An Integrated Epidemiological and Economic Model of COVID-19 NPIs in Argentina

Adolfo Rubinstein, Eduardo Levy Yeyati, Alejandro López Osornio, Federico Filippini, Adrian Santoro, Cintia Cejas, Ariel Bardach, Alfredo Palacios, Fernando Argento, Jamile Balivian, Federico Augustovski, Andrés Pichón Riviere[1]

Abstract

We added a multi-sectoral economic framework to a SVEIR epidemiological model, combining the economic rationale of the DAEDALUS model with a detailed treatment of lockdown fatigue and declining compliance with Public Health and Social Measures reported in recent empirical work, to quantify the epidemic and economic benefits and costs of alternative lockdown and PHSM policies, both in terms of intensity and length. Our calibration replicates key features of the case and death-curves and economic cost for Argentina in 2021. The model allows us to quantify the short-term policy trade-off between lives and livelihoods and show that it can be significantly improved with targeted pharmaceutical policies such as vaccine rollout to reduce mainly severe disease and the death toll from COVID-19, as has been highlighted by previous studies.

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[1] *The authors are grateful for the generous support of the World Health Organization. All authors are from IECS, except Eduardo Levy Yeyati (Universidad Torcuato Di Tella) and Federico Filippini (CEPE-Di Tella).*

1. Introduction

The global pandemic is not over yet, and it will remain necessary to continue to adapt the public health and social measures (PHSM) to occasional surges of this or other viral pandemics that may arise in the future. In this regard, policy makers will need to take into account not only the epidemiological impact but also the macroeconomic impact to base their response and the calibration of their PHSM to protect both lives and livelihoods, considering social values and trade-offs.

Since March 2020, many governments have had to introduce stringent mobility measures to counter the pandemic, severely restricting social and economic activity. These early policies had an outsized impact on workers and working hours across the world. In many cases, the individual and macroeconomic costs were so high that their restrictions were hard to sustain and increasingly ineffective over time. Fortunately, vaccines enabled the gradual removal of such restrictions, allowing the economy to re-open progressively whilst health outcomes continued to improve.

Our multidisciplinary team at IECS has been working since the beginning of the pandemic in building a model focused on the epidemiological and health system preparedness and response in Latin America and the Caribbean to help answer pressing questions for policymakers on COVID 19 pandemic. The model is open access and open code, highly flexible, allowing it to customize and accommodate different mix and stringency of Public health and social measures (PHSM) as well as vaccination uptake and effectiveness, and calibrate its main parameters to the specific context of each country. For each case, the model projects the key outcomes and outputs of the epidemic and health system capacity.

We extended our epidemiological model to gauge the macroeconomic impact of the PHSM. Specifically, we added a multi-sectoral economic framework to the SVEIR model described in Santoro et al.[1], incorporating the economic rationale of the DAEDALUS workhouse model combined with a more detailed treatment of restriction fatigue consistent with the declining compliance with PHSM reported in recent empirical work. The extended model helps quantify the benefits and costs of the different lockdown and PHSM policies in terms of the epidemic and economic perspectives, both in terms of intensity and length.

More precisely, when the priority is to curb the case-curve (a "safety-focused" approach), the economy will have to endure a lengthy lockdown and a likely sizable decline in GDP. Conversely, if the policymaker has a rather "economy-focused" approach, attempting to minimize the economic losses, the mortality rate might shift upwards.

The aim of this work is to show that the policy trade-off can be significantly improved with targeted pharmaceutical policies such as vaccine rollout to reduce mainly severe disease and the death toll from COVID-19, as has been highlighted by previous studies.

Several recent papers independently investigate the economic and epidemiological approaches in SEIR models. We contribute to these efforts by explicitly acknowledging the pecuniary costs and the varying effectiveness (over time and across population groups) of epidemiological actions, by building a simulator of a menu of different policies at the disposal of the policymaker (as opposed to computing a unique optimum based on a given objective function).

Moreover, our model explicitly accounts for the diminishing effect of the stringent mobility measure on the spread of the COVID. We measure the lockdown fatigue using high-frequency metrics on *de jure* restrictions to social interactions and *de facto* compliance to these following Goldstein et at.[2] The lockdown fatigue simultaneously reduces the economic costs (mobility normalizes over time) of the PHSM measures but also significantly reduces the contribution of PHSMs in terms of their effect in reducing COVID-19 related fatalities. Our calibration is able to replicate the key features regarding the case-curve and economic cost for Argentina during 2021.

2. Economic and Epidemiological Model

This project is focused on modeling the epidemiological and the economic frameworks in two linked buckets or submodels for Argentina. Each bucket only keeps the relevant features for their interaction. For instance, the epidemiological model does not benefit from the sectoral disaggregation features in the economic part while the latter makes several simplifications regarding the age segments. In this way, each of the frameworks maximize the predictive content regarding their variable of interest (i.e. epidemiological and economic) while retaining the insightful interactions between them. In this section, we first describe the epidemiological framework, we then turn to the economic framework and finally we outline the links between both submodels or buckets (but also models in their own sense).

2.1. Epidemiological Framework

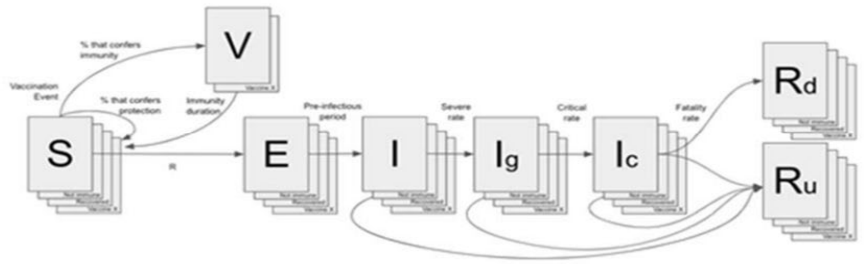
Our epidemiological model deploys a compartmental model approach as it considers several compartments to represent the population at different age groups. This dynamic transmission model considers flows to represent transitions and progression between different states. This model provides a framework in which the number of people in separate compartments (each homogeneous for some specified characteristic) and the relationships between those compartments that model population dynamics, can be described in mathematical terms. The individuals of the population in our model were initially divided into the following compartments: the non- infected and susceptible (S), the exposed (E), the infected (I), and the recovered (R). The model used on the initial version was an enhanced SEIR model with added compartments to represent states related to essential resources use and death.

We also expanded the epidemiological section of this model with two main sets of modifications. Firstly, to study the impact of vaccination strategies by adding a representation of different immunity states, related to vaccination and natural immunity. Secondly, to analyze the differential impact of PHSM or immunization strategies by incorporating age compartments (and their contact matrices).

By adding a V compartment, we transform the SEIR model into a SVEIR model, allowing to represent the transition of the susceptible population to a vaccination (V) compartment.

The model design allows subjects who have received a vaccine to be reinfected, transmit disease, and develop symptoms/severe disease, as is shown in figure 1:

Figure 1. SVEIR model



SVEIR Model: vaccinated individuals are represented in all compartments and are modeled with different transition coefficients

The model requires separate compartments for different age groups, where different vaccination strategies could be applied to respond to a variety of scenarios. Each age group would have different complications and mortality rates. The age stratification will also be instrumental when modeling the potential PHSM that differentially affect age strata and settings.

In addition, our model sets a reproduction value (R0), based on a contact matrix representing the number of contacts between all groups and an effectiveness matrix that defines how “effective” (in terms of infectiousness) these contacts were. To improve the reproduction of transmission dynamics, we incorporate specific age-strata mixing patterns matrices to represent the social interactions and effective contact rates at each of the 4 settings we included: home, school, work and community.

Modifiers for these matrices can be derived from a model representing the impact of PHSMs on each, like schools closing, stay at home, shielding the elderly, mandatory masks, public transport restrictions, etc.

To model the impact of vaccination rollout, including periodic boosters, our model allows us to parameterize the effectiveness of vaccines differentially according to immunity states. Regarding vaccination and immunity, we consider an "incomplete vaccination scheme" when individuals have received only the first dose. After the second dose, the immunity state is considered to be a "complete vaccination scheme". After booster doses, the immunity state is considered as “completed and reinforced”.

