# **Economic Impacts of an Epidemiologic Model:** The Senegalese Case of COVID-19 in a Computable General Equilibrium-Multi-Agent System Model.

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**Date** April 2021

**Working Paper** 2021-06

PEP Working Paper Series
ISSN 2709-7331

# Economic Impacts of an Epidemiologic Model: The Senegalese Case of COVID-19 in a Computable General Equilibrium-Multi-Agent System Model


## Abstract

Senegal is a developing country in West Africa whose current economic crisis is intimately linked to the COVID-19 pandemic. Necessary containment measures brought with them a significant economic cost, and de-confinement was designed to obtain a quick economic recovery. At the same time, de-confinement was accompanied by new protectives to activity (physical distancing, limitations on internet activities, etc.). A lockdown implies a trade off in terms of economic and health impacts. Using a multi-agent model elaborated as an epidemiological model, we evaluate the effect of government policies to counter the COVID-19 pandemic and then use a Computable General Equilibrium model to evaluate the economic impacts of those policies. Those two models are combined in a top-down approach. Finally, we discuss the possibilities offered by a variety of scenarios when a pandemic appears in the economy.



**JEL:** H32; C68; I15

**Keywords:** Senegal, pandemic, lockdown, CGE model, agent based model


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## Acknowledgements


This research work was carried out with financial and scientific support from the Partnership for Economic Policy (PEP) (www.pep-net.org) with funding from the Department for International Development (DFID) of the United Kingdom (or UK Aid) and the Government of Canada through the International Development Research Center (IDRC). The authors are also grateful to anonymous referees for valuable comments and suggestions.

## Table of Contents


**I. Introduction** 1

1.1 Context of the Study 1

1.2 Research Questions and Objectives 1

**II. The Methodology** 2

2.1. A Multi-Agent System (MAS) 3

2.2. The Computable General Equilibrium Model 3

**III. Simulation Exercises** 7

3.1. Laissez-Faire Scenario 7

3.2. Lock down Scenario 7

3.3. Results 11

**IV. Conclusions and Policy Implications** 17

References 18

Appendix 20


## List of Tables


Table 1: Variation of Patient Rate by Sector (%) ........ 12
Table 2: Variation of Composite Labor Demand (%) ........ 13
Table 3: Variation in SectorB-based Production (%) ........ 14
Table 4: Variation of Price by Market (%) ........ 15
Table 5: Variation in Imported Goods (%) ........ 16
Table 6: Variation in the Unemployment Rate (%) ........ 17

# I. Introduction

## 1.1 Context of the Study

Senegal is a developing country in West Africa whose current economic crisis is intimately linked to the COVID-19 pandemic. Globally, containment measures brought with them a significant economic cost, and de-confinement measures initiated by several countries were designed to bring about a quick economic recovery. At the same time, de-confinement was accompanied by new protective measures (physical distancing, working at home, etc.). Changes in the proportion of healthy vs. infected people can affect economic activity and lead to such effects as reductions in productivity.

## 1.2 Research Questions and Objectives

Using a multi-agent model, we evaluated the effect of government policies to counter the pandemic. Most countries, especially low- and middle-income countries, were not prepared to face COVID-19 and were surprised by its spread across their territories. Thus, in addition to the advice given by national and international scientists specializing in biology, medicine, or economy, simulation and forecasting tools make it possible to understand the nature of the crisis and eventually to manage it in the short, medium, and long term (Currie et al., 2020).

Simulation techniques are many and have been used in a variety of contexts (see, for example, Prem et al., 2020; Anastassopoulou et al., 2020; and Hsiang et al., 2020). Many of these tools come from mathematical modeling, using for example, the SIR model and its extensions (Wu et al., 2020; Roda et al., 2020; Giordano et al., 2020; and Ivorra et al., 2020, e.g.) or linear regression (Rustam et al., 2020). Some, such as neural networks, come from the field of artificial intelligence (deep learning, for instance; see Chimmula & Zhang, 2020) or fuzzy neural networks (Al-Qaness et al., 2020).

We used a multi-agent system (hereafter, MAS) to simulate the effect of non-compliance with infection-prevention measures after de-confinement in Senegal. In computer science, a MAS (see Weiss, 1999) is a distributed artificial intelligence system composed of a set of agents (each of which represents a process, a robot, a human being, etc.) that is placed in a particular environment and acts according to specific relationships.

The epidemiological model that we used was calibrated on Senegalese data and is particularly powerful because it allowed us to predict the evolution of the pandemic, taking into account factors that were favorable to its reduction or to its expansion. As one example, respect for physical distancing by a certain percentage of the population will reduce the percentage of infected people. Conversely, large gatherings (e.g., unlimited access to beaches) could favor the expansion of the pandemic. Depending on the kind of measures imposed by the Senegalese authorities and the way the population reacted to the advice of health authorities, the model made it possible to project the virulence of the pandemic and to measure the potential number of people affected.

