COVID Risk Mitigation

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Abstract. We present modeling experiments to predict the COVID-19 pandemic evolution at a country level, as a theoretical Markov Decision Process framework, inspired by SEIR compartmental models. This allows us to formulate a "pandemic response" episodic Reinforcement Learning task, which can be used to design and study policies to control such pandemics. After fitting parameters of the model to actual measures taken by various countries, we perform counter-factual analysis to predict the outcome of different strategies.

Keywords: reinforcement learning, disease modelling, optimization, COVID-19

1 Motivation

Following the ongoing COVID-19 pandemics across the world, policy-design and decision-making has been a key aspect to reduce the prevalence of the disease in a country's population, mainly due to the absence of a known effective treatment and/or cure to treat infected individuals.

In this sense, the measures taken to reduce the number of deaths via decreasing the number of infected people (in order to avoid the overflow of treatment-seeking people in health facilities) and prevent a strong economic recession have been at the center of the debate for governments, resulting in several approaches in different countries, ranging from a kind of "COVID-negationism" to strict and long-lasting lockdowns.

In order to cope with the inherent trade-of between enforcing strict distancing policies (thus reducing contacts but heavily impacting commerce and workforce production) and continuing a "pre-pandemic" population dynamic (thus leading to a very high number of infections, overflowing health facilities and a very high number of deaths), we give in this extended abstract the main ideas of a country-based simulation model to assess the impact of social distancing measures both on the number of deaths and on the value production from different work sectors.

Policy evaluation using on-line data remains a more or less open subject due to the novelty of this problem: the global impact of the current pandemic compared to previous ones [1]. A notable example of this subject is a data-driven a policy effect forecast [2] offering a counterfactual analysis framework for different countries, which is also one of the motivations for this project: rather than having only a simulation model based on the unfolding COVID-19 scenario, something much more interesting is try to separate the observable evolution of a pandemic from some of its causes (e.g. lockdowns) [3].

In this sense, data availability plays a central role but also tricks the mixing between 2 separate areas such as epidemiological models and macroeconomic analysis. From one side, the long-term approach of GDP forecasting, alongside with the sparsity of general economic indicators (which are available at least at a monthly rate) makes impossible to "plug in" rapid-evolving externalities such as an ongoing pandemic and to see its immediate effects (by the nature itself of macro-economic models), whereas these short-term effects are a major concern of policy makers (e.g. unemployment claims, school closures, transport reduction). From another side, daily-available data such as stock market value, does not necessarily correlates with production and growth,[1] [2] which motivates looking for other ways to measure economic impact at a (relatively) instantaneous rate as the one COVID-19 evolves at, which is the gap our model plans to fill.

2 Contribution

Reducing deaths as a result of a "good" crisis response is not only a public health concern. Reduced morbidity and access to good healthcare facilities not only correlates to GDP growth [4], but more generally an increase in adult morbidity leads to a fall of economic growth [5]. For this reason, considering deaths from a) COVID-19 and b) estimates from secondary sources such as psychological fatigue [6] during a pandemic scenario, untreated preexisting conditions due to health facilities being prioritized for COVID-19, among other sources [7] [8]; would give us a fair view over future performance in the economy at the same time as permitting a daily change dynamics. We will work with the following hypotheses:

1. Rolling pandemic of only one disease
2. No re-infection of recovered individuals is possible
3. Each state (e.g. susceptible, infected, recovered, etc.) is mutually exclusive
4. Each economic sector is independent and there's no transport between them
5. Available data is representative (i.e. we do dot include case testing uncertainties, unreported deaths, etc.)

We aim for an indirect measurement of economic damage of a crisis via pandemic-related and secondary deaths and the cost of putting in place disease-mitigation measures such as social distancing, lockdowns and so on. In particular, we consider a SEIRD model with several populations, each one of them being an economic activity sector with no transport between them.

One key aspect of dealing with a pandemic due to an infectious disease such as COVID-19 is the number of deaths. These deaths can come from an infectious episode or dues to collateral reasons and are the main component of reward penalty. Also, the rates (such as transmission and morbidity) are affected by the

[1] `https://fivethirtyeight.com/features/the-economy-is-a-mess-so-why-isnt-the-stock-market/`

[2] `https://www.reuters.com/article/us-health-coronavirus-markets-disconnect/resurgent-wall-street-disconnected-from-reality-on-the-ground-idUSKBN22O39D`

policy stringency thus subject to an economic sector-wise dependence. This is precisely the economic side of the model: the policy impact across the different economic sectors of a country.

We do not specify a direct (cash) cost of the form $f(s) = \text{cost}_s \in \mathbb{R}$ of implementing such measures because of a) the inherent sparsity of macro-economic data (which is both necessary for policy design in a broad sense but impossible to have at a daily basis) and b) the indirect effect s has over the transmission and morbidity rates, where a reduction in mobility directly correlates to a decrease in production [9]

For these reasons, we define the instant reward function of COVID-19 response policy in a country of n economic sectors as: $r(t) = -\sum_{i=1}^{n} [D_i(t) + F_i(t)] - c_s \sum_{i=1}^{n} s_i(t)$

And the cumulative reward over a simulation episode as $R(T) = \sum_{t=0}^{T} r(t) = -\sum_{t=0}^{T} \sum_{i=1}^{n} [D_i(t) + F_i(t)] - c_s \sum_{t=0}^{T} \sum_{i=1}^{n} s_i(t)$

Out of the instantaneous reward function, it is possible to specify a country's response problem as an constrained minimization problem, or rather four variants of it depending on how we pose the problem of "fighting" COVID-19. The possible problem setups for decision makers: is the strategy trying to minimize deaths over costs? the other way around? is it an anti-health system collapse strategy?

