Between Lives and Economy: Optimal COVID-19 Containment Policy in Open Economies

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Introduction

Introduction

Motivation

- Facing the Nth waves of COVID-19, an important (and recurring) question is how stringent containment policies should be?
- Tough choices to make for policy makers worldwide: Lives vs Economy. Policies differ a lot across countries.
- Macro literature has studied optimal containment policies extensively, but almost all in closed-economy context.

What This Paper Does

- We ask what are the optimal containment polices in open economies?
- Combine a multi-country, multi-sector model of international trade with full-fledged input-output linkages (Eaton and Kortum 2002; Caliendo and Parro 2014) with an standard epidemiological compartmental model (SIRD).
- Compute national optimal policies for long-run welfare, and examine how far a country's current policy is from the welfare frontier.
  - As an intermediate step, we also examine a case where a global planner solves an optimal policy that applies to all countries to maximize global long-run welfare. Found some interesting messages.
- Challenge: how to compute in such a large space of candidate policies?

Preview of Results

- A laissez-faire policy might not be all that bad in terms of long-run real income, but it is a drastically worse policy in welfare terms because of risk aversion.
- All countries welfare and real income improve by adopting the optimal policies, and some countries should relax their containment measures whereas others should tighten up.
- Who are far from the welfare frontier? The welfare gains are much larger for those which need to tighten up than those which need to relax.
- Optimal policies in open economies differ substantially from those in closed economies in welfare terms.

Literature

On Macro Literature:

- embedding SIRD models (Kermack 1927) into macroeconomic models to study various aspects of the tradeoff between lives and economy. See, for examples, Acemoglu et al. (2020), Alvarez et al. (2020), Atkeson (2020), Eichenbaum et al. (2020), Farboodi et al. (2020), Jones et al. (2020), Krueger et al. (2020), and Piguillem and Shi (2020).
- Budish (2020): $R \leq 1$ as a policy constraint.
- Our work differs from all of the above in our focus on analyzing optimal containment policies in an open-economy context.

Introduction

Literature

On Trade Literature:

- Closely related: Antras et al. (2020), Fajagelbaum et al. (2020), and Argente et al. (2020) who all consider disease dynamics in a general equilibrium model of trade in either a city or an international-trade setting.
- Broadly related: includes Chen et al. (2020), Bonadio et al. (2020), and Eppinger et al. (2020), who study the role of trade and/or input-output linkages in the pandemic's shocks on the economy.
- Obviously different....

Model

Model

Environment

- K countries, each with N_k population, which is constant over time.
- J sectors which differ in their WFH capacity
- Productivity differs by country, sector, and varieties within the sector.
- Countries differ in population composition $(S_{i,t}, I_{i,t}, R_{i,t}, D_{i,t})$ and the rates of disease transmission.
- Input-output linkages
- Labor is the fundamental input for the production.
- Balanced trade.
- Perfect competition in all markets.

Model

Preference

- Utility of an individual in country i at period t:

$$u_i = \sum_{t=0}^{T} \rho^t u\left(q_{i,t}\right),$$

where

$$q_{i,t} = \prod_{j=1}^{J} (q_{i,t}^{F,j})^{\alpha_i^j},$$

where sector-j good for final consumption is given by

$$q_{i,t}^{F,j} = \left[\int_0^1 q_{i,t}^{F,j}(\omega)^{\frac{\kappa-1}{\kappa}} d\omega\right]^{\frac{\kappa}{1-\kappa}}.$$

Model

Production

- Production function of variety ω in sector j and country i

$$y_{i,t}^{j}(\omega) = \frac{z_i^j(\omega)\left[B_{i,t}^{j} L_{i,t}^{j}(\omega)\right]^{\beta_i^j} M_{i,t}^{j}(\omega)^{1-\beta_i^j}}{(\beta_i^j)^{\beta_i^j}(1-\beta_i^j)^{1-\beta_i^j}},$$

where $B_{i,t}^{j}$ is the pandemic shock parameter to be specified later, and $M_{i,t}^{j}(\omega)$ is the composite of intermediate goods:

$$M_{i,t}^{j} = \prod_{l=1}^{j} (q_{i,t}^{M,l})^{\gamma_i^{j,l}}$$

$$q_{i,t}^{M,l} = \left[\int_0^1 q_{i,t}^{M,l}(\omega)^{\frac{\kappa-1}{\kappa}} d\omega\right]^{\frac{\kappa}{1-\kappa}}.$$