General-equilibrium models have already been proposed to measure the impact of lockdown measures. Among these, the complete closure of certain non-priority sectors not only reduces production to zero during the months of containment but also generates, as an indirect effect, substantial reduction in production (with a resultant loss of employment) in non-confined sectors.

Mathouraparsad and Decaluwé (2020) identified the main economic channels through which the effects of the pandemic are felt and suggested ways to analyze these transmission mechanisms. In addition to the supply shocks that affect non-priority sectors, other sectors may be affected by a decline in final demand. Declines in investment or postponements of productive investment are certainly important, but reduction in household income and consumption following job losses is equally significant. In addition, restrictions on international trade because of diminished global demand (including tourism) can have major effects on economic systems.

From our point of view, however, COVID-related distancing and other protective measures appear to have resulted in several simultaneous phenomena, all of which have affected the functioning of the labor market: (1) telework and all forms of remote work; (2) work stoppage for health reasons; (3) time spent on health measures (hand washing, wearing sanitary equipment, dressing and undressing); and (4) camouflaged or legal absenteeism (workers' right of refusal).

Our research used an original model of pandemic spread calibrated on Senegalese data to infer the economic consequences of a laissez-faire strategy (in which no protective measures were employed) versus a lockdown strategy. An additional objective was to compare the effects on GDP of mitigation and recovery measures introduced by Senegalese authorities.

## II. The Methodology

The model is composed of two modules. One is an epidemiologic model based on the MAS approach. The model generates results on the evolution of the number of infected individuals and computes the ratio of sick people who are unable to work. Absenteeism is next introduced in each activity, and the CGE model simulates the effects on the rest of the economy.

## 2.1. A Multi-Agent System (MAS)

Silva et al. (2020) used a MAS to simulate the health and economic effects of the COVID-19 pandemic, and Bouchnita and Jebrane (2020) employed a MAS to simulate the effects of lockdown by introducing age and comorbidities as risk factors. Our approach also used a MAS, which had already been used in another region (Regis, Manicom & Doncescu, 2020), together with risk factors (age, hypertension, and diabetes) to simulate the COVID-19 epidemic in Senegal.

For the MAS, we used and modified a model implemented on the NetLogo platform (Wilensky, 2016) called epiDEM Travel and Control (Yang & Wilensky, 2011). epiDEM Travel and Control is based on Yang and Wilensky's epiDEM basic (see also Wang, et al., 2016, and Smith & Broniatowski, 2016), an epidemic model developed on NetLogo. Ease of adaptation and of redoing simulations, especially for countries with low resources, justified the choice of the well-known NetLogo platform and an open-access multi-agent epidemiological model. The epiDEM Travel and Control model focuses on the spread of a disease among agents who can travel among different regions (or not) while observing infected, recovered, and possibly quarantined people.

We classified infected people into two groups (mild and critical) according to age and risk factors. In our simulation, each agent represented a group of persons in the same age range. We adjusted the parameters of the original model to allow free movement of people whether or not they were infected (no social distancing or quarantine) unless the scenario imposed lockdown. Each agent represented a group of 10,000 Senegalese. According to medical data (Zhou et al., 2020), average-recovery-time—representing the average duration of the disease—was thirty-seven days. In addition, because of the very high density of the Dakar region (the City of Dakar and its administrative region), we took population density into account as a factor of propagation.

For the start of the pandemic, and given the small number of identified cases when we launched the simulation (around 2,000 in May 2020), we multiplied the number of positive tests cases by eight to yield slightly fewer than 20,000 cases, or two infected agents (this calculation was based on studies that calculated the number of real cases). These two infected agents were introduced at the start of the simulation because the Dakar region potentially receives more "imported cases"—that is, infected people from abroad.

## 2.2. The Computable General Equilibrium Model

To measure the economic impact of the health crisis, we implemented the static computable general equilibrium model of Mendy et al. (2020) to the Senegalese economy. The accounting framework for the resolution of this model was Senegal's 2014 Social Accounting Matrix, which took six institutional units into account: households in Dakar, households in other urban centers, households in rural areas, firms, the state, and the rest of the world as well as eight factors of production, twenty-seven sectors of activity, and forty-eight products/services. The model applies to a small economy for which world prices are given.

### 2.2.1 Specifics of the Model

We distinguished two factors of production: composite labor and composite capital. The composite labor factor was disaggregated into six segments according to qualification and gender.

A sector's production function is expressed as a Leontief-type function that combines fixed volume shares of value added and intermediate consumption. On the other hand, value added is a constant elasticity of substitution (CES) function that combines composite labor and composite capital. Composite labor is a CES function combining six categories of labor.

