}^{in}x_{jm}^{in} - f^{in}(x^{in}) - \sum_{j=1}^{I}\sum_{m=1}^{M}c_{jm}^{in}(x_{jm}^{in}) + \alpha_0(\sum_{j=1}^{I}\sum_{m=1}^{M}x_{jm}^{in}) + \sum_{g=1}^{G}\alpha_g(\delta_g^{in})$$

$$s.t.: \sum_{j=1}^{I}\sum_{m=1}^{M}x_{jm}^{in} \le U_{in},$$

$$\sum_{j=1}^{I}\sum_{m=1}^{M}x_{jm}^{in} - \delta_g^{in} \le A_g^{in}, \quad \forall g,$$

$$x_{jm}^{in} \ge 0, \quad \forall j, m,$$

$$\delta_g^{in} \ge 0, \quad \forall g.$$

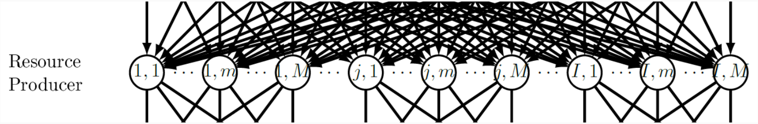
Reformulate the previous optimization problem into VI problem:

Resource owner's optimality condition

$$\sum_{i=1}^{I}\sum_{n=1}^{N}\sum_{j=1}^{I}\sum_{m=1}^{M}\left[\frac{\partial f^{in}(x^{in*})}{\partial x_{jm}^{in}}+\frac{\partial c_{jm}^{in}(x_{jm}^{in*})}{\partial x_{jm}^{in}}-\rho_{0jm}^{in*}-\frac{\partial \alpha_0(x_{jm}^{in*})}{\partial x_{jm}^{in}}\right.$$
$$\left.+\lambda_{in}^{0*}+\sum_{g=1}^{G}\mu_{ing}^{0*}\right]\times(x_{jm}^{in}-x_{jm}^{in*})$$
$$+\sum_{i=1}^{I}\sum_{n=1}^{N}\sum_{g=1}^{G}\left[-\frac{\partial \alpha_g(\delta_g^{in*})}{\partial \delta_g^{in}}\right]\times(\delta_g^{in}-\delta_g^{in*})$$
$$+\sum_{i=1}^{I}\sum_{n=1}^{N}\left[U_{in}-\sum_{j=1}^{I}\sum_{m=1}^{M}x_{jm}^{in*}\right]\times(\lambda_{in}^{0}-\lambda_{in}^{0*})$$
$$+\sum_{i=1}^{I}\sum_{n=1}^{N}\sum_{g=1}^{G}\left[A_g^{in}-\sum_{j=1}^{I}\sum_{m=1}^{M}x_{jm}^{in*}+\delta_g^{in*}\right]\times(\mu_{ing}^{0}-\mu_{ing}^{0*})\geq 0,$$
$$\forall(Q^0,\mathfrak{d}^0,\lambda^0,\mu^0)\in\mathcal{K}^1,$$

where, $\mathcal{K}^1\equiv\{(Q^0,\mathfrak{d}^0,\lambda^0,\mu^0)|(Q^0,\mathfrak{d}^0,\lambda^0,\mu^0)\in R_+^{I^2MN+2ING+IN}\}$.

Resource producer's problem (1 of 2)



$$max: \sum_{s=1}^{S} \rho_{1s}^{jm*} x_s^{jm} - \sum_{j=1}^{I}\sum_{n=1}^{N} \rho_{0jm}^{in*} x_{jm}^{in} - f^{jm}(x_{jm}) - \sum_{s=1}^{S} c_s^{jm}(x_s^{jm})$$

$$+ \beta_0(\sum_{s=1}^{S} x_s^{jm}) + \sum_{g=1}^{G} \beta_g(\delta_g^{jm})$$

$$s.t.: \sum_{i=1}^{I}\sum_{n=1}^{N} x_{jm}^{in} \cdot \psi_{jm}^{in} \leq \sum_{s=1}^{S} x_s^{jm},$$