Model

Costs and Prices

- For unit productivity $z^j_{i,t}(\omega) = 1$, the unit cost of production is

$$c^j_{i,t} = \left(\frac{w_{i,t}}{B^j_{i,t}}\right)^{\beta^j_i} (P^{M,j}_{i,t})^{1-\beta^j_i},$$

- Perfect competition implies that

$$p^j_{n,t}(\omega) = \min_i \left\{ \frac{c^j_{i,t}\tau^j_{i,n}}{z^j_{i,t}(\omega)} \right\}.$$

- Price indices:

$$P^j_{i,t} = \left(\int_0^1 p^j_{i,t}(\omega)^{1-\kappa} d\omega\right)^{\frac{1}{1-\kappa}}, P^{M,j}_{i,t} = \prod_{l=1}^{J} \left[P^l_{i,t}\right]^{\gamma^{j,l}_i}, P_{i,t} = \prod_{j=1}^{J} \left[P^j_{i,t}\right]^{\alpha^j_i}.$$

Model

SIRD Model in Epidemiology

1. **S**usceptible: $S_{i,t}$, people who have not been exposed to the disease
2. **I**nfectious: $I_{i,t}$, people who have contracted the disease
3. **R**ecovered: $R_{i,t}$, people who have recovered and are immune
4. **D**eceased: $D_{i,t}$, died from the disease

The epidemiological evolution is characterized as

$$
\begin{aligned}
S_{i,t+1} &= S_{i,t} - T_{i,t} \\
I_{i,t+1} &= I_{i,t} + T_{i,t} - (\pi^r + \pi^d_{i,t}) I_{i,t} \\
R_{i,t+1} &= R_{i,t} + \pi^r I_{i,t} \\
D_{i,t+1} &= D_{i,t} + \pi^d_{i,t} I_{i,t}, \\
\pi^d_{i,t} &= \pi^d + \delta \times \frac{I_{i,t}}{N_i}.
\end{aligned}
$$

Model

Containment Policies

- Even in a complete lock-down, the economy does not simply freeze.
- People work at home as much as possible.
- Let μ_i^j be the capacity to work from home for sector j in country i.
- Let $\eta_{i,t} \in [0, 1]$ be the containment measure of country i at time t.

Model: Lockdown Policy

Containment Policies

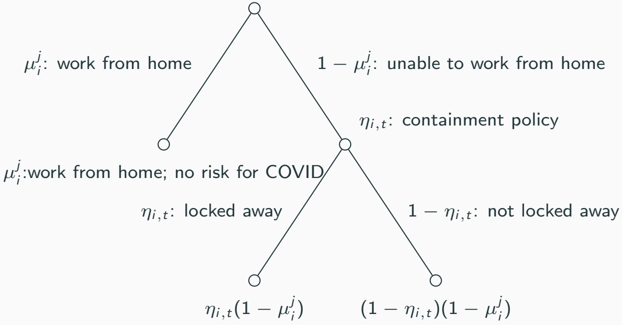


Figure 1: Containment Policy and Work from Home

Model

SIRD Model in Epidemiology

- The newly infected evolves according to

$$T_{i,t} = \frac{(1-\eta_{i,t})\pi_i^I \times (S_{i,t} I_{i,t}) + \pi_i^L \sum_{j=1}^{J} \left[(1-\eta_{i,t})(1-\mu_i^j)\ell_{i,t}^j\right](S_{i,t} I_{i,t})}{N_i},$$

  people get infected via regular interaction and going to workplaces.

- Infected people are not as productive. The effective labor force at t is

$$L_{i,t} = S_{i,t} + R_{i,t} + \alpha^I I_{i,t}$$

  $1-\alpha^I$ measures the productivity loss of contracting the disease.

Labor force evolves according to Macro SIRD, wages, prices and trade are determined by the equilibrium of the Ricardian model.

