Reflections on the Impact of "Flatten the Curve" on Interdependent Workforce Sectors

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Acknowledgments
Presentation Outline

▪ EVOLUTION OF “FLATTEN THE CURVE”
▪ SUPPRESSION AND MITIGATION MEASURES
▪ ECONOMIC INPUT-OUTPUT MODEL AND EXTENSIONS
▪ DATA SOURCES
▪ CASE STUDY AND RESULTS
▪ DISCUSSION, Q&A
The “flatten the curve” concept has gained significant attention in the midst of the COVID-19 pandemic. The aim is to decrease the peak of an epidemic wave so as not to exceed the capacity of healthcare systems.

World leaders have implemented nonpharmaceutical interventions (NPIs).

NPIs include containment, suppression, and mitigation.

Research Question: To what extent do NPIs affect workforce across different interdependent sectors?
EVOLUTION OF FLATTEN THE CURVE
The origins of the “flatten the curve” graph can be traced back to the Centers for Disease Control and Prevention.
Different color shadings to contrast the epidemic waves associated with intervention scenarios.

**SOURCE:** London and Milan, Feb 29 2020, The Economist: Covid-19 is now in 50 countries, and things will get worse
A horizontal line was added to represent the healthcare system capacity.

**SOURCE:** Harris, D., February 28, 2020.
Twitter: [https://twitter.com/drewaharris/status/1233267475036372992](https://twitter.com/drewaharris/status/1233267475036372992)
Evolution of Flatten The Curve (cont’d)

- Animation has also been created to illustrate ways with which the curve can be flattened.

SUPPRESSION AND MITIGATION MEASURES
A pandemic refers to a widespread outbreak of a disease, often infecting large populations across the globe.

Pandemics have disrupted modern civilization in several occasions:

The 1918 “Spanish Flu” marked one of the deadliest pandemics in modern times:
- 50+ million mortalities worldwide and 500,000+ people in the US (Taubenberger and Morens 2006).
To date:

The world has borne witness to the devastating and unprecedented impacts of the COVID-19 pandemic caused by the SARS-CoV-2 virus.

IMAGE SOURCE: CDC Website
INTERVENTION MEASURES

- Effective pharmaceutical interventions (e.g., vaccines, antivirals) are not immediately available for novel viruses.

- Health agencies rely on nonpharmaceutical interventions, or NPIs, to manage the spread of infections.

- Examples of NPIs:
  - Testing, isolation, hand hygiene, personal protective equipment (PPE), social distancing, travel restrictions, and school/work closures, among others.

- Recent articles have distinguished several categories of NPIs: containment, suppression, and mitigation.
**CONTAINMENT**

- **Containment** is the approach of managing individual infection chains:
  - broad testing, contact tracing, isolation of travelers coming from high-prevalence areas, travel restrictions, among others

- Containment is effective only:
  - When applied prior to the occurrence of community transmission
  - Or, after community transmission has been adequately suppressed.
**SUPPRESSION**

- **Suppression** aims to decrease the basic reproduction number (R0) to a value lower than 1.
  - This brings community transmission down to levels where implementation of containment will be feasible.

- Suppression measures include:
  - Quarantine, in addition to implementing some of the containment measures like broad testing and travel restrictions.

- Suppression can be effective in decreasing the duration of the first wave, but:
  - The likelihood and severity of a second or subsequent waves can be more extreme in the absence of vaccines, relative to mitigation.
**Mitigation** ("flatten the curve") does not aim to completely stop the transmission, but:

- To lower R0 enough sufficiently that the medical system can handle peak demand.

Mitigation measures aim to delay further spread of the disease such as:

- Social distancing, PPEs, and hand hygiene.

**Advantages:**

- Less restriction on contact
- Herd immunity (assuming low or negligible risk of reinfection)
ECONOMIC INPUT-OUTPUT MODEL AND EXTENSIONS
Leontief I-O Model

- Introduced by Wassily Leontief in the 30’s to study transactions among producers and consumers in the economy.