$$\sum_{s=1}^{S} x_s^{jm} - \delta_g^{jm} \leq B_g^{jm}, \quad \forall g,$$

$$x_s^{jm} \geq 0, \quad \forall s,$$

$$\delta_g^{jm} \geq 0, \quad \forall g.$$

Resource producer's optimality condition

$$\sum_{i=1}^{I}\sum_{n=1}^{N}\sum_{j=1}^{I}\sum_{m=1}^{M}\left[\frac{\partial f^{jm}(x^{*}_{jm})}{\partial x^{in}_{jm}} + \rho^{in*}_{0jm} + \psi^{in}_{jm}\lambda^{1*}_{jm}\right] \times (x^{in}_{jm} - x^{in*}_{jm})$$

$$+\sum_{j=1}^{I}\sum_{m=1}^{M}\sum_{s=1}^{S}\left[\frac{\partial c^{jm}_{s}(x^{jm*}_{s})}{\partial x^{jm}_{s}} - \rho^{jm*}_{1s} - \frac{\partial \beta_0(x^{jm*}_{s})}{\partial x^{jm}_{s}} - \lambda^{1*}_{jm} + \sum_{g=1}^{G}\mu^{1*}_{jmg}\right] \times (x^{jm}_{s} - x^{jm*}_{s})$$

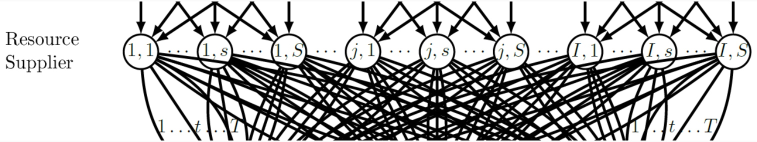
$$+\sum_{j=1}^{I}\sum_{m=1}^{M}\sum_{g=1}^{G}\left[-\frac{\partial \beta_g(\delta^{jm*}_{g})}{\partial \delta^{jm}_{g}}\right] \times (\delta^{jm}_{g} - \delta^{jm*}_{g})$$

$$+\sum_{j=1}^{I}\sum_{m=1}^{M}\left[\sum_{s=1}^{S}x^{jm*}_{s} - \sum_{i=1}^{I}\sum_{n=1}^{N}x^{in*}_{jm}\cdot\psi^{in}_{jm}\right] \times (\lambda^{1}_{jm} - \lambda^{1*}_{jm})$$

$$+\sum_{j=1}^{I}\sum_{m=1}^{M}\sum_{g=1}^{G}\left[B^{jm}_{g} - \sum_{s=1}^{S}x^{jm*}_{s} + \delta^{jm*}_{g}\right] \times (\mu^{1}_{jmg} - \mu^{1*}_{jmg}) \geq 0,$$

$$\forall (Q^0, Q^1, \mathfrak{d}^1, \lambda^1, \mu^1) \in \mathcal{K}^2,$$

where, $\mathcal{K}^2 \equiv \{(Q^0, Q^1, \mathfrak{d}^1, \lambda^1, \mu^1) | (Q^0, Q^1, \mathfrak{d}^1, \lambda^1, \mu^1) \in R_{+}^{I^2MN+IMS+2IMG+IM}\}$.



$$max: \sum_{t=1}^{T}\sum_{k=1}^{K} \rho_{2tk}^{js*} x_{tk}^{js} - \sum_{j=1}^{I}\sum_{m=1}^{M} \rho_{1s}^{jm*} x_{s}^{jm} - f^{js}(x^{js}) - \sum_{t=1}^{T}\sum_{k=1}^{K} c_{tk}^{js}(x_{tk}^{js})$$

$$S.t.: \quad \sum_{k=1}^{K}\sum_{t=1}^{T} x_{tk}^{js} \leq \sum_{m=1}^{M} x_{s}^{jm},$$

$$x_{tk}^{js} \geq 0, \quad \forall t, k.$$

Resource supplier's problem (2 of 2)

Resource supplier's optimality condition

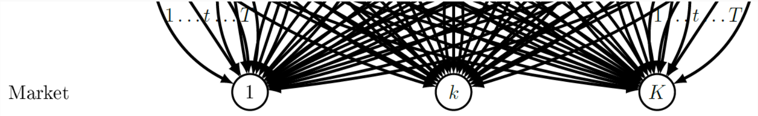
$$\sum_{j=I}^{I}\sum_{s=1}^{S}\sum_{t=1}^{T}\sum_{k=1}^{K}\left[\frac{\partial f^{js}(x^{js*})}{\partial x_{tk}^{js}}+\frac{\partial c_{tk}^{js}(x_{tk}^{js*})}{\partial x_{tk}^{js}}-\rho_{2tk}^{js*}+\lambda_{js}^{2*}\right]\times(x_{tk}^{js}-x_{tk}^{js*})$$