On the other hand, both for vaccination and for the basic parameters of the model (infectious fatality rate -(IFR-), risk of severe or critical disease, duration of natural immunity and vaccine protection) the model incorporates an estimate of the proportional prevalence of each circulating virus variant, and at different points in time. Thus, it modifies the values of the aforementioned variables according to the characteristics assigned to each variant.

Epidemiological transitions to new variants are modeled with a date of appearance of the variant and a period that defines the time it takes for it to become the predominant variant (i.e. Gamma until mid-2021, then Delta, and Omicron at the end of the year).

2.2. Economic Framework

The economic component accounts for two key features: the economic cost imposed by the stringent mobility measures, and its interaction with the lockdown fatigue, namely, the degree of compliance with the epidemiological measures. The model builds on Santoro et. al.[1], Acemoglu et al.[3] and the DAEDALUS (Imperial College of London, 2020)[4] and measures the economic impact of the pandemic at a sectoral level, as policymakers choose the stringency of the lockdown measures aimed to prevent the spread of the COVID-19 virus.

For the macro-economic model, we simplify the age-segmentation as it focuses on the population within three age groups relevant for the working segmentation: school- age children (including preschoolers), working-age adults, and the retired. The total population of Argentina is about 47 million people according to latest census (May 2022). The working-age population represents around 62.1% of the total, which is further divided into active (73.4% of working-age population) and inactive (26.6% of working-age population) segments.

The model assumes that stringent mobility measures affect working hours at the intensive level, i.e. how much active workers contribute to the economic output. For this reason, we only focus on the individuals actively participating in the labor market, which are composed of those employed (17.5 million) and unemployed (1.4 million) people. Employed workers, in turn, can be employed (formal or informal) or self-employed.

We assume that neither school-age, retired nor inactive working-age people contribute to the value-added of the economy in the short-term, and that each of the aforementioned shares in the labor force remain constant at the pre-pandemic levels over the intervention horizon.

In turn, economic sectors can be partially or fully closed during the intervention horizon. In the model, this translates into a certain proportion of the active workforce within each sector that may be partially or fully prevented from working (so that they become de facto inactive) in any given period, depending on the extent to which specific sectors are closed due to the PHSM.

Thus, the impact on the labor market is captured by adjusting working hours (as opposed to temporary layoffs or changes in the share of workers within sectors or into inactivity). It deserves to be noted that this approach, to the extent that it implicitly assumes labor disruptions to be fully reversible, yields a conservative evaluation of the actual economic impact of PHSMs, which in practice may me both more persistent (if some of the hours lost reflect job destruction, those displaced workers may take time to relocate) and structural (lockdowns may lead to a downsizing or termination of economic units and a permanent shift in labor demand, for example, from contact-heavy, low-skilled labor-intensive offline activities to middle-skill and more capital-intensive online activities, and associated value chains).

The population of pre-schoolers aged 0-4, pupils aged 5-19, retired aged 65+ and adults aged 20-64 who are not in the labor force (which add up to 22.6 million) together with the unemployed are referred to as the “community”. We assume that people in the community are not exposed to work contact.

In sum, whereas the number of individuals in the three non-working age community groups remains fixed, the working-age community population is dependent on the current economic configuration, i.e., on the extent to which economic sectors are closed for production and economically inactive adults in the labor force join the working-age community.

Production structure

There are N (=16) main economic sectors/categories, including the public sector (table 1). The productive sectors are engaged both in economic production and in the spread of infection – as long as production requires working mobility. The intensity of production and the spread of the infection crucially depend on the hours worked. To be clear, more work hours translate into more “work contacts”, which influences the contact matrix of the epidemiological part of the model.

Table 1. Economic structure of Argentina, pre-pandemic

	Economic structure, pre-pandemic	Gross value added, mn ARS	% Total GVA	Labor force, in Thousands	% Total labor force	Annualized working hours	% Working hours
	Total	**18,340,548**	**100%**	**20,855**	**100%**	**32,548,570**	**100%**
A	Agriculture and animal production	1,037,669	6%	1,387	7%	2,132,683	7%
B	Fishing and aquaculture	76,648	0%	22	0%	65,656	0%
C	Mining and quarrying	866,380	5%	103	0%	231,290	1%
D	Manufacture industry	3,154,755	17%	2,326	11%	4,160,291	13%
E	Electricity, gas, and water supply	392,054	2%	128	1%	196,572	1%
F	Construction	830,774	5%	1,727	8%	2,854,296	9%
G	Wholesale and retail trade	3,190,187	17%	3,578	17%	6,690,757	21%
H	Hotels, accomodations and restaurants	423,205	2%	677	3%	1,113,628	3%
I	Transportation, storing and communicatio	1,183,208	6%	1,201	6%	2,370,675	7%
J	Financial intermediation	652,569	4%	308	1%	489,879	2%
K	Real estate	2,107,509	11%	1,460	7%	2,339,880	7%
L	Public administration and defense	1,577,551	9%	1,601	8%	2,840,571	9%
M	Education	1,118,658	6%	2,145	10%	1,776,165	5%
N	Social security and health services	1,026,135	6%	1,333	6%	1,992,427	6%
O	Social work activities and others	565,131	3%	1,117	5%	1,623,055	5%
P	Household activities	138,115	1%	1,742	8%	1,670,744	5%

Source: Indec (Argentina)

The economic cost of the stringent mobility measures is computed relative to the pre-pandemic output. Here we are implicitly assuming no pre-pandemic growth trend – which is a reasonable assumption for Argentina. In other words, this assumption will not underestimate the cost of the measures for the case of Argentina. While this may underestimate the cost for other countries with positive pre-pandemic growth trends, the model can be easily adapted to any arbitrary trend growth.

In the pre-pandemic world, each economic sector is fully operational, and the final (consumption) product of each sector contributes to the country's gross domestic product (GDP), as represented by its gross value added (GVA), including exports. The value added considers that the production of several sectors is used as intermediate inputs by other sectors in creating their own final products.

The sectoral structure of the output is described in Table 1. With the announcement of the first round of PHSM, the government determined a set of essential activities: food manufactures and retail, some financial intermediary activities, and health services. That list was later extended to order low-contact intensive export-oriented manufacture activities and construction. These priorities are embedded into the calibration – adjusting for the elasticity of each sector to the different measures.

For completeness, Table 1 also shows the sectoral structure of the labor market.

Following the DAEDALUS mode[4], the flows between sectors are represented by a input-output matrix. The elements of the matrix describe the monetary value of flows from one sector used as inputs to the production process of other sectors. Let zij be the element (i,j) of the input-output matrix Z. The monetary value of total production of sector yi is given by yi=j=1Nzij+fi which sums inputs produced for other sectors and final consumption products fi by sector i. Let aij=zij/yj be the fraction of output of sector i used in sector j so that

yi=j=1Naijyj+fi

The value of all flows is represented in 'basic' prices, which exclude the margins secured by producers. The I/O matrix is calibrated according to the OECD release for the calendar year 2019, and we are therefore constrained to using these estimates in our application. Like the DAEDALUS[4], we assume a Leontief production function for each sector, so that the proportionate contributions of inputs from other sectors, the workforce, and value-added remain unchanged whatever its level of operations.

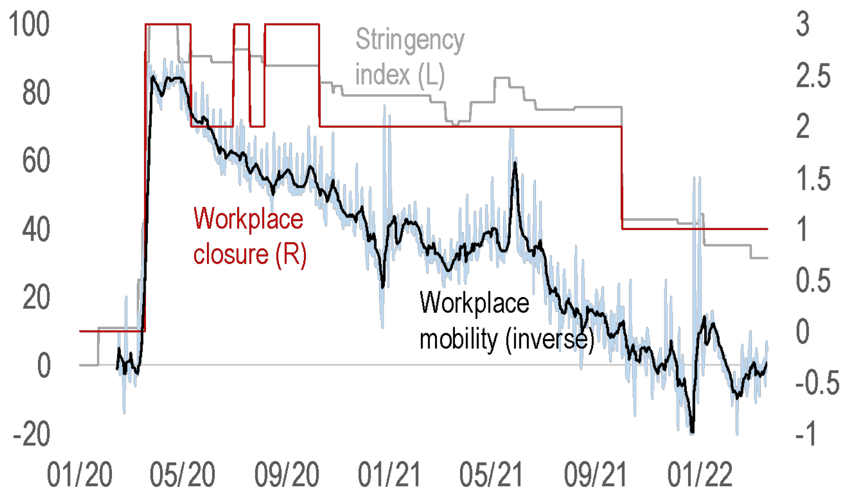
We denote the (equilibrium; pre-pandemic) output level for sector i by yi*=giwi*, where wi* is the pre-pandemic workforce and gi is the output per worker (labor productivity) of sector i. For simplicity we assume that aij (interdependence between sectors), gi (labor productivity) and fi (final consumption) are constant and held at pre-pandemic values, although the pandemic may have a direct effect on the productivity of the workers in each sector resulting in a smaller or higher gi in comparison to the pre-pandemic period.