The initial factor endowments of households play an important role in transmitting the effects of the shock to households. Each household receives a share of factor income from unskilled labor, medium-skilled labor, high-skilled labor, and private capital. A fixed proportion of transfers from the government, the rest of the world, and other households, in addition to dividends paid by firms, also go to households. The structure of consumption that is affected by price changes is also decisive in the transmission of the effects of the shock to households.

The consumption of each product is valued at the price of the composite good. It is a LES-type function known as the Stone Geary linear expenditure system. It distinguishes between incompressible and discretionary consumption. The specificity of this demand function is that it includes a minimum basket of consumption: that is, the volume of a product that the consumer must have available to maintain a minimum standard of living.

Life may not have a price, but it does have a cost. For decision makers, balancing between infections and growth is a challenge. We introduced an objective function of the government, assuming that government wanted to minimize both the loss generated by a reduction in production and the number of infected people. Our indicator of the magnitude of the loss is the following:

$$\mathrm{Loss} = (1 - \alpha)\mathrm{growth} - \alpha \mathrm{Inf} \tag{1}$$

With $\mathrm{Inf}$ being the number of infected people and $\mathrm{growth}$ being economic growth, $\alpha$ is the weight of the health situation in the loss function, which is calibrated to 0.15, meaning that greater importance to the economic situation.

This loss function determines opportunity cost by revealing the level of economic loss (decline in GDP) that can be reconciled with an increase in the number of infected cases. A decision-maker who wants to minimize loss can use this indicator to determine the extent of economic support required to achieve a level of GDP consistent with a given number of infected cases

$$\frac{dInf}{dgrowth} = 1 - \frac{1}{\alpha}$$

### 2.2.2. Modelling the Labor Market

On one hand, we segmented the labor market according to three levels of qualification: the highly qualified (employees who had obtained at least a baccalaureate), the moderately qualified (those who had completed at least the primary-school cycle), and the unskilled (those with no education or those who had not completed the primary-school cycle). These were respectively distributed according to gender (men and women) to distinguishing six segments of the labor market.

On the other hand, we took into account the rigid character of the labor market by introducing unemployment endogenously in accordance with the wage-curve approach developed by Blanchflower and Oswald (1995). Workers were assumed to be mobile within activities but not between segments of the labor market.

Composite labor demand is the level of total employment by sector using a CES aggregating function and distinguishing the combinations of worker types:

$$LDC_j = B_j \left[ \sum_l \theta_{lj}^{LD} LD_{lj}^{-\rho_j^{LD}} \right]^{-\frac{1}{\rho_j^{LD}}} \qquad (2)$$

with $LDC_j$ the composite labor demand in sector j $LD_{lj}$ the labor demand in workers of Type l in sector j $B_j$ the scale parameter, $\theta_{li}^{LD}$ t Is the distributive share and sigma the elasticity of substitution.

We assumed that workers' productivity may be affected by the evolution of the disease. If a worker is infected, he or she is out of the labor market. This creates absenteeism in the industry. To capture this aspect, we assign to the distributive share of workers demand $\theta_{li}^{LD}$ a rate $\tau_l$ defined as the ratio of the number of infected cases by type l $LDI_{lj}$ to the total number $LD_{lj}$ of type l workers in each activity.

$$\theta_{lj}^{LD} = \beta_{lj}^{LD}(1 - \tau_l) \qquad (3)$$

$$\tau_l = \frac{\sum_j LDI_{lj}}{\sum_j LD_{lj}} \qquad (4)$$

with $\beta_{lj}^{LD}$ the distributive share of the la labor demand for type l workers in the sector J. This distributive share is calibrated with the data from the SAM. At the initial stage, the absenteeism rate $\tau_l$ is equal to zero. The number of infected workers $LDI_{lj}$ is generated by the MAS.

### 2.2.3. Calibration and Closure

The specification of the production functions, the behavior of household consumption, and import and export demand and supply require parameters that include the income elasticity of demand, the Frisch parameter, the elasticity of substitution between capital and labor, the elasticity of substitution between imported and local products, the CET elasticity between external and local sales and, finally, the elasticity of foreign demand. The exchange rate (the numeraire) and the current account balance in foreign currency are fixed.

# III. Simulation Exercises

In the aftermath of containment, most countries lifted the majority of restrictions with the exception of handwashing and social-distancing measures. As people were freed to move or travel, they carried the virus across borders. An upsurge of cases was then observed which led to a sharp increase in the number of patients. First, we simulated an exogenous increase in “imported” infections in the epidemiologic model to generate the number of ill workers and then introduced absenteeism into the sectors.

## 3.1. Laissez-Faire Scenario

In the “laissez faire” scenario, we were interested in the effects of the opening of borders and the multiplication of “imported” cases of COVID (that is, tourists or returning Senegalese who had been infected abroad. Our MAS simulation tool was able to evaluate the number of infected cases, the number of severe cases, and their distribution according to sex and age. All the calculations took into account the epidemiologic characteristics of the Senegalese population. The results show variations in patient rate by sector. Indeed, the MAS represents agents according to their status as active or inactive workers and distinguishes active workers by sector.