$$+\sum_{j=1}^{I}\sum_{m=1}^{M}\sum_{s=1}^{S}\left[\rho_{1s}^{jm*}-\lambda_{js}^{2*}\right]\times(x_{s}^{jm}-x_{s}^{jm*})$$

$$+\sum_{j=I}^{I}\sum_{s=1}^{S}\left[\sum_{m=1}^{M}x_{s}^{jm*}-\sum_{k=1}^{K}\sum_{t=1}^{T}x_{tk}^{js*}\right]\times(\lambda_{js}^{2}-\lambda_{js}^{2*})\geq 0,$$

$$\forall(Q^1,Q^2,\lambda^2)\in\mathcal{K}^3,$$

where, $\mathcal{K}^3\equiv\{(Q^1,Q^2,\lambda^2)|(Q^1,Q^2,\lambda^2)\in R_{+}^{IMS+ISTK+IS}\}$.



The spatial price equilibrium condition is given by

$$\rho_{2tk}^{js*} + \hat{c}_{tk}^{js*}(x_{tk}^{js*}) \begin{cases} = \rho_{3k}^{j}(d^*) & \textit{if} \quad x_{tk}^{js*} > 0 \\ > \rho_{3k}^{j}(d^*) & \textit{if} \quad x_{tk}^{js*} = 0 \end{cases} \qquad \forall j, s, t, k.$$

Demand market's optimality condition

$$\sum_{j=1}^{I}\sum_{s=1}^{S}\sum_{t=1}^{T}\sum_{k=1}^{K}[\rho_{2tk}^{js*}+\hat{c}_{tk}^{js}(x_{tk}^{js*})]\times(x_{tk}^{js}-x_{tk}^{js*})-\sum_{j=1}^{I}\sum_{k=1}^{K}\rho_{3k}^{j}(d^*)\times(d-d^*)\geq 0,$$

$$\forall (Q^2,d)\in\mathcal{K}^4,$$

where, $\mathcal{K}^4 \equiv \{(Q^2,d)|Q^2\in R_+^{ISTK},\ d\in R_+^{IK}\}$.