3 Results

The fit our our model from France using a simplified version of the model on the 180 days of the breakout (only one economic sector with "sigmoid steps"[3] for transmission and morbidity rates) gives a MAE of 552.73 for the infections and 280.94 for the deaths.

We study also the relation between putting stringent measures and reducing the transmission rate of COVID-19 (note that the stringency over the training period was not an input of the model)

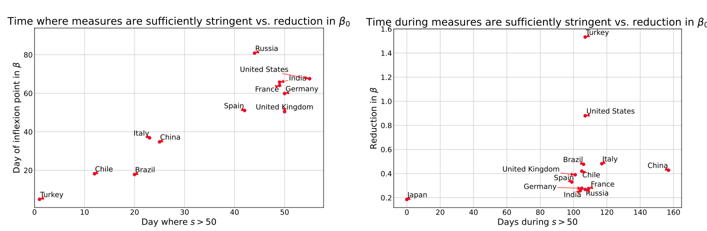

Fig. 1. Scattering of a) the time of measures being sufficiently stringent t_0^s according to OxCGRT [10] vs. the time of inflection t_0^β of the sigmoid step; and b) the length of sufficiently stringent measures vs. the reduction L^β in the transmission rate.

[3] For time dependance of β_i and μ we consider a "sigmoid step" function f parametrized by $C_0^f > 0,\ |L^f| \leq C_0^f,\ k^f > 0$ and $t_0^f \geq 0$, which has the advantage of modelling a smooth transition between two values. :$f(t) = C_0^f + \frac{L^f}{1+e^{-k^f(t-t_0^f)}}$

4 Conclusion

The presented results show a promising path to decouple a country's features and actions from an infectious disease evolution (in our case, COVID-19). The case for the moment where the transmission is reduced as a product of enforcing stringent measures is very clear, whereas the coupled impact of a country's context and attributes needs further studies.

With a mapping from s to β, μ it is possible to "plug-in" a previously characterized disease within a country's situation and simulate the evolution of an epidemic episode. Here in this project we provide the framework to such a model to then study the effect of disease-response measures in different economic sectors and a way to measure the mixed epidemiological and economical cost of those measures. A possible path in defining the cost of measures c_s is by the current estimations from the International Monetary Fund[4]

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References

1. E. Petersen, M. Koopmans, U. Go, D. H. Hamer, N. Petrosillo, F. Castelli, M. Storgaard, S. A. Khalili, and L. Simonsen, "Comparing SARS-CoV-2 with SARS-CoV and influenza pandemics," *The Lancet Infectious Diseases*, Jul. 2020. [Online]. Available: https://doi.org/10.1016/s1473-3099(20)30484-9
2. Z. Qian, A. M. Alaa, and M. van der Schaar, "When and How to Lift the Lockdown? Global COVID-19 Scenario Analysis and Policy Assessment using Compartmental Gaussian Processes," *arXiv:2005.08837 [physics, stat]*, Jun. 2020, arXiv: 2005.08837. [Online]. Available: http://arxiv.org/abs/2005.08837
3. A. Goodman-Bacon and J. Marcus, "Using Difference-in-Differences to Identify Causal Effects of COVID-19 Policies," Social Science Research Network, Rochester, NY, SSRN Scholarly Paper ID 3603970, May 2020. [Online]. Available: https://papers.ssrn.com/abstract=3603970
4. B. C. Alkire, A. W. Peters, M. G. Shrime, and J. G. Meara, "The economic consequences of mortality amenable to high-quality health care in low- and middle-income countries," *Health Affairs*, vol. 37, no. 6, pp. 988–996, Jun. 2018. [Online]. Available: https://doi.org/10.1377/hlthaff.2017.1233
5. K. Javaid, M. Neidhardt, T. Reynolds, A. Cullen, C. L. Anderson, J. Long, and L. Manhart, "Morbidity and Economic Growth," Evans School Policy Analysis & Research Group (EPAR), Tech. Rep. 293, Mar. 2015, library Catalog: evans.uw.edu. [Online]. Available: https://evans.uw.edu/policy-impact/epar/research/morbidity-and-economic-growth

[4] `https://www.imf.org/en/Topics/imf-and-covid19/Fiscal-Policies-Database-in-Response-to-COVID-19`

6. A. Brodeur, A. E. Clark, S. Fleche, and N. Powdthavee, "Assessing the impact of the coronavirus lockdown on unhappiness, loneliness, and boredom using google trends," 2020.
7. J. Aron and J. Muellbauer, "A pandemic primer on excess mortality statistics and their comparability across countries," Jun. 2020. [Online]. Available: https://ourworldindata.org/covid-excess-mortality
8. S. H. Woolf, D. A. Chapman, R. T. Sabo, D. M. Weinberger, and L. Hill, "Excess deaths from COVID-19 and other causes, march-april 2020," *JAMA*, Jul. 2020. [Online]. Available: https://doi.org/10.1001/jama.2020.11787
9. OECD, "Evaluating the initial impact of COVID-19 containment measures on economic activity," Apr. 2020. [Online]. Available: https://www.oecd.org/coronavirus/policy-responses/evaluating-the-initial-impact-of-covid-19-containment-measures-on-economic-activity-b1f6b68b/
10. T. Hale, N. Angrist, B. Kira, A. Petherick, T. Phillips, and S. Webster, "Variation in government responses to COVID-19," Blavatnik School of Government, Working Paper 6, 2020. [Online]. Available: http://www.bsg.ox.ac.uk/covidtracker