- The primary reference to I-O analysis is:
Simple I-O Example

Based on the example in Miller and Blair [2009]:

<table>
<thead>
<tr>
<th>Industries</th>
<th>1</th>
<th>2</th>
<th>Final Demand (c)</th>
<th>Total Output (x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150</td>
<td>500</td>
<td>350</td>
<td>1000</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>100</td>
<td>1700</td>
<td>2000</td>
</tr>
<tr>
<td>Value Added</td>
<td>650</td>
<td>1400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Input (x^T)</td>
<td>1000</td>
<td>2000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Final demand (c) and total output (x) can be read directly from the table:

\[
\mathbf{x} = \begin{bmatrix} 1000 \\ 2000 \end{bmatrix} \quad \mathbf{c} = \begin{bmatrix} 350 \\ 1700 \end{bmatrix}
\]

Leontief Matrix (A) is determined by normalizing the shaded cells by the corresponding column sum:

\[
\mathbf{A} = \begin{bmatrix} 150/1000 & 500/2000 \\ 200/1000 & 100/2000 \end{bmatrix} = \begin{bmatrix} 0.15 & 0.25 \\ 0.20 & 0.05 \end{bmatrix}
\]
Leontief balance equation is: \( \mathbf{x} = \mathbf{Ax} + \mathbf{c} \)

\[
\begin{bmatrix}
1000 \\
2000
\end{bmatrix}
= \begin{bmatrix}
0.15 & 0.25 & 1000 \\
0.20 & 0.05 & 2000
\end{bmatrix}
+ \begin{bmatrix}
350 \\
1700
\end{bmatrix}
\]

\[
\begin{bmatrix}
1000 \\
2000
\end{bmatrix}
= \begin{bmatrix}
650 \\
300
\end{bmatrix}
+ \begin{bmatrix}
350 \\
1700
\end{bmatrix}
\]

Final Demand (c), also called GDP
Intermediate Demand (Ax)
Output (x), also called Supply
Note that the Leontief Balance equation can be expressed as:

\[ x = Ax + c \]
\[ x = (I - A)^{-1}c \]

Definition: Let \( L \) denote the inverse matrix. This is called the Total Requirements Matrix (or Leontief Inverse).

\[ L = (I - A)^{-1} \]

In our example, \( L \) is computed as follows:

\[
L = (I - A)^{-1} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} 0.15 & 0.25 \\ 0.20 & 0.05 \end{bmatrix} = \begin{bmatrix} 0.85 & -0.25 \\ -0.20 & 0.95 \end{bmatrix}^{-1}
\]
Key Sectors Based on US I-O Table*

<table>
<thead>
<tr>
<th></th>
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</tbody>
</table>

Total Output Requirement: 2.2524 1.8805 1.4012 1.9675 2.4843 1.5795 1.5393 1.9622 1.8996 1.6265 1.5673 1.6988 1.8473 1.6882 1.7806
Rank: 2 6 15 3 1 12 14 4 5 11 13 9 7 10 8

**Note:** There are other approaches for key sector analysis, such as those that use eigenvectors.

The inoperability I-O model is derived on the basis of the original Leontief I-O model [Haimes and Jiang, 2002; Santos and Haimes 2004, among others].

- Inoperability \( q_i \) is the proportion with which a sector \( i \) is disrupted.
- Let \( x_i \) be the ideal production.
- Let \( \tilde{x}_i \) be the disrupted production.

\[
q_i = \frac{x_i - \tilde{x}_i}{x_i}
\]

The formulation of the IIM is as follows.

\[
q_i = \sum_j a_{ij}q_j + c_i \iff q = A^*q + c^*
\]
Dynamic Inoperability Input-Output Model (DIIM)

- Dynamic Inoperability Input-Output Model (DIIM) [Lian and Haimes 2006] provides an approach for modeling the recovery of inoperable sectors following an initial disruption

\[ q(t + 1) = q(t) + K[A^*q(t) + c^*(t) - q(t)] \]

- Matrix K measures sector resilience, which is a function of the time to reach acceptable level of recovery

- The remaining variables are defined similarly as the static IIM
Direct and Indirect Impacts