$$
\begin{aligned}
&\sum_{i=1}^{I}\sum_{n=1}^{N}\sum_{j=1}^{I}\sum_{m=1}^{M}\left[\frac{\partial f^{in}(x^{in*})}{\partial x_{jm}^{in}}+\frac{\partial f^{jm}(x_{jm}^{*})}{\partial x_{jm}^{in}}+\frac{\partial c_{jm}^{in}(x_{jm}^{in*})}{\partial x_{jm}^{in}}-\frac{\partial \alpha_{\mathbf{0}}(x_{jm}^{in*})}{\partial x_{jm}^{in}}+\lambda_{in}^{\mathbf{0}*}+\psi_{jm}^{in}\lambda_{jm}^{\mathbf{1}*}+\sum_{g=1}^{G}\mu_{ing}^{\mathbf{0}*}\right]\times(x_{jm}^{in}-x_{jm}^{in*})\\
&+\sum_{j=1}^{I}\sum_{m=1}^{M}\sum_{s=1}^{S}\left[\frac{\partial c_{s}^{jm}(x_{s}^{jm*})}{\partial x_{s}^{jm}}-\frac{\partial \beta_{\mathbf{0}}(x_{s}^{jm*})}{\partial x_{s}^{jm}}-\lambda_{jm}^{\mathbf{1}*}-\lambda_{js}^{\mathbf{2}*}+\sum_{g=1}^{G}\mu_{jmg}^{\mathbf{1}*}\right]\times(x_{s}^{jm}-x_{s}^{jm*})\\
&+\sum_{j=I}^{I}\sum_{s=1}^{S}\sum_{t=1}^{T}\sum_{k=1}^{K}\left[\frac{\partial f^{js}(x^{js*})}{\partial x_{tk}^{js}}+\frac{\partial c_{tk}^{js}(x_{tk}^{js*})}{\partial x_{tk}^{js}}+\hat{c}_{tk}^{js}(x_{tk}^{js*})+\lambda_{js}^{\mathbf{2}*}\right]\times(x_{tk}^{js}-x_{tk}^{js*})\\
&-\sum_{i=1}^{I}\sum_{n=1}^{N}\sum_{g=1}^{G}\frac{\partial \alpha_{g}(\delta_{g}^{in*})}{\partial \delta_{g}^{in}}\times(\delta_{g}^{in}-\delta_{g}^{in*})-\sum_{j=1}^{I}\sum_{m=1}^{M}\sum_{g=1}^{G}\frac{\partial \beta_{g}(\delta_{g}^{jm*})}{\partial \delta_{g}^{jm}}\times(\delta_{g}^{jm}-\delta_{g}^{jm*})\\
&-\sum_{j=1}^{I}\sum_{k=1}^{K}\rho_{\mathbf{3}k}^{j}(d^{*})\times(d-d^{*})+\sum_{i=1}^{I}\sum_{n=1}^{N}\left[U_{in}-\sum_{j=1}^{I}\sum_{m=1}^{M}x_{jm}^{in*}\right]\times(\lambda_{in}^{\mathbf{0}}-\lambda_{in}^{\mathbf{0}*})\\
&+\sum_{j=1}^{I}\sum_{m=1}^{M}\left[\sum_{s=1}^{S}x_{s}^{jm*}-\sum_{i=1}^{I}\sum_{n=1}^{N}x_{jm}^{in*}\cdot\psi_{jm}^{in}\right]\times(\lambda_{jm}^{\mathbf{1}}-\lambda_{jm}^{\mathbf{1}*})+\sum_{j=I}^{I}\sum_{s=1}^{S}\left[\sum_{m=1}^{M}x_{s}^{jm*}-\sum_{k=1}^{K}\sum_{t=1}^{T}x_{tk}^{js*}\right]\times(\lambda_{js}^{\mathbf{2}}-\lambda_{js}^{\mathbf{2}*})\\
&+\sum_{i=1}^{I}\sum_{n=1}^{N}\sum_{g=1}^{G}\left[A_{g}^{in}-\sum_{j=1}^{I}\sum_{m=1}^{M}x_{jm}^{in*}+\delta_{g}^{in*}\right]\times(\mu_{ing}^{\mathbf{0}}-\mu_{ing}^{\mathbf{0}*})\\
&+\sum_{j=1}^{I}\sum_{m=1}^{M}\sum_{g=1}^{G}\left[B_{g}^{jm}-\sum_{s=1}^{S}x_{s}^{jm*}+\delta_{g}^{jm*}\right]\times(\mu_{jmg}^{\mathbf{1}}-\mu_{jmg}^{\mathbf{1}*})\geq\mathbf{0},\\
&\forall(Q^{\mathbf{0}},Q^{\mathbf{1}},Q^{\mathbf{2}},\eth^{\mathbf{0}},\eth^{\mathbf{1}},d,\lambda^{\mathbf{0}},\lambda^{\mathbf{1}},\lambda^{\mathbf{2}},\mu^{\mathbf{0}},\mu^{\mathbf{1}})\in R_{+}^{\mathbf{2}(I^{\mathbf{2}}MN+ING+IMG+IMS+ISTK)+I(N+M+S+K)},
\end{aligned}
\tag{3}
$$

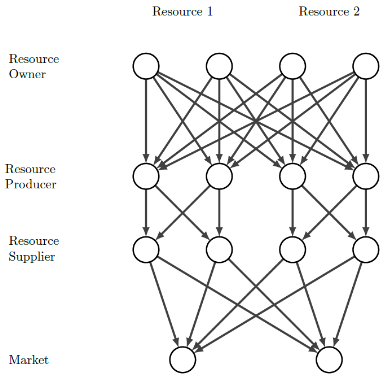
Algorithms that solve variational inequalities

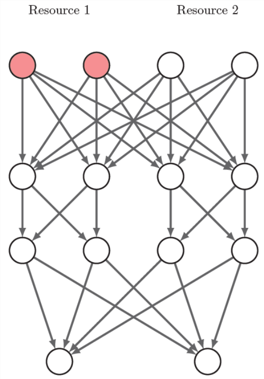
- Lemke-Howson algorithm (Lemke and Howson Jr, 1964; Eaves, 1978)
- Newton-based (Newton, Quasi-Newton, linearized Jacobi, projection) methods (Cottle, 1966; Korpelevich, 1976; Pang and Chan, 1982)
- Fixed-point method (Scarf, 1967)
- Euler method (Dupuis and Nagurney, 1993; Zhang and Nagurney, 1995).