Model

International Trade under Containment Measures

- The share of sector j goods n purchased from i ($\pi^j_{i,n,t}$) is followed by the gravity equation:

$$\pi^j_{i,n,t} = \frac{T^j_i \left[\left(w_{i,t}/B^j_{i,t} \right)^{\beta^j_i} \left(P^{M,j}_{i,t} \right)^{1-\beta^j_i} \tau^j_{i,n} \right]^{-\theta}}{\sum_{k=1}^{K} T^j_k \left[\left(w_{k,t}/B^j_{k,t} \right)^{\beta^j_k} \left(P^{M,j}_{k,t} \right)^{1-\beta^j_k} \tau^j_{k,n} \right]^{-\theta}},$$

  where $B^j_{i,t} \equiv \mu^j_i + (1-\eta_{i,t})(1-\mu^j_i) = 1 - \eta_{i,t}(1-\mu^j_i)$
- $\eta_{i,t}$ and μ^j_i can reshape comparative advantages.
- Country i gains comparative advantage in j if it has a larger presence in the high WFH sectors (larger μ^j_i);
- Such comparative advantages are strengthened/dampened when country i's containment measure become less/more stringent.

Model

Equilibrium

An equilibrium is a path of SIRD objects $\{S_{i,t}, I_{i,t}, R_{i,t}, D_{i,t}, T_{i,t}\}$, effective labor forces $\{L_{i,t}\}$, wages $\{w_{i,t}\}$, price indices $\{P^{j}_{i,t}, P^{M,j}_{i,t}, P_{i,t}\}$, trade shares $\{\pi^{j}_{i,n,t}\}$, total expenditures on sectoral goods $\{X^{j}_{k,t}\}$, and sectoral labor shares $\{\ell^{j}_{i,t}\}$ for all i, j, and t such that:

- All firms maximize their profits;
- All consumers maximize their utility;
- All markets are cleared;
- Satisfying SIRD evolution;

Model

Between Economy and the Pandemic

- $B_{i,t}^{j} \equiv 1 - \eta_{i,t}(1 - \mu_{i}^{j})$ reshapes compararive advantages and changes employment shares $\ell_{i,t}^{j}$.
- The two forms exogenous and endogenous economic forces that affects disease transmission.
- The speed of disease transmission affects the labor supply (and hence wages and comparative advantages) in the next period.
- A country's containment policies affect its own and other countries' sectoral employment shares ...

Model: Welfare

Welfare

$$U_i = \sum_{t=0}^{T} \rho^t \left[(S_{i,t} + R_{i,t})\, u\left(\frac{w_{i,t}}{P_{i,t}}\right) + I_{i,t} u\left(\frac{\alpha^I w_{i,t}}{P_{i,t}}\right) + D_{i,t} u\,(0) \right].$$

- Assume u is increasing and concave.
- If $u(0) \neq 0$, its value reflects the psychological cost of mortality.
- We set $u(0) = 0$ for a cleaner analysis. When u is linear, welfare collapse to real income.

$$U_i = \sum_{t=0}^{T} \rho^t \frac{w_{i,t} L_{i,t}}{P_{i,t}}.$$

Parameterization

Parameterization

Data Sources

- The World Input-Output Database (WIOD), latest available year is 2014
    - $K = 42$ and $J = 6$.
    - Trade shares, input-output structure.
    - Factor shares, consumption shares
- CEPII: Geography
- Dingle and Neiman (2020): Capacity to work from home (μ_i^j).
- Hale et. al (2020): Stringeny Index from Government Response Tracker ($\eta_{i,t}$, until 11/16/2020)
- JHU: Covid-19 related data, new confirmed number, total confirmed number (until 11/16/2020)

Parameterization

Epidemiological Parameters

- Key objects: infection probabilities π_i^I and π_i^L, which are country-specific as they may reflect country-specific environments such as health system, institution, geography, climate, or culture.
- Also, for the epidemiological evolution to commence, an estimate of $I_{i,0}$ is required, as it is generally unknown.
- For each country, parameters $\{\pi_i^I, \pi_i^L, I_{i,0}\}$ are estimated by the **non-linear least-squares** method that minimizes the squared distance in the total confirmed cases between data and model.
- Model Fit: cross-country average and standard deviation of R^2 are 0.88 and 0.067, respectively.