During each period in the pandemic, the achieved output is yi=giwi where the effect of the pandemic works through the reduction in the number of workers, and not reduced work productivity, that is wi=xiwi*. To be clear, xi denotes a modifier to the working hours which depends on several factors such as the degree of essentiality of each sector – more details below.

The policymaker, for the economic model, controls the intensity of the PHSM, i.e., the closure of workplaces. At each decision period, the policymaker chooses the degree of workplace closure, which can take one the following values: 0: no measures; 1: recommended (discretionary) closure; 2: closure of some activities; 3: closure of all activities except essentials. We denote by pt the stringent mobility measure, i.e. pt ∈0, 1, 2, 3.

Figure 2 depicts the workplace closure measure, pt, from Oxford University for Argentina. Relative to the overall stringency index, the workplace closure displays lower variation. Interestingly, however, workplace mobility displays a wider range of variation. This figure also shows the (negative) relationship between the workplace mobility from Google (shown inverted in the chart) and different measures of recommended stringency. The strength of the relationship weakens overtime reflecting the lockdown fatigue of the workers (see explanation below). That is, workplace mobility “normalized” much in advance relative to the stringency measure.

Figure 2. Workplace closure



Source: Google, Oxford University

For each sector, even if labor productivity remains unchanged, there is a minimum level of working hours depending on essentiality, the ximinyi*<giwi<yi*. We make this simplifying assumption because

there is no empirical evidence on the relative impact of the pandemic's impact on numbers of individuals working versus work productivity by sector.

The aggregate impact on gi varies within sectors. To be sure, there is a high degree of uncertainty in the estimation of gi as the demand for products and services may also be affected due to the reduction in income, the economic uncertainty and attempts to avoid contagion.

Lockdown Fatigue

One of the reasons why stringent lockdowns did not curb and control the pandemic (and at the same time buffered the full negative economic impact) relates with the so-called "lockdown fatigue" [5]. The term that conflates both the psycho-sociological aspects of a protracted isolation, including those related to living conditions such as habitat, overcrowding, in-house amenities, and a growing necessity, particularly relevant for low-income and informal households without alternative sources of income, to engage in economic activity. The result was an increase in mobility, in particular among informal workers, even before the stringent measures were relaxed. Clearly, this increase in mobility may have further contributed to the spreading of the disease.

On the other hand, an increase in the rate of daily deaths make Individuals to reduce their mobility. This self-regulation of individuals may reinforce the stringency of the measure (alternatively, limit non-compliance), as we show in Figure 3 on the integration of epi and economic models. In other words, the effectiveness of mobility restrictions was the result of a changing balance between economic pain and fear.

In the model, the "lockdown fatigue" affects the effective working hours in the following way,

$$xit=fpt,t,i$$

where pt denotes the intensity of the PHSM measure, i.e., the closure of workplaces, t refers to the lockdown fatigue and i captures the sectoral degree of essentiality, informality and other factors that might mitigate the impact of the lockdown on working hours. In turn, t depends on the headline number of deaths reported by the country and the length and stringency of the lockdown within a two-month timespan.

The lockdown fatigue is estimated as the difference between the *de jure* workplace mobility and the fitted values from an OLS regression using monthly data on time since the beginning of the stringency measures (and its interaction with the degree of workplace closure), the reported number of deaths from seven days before, and the broad stringency index.

Table 2 displays the regression results for Google mobility on the drivers mentioned above. Let mobt denote the predicted value for Google mobility. The fatigue function is computed as f=100-19.14×pt+mobt.

Table 2. OLS Google mobility

Google mobility	Coef.	t
Workplace closure	-42.17619***	-8.61
Reported deaths (previous week)	-0.005177*	-1.98
Sq.: reported deaths (previous week)	0.00000589*	1.79
Time since first measures	-3.673106**	-1.85
Sq.: Time since first measures	0.1414084**	2.1
Time x Workplace closure	15.33772***	3.93
Deaths x Workplace closure	-0.0004777***	-2.33

Economic Cost

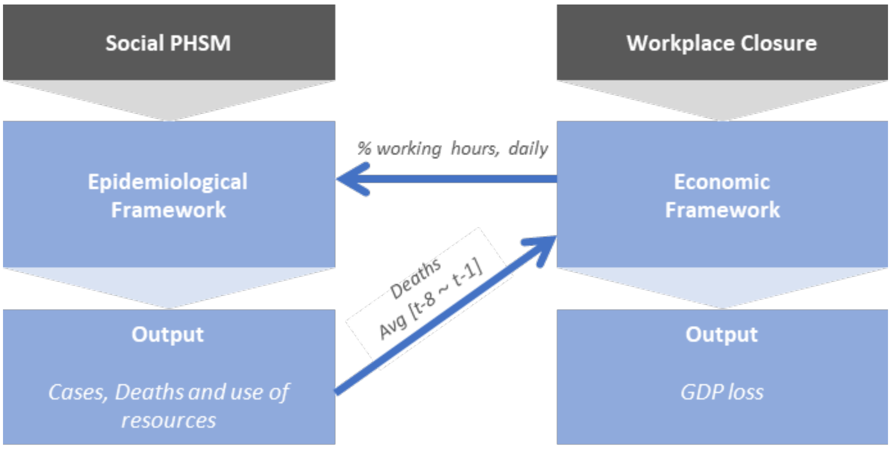
This lengthy lockdown has significant economic costs. We focus on the direct economic costs stemming from the deviation of the working hours. The economic costs are computed according to the following equation,

j=1Nt=0Txjtwi*1-i=1Naij-yj*

2.3. Integration between epidemiological and economic frameworks

The epidemiological and economic framework do not work on isolation. There are two channels of interaction. These interactions are displayed in figure 3.

Figure 3. Interaction Epi/Econ Model



Firstly, from the economic to the epidemiological frameworks, the economic model determines the working hours which are an input to determining work-related contacts and, in turn, the spread of the virus. Thus, working hours, an output from the economic bucket, are an input for the epidemiological bucket, as a reduction of hours worked *in the workplace* affects the contact matrix (e.g., work contacts or contacts in the public transport).

Secondly, from the epidemiological to the economic frameworks, the lockdown fatigue also is also related to the daily reported deaths through the fear factor: there is a greater adherence to PHSM at times when there is a greater number of deaths. Daily reported deaths, t, is represented as the average number of deaths of the previous 7 days (between t-8 and t-1). This average, an output from the epidemiological side of the model, feeds into the 'fatigue equation' that, in turn, impacts on the number of working hours.

The simulation of the two models runs recursively. For each decision period, the economic model takes the epidemiological output (deaths of the previous 7 days) as an input, whereas the epidemiological model takes the economic output (working hours) as an input. This setup allows for insightful for an insightful yet simple feedback between the two models.