Small Scale Examples

Example 1: un-incentivized v.s. incentivized network

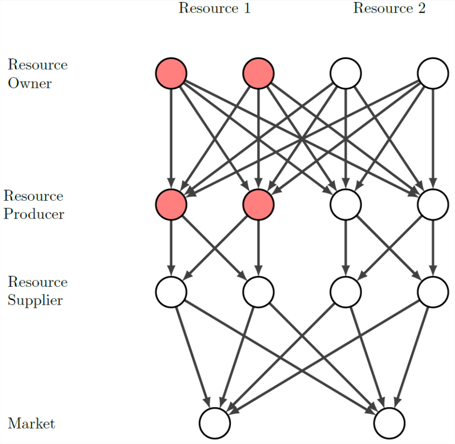
In this example, we examine the output quantities of firms, market prices, and welfare estimates between the following two networks.





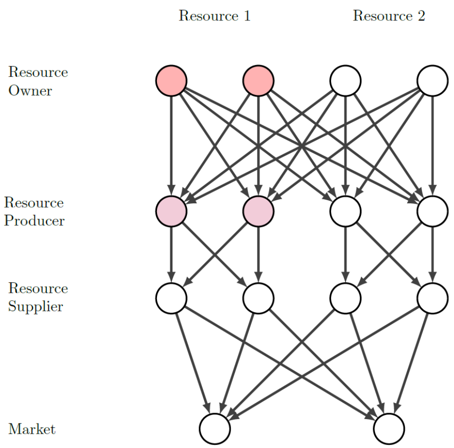
Example 2: Critical resource shortage relief

In this example, resource 1 emerges to be a critical shortage in supplies. To relieve such distress, both resource owner and producer of resource 1 receive flat-rate incentives.



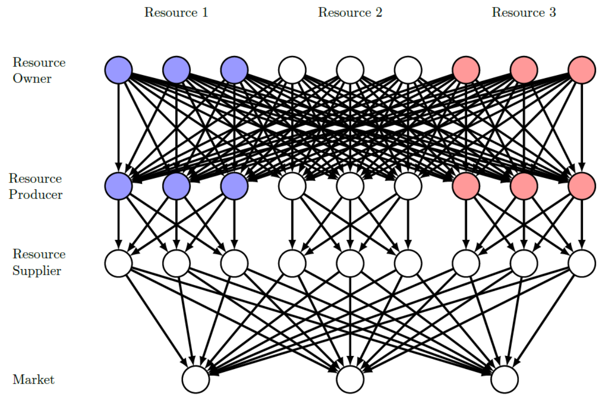
Example 3: Monetary policies with limited budget

In this example, a government has limited budget on the total of incentives. This example gives insight to who should get the stimulus. Owners or producers?



Example 4: a balanced monetary-fiscal policy with taxation and incentive

We examine a monetary-fiscal policy by which a tax scheme is applied to an undesired resource (e.g., a conventional energy with adverse environmental effect), and an incentive scheme is applied to a desired resource (e.g., a new clean energy). In this example, resource 1 is taxed, while resource 3 is incentivized.



Summary

In this ongoing research:

1. We construct a general scarce resource supply chain network equilibrium model under fiscal/monetary policies.
2. The model is formulated in variational inequalities; the optimality conditions for the resource representatives of the network are derived.
3. Small scale examples are furnished to demonstrate the application of the model.

Thank you!

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References

Yun Bai, Yanfeng Ouyang, and Jong-Shi Pang. Biofuel supply chain design under competitive agricultural land use and feedstock market equilibrium. *Energy Economics*, 34(5): 1623–1633, 2012.

Yun Bai, Yanfeng Ouyang, and Jong-Shi Pang. Enhanced models and improved solution for competitive biofuel supply chain design under land use constraints. *European Journal of Operational Research*, 249(1):281–297, 2016.

Amirsaman H. Bajgiran, Jaejin Jang, Xiang Fang, and James H. Peoples. A biofuel supply chain equilibrium analysis with subsidy consideration. *International Journal of Energy Research*, 43(5):1848–1867, 2019. ISSN 1099114X. doi: 10.1002/er.4422.

Craig Bakker, Benjamin F Zaitchik, Sauleh Siddiqui, Benjamin F Hobbs, Elena Broaddus, Roni A Neff, Jonathan Haskett, and Cindy L Parker. Shocks, seasonality, and disaggregation: Modelling food security through the integration of agricultural, transportation, and economic systems. *Agricultural systems*, 164:165–184, 2018.