Parameterization

Epidemiological Parameters

- Following the literature, assume it takes on average 18 days to either die or recover from the disease.
- Case mortality rate is set to 3.7% (Liang et al. 2020)

$$\pi^d = 0.037 \times \frac{1}{18}$$
$$\pi^r = (1 - 0.037) \times \frac{1}{18}$$

- $\delta = 0.05 \times \frac{1}{18}$ to reflect medical preparedness

Parameterization

Economic Parameters

- Elasticity
  - Trade elasticity $\theta = 4$, from Simonovska and Waugh (2014)
  - Following Farboodi et al. (2020), we set the annual discount rate as 0.95; as daily data is used, $\rho = 0.95^{\frac{1}{365}} \approx 0.99986$
- Preference
  - Per-period utility as

    $$u(q) = \frac{(q+1)^{1-\sigma} - 1}{1-\sigma},$$

    with $\sigma = 1.5$ (Low et al. 2015).
  - α_i^j: Sectoral final consumption shares from WIOD.
- IO-linkage $\gamma_i^{j,k}$: sectoral intermediate usage shares from WIOD.
- Labor share β_i^j: WIOD
- WFH capacity μ_i^j: Dingle and Neimann (2020)

Optimal Containment Policy

Optimal Containment Policy

Short Run vs. Long Run

- The online appendix shows a short-run counter-factual analysis in which all countries imitate South Korea's containment policies up to November 16.
- The Korean policies turn out to be too stringent for a majority of countries as the economic values of saved lives are not sufficient to cover the losses of real income in this 11-month span.
- The problem with that analysis is obvious: the losses of real income are temporary, but the loss of lives must be evaluated in the long run.
- As our focus is on optimal containment policies, our analysis is necessarily long-run.

Optimal Containment Policy

Effective Reproduction Number

- Effective reproduction number $R_{e,i,t}$: the number of cases directly generated from one case.

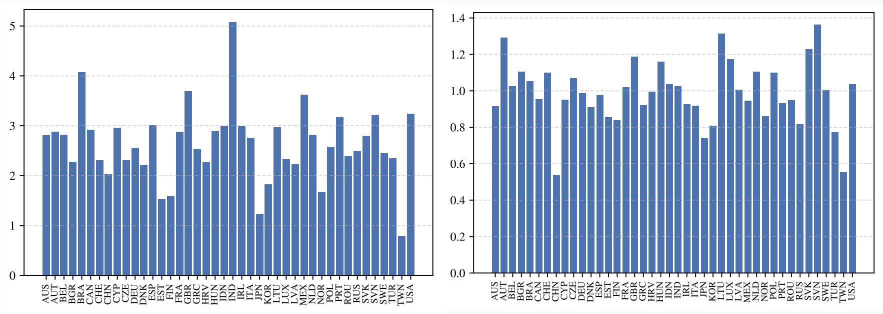
$$R_{e,i,t} \equiv \frac{T_{i,t}}{I_{i,t}} \times 18 = (1-\eta_{i,t})\left[\pi_i^I + \pi_i^L \times \sum_{j=1}^{J}(1-\mu_i^j)\ell_{i,t}^j\right] \times 18 \times \frac{S_{i,t}}{N_i}$$

$$= (1-\eta_{i,t}) \times R_{0,i,t} \times \frac{S_{i,t}}{N_i}.$$

- Two main strategies for combating the disease.
  1. Impose sufficiently stringent containment measures so that the effective reproduction number goes below 1, in which case the disease spread slows down, and to wait for vaccines.
  2. Use various ways to “protect the vulnerable” while letting the disease spread faster in the hope for herd immunity.

Optimal Containment Policy

Effective Reproduction Number



(a) Average basic reproduction number **(b)** Average effective reproduction number

Figure 2: Current $\bar{R}_{e,i}$ and Results under a Uniform $\widetilde{R}_e$

Optimal Containment Policy

Effective Reproduction Number

- Cross-country variation in $R_{e,i,t}$ smaller than that in $R_{0,i,t}$.
- The scale of average $R_{e,i,t}$ is much smaller than that of average $R_{0,i,t}$ with the former hovering around 1.
- Strong containment effort from governments across the globe in slowing disease spread.
- Anticipation for vaccines.
- Even though several vaccines have been successfully developed, how soon the pandemic will end depends on their rollout.