Additionally, the two models are linked through a table of equivalences between the qualitative PHSMs of the epidemiological model and the scale of restrictions used by the economic model (table 3), where stringency is included as a parameter (with values that go from 0 to 3):

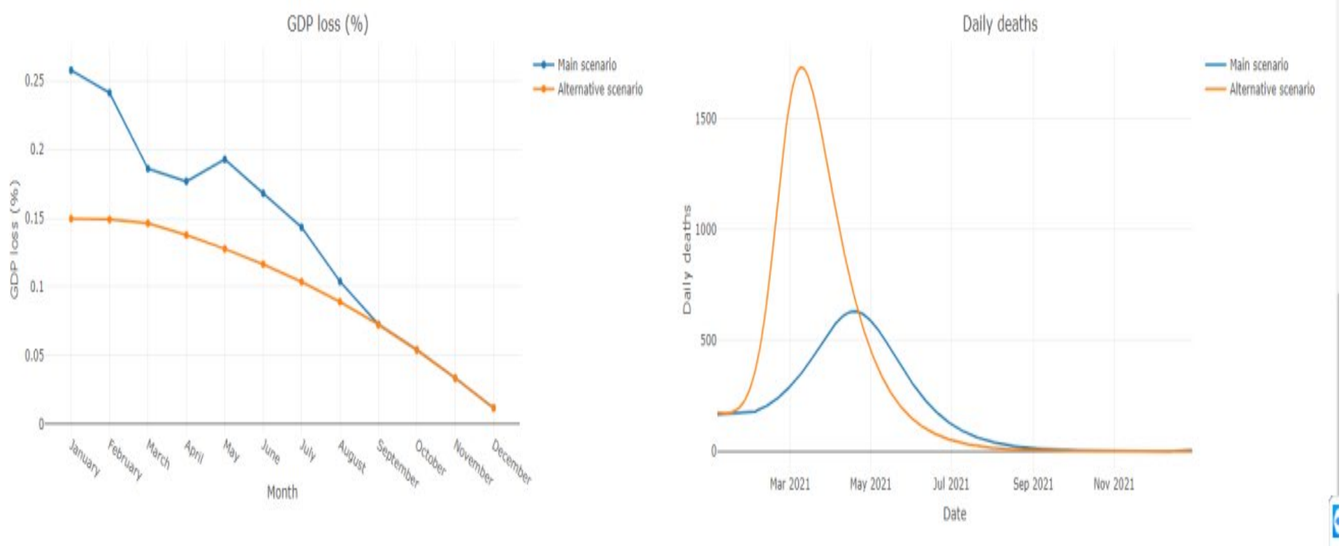
Table 3. Equivalences between PHSMs and the scale of restrictions.

PHSM (Epi)	Stringency level (Eco)
Physical distancing	0
Physical distancing + Shielding of older people	0
Physical distancing + Shielding of older people + Self isolation	1
Physical distancing + Shielding of older people + Self isolation + School closures	2
Physical distancing + Shielding of older people + Lockdown + School closures	3

3. Preliminary results

The visual interface of the model incorporated two sections for the visualization of the epidemiological and economic integration results. First, the "ECO Model" section describes the economic costs in terms of GDP losses and daily COVID-19 deaths for the year 2021, comparing the sequence of applied policies and a user-customized sequence as shown in the example (figure 4).

Figure 4. GDP loss and daily deaths plots



This new version also illustrates the trade-off between different simulated scenarios, from the least restrictive (scenario 5) to the most restrictive (scenario 1) in two time periods (first half of 2021 and full year 2021).

The latest version of the code is uploaded in the following link. Here you can find the simulation for the number of cases, deaths and hospitalizations, along with the economic cost. The policy maker can choose one of the following PHSM (figure 5):

Figure 5. PHSMs user interface

The green button denotes the less stringent scenario (both in terms of the sanitary and economic measures) and the red bottom encompass a full lockdown (coupled with a workplace closure of p=3).

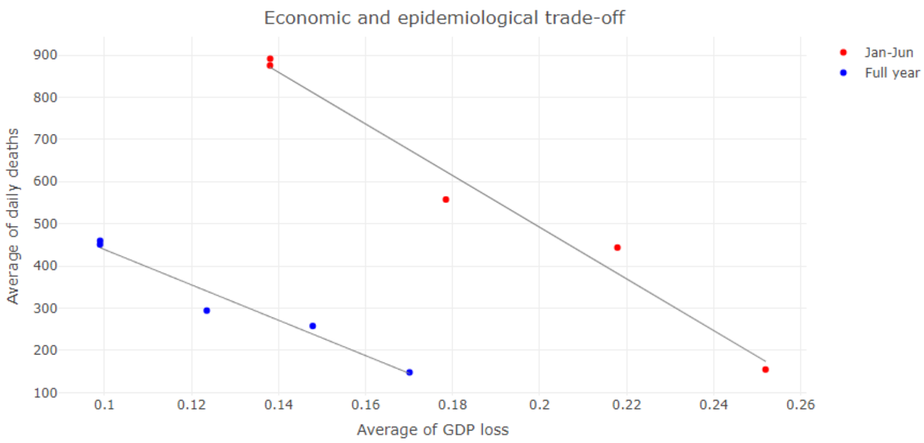
The benchmark simulation replicates the cases-curve for 2021, using estimated values for 2020. The following chart denotes the sequence of measures and policies followed by the Argentinean government during 2021 (figure 6). The estimated economic cost measured by the GDP loss is close to 14% (compared to the pre-pandemic level) for the full year.

Figure 6. PHSM of Argentina in 2021

Crucially, the model allows simulating the performance of different PHMS scenarios in the epi-econ space, in this case represented by deaths and output losses. Figure 7 depicts the simulated performance of Argentina for 2021, where each point represents the five different PHMS approach used in the epidemiological bucket: the point in the bottom-left of the chart stands for the full lockdown (for the whole year), with a more modest death toll at the expense of a larger economic loss, and that in the upper-right corresponds to the minimal intervention (the green bottom), with little economic cost at the expense of a sizable death count –three times larger than with the full lockdown. This chart highlights the trade-off faced by the policy maker, quantifying (and therefore, mitigating) the uncertainty that policy makers had at the beginning of the pandemic.

As can be seen, the slope of the tradeoff flattens (and the average death toll declines) as the window widens and the vaccinated population increases –another aspect that the model allows to quantify.

Figure 7. Economic and epidemiological trade-off. Argentina 2021.



Annex 1. Data update

Epidemiological Parameters

As detailed before, we modified the 2020 SEIR model[1] through the introduction of a compartmental SVEIR approach.

To improve the accuracy of the model, the population was stratified by age (0-17, 18-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80+) to be able to apply different vaccination strategies and better represent the risk of each age group. Another improvement of the model was to establish the number of infections by means of a contact matrix and an effective contact matrix. Thus, the model establishes a reproduction value (R0), based on the first matrix, which represents the number of contacts arising from the interaction between the different groups, and an effectiveness matrix that defines how "effective" (in terms of contagiousness) these contacts are.

A literature search was performed in the Medline and Lilacs databases for parameters related to COVID-19 and health service use (days of hospitalization, proportion of patients requiring hospitalization in general wards and intensive care units, mortality rates, and others) to feed the model. We also searched for information on the efficacy and effectiveness of the COVID-19 vaccines (in clinical trials and real-world studies). In addition, official websites from the ministries of health were assessed for Argentine country-specific information on the vaccination rollout. The data were updated every six months and to the strata needed for the model based on the population pyramid of Argentina.

COVID-19 disease-related parameters

The main parameters used were the rates of the different disease states; symptomatic disease without hospitalization, hospitalization with or without intensive care unit (ICU), and infection fatality rate (IFR). In addition, length of hospital stay was considered for patients requiring hospitalization, for patients requiring ICU, and for patients admitted to the common ward only. The severity of the disease was divided into severe and critical, based on whether or not ICU admission was required. Table 4 shows estimates of infection fatality rates[6], the proportion of severe and critical patients, and length of hospital stay (common ward and ICU) by age group. These parameters were adapted to the age groups used in this model.

COVID-19 vaccine-related parameters

We obtained data on the effectiveness or efficacy of all COVID-19 vaccines that have been used in Argentina. The weighted average effectiveness value of the vaccination campaign for the country and for each outcome and the number of doses given were estimated. We calculated this using the percentage coverage of the different vaccines that had been introduced in Argentina. For the “standard vaccination” campaign base case, we estimated a simple average of the effectiveness vaccine value of the country. Finally, we selected the higher vaccine effectiveness values available per outcome (and per total number of doses) to populate the optimistic scenario.

Other epidemiological and transmission dynamic parameters

Regarding disease transmission dynamics, the model establishes the number of social infections using a contact matrix and an effective contact matrix. The reproduction value (R0), based on the first one, represents the number of contacts arising from the interaction between the different age groups in different settings: home, work, schools, community, and the latter defines how "effective" (in terms of contagiousness) these contacts are. The contact matrix was established based on data published by Prem et al.[3], which established the contacts per country prior to the pandemic in different settings (work, home, school, etc.) and age groups. We used Argentina’s specific contact matrix. The matrix of effective contacts was constructed on the basis of susceptibility and infectiousness for each age group. The combination of these two matrices generates the expected number of cases. Measures that reduce contacts (vaccination or public health policies) therefore have an impact on one of these matrices, either by reducing the number of contacts (e.g., school closures) or their effectiveness in transmitting the virus (e.g., vaccination)[7].