Deniz Besik and Anna Nagurney. Quality in competitive fresh produce supply chains with application to farmers' markets. *Socio-Economic Planning Sciences*, 60:62–76, 2017.

Yann Bramoullé, Rachel Kranton, and Martin D'amours. Strategic interaction and networks. *American Economic Review*, 104(3):898–930, 2014.

Marjolein C.J. Caniëls and Cees J. Gelderman. Power and interdependence in buyer supplier relationships: A purchasing portfolio approach. *Industrial Marketing Management*, 2007. ISSN 00198501. doi: 10.1016/j.indmarman.2005.08.012.

Joseph P. Cannon and William D. Perreault. Buyer-seller relationships in business markets. *Journal of Marketing Research*, 1999. ISSN 00222437. doi: 10.2307/3151999.

Richaard W Cottle. Nonlinear programs with positively bounded Jacobians. *SIAM Journal on Applied Mathematics*, 14(1):147–158, 1966.

Augustin Cournot. Researches into the mathematical principles of the theory of wealth. *Competition Policy International*, 1838. ISSN 15540189. doi: 10.2307/2299776.

Stella Dafermos and Anna Nagurney. Sensitivity Analysis for the General Spatial Economic Equilibrium Problem. *Operations Research*, 32(5):1069–1086, 1984. doi: 10.1287/opre.32.5.1069. URL https://doi.org/10.1287/opre.32.5.1069.

Stella Dafermos and Anna Nagurney. Oligopolistic and competitive behavior of spatially separated markets. *Regional Science and Urban Economics*, 1987. ISSN 01660462. doi: 10.1016/0166-0462(87)90048-2.

Paul Dupuis and Anna Nagurney. Dynamical systems and variational inequalities. *Annals of Operations Research*, 44(1):7–42, 1993.

B Curtis Eaves. Computing stationary points. In *Complementarity and Fixed Point Problems*, pages 1–14. Springer, 1978.

Stephen Enke. Equilibrium among spatially separated markets: Solution by electric analogue. *Econometrica: Journal of the Econometric Society*, pages 40–47, 1951.

Nabeel Hamoud and Jaejin Jang. A game theoretic analysis of a closed-loop water-energy nexus: The effect of technology efficiency and market competition on the market equilibrium and social welfare. *International Journal of Energy Research*, 2020.

Shelby D Hunt. *A General Theory of Competition*. 2000.

Matthew O Jackson and Yves Zenou. Games on networks. In *Handbook of game theory with economic applications*, volume 4, pages 95–163. Elsevier, 2015.

G M Korpelevich. The extragradient method for finding saddle points and other problems. *Ekonomika i Matematicheskie Metody*, 12:747–756, 1976.

Jeffrey A Krautkraemer. Economics of natural resource scarcity: The state of the debate. Technical report, 2005.

Carlton E Lemke and Joseph T Howson Jr. Equilibrium points of bimatrix games. *Journal of the Society for industrial and Applied Mathematics*, 12(2):413–423, 1964.

Michael K Lim and Yanfeng Ouyang. Biofuel supply chain network design and operations. In *Environmentally Responsible Supply Chains*, pages 143–162. Springer, 2016.

Yi Luo and Shelie Miller. A game theory analysis of market incentives for US switchgrass ethanol. *Ecological economics*, 93:42–56, 2013.

Amir H Masoumi, Min Yu, and Anna Nagurney. A supply chain generalized network oligopoly model for pharmaceuticals under brand differentiation and perishability. *Transportation Research Part E: Logistics and Transportation Review*, 48(4):762–780, 2012.

Emerson Melo. A Variational Approach to Network Games. *Fondazione Eni Enrico Mattei Working Papers*, (paper 1230), 2018. URL `https://services.bepress.com/feem/paper1230`.

Parinaz Naghizadeh and Mingyan Liu. Provision of public goods on networks: on existence, uniqueness, and centralities. *IEEE Transactions on Network Science and Engineering*, 5(3): 225–236, 2017.

Anna Nagurney. *Supply chain network economics: dynamics of prices, flows and profits*. Edward Elgar Publishing, 2006.

Anna Nagurney and Kanwalroop Kathy Dhanda. Marketable pollution permits in oligopolistic markets with transaction costs. *Operations Research*, 48(3):424–435, 2000.