- DIIM shows
  - Direct impacts and subsequent recovery of sectors directly affected by a disruptive event
  - Indirect impacts and subsequent recovery of sectors not directly affected by a disruptive event

- Two-sector example:
  - Sector 1 initially NOT inoperable
  - Sector 2 initially inoperable
### Juxtaposition of Data and Model Parameters

#### Table

<table>
<thead>
<tr>
<th>Column</th>
<th>Agriculture</th>
<th>Manufacturing</th>
<th>Trade</th>
<th>Service</th>
<th>Electric Power</th>
<th>Transportation</th>
</tr>
</thead>
<tbody>
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<td>Agriculture</td>
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<td>Red</td>
<td>Red</td>
<td>Green</td>
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<tr>
<td>Manufacturing</td>
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<tr>
<td>Electric Power</td>
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<tr>
<td>Transportation</td>
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<td>Orange</td>
<td>Orange</td>
<td>Orange</td>
<td>Orange</td>
<td>Orange</td>
</tr>
</tbody>
</table>

#### Diagram

- **A**
- **c_i*(t)**
- **K_i**
- **S_i**
- **q_i*(t)**

**BEA**

**IMPLAN**

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DATA SOURCES
ECONOMIC INPUT-OUTPUT ACCOUNTS (IMPLAN)

Impact Results Overview

Economic indicators by Impact

<table>
<thead>
<tr>
<th>Impact Type</th>
<th>Employment</th>
<th>Labor Income</th>
<th>Value Added</th>
<th>Output</th>
<th>Direct</th>
<th>Indirect</th>
<th>Induced</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Direct</td>
<td>2.26</td>
<td>$2,451,578.49</td>
<td>$8,987,073.44</td>
<td>$1,000,000.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 - Indirect</td>
<td>1.43</td>
<td>$333,117.81</td>
<td>$1,389,668.86</td>
<td>$1,233,668.29</td>
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<td></td>
</tr>
<tr>
<td>3 - Induced</td>
<td>2.01</td>
<td>$1,057,460.09</td>
<td>$1,185,527.85</td>
<td>$311,523.56</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Tax Results

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Proprietor Income</th>
<th>Tax on Production and Imports</th>
<th>Household Income</th>
<th>Enterprises Income</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Federal Government NonDefense</td>
<td>$1,200.09</td>
<td>$1,117.33</td>
<td>$11,833.54</td>
<td>$35,147.81</td>
<td>$8,887.90</td>
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<tr>
<td>2</td>
<td>State/Local Government Nondefense</td>
<td>$1,096.77</td>
<td>$1,473,523.64</td>
<td>$1,473,523.64</td>
<td>$3,585.52</td>
<td>$167,576.54</td>
</tr>
</tbody>
</table>

Top 5 Employment Industries

Top 5 Output Industries

Top 5 Value Added Industries
Input-Output Accounts Data

Data Files

Supply Tables
- Domestic supply of commodities by industry
  - 1997-2018: 15 Industries
  - 2007, 2012: 405 Industries

Use Tables
- Use of commodities by industry
  - 1997-2018: 15 Industries
  - 2007, 2012: 405 Industries
DISEASE OUTBREAK SURVEILLANCE

- Reproduction number (R0): describes the transmissibility of infectious agents.
- Laboratory-based surveillance data pertaining to respiratory and enteric viral diseases (CDC, 2020).
- Syndromic surveillance provides earlier detection by analyzing statistical data (Lombardo et al., 2003).
- An epidemic curve (“epi curve”) can be constructed from data published by health agencies and research institutions.
Johns Hopkins COVID-19 Dashboard

Total Confirmed: 3,224,079

Confirmed Cases by Country/Region/Sovereignty:
- 1,043,595 US
- 239,639 Spain
- 203,591 Italy
- 166,628 France
- 166,443 United Kingdom
- 161,985 Germany
- 117,589 Turkey
- 106,498 Russia
- 94,640 Iran

Lead by JHU CSSE. Automation Support: Earl Living Atlas team and JHU APL. Contact US. FAQ.
CDC Surveillance Data

U.S. State and Local Public Health Laboratories Reporting to CDC:
Number of Specimens Tested and Percent Positive for SARS-CoV-2
March 1, 2020 - April 18, 2020

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CASE STUDY AND RESULTS
Recent articles have underscored the efficacy of implementing suppression and mitigation measures.