The following were considered as health policies: school closures, social distancing, shielding of senior citizens, self-isolation, a combination of all the above measures, strict measures (where different reductions in contacts in transportation, work, and leisure were assumed due, among other things, to the increase in work from home and the "shielding" of the elderly) and lockdown. These measures had an impact on the percentage reduction of the contact matrix in each setting depending on the measure (table 5).[7]

Vaccines

To establish the effectiveness of vaccination, priority was given to the best quality evidence for each of the outcomes for each of the vaccines administered in Argentina (infection, hospitalization, need for ICU, death) both for a single dose and for the complete schedule. An estimation of the global effectiveness of the vaccines for the mentioned outcomes was made. For this purpose, the number of vaccines used in each country was estimated.

Data were collected in Argentina on doses applied. Total doses applied were considered for the weighted estimate. Table 6 shows the weighted efficacy for each of the outcome variables (infection, hospitalization, ICU requirement, and death) for Argentina. It was estimated for both one and two doses. For the estimation of the measure of effect, priority was given to effectiveness data (real-life evidence), and in cases where such data were not available or were of low methodological quality, efficacy data were used.

For the estimation of uncertainty, the variability in the efficacy estimators reported for the most widely used vaccines in the region, which accounted for 83% of the total, was considered for the analysis[8–10]

To estimate the uncertainty of the vaccines for each country, the relative difference between the extremes of the 95% confidence interval in relation to the central estimate was obtained for the infection outcome variable (2nd dose) of the three most widely used vaccines in the country, the largest value (12%) was chosen.[8–10]

Table 4. Parameters

Age strata	***Proportion of patients admitted to general ward***	***Proportion of patients admitted to ICU***	***Infection Fatality Rate (%)***[6]	***Length of stay in general ward***	***Length of stay in ICU***
0-17	0,363% (0,237%-0,569%)	0,097% (0,050%-0,151%)	0,009% (0,000%-0,080%)	2 (1- 4)	14 (9-24)
18-29	0,364% (0,238%-0,57%)	0,097% (0,050%-0,152%)	0,028% (0,000%-0,328%)	3 (2-6)	14 (9-24)
30-39	0,537% (0,435%-0,664%)	0,143% (0,091%-0,176%)	0,075% (0,010%-0,820%)	3 (2-6)	14 (9-24)
40-49	0,852% (0,682%-0,994%)	0,348% (0,198%-0,406%)	0,187% (0,025%-1,605%)	3 (2-6)	16 (10-32)
50-59	2,574% (1,980%-3,3%)	1,326% (0,673%-1,7%)	0,461% (0,074%-2,904%)	4 (2-7)	17 (18-28)
60-69	4,425% (3,399%-5,772%)	2,475% (1,219%-3,228%)	1,123% (0,255%-4,946%)	4,5 (2,5-8)	17 (10-27)
70-79	9,920% (7,440%-13,64%)	6,080% (2,827%-8,36%)	2,681% (0,870%-3,170%)	5 (3-9)	14 (8-22)
80+	20,563% (6,854%-67,857%)	9,437% (2,156%-31,143%)	7,968% (3,907%-16,583%)	5 (3-9)	12 (6-23)
Total	2,23%	0,77%	0,521% (0,179%-1,936%)		

Table 5. Contact Matrix

	Home contacts	*Work contacts*	*School contacts*	Other contacts	*Infectiousness rate*
Baseline rates	100%	100%	100%	100%	100%
Schools closure	100%	100%	0%	100%	100%
Social distancing	100%	50%	100%	50%	100%
Shielding of elderly citizens	100%	25% (≥70 years); 100% (others)	100%	25% (≥70 years); 100% (others)	100%
Self-isolation	100%	100%	100%	100%	65%
Combination of all measures	100%	25% (≥70 years); 50% (others)	0%	25% (≥70 years); 50% (others)	65%
Stringent measures	100%	25% (≥70 years); 65% (others)	100% (opened schools); 0% (closed schools)	16% (≥70 years); 59% (others)	25% (≥70 years); 50% (others)
Lockdown	100%	10%	10% (opened schools); 0% (closed schools)	10%	65%

Table 6. Efficacy of vaccines

Doses	*Symptomatic Covid-19*	*Hospitalization for COVID-19*	*ICU*	*Mortality*
1 dose	74.46% (66-83)	87.01% (77-97)	97.3% (86-100)	83.24% (73-93)
2 doses	79.94% (70-90)	96.45% (85-100)	99.31% (87-100)	99.35% (87-100)

Annex 2. Participation and involvement of policy makers in model development

This project included, by design, the conformation of an advisory board composed of a variety of key stakeholders, from policy makers from different areas of government (political, health, economics and production sectors at national, provincial and municipal level) to national legislators (senators and deputies) as well as top managers of private or social security insurances. All these decision-makers have been involved in policy decisions on public health and social measures (PHSM) and vaccination strategies since the beginning of the pandemic in our country. The advisory board has been convened to provide face validity as well as inputs on how the model is responding to the relevant inquiries about the epidemiological and macroeconomic impact of the pandemic.

We have followed a pre-defined five-stage engagement process with policy makers in order to ensure that the inputs generated through this interaction provide information for the model to reach the greatest impact on the decision-making process.

The stages are being undertaken as follows:

Stage 1: identification of relevant policy makers and invitation to participate and respond to key questions about the PHSM and vaccination policies in Argentina along the pandemic.

Stage 2: Introduction to the main objectives of the modeling study and delivery of a survey to get their inputs on the face validity of the model, as well as different strategies related to vaccination and PHSM

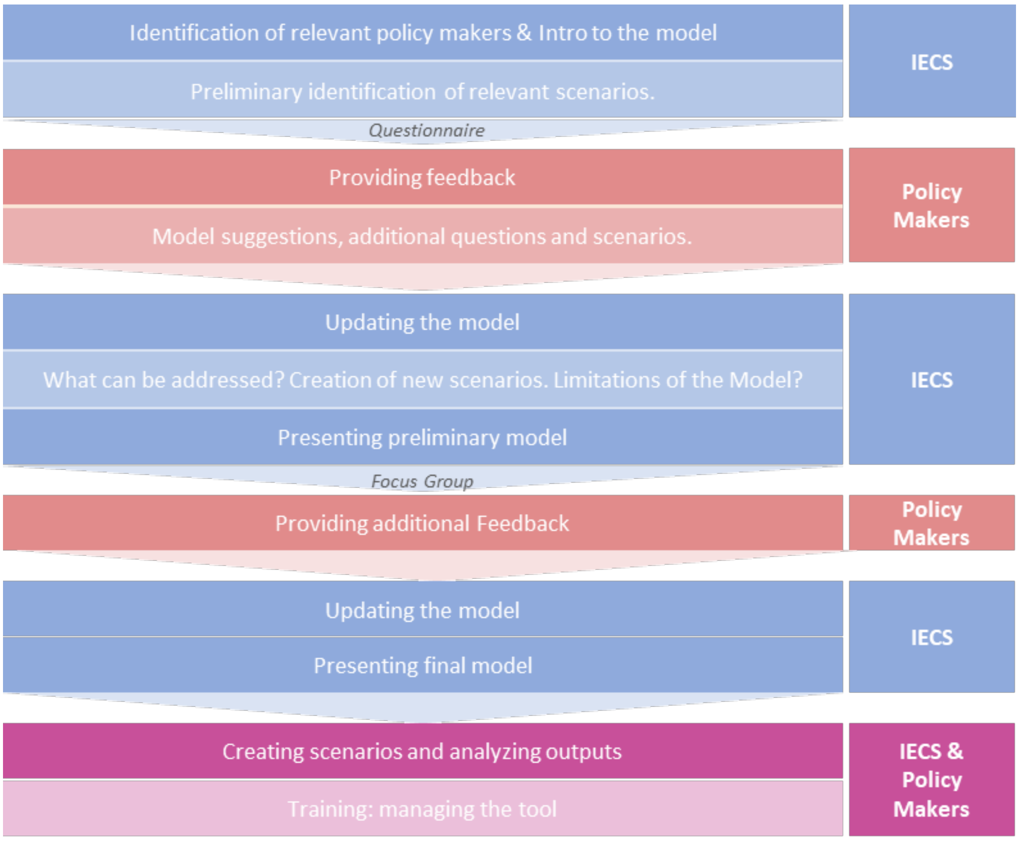
Stage 3: Analysis of preliminary results of the survey in order to refine initial questions and advance with further questions and new scenarios to be studied for future inclusion in the model.

