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Target and Trade Systems for Mass Vaccination

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Introduction

- Most countries have failed to achieve levels of COVID-19 vaccination needed to achieve domestic herd immunity.
- This is also true in the U.S., which failed to meet President Biden's two Fourth of July COVID-19 vaccination targets (see, **Figure 1**):
  - 160 million adults fully immunized (actual: 157.8 million).
  - 70% of adults (~=190.5 million) with at least one dose vaccine (actual: 182.8 million).
- Vaccine lotteries and subsidies have had limited success in inducing voluntary vaccination due to vaccine hesitancy and opposition (**Figure 2**).

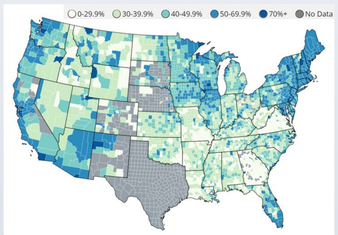

Figure 1. *% of County Population with at Least One Dose of COVID-19 Vaccine (CDC, 7-8-2021)*

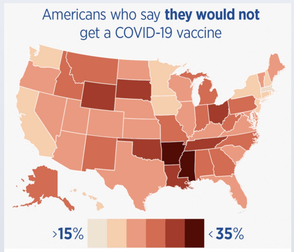

Figure 2. *% of State Population Opposed to COVID-19 Vaccination (Harvard, COVID States Project)*

- Opposition to vaccine mandates is widespread for ethical and other reasons and may not be efficient given heterogeneous marginal costs of vaccination across sub-populations and individuals (**Figure 3**).

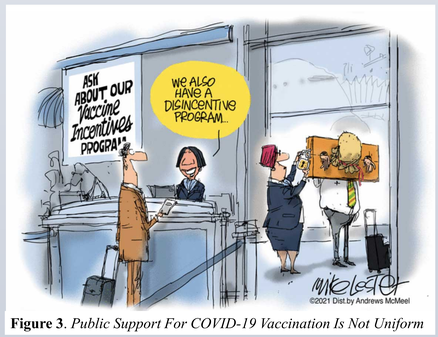

Figure 3. *Public Support For COVID-19 Vaccination Is Not Uniform*

- An alternative to these two approaches is a **vaccine target and trade system**, which would create a **virtual market for vaccine allowances**.
  - Akin to a cap and trade system which have been successfully used around the globe to regulate emissions and in other contexts (**Figure 4**), under a vaccine target and trade system **regulators would first select a predetermined vaccine target**, such as that necessary to achieve domestic herd immunity.
  - In addition, **sub-populations/individuals would be assigned a vaccine obligation**. They could meet this obligation in one of two ways:
    - **Purchase sufficient vaccine allowances from the vaccine allowance market in lieu of vaccination** to meet their obligation.
    - **Choose to become vaccinated** and in so doing, generate vaccine allowance in excess of their obligation, which they could then sell on the vaccine allowance market.

Policy	Virtual Market Scope	Virtual Instrument	Virtual Market Participants
Renewable Fuel Standard (RFS)	Federal: Mandated Standards across the U.S. for blended fuels	Renewable Identification Numbers	Producers of petroleum-based fuel (gasoline, diesel, jet fuel, and heating oil)
Corporate Average Fuel Economy (CAFÉ)	Federal: Mandated Standards across the U.S. for vehicle manufacturers	Credits (Domestic Passenger, Imported Passenger, and Light trucks	Automobile Manufacturers of passenger cars, and light trucks
Renewable Portfolio Standards (RPS)	State: (Voluntary) Individual Standards for an electric utility providers portfolio	Renewable Energy Certificates	Investor-Owned Utilities, municipalities, and electric cooperatives

Figure 4. *Other Target and Trade Systems Commonly Used in the U.S.*

Theory

Model Set-up:

- Consider a heterogeneous population of individuals with different preferences. Suppose there are sub-populations of individuals, each of whom can be represented by a representative consumer j.
- Suppose a government wished for 80% vaccination of its population of size J to be vaccinated. The total target is thus $0.8J$.
- This target is distributed across sub-populations through the assignment of **Vaccine Obligations** (VO), o_j, across sub-populations, such that $\sum_j^J o_j = 0.8J$.
- One option is a **uniform VO** of o_j= 0.8 across all sub-populations.
- There are many possible assignments of VOs across sub-populations which can be used to achieve equity goals and possibly induce greater participation of select sub-populations.
- Suppose that vaccination generates marginal external benefits according to the function, $MEB_V\left(\sum_{j=1}^J v_j\right)$, such that $MEB_V' < 0$.

Consumer Preferences:

- Each representative consumer j has preferences which can be represented by a utility function,
  - $U_j(n_j, v_j) = n_j - C_j(v_j)$,
  - Where $C_j(v_j)$ is the private, possibly public, cost function reflecting their assessment of the cost, possibly benefit, to being vaccinated themselves.
  - Observe that the **marginal costs vaccination, $MC_V^j = \frac{\partial C_j}{\partial v_j}$, likely differ significantly across sub-populations for a whole host of reasons**: heterogenous public health impacts of COVID-19, heterogenous equity preferences (some may account for vaccine spillovers on others), heterogenous risk preferences and/or beliefs about the credibility of science underlying COVID-19 and/or vaccination, and/or heterogenous ethical and religious beliefs.
  - Note also that C_j''>0, and n_j is all other consumption (e.g., the numeraire good), whose price is normalized to one. Representative consumers also receive exogeneous income, W_j.
- Each representative consumer has a vaccine obligation $o_j \geq 0$, and taking the price of vaccine allowances, $p > 0$, as given, they maximize utility according to:
  - Max $n_j - C_j(v_j)$
    - Choosing: $n_j \geq 0, v_j \geq 0, y_j \gtreqless 0$
    - Subject to: $v_j + y_j \geq o_j$ and $n_j + py_j \leq W_j$
  - The solution to this problem, provides the inverse supply (or marginal cost) curves for vaccination for the sub-population as well as the amount of vaccine allowances demanded/supplied, $y_j = \sigma_j - v_j$.