Ferguson et al. (2020) have emphasized the urgency of implementing mitigation and suppression measures.

Such measures could reduce the number of mortalities from the millions to hundreds of thousands (Pueyo 2020).
The daily number of new infections can be expressed in terms of a percentage relative to the population of the affected region.

This percentage is typically referred to as the *attack rate* in epidemiological literature.

Using the attack rate data in epi curves, it is possible to estimate the resulting disruption to various workforce sectors.

**NOTE:** The CDC website uses a more formal term “incidence proportion” in lieu of attack rate. See: https://www.cdc.gov/csels/dsepd/ss1978/lesson3/section2.html.
Workforce as a Production Factor

- When a production factor is degraded (e.g., workforce), the output of a dependent economic sector also decreases.

- This can be done by computing the ratio of the contribution of workforce to the production output of each sector.

- Economic sectors and infrastructure systems depend on their workforce in varying degrees.

- As the level of labor dependence increases for a sector, its expected economic loss is also expected to rise in the event of workforce-debilitating events, like pandemics.
Some sectors are less labor-intensive than others.

A case in point, automation in sectors such as advanced manufacturing has reduced dependence on workforce, which were traditionally labor intensive.

Furthermore, it is possible to account for the flexibility of some economic sectors to perform workforce continuity strategies (e.g., teleworking):

– Healthy workers in quarantine are assumed to be able to work remotely; hence reducing the impact of business closures.
### Hypothetical Scenarios Using Actual IO Data for USA

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1: Baseline</th>
<th>Scenario 2: Mitigation</th>
<th>Scenario 3: Suppression</th>
<th>Scenario 4: Suppression + Continuity</th>
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</thead>
<tbody>
<tr>
<td><strong>Start (Day)</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Peak (Day)</strong></td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td><strong>End (Day)</strong></td>
<td>60</td>
<td>90</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td><strong>Peak Attack Rate</strong></td>
<td>50%</td>
<td>25%</td>
<td>10%</td>
<td>10%</td>
</tr>
</tbody>
</table>

**Notes:**

- Scenario 4 is a re-simulation of Scenario 3, considering workforce continuity strategies in the sectors.
- The peak did not change, but workforce continuity further flattens the curve because healthy workers in quarantine are assumed to be able to work remotely, and hence reducing the impact on business closures.
- Examples of continuity strategies: teleworking, transitioning services to online platform, curbside pick-up or delivery for stores and restaurants.
Results for Four Scenarios

Economic Loss Curves for: (1) Baseline Scenario, (2) Mitigation, (3) Suppression, (4) Suppression + Workforce Continuity

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Some Observations

- The magnitude of losses depend on the size of the sector (GDP), as well as the labor-dependence of the sectors.

- Sectors that contribute highly to GDP were among the most affected sectors:
  - State and local government; Wholesale trade; and Construction are among the highest contributors to the GDP.

- Furthermore, the prevalence of labor-dependent sectors can also be observed in the rankings albeit their moderate contribution to the GDP:
  - Administrative and support services; Hospitals; Management of companies and enterprises; and Food services and drinking places.
Impact of Workforce Continuity

- It can be observed that the sector rankings have significantly changed in Scenario 4, relative to the first three scenarios.