Stage 4: Development of an interactive session with policy makers to showcase the functionalities and results of the integrated model in order to trigger a deliberation process on the model's projections and potential public policy interventions.

Stage 5: Training session to learn about the use of the model for a selected group of decision-makers and/or analysts designated by the policymakers

The different steps in the engagement process are depicted in box 1, below.

Box 1. Engagement process and stages of involvement of the Advisory Board



We have identified and contacted 30 policy makers belonging to the health and other sectors of the economy who were willing and accepted to collaborate with the development and refining of the mode and policy questions. We also included mayors of large and mid-size cities in the countries. All were contacted via email (see list of participants and their positions below).

Name	Position	Institution
David Aruachan	General Manager	Superintendency of Health Services
Sonia Tarragona	Chief of Staff	National Ministry of Health
Alejandra Venerando	Minister of Health	Ministry of Health. Province of San Juan
Ricardo Cardozo	Minister of Health, Corrientes	Ministry of Health. Province of Corrientes
Silvana Grosso	Director of Quality Management	Ministry of Health. Province of Corrientes
Mariano Althabe	Director	Social Health Insurance for the Judiciary (OSPJN)
Miguel Angel Fernandez	Mayor	Trenque Launquen. Province of Buenos Aires
Ruben Manzi	National Deputy for the Province of Catamarca	Honorable National Chamber of Deputies
Hugo Magonza	General Director	Center for Medical Education and Clinical Research (CEMIC)
Daniel Ferrante	Undersecretary of Health Planning	Buenos Aires City Government
Mario Sanchez	Project Manager	Interamerican Development Bank (IDB)
Rafael Rofman	Director of Social Protection Program	Center for the Implementation of Public Policies Promoting Equity and Growth (CIPPEC)
Diego Alonso	General Director of Health Integration	Ministry of Health. Province of Córdoba
Mario Fiad	National Senator for the Province of Jujuy	Honorable Senate of the Nation of Argentina
Pablo Yedlin	National Senator for the Province of Tucumán	Honorable Senate of the Nation of Argentina
Luis Gimenez	Medical Director	OMINT (Private health insurance)
Claudia Najul	National Senator for the Province of Mendoza	Honorable Senate of the Nation of Argentina
Clara Zerbino	Director of Financing Strategies	National Ministry of Health
Gustavo Beliz	President of the Economic and Social Council. Secretary of Strategic Affairs of the	Economic and Social Council. Government of Argentina
Matias Kulfas	Minister of Productive Development	National Ministry of Productive Development
Martin Guzman	Minister of Economy	National Ministry of Economy
Ana Castellani	Secretary of Public Management and Employment	Cabinet of Ministers. Government of Argentina
Enrique Vaquie	Minister of Economy and Energy	Ministry of Economy and Energy. Province of Mendoza
Diego Valenzuela	Mayor	3 de Febrero. Province of Buenos Aires
Pablo Javkin	Mayor	Rosario. Province of Santa Fe
Fernando Straface	Secretary-General and Foreign Affairs	Buenos Aires City Government
Luciano Laspina	National Deputy for the Province of Santa Fe	Argentine Chamber of Deputies
Fernando Morra	Economic Policy Secretary	National Ministry of Economy
María Apólito	Knowledge Economy Undersecretary	National Ministry of Productive Development

In the email, we explained the main objectives of the modeling study as well as the main features of the model. In addition, we asked them to fill out a google form survey. This survey was anonymous and confidential, in order to guarantee the anonymity of the responses. After a brief description of the main aspects of the model, policy makers were presented with a series of policy questions that could potentially be answered with the model. The objective was to investigate about face validity issues, as well as, the relevance of these questions, prioritize them, and eventually identify other questions that were relevant to the policy makers. These were the main questions initially shared with this group:

1. What was the economic and epidemiological impact of the different measures implemented during the pandemic?

2. For how long should strict lockdown be maintained in order to balance epidemiological and macroeconomic impact?

3. What was the impact of vaccination strategies in relation to PHSM?

4. What would happen if it were decided to prioritize vaccination in the productive age group while isolating the elderly and high-risk persons (unvaccinated)?

5. If less restrictive and segmented measures by age group had been used during the first months of the pandemic, what would have been the epidemiological and macroeconomic impact?

6. What was the health and economic impact of school closures?

7. What was the estimated impact in terms of loss of GDP related to vaccination and what would have been the difference in macro-economic impact if Argentina had been able to implement an earlier and more aggressive vaccination campaign?

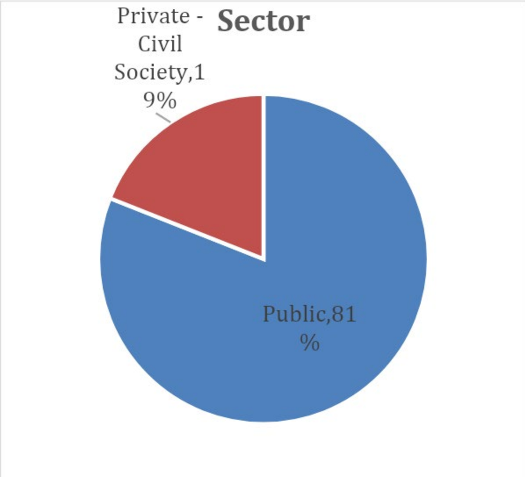
In addition, the survey inquired about the following aspects:

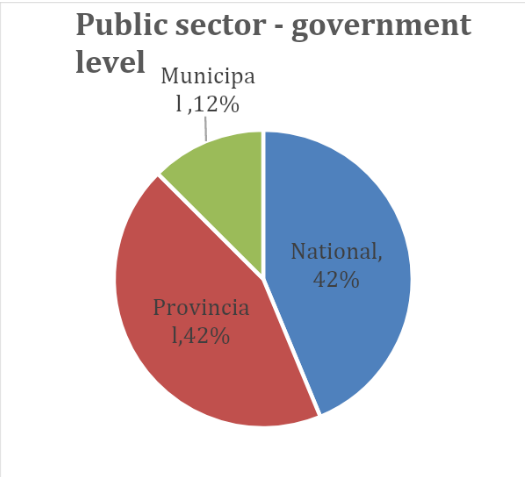
- Sector and level of government to which the decision-maker belongs. - Combination of the most relevant scenarios for decision making process policies in their area. - Prioritization of groups in case of limited vaccine quota and considering that the vaccination process can be complemented with restrictive measures. - Alternative scenarios they would be interested in evaluating. - Questions they would ask the model to evaluate and learn from the past. - Use in their area of work of some model to inform decision making during pandemic. - Utility of models to help make decisions that consider the effects of different scenarios both, in terms of health effects and macroeconomic impact.
- Level of interest in using the proposed tool.

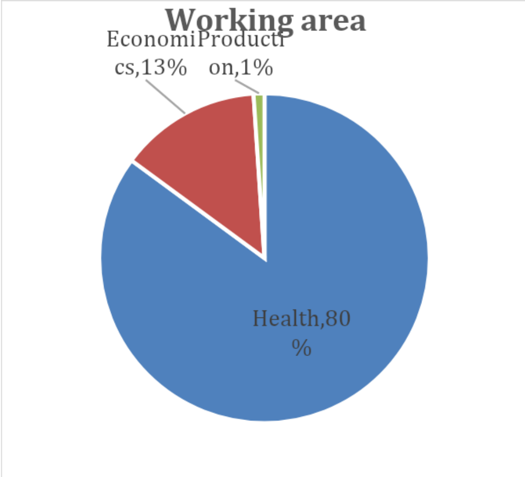
The survey also presented policy makers with a series of PHSMs and different vaccine prioritization schemes to be evaluated. We are currently working on stage 3 on the analysis of the preliminary results of the survey. At this time, 22 responses were received. The preliminary analysis of the responses is presented below:

Sector

We received 22 responses from policy makers (73% response rate), (81% n=18) belonging to the public sector and 19% (n=4) from the private sector or civil society. Considering decision-makers of the public sector, 42% (n=8) belong to the national level of government, 42% (n=8) to the provincial level and 12% (n=2) to the municipal level. Eighty percent (n=18) of the decision-makers who responded performed their work in the health sector, and 20% in finance and economic offices (13% (n=3) in economics and 7% (n=1) in production). See charts below.