Optimal Containment Policy

Setting Up the Long-Run Environment

- Assume that the pandemic ends in two years ($t = 730$) from January 1, 2020.
- Since COVID-19 is no longer contagious, containment policies are scrapped for $t > 730$.
- Compute a baseline in which countries are assumed to keep doing what they have been doing.
    - Their policies from November 16, 2020 onward are projected to entail their realized averages of $R_{e,i,t}$ for the period from the onset of the outbreaks to November 16.
    - Their actual policies up to November 16 are used in simulating the baseline.

Optimal Containment Policy

Reducing the space of candidate policies

- Infeasible to compute the entire time path of optimal policies for each of the 42 countries.
- Use the effective reproduction number as the policy target.
- It reflects the speed of disease spread and is the central concern for epidemiologists and doctors who lead government responses.
- A front-load patten, e.g., Alvarez et al. (2020) and Jones et al. (2020).

Optimal Containment Policy

Two Steps

1. A simpler problem in which a global social planner decides an effective reproduction number $\widetilde{R}_e$ that applies to all countries such that the global welfare is maximized.
2. Each country solves its own optimal policies given other countries' policy choices (Nash equilibrium).

Optimal Containment Policy

Optimal Uniform $\widetilde{R}_e$

- A global social planner decides on an effective reproduction number $\widetilde{R}_e$ such that all countries set up their containment policies $\widetilde{\eta}_{i,t}$ to match $\widetilde{R}_e$, whenever possible.
- Namely, for each country i, $\{\widetilde{\eta}_{i,t}\}_{t=t_i^*}^{730}$ satisfy

$$R_{e,i,t} = (1 - \widetilde{\eta}_{i,t}) \left[\pi_i^I + \pi_i^L \sum_{j=1}^{J} (1 - \mu_i^j) \ell_{i,t}^j \right] \times 18 \times \frac{S_{i,t}}{N_i} \leq \widetilde{R}_e,$$

where the equality holds if a positive solution of $\widetilde{\eta}_{i,t}$ exists; otherwise $\widetilde{\eta}_{i,t} = 0$ and the inequality holds.

Optimal Containment Policy

Long-run: Uniform Effective Reproduction Number

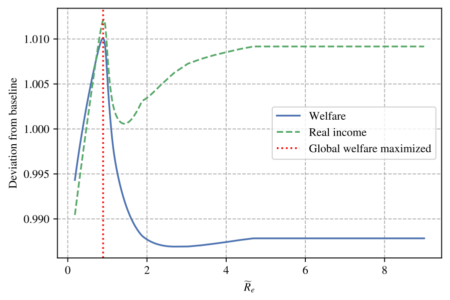


Figure 3: Deviation from the baseline: Global welfare and real income under $\widetilde{R}_e$

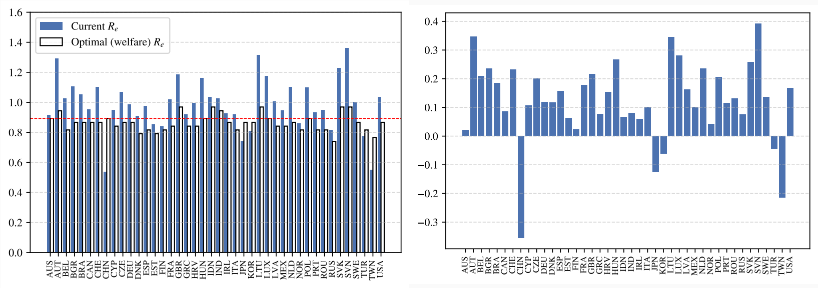
Deaths are extreme outcomes disliked by risk averse agents; the cost of mortality is amplified in welfare terms so that it overcomes the real-income gains to entail a welfare loss.

Optimal Containment Policy

Optimal National $\widetilde{R}_{e,i}$

- Consider optimal policies such that each national planner maximizes the country's welfare by choosing the country's effective reproduction number $\widetilde{R}_{e,i}$ given other national planners' choices.
- The solution is, indeed, a Nash equilibrium of optimal national policies.
- Using a fixed point algorithm is easier than searching in the grid-size^{42} space.
- Focus the grid search around $\widetilde{R}_e^*$.