- The changes in rankings can be attributed to the capability of the sectors to have workforce continuity plans, hence enabling them to further reduce their projected losses.
  - For example, the impact on State and local general government has improved (i.e., ranking has changed from 1 to 5).
  - In contrast, the impact on Wholesale trade has worsened (i.e., ranking has changed from 7 to 2).
  - New sectors emerged in the new rankings such as Other retail; and Administrative and support services.
“Flatten the Curve” for the Four Scenarios

Summary of Economic Loss Curves for: (1) Baseline Scenario, (2) Mitigation, (3) Suppression, (4) Suppression + Workforce Continuity
### Summary of Losses for the Four Scenarios

<table>
<thead>
<tr>
<th>Scenario 1: Baseline</th>
<th>Scenario 2: Mitigation</th>
<th>Scenario 3: Suppression</th>
<th>Scenario 4: Suppression + Continuity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss ($M)</td>
<td>1,336,565</td>
<td>714,890</td>
<td>380,711</td>
</tr>
<tr>
<td>% GDP Loss</td>
<td>7%</td>
<td>4%</td>
<td>2%</td>
</tr>
<tr>
<td>% Reduction from Scenario 1</td>
<td>0%</td>
<td>47%</td>
<td>72%</td>
</tr>
</tbody>
</table>
DISCUSSION
On Economic Losses

- Hypothetical simulations of 4 scenarios suggest that mitigation and suppression measures can flatten the curve and reduce economic losses.

- Results are counterintuitive!
  - Suppression and mitigation also drastically degrade the operability of the economic sectors due to enforced business/school closures.

- However, the baseline scenario—which assumes significantly fewer closures—may lead to steeper and faster incidences of absenteeism
  - More workers getting sick or caring for sick family members, ultimately increasing the economic losses.
Other Remarks on Workforce and Economic Loss

- Correia et al. (2020) concluded that US cities that implemented more aggressive and prolonged social distancing measures emerged with higher employment growth years after the 1918 Spanish Flu pandemic.
Nonetheless, an important caveat has to be made with the complexities and uncertainties surrounding COVID-19.

- Steep escalation of unemployment rates and sector-specific losses are currently being experienced worldwide.
- There will come a point in time that prolonged suppression and mitigation measures may result in global economic collapse.

Government assistance and creative approaches have to be put in place to cushion the losses to vulnerable sectors.

- Curbside pick-up or delivery for stores and restaurants.
- Leverage IT and virtual services to continue sector production.
Why then are governments cautious and generally averse with the implementation of containment, suppression, and mitigation measures?

The main argument is that such measures may impinge on personal liberty.

Previous studies (see, for example, Hawkley and Capitanio, 2015) have concluded that social isolation:
  – Adversely affects mental health
  – Increases the risk of anxiety, depression, and substance use
On Isolation

- Alafrangy (2020), who worked in NASA’s Human Exploration Research Analog (HERA) project, shared his experience in a confined environment for 45 days:

“The impact of isolation on humans, which are by nature social beings, can be profound. My time in HERA allowed me to develop a few techniques to mitigate the effects of isolation, which can be applicable to the current COVID-19 situation. I learned that following a strict schedule helped me keep busy and remain active. As the days and weeks went by, I noticed my progress with various tasks and experiments, which undoubtedly fueled me with energy and focus to keep going. Conflict within confinement is bound to arise as nobody is immune to it. It is not difficult however, to understand that this isolation affects everyone, and that people may react differently.”
On Socioeconomic Disparities

- Enforcement of quarantine may further expose and amplify the inequality across various socioeconomic groups.

- The impact of COVID-19 on lower income groups has been found to be much more profound:
  - Impeded their ability to access basic resources, employment, as well as services such as healthcare and online education.

- Studies also have indicated that low-income groups are more susceptible to contracting the disease itself.
  - Further compounds the socioeconomic disparities associated with COVID-19.
Parting Thoughts

▪ In sum, containment, suppression, and mitigation measures can have a significant impact on the extent to which the curve can be flattened.

▪ They could reduce the impact on the workforce, healthcare systems, and continuity of government.

▪ The COVID-19 pandemic is an unprecedented disaster that has exposed major challenges and constraints in our socioeconomic and infrastructure systems.

▪ Current disaster management policies need to be enhanced to minimize the impact of pandemics and future disasters.
There were 3 different waves of illness during the pandemic, starting in March 1918 and subsiding by summer of 1919. The pandemic peaked in the U.S. during the second wave, in the fall of 1918. This highly fatal second wave was responsible for most of the U.S. deaths attributed to the pandemic.
Q & A