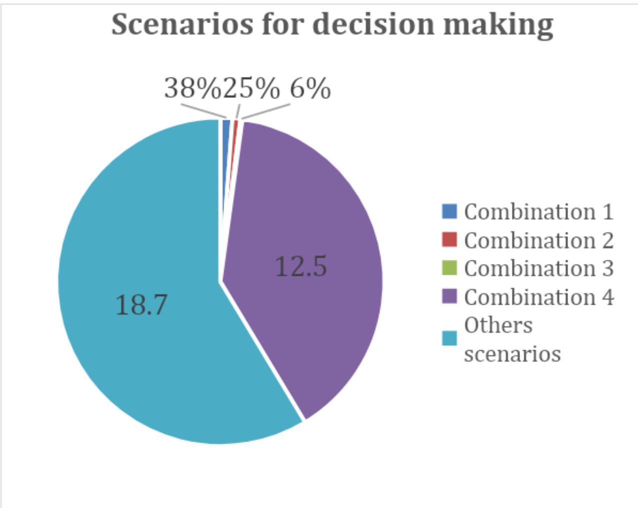




Scenarios for decision making

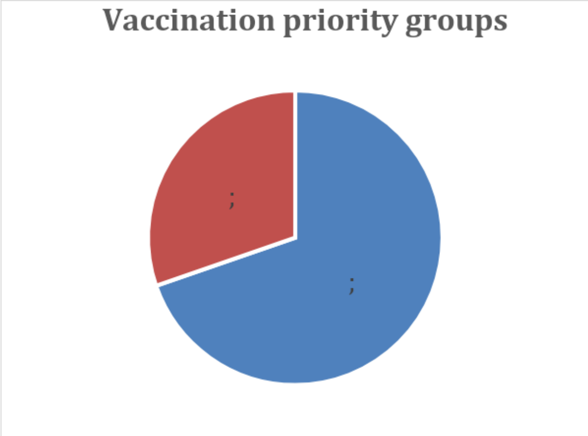
The participants in the survey proposed some additional scenarios not initially contemplated: 1) Isolation of high risk population until most of the population were covered by vaccination, use of masks, social distancing and gauging until advanced vaccination uptake. 2) Lockdown or restrictions according to epidemiological indicators and availability of vaccines, moving to lifting PHSM except for vulnerable or high risk groups. 3) Use of masks, social distancing and gauging. When vaccination uptake is high, move towards "normality".

Regarding the combination of scenarios that would be most relevant to evaluate further, 37.5% (n=8) chose **combination 1** (self-isolation of the elderly, use of masks and social distancing and gauging for the rest of the population without closing industry and businesses); 25% (n=6) chose **combination 2** (initial mandatory isolation, closure of non-essential sectors and relaxation of measures as vaccination progressed); 6.3% (n=1), chose **combination 3** (only use of masks, social distancing and gauging for the entire population); and 12.5% (n=3) selected **combination 4** (vaccination progress without any isolation or social distancing measures). Finally, 18.7% (n=4) answered that they would use other scenarios. See chart below.

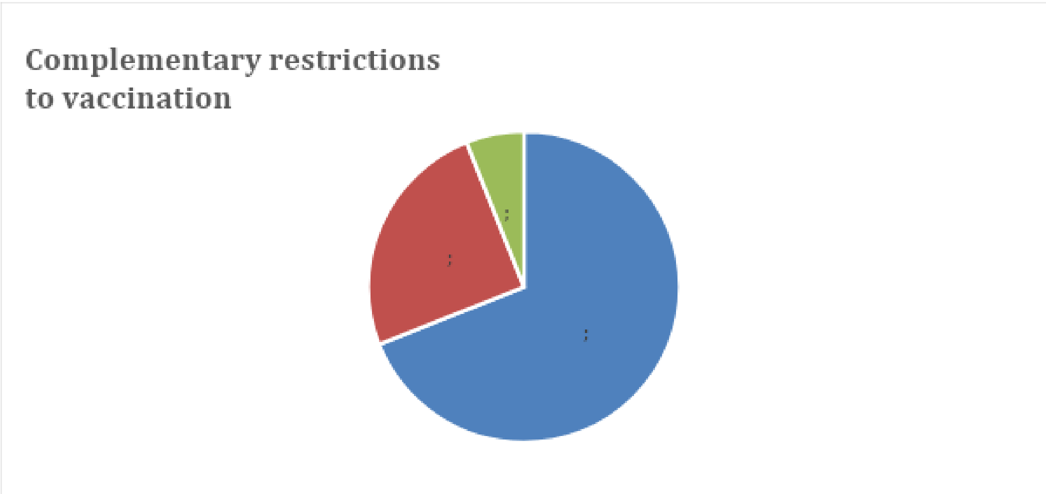


Prioritization of population subgroups for vaccination

When participants took into account a limited vaccine supply and complemented with restrictive measures, 70% (n=15) would first vaccinate adults over 65 years and 30% (n=7) would vaccinate the population group between 20 and 64 years. See chart below.

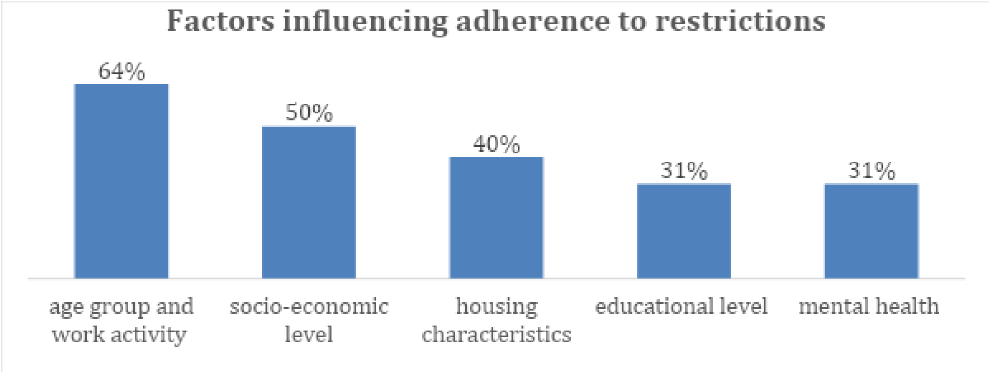


Regarding the type of restriction that would complement the vaccination plan, 69% (n=15) mentioned social distancing and use of masks, while 25% (n=6) complemented it with isolation of those over 65 years old, and 6% (n=1) with distancing, use of masks, gauging closed places, work shifts in factories and teleworking in services. See chart below.



Restrictions

In relation to what factors policy makers consider to influence adherence to restrictions: 64% (n=14) mentioned age group and work activity (formal or informal); 50% (n=11) mentioned socio-economic level; 40% (n=8) mentioned housing characteristics; 31% (n=7) mentioned educational level and this same percentage also mentioned mental health and emotional impact on the family. See chart below.

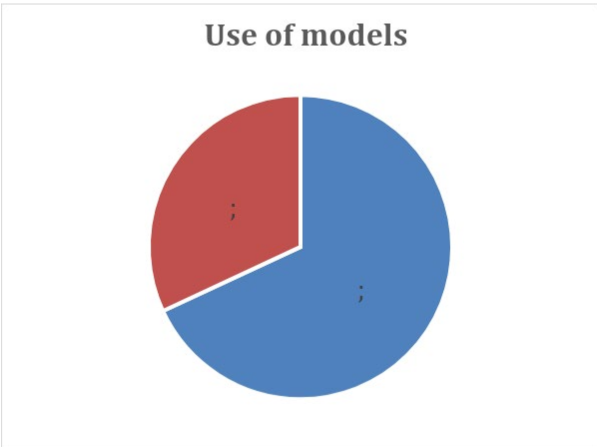


Suggested model questions

Policy makers also suggested additional questions to be responded by the model: 1) Can the model measure the impact that severe and prolonged isolation of older adults has had on cases and mortality? 2) Can the model measure what impact the severe and prolonged isolation of older adults has had on mortality not directly related to COVID-19? 3) Can the model measure what impact severe and prolonged isolation of older adults has had on mortality not directly related to COVID-19? 4) What measures should be evaluated to reduce the health impact of the outbreak, with less impact on the economy? 5) What is the effectiveness and impact of each measure? 6) What is the most appropriate testing strategy? 7) How long should each measure be used? 8) What was the result of strict isolation in terms of health?