Anna Nagurney and Pritha Dutta. Competition for blood donations. *Omega (United Kingdom)*, 85:103–114, 2019. ISSN 03050483. doi: 10.1016/j.omega.2018.06.001. URL https://doi.org/10.1016/j.omega.2018.06.001.

Anna Nagurney and Dmytro Matsypura. A supply chain network perspective for electric power generation, supply, transmission, and consumption. In *Optimisation, econometric and financial analysis*, pages 3–27. Springer, 2007.

Anna Nagurney, June Dong, and Ding Zhang. A supply chain network equilibrium model. *Transportation Research Part E: Logistics and Transportation Review*, 2002. ISSN 13665545. doi: 10.1016/S1366-5545(01)00020-5.

Anna Nagurney, Zugang Liu, and Trisha Woolley. Optimal endogenous carbon taxes for electric power supply chains with power plants. *Mathematical and Computer Modelling*, 44 (9-10):899–916, 2006.

J. F. Nash. Equilibrium points in n-person games. *Proceedings of the National Academy of Sciences*, 1950. ISSN 0027-8424. doi: 10.1073/pnas.36.1.48.

John Nash. Non-cooperative games. *Annals of mathematics*, pages 286–295, 1951.

Jong-Shi Pang and Donald Chan. Iterative methods for variational and complementarity problems. *Mathematical programming*, 24(1):284–313, 1982.

Francesca Parise and Asuman Ozdaglar. A variational inequality framework for network games: Existence, uniqueness, convergence and sensitivity analysis. (2010), 2017. ISSN 0899-8256. doi: 10.1016/J.GEB.2018.11.012. URL http://arxiv.org/abs/1712.08277.

Jeffrey Pfeffer and Gerald R Salancik. The external control of organizations: A resource dependence approach, 1978. ISSN 00018392.

Jeffrey Pfeffer and Gerald R Salancik. *The external control of organizations: A resource dependence perspective*. Stanford University Press, 2003.

J Ben Rosen. Existence and uniqueness of equilibrium points for concave n-person games. *Econometrica: Journal of the Econometric Society*, pages 520–534, 1965.

Nathan Rosenberg. Innovative responses to materials shortages. *The American Economic Review*, 63(2):111–118, 1973.

Paul A. Samuelson. American Economic Association Spatial Price Equilibrium and Linear Programming Author (s): Paul A . Samuelson Source : The American Economic Review , Vol . 42 , No . 3 (Jun ., 1952), pp . 283-303 Published by : American Economic Association Stable URL. 42(3):283–303, 1952.

Herbert Scarf. The approximation of fixed points of a continuous mapping. *SIAM Journal on Applied Mathematics*, 15(5):1328–1343, 1967.

Takashi Takayama and George G Judge. Spatial equilibrium and quadratic programming. *American Journal of Agricultural Economics*, 46(1):67–93, 1964.

Xiaolei Wang, Yanfeng Ouyang, Hai Yang, and Yun Bai. Optimal biofuel supply chain design under consumption mandates with renewable identification numbers. *Transportation Research Part B: Methodological*, 57:158–171, 2013.

Haixiang Wu, Bing Xu, and Ding Zhang. Closed-Loop Supply Chain Network Equilibrium Model with Subsidy on Green Supply Chain Technology Investment. *Sustainability*, 11(16): 4403, 2019.

Kai Wu, Anna Nagurney, Zugang Liu, and John K Stranlund. Modeling generator power plant portfolios and pollution taxes in electric power supply chain networks: A transportation network equilibrium transformation. *Transportation Research Part D: Transport and Environment*, 11(3):171–190, 2006.

Min Yu, Jose M. Cruz, and Dong “Michelle” Li. The sustainable supply chain network competition with environmental tax policies. *International Journal of Production Economics*, (May):1–14, 2018. ISSN 09255273. doi: 10.1016/j.ijpe.2018.08.005. URL https://doi.org/10.1016/j.ijpe.2018.08.005.

Ding Zhang. A network economic model for supply chain versus supply chain competition. *Omega*, 34(3):283–295, 2006.

Ding Zhang and Anna Nagurney. On the stability of projected dynamical systems. *Journal of Optimization Theory and Applications*, 85(1):97–124, 1995.

Xiaodong Zhang and Velimir V Vesselinov. Energy-water nexus: Balancing the tradeoffs between two-level decision makers. *Applied Energy*, 183:77–87, 2016.