Long-run: Optimal Effective Reproduction Numbers



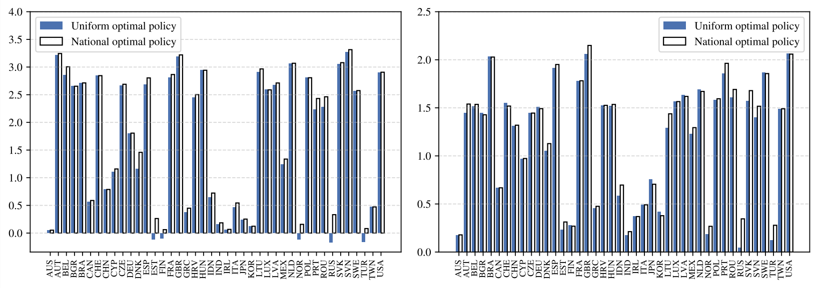
(a) Current $\bar{R}_{e,i}$ and optimal $\widetilde{R}^*_{e,i}$ **(b)** Deviation of $\bar{R}_{e,i}$ from $\widetilde{R}^*_{e,i}$

Figure 4: Optimal Effective Reproduction Numbers vs Actual Ones

(1) 40 out of 42 $\widetilde{R}^*_{e,i}$'s are less than 1. (2) $\widetilde{R}^*_{e,i}$ hovers $\widetilde{R}^*_{e}$ and varies slighter than $\bar{R}_{e,i}$. (3) Large overlap between those that need to tighten up significantly and those whose $\bar{R}_{e,i}$ is high.

Optimal Containment Policy

Long-run: Optimal Effective Reproduction Numbers



(a) Welfare improvements from the baseline

(b) Real-income improvements from the baseline

Figure 5: Welfare and Real-Income Improvements Under Optimal Policies

Optimal Containment Policy

Intuition behind the Asymmetry

- Long-run cost of mortality factors in both the real income and welfare, but weighs more in welfare because risk averse agents dislike extreme outcomes.
- Those countries that need to tighten up are those that also have suffered from faster disease spreads, which indicate high costs of mortality. So, welfare gains are amplified beyond real-income gains.
- For countries that need to relax, some can also gain substantially in real income, but as relaxation implies more deaths, the welfare gains are thus dampened.

Optimal Containment Policy

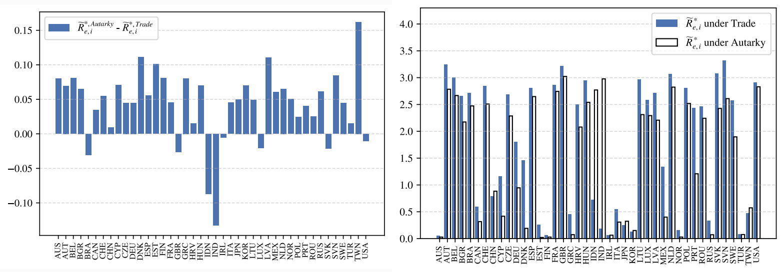
The Roles of International Trade

- The Role of Trade: Shut countries down to autarkies. Same as solving each country's problem in a closed economy.
- Measure the the difference in welfare improvements in the two scenarios by

$$\frac{|\text{Welfare Improvement under Autarky - Welfare Improvement under Trade}|}{\text{Welfare Improvement under Trade}}.$$

Optimal Containment Policy

The Role of Trade



(a) Deviation in optimal $\widetilde{R}^{*}_{e,i}$ under trade from that under autarky

(b) Welfare improvement from the baseline (%): trade and autarky

Figure 6: Comparison of Optimal Policies between Trade and Autarky

Gains from trade imply that countries can afford choose more stringent policies to be more focused on saving lives for long-run gains. The simple average of relative difference across countries is 0.72.

Conclusion

Conclusion

- A novel approach to compute optimal policies in this model with rich cross-sectional links across countries and sectors, and with these links interacting with disease dynamics.
- The takeaway messages:
  1. For the global planner's problem, a laissez-faire policy actually enhances long-run real income, but it is a drastically worse policy in welfare terms because of risk aversion.
  2. For optimal national policies, a majority of countries need to tighten up, whereas only a handful of countries need to relax. An interesting asymmetry is that substantial welfare gains occur only in the countries that need to tighten up significantly.
  3. Incorporating international trade implies substantially different optimal policies in welfare terms.
- When psychological costs of mortality are considered ...