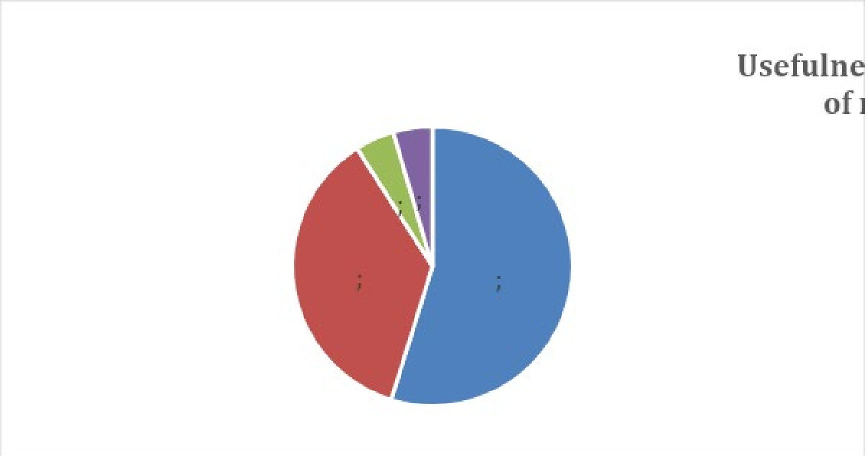
Use of models for decision making

When policy makers were asked if any models were used in their area to inform decision making during the pandemic, 64% (n=14) responded that they had not used any model and 36% (n=8) answered that they had. See chart below.



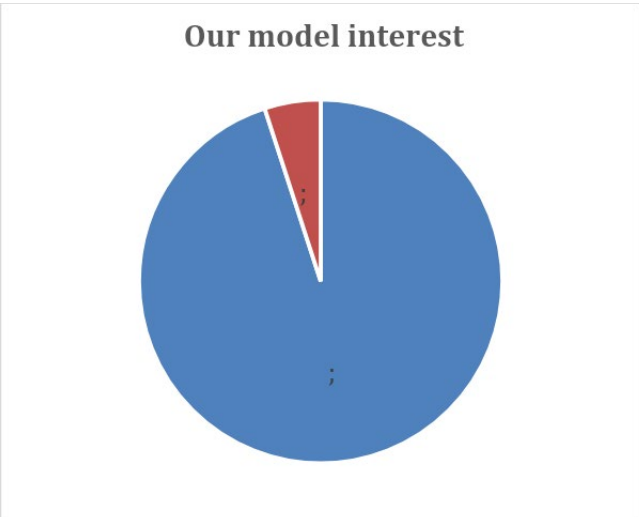
In those cases, where a model was used, it was mentioned that: 1) The results obtained by the model were not good enough to respond adequately to the “real world” scenarios. 2) Models were only used for monitoring ICU beds. 3) It was only a basic epidemiological model that contemplated reported cases, ICU bed occupancy, mobility and also for case and contact tracing

When asked how useful they thought it would be to have a model to help make decisions on the integrated epidemiological and macroeconomic impact, considering different scenarios, 54,5% (n=12) responded that it would be very useful, 36% (n=8) useful, 4,5% (n=1) somewhat useful, and 4,5% (n=1) slightly useful. See chart below.

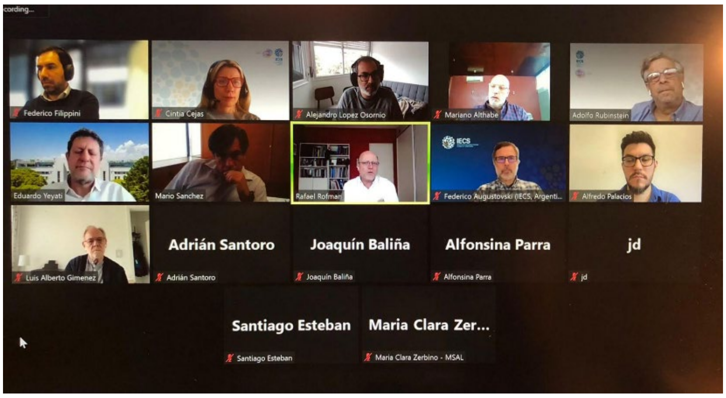


Interest in our model

Finally, they were asked if they would be interested in having someone from their work teams to learn about how to use this tool, 95% (n=21) responded positively, while 5% (n=1) mentioned that they would not be interested. See chart below.



As it was mentioned in the previous report, after completing the previous steps (stages 1-3), we proceed to stage 4 inviting our policy makers to participate in an interactive session to showcase the functionalities and results of the integrated model in order to trigger a deliberation process on the model's projections and potential public policy interventions. This session took place on June 28 at 12 a.m. (Argentina time), with participation of many decision makers. For those who had confirmed but could not attend the session, we sent them the recording of the session and obtained their written feedback.



During the session, we presented the integrated model, its basis, parameters, construction and operation. Then a demo was made so that the different scenarios could be observed through the following link https://iecs.shinyapps.io/covid-model-v2/

Many relevant questions were raised by policy makers and some recommendations were considered to be incorporated for further developments of the model, such as the social impact in addition to epidemiological and macroeconomic impact (in term of poverty, job destruction, labor informality, etc.), piloting and validating the model in other countries in the Region, and impact at subnational levels.

The meeting concluded with the decision-makers' interest in interacting with the model and selecting some consultants to be trained in its use.

Recommendations of policy makers: inclusion of social impact and extension of this integrated model to other similar countries

One of the key contributions of the paper is to quantify the economic costs of the different stringency measures acknowledging the heightened degree of uncertainty faced by the policy makers. This uncertainty could have undermined these economic costs by policy makers pushing very tough lockdowns at the beginning of the pandemic. In this vein, we are answering one of the key questions from the panel (‘what measures should be evaluated to reduce the health impact of the outbreak, with less impact on the economy?’) in a concise way. In particular, the model allows to simulate any sequence of PHSM stringency and duration and map them onto the health-economic outcomes space, highlighting the tradeoff between lives and likelihood, if any, in a non-trivial way, including the deleterious impact of lockdown fatigue and the mitigating impact of vaccination.

There are a number of important additions that could be included in the model without altering its main logic. For example, it could be extended to account for the incidence of the socio-demographic composition of the labor force, including gender, informality and household income, thereby allowing for cross-country comparisons in the region. Thus, it could be used to shed light on the relative underperformance of countries like Peru or Colombia due to informality, or to flag the differential impact according to skill intensity, informality and feminization rates of specific sectors, or to zoom in on how the tradeoff differs for alternative representative households. As raised by some policy makers, incorporate in the model the dimension of social impact, in addition to epidemiologic or macroeconomic impact, through metrics that could capture the increase of poverty, job destruction and informal labor seemed to be highly relevant to be worked out in further model developments. Another issue raised by policy makers was the possibility to extend this model to other countries of LA&C as a sort of "validation test". To test the model in other countries, particularly those that are similar to Argentina, would allow us to disentangle some differences across countries regarding the variability of health and economic outcomes.

In summary, our user friendly, open source, transparent and interactive integrated epi-econ model was developed to facilitate policy maker's decisions by allowing the user to modify its parameters according to the specific pandemic trajectory, SPHM implemented, policy context and vaccination strategy in Argentina. Thus, this model 'adjust' for the potential impact and interactions of social and public health interventions and vaccination on COVID 19 epidemic on epidemiologic and economic outputs. Our integrated model to assess the impact of COVID-19 pandemic in Argentina, constitutes a tool that articulates scientific knowledge, empirical evidence, and public policies in a fully transparent framework that could be extended to other countries in the region of Latin America and the Caribbean.

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