Market Clearing for Vaccine Allowances:

- The vaccine allowance market clears when $\sum_{j=1}^J y_j \geq \sum_{j=1}^J o_j$ given vaccine allowance price $p > 0$. For vaccine target, V_{PO}, market clearing in vaccine allowances market is depicted in **Figure 5**, as well as the welfare gains from a vaccine target and trade system with a uniform VO relative to a universal vaccine mandate.

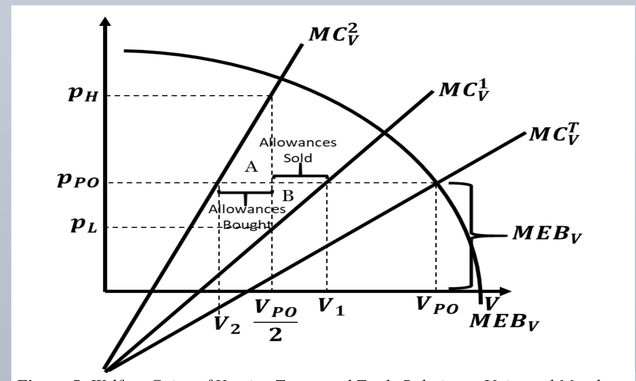

Figure 5. *Welfare Gains of Vaccine Target and Trade Relative to Universal Mandate*

Extensions

- Uncertainty in MEB and MC.
  - It is difficult to identify the MEB and MC curves, which are likely to reflect considerable uncertainty, as depicted in **Figure 6**.
  - Data is constantly getting updated, and the virus continues to mutate, although we have been working on estimating MC curves using data on lotteries and vaccinations from the CDC, which is ongoing.

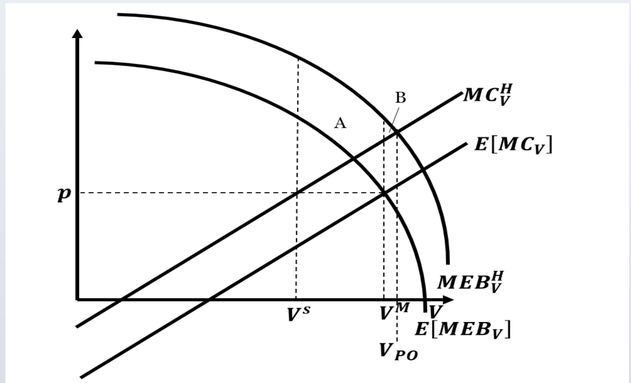

Figure 6. *Welfare Implications of Vaccine Target and Trade System Under Uncertainty*

Practical Challenges

- Likely will need heterogeneous vaccine obligations to address equity issues.
- Need to account for possible unvaccinated hotspots.
- We would also need to account for heterogeneous compliance and enforcement.
- Need to account for costs of implementation.
- Fortunately, many of these practical challenges have been overcome whenever these virtual markets have been deployed in other contexts.

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References

Bacon, John. "'Joints for Jabs': Washington State Turns to Marijuana Giveaways to Encourage Residents to Get Vaccinated." USA Today. Gannett Satellite Information Network, June 8, 2021.

Bird, Mike. "The Straightforward Economics of Vaccine Lotteries." The Wall Street Journal. Dow Jones & Company, June 3, 2021.

"CDC COVID Data Tracker." Centers for Disease Control and Prevention. Centers for Disease Control and Prevention. Accessed July 21, 2021.

Diaz, Jaclyn. "Guns, Trucks And Trips: West Virginia Expands Prizes For Vaccinated Residents." NPR. NPR, June 2, 2021.

EPA. Environmental Protection Agency. Renewable Fuel Standard. Accessed July 21, 2021.

"FOTW #1135, May 25, 2020: Corporate Average Fuel Economy Standards Finalized Through 2026." Energy.gov. Accessed July 21, 2021. Gross, Jenny. "Yes, Your Employer Can Require You to Be Vaccinated." *The New York Times*, June 9, 2021.

"Home: National Highway Traffic Safety Administration (NHTSA)." National Highway Traffic Safety Administration. Accessed July 21, 2021.

James F. Smith. February 23, 2021. "Tracking Attitudes and Behavior on COVID in All 50 States, Week by Week." Harvard Kennedy School. Accessed July 21, 2021.

Kearney, Melissa Schettini. "State Lotteries and Consumer Behavior." Journal of Public Economics. North-Holland, January 11, 2005.

Keohane, Nathaniel. *Markets and the Environment*. Washington, DC: Island Press/Center for Resource Economics, 2016.

"Laws & Regulations." NHTSA. Accessed July 21, 2021.

Lopez, German. "Ohio's Vaccine Lottery Is a Winner No Matter What ." Vox. Vox, May 28, 2021.

Megan Cleveland, Laura Shields. State Renewable Portfolio Standards and Goals. Accessed July 21, 2021.