## 3.2. Lockdown Scenario

In the lockdown scenario, we considered a containment measure impose by the authorities following the introduction of an initial case of the COVID. However, we assumed that a certain proportion of the population would not respect protective and distancing measures. In the absence of an estimate for Senegal, we approximated this proportion with information derived from other countries. In our calculation we assumed that 15 % of the population would not follow the measures imposed by health authorities.

The MAS simulated containment scenarios according to the amount of time between the start of the pandemic and containment measure (it could correspond to days, weeks, or months). In the presentation of results, we retained solely the immediate containment hypothesis as if the government had decided very quickly on measures after the beginning of the pandemic, This was, however, obtained at the price of repercussions for economic activity. Containment implies the cessation of certain activities. There is, therefore, an exogenous supply shock. Basing our work on Mathouraparsad and Decaluwé (2020), we introduced a multidimensional shock on both the demand and the supply sides.

### 3.2.1. A Multidimensional Supply Shock

Measures to prevent the spread of COVID-19 are well known: social distancing, closing of enterprises, compulsory confinement of the population, bans on movement, etc. It can probably be said that this is the first time in economic history that governments have taken the decision to stop producing goods and services altogether in many sectors. In doing so, the COVID-19 pandemic did not simply slow growth, as was the case in previous pandemics, but halted the production of entire sectors of the economy with immediate consequences for household incomes.

In order to measure the impact of these measures on the economy, we divided the industries into two distinct groups:

- "Priority" activities that were allowed to continue
- "Non-priority" activities that faced a ban

#### A.1 Classification of Industries

Sectors that were allowed to remain open are considered "priority" sectors because they provide products or services deemed essential, including activities linked to the food chain, agriculture, food processing, grocery distribution, bakeries and other food producers; the food industry; and those that involve energy, financial services, telecommunications, etc. These sectors continued to operate "normally" and to respond to household demand even as they were subjected to chain reactions that revealed the interdependencies of economic systems. Thus, as a ripple effect, these activities (such as transport or fuel sales) were affected by the cessation of production in other sectors.

Secondly, "non-priority" sectors closed either because they could not meet the criterion of social distancing in their activities or because containment measures were aimed directly at them (highways, ports and airport, civil engineering facilities, hotels and restaurants, drink services, non-traded services, other services). In the end, services such as these were most heavily penalized.

In the CGE, short-term wage rates are fixed, and the labor market adjustment is Keynesian. The increase (protected sectors) or decrease (priority and non-priority sectors) in labor demand results in a decrease or increase in unemployment.

In terms of simulation, we captured the effects of two month of confinement via a fall in the output of non-priority sectors equivalent to two months of production. It was therefore assumed that output during this period was zero or, on average, 17.0% of annual production level

#### A.2 Loss of Productivity in "Protected" and "Priority" Sectors

Lockdown measures directly affect worker productivity through a variety of channels. Distancing measures, while possible in some sectors of activity, may be difficult to implement in others and may ultimately lead to a complete cessation of activities, with workers exercising their right to withdraw or businesses simply deciding to close. Health institutions and professionals may lack resources and some medical personnel may be infected, any of which may affect their labor productivity.

Moreover, an increase in the number of infections reduces the number of available workers, and legal regulations may mean that industries do not want to or are unable to replace workers in the short term. The economic shock will also depend upon the structure of the economic system; overall, however, absenteeism reduces the number of workers available. The sectors suffering from a reduction in the number of workers will increase pressure on available workers as they become relatively scarcer on the market. Businesses could adjust by requesting more effort from healthy workers and paying supplementary wages.

In the CGE, we changed the labor parameter in our production functions. The degree of decline in productivity varied from one industry to another and affected output differently, taking into account the nature of the technologies. The diagram of transmission mechanisms of the shock can be summarized as follows:

- A lockdown period leads to production stoppage in "non-priority" sectors;
- The resulting drop in production leads, by a knock-on effect, to a reduction in intermediate demand, a component of total demand for the "priority" sectors;
- The decline of production in priority and non-priority sectors leads, at constant wages, to a reduction of employment, an increase in the number of unemployed, and a reduction in labor income; and
- The drop in labor productivity generated by infected workers leads to a loss in total factor productivity that varies among sectors.

### 3.2.2. A Multi-Dimensional Demand Shock

In economic jargon, it is said that demand plays a "multiplier" role in economic activity, increasing production when the shock is positive and acting in the opposite direction when there is a downturn. We focused on two components of demand: household consumption and demand from the rest of the world.

#### B.1. A Change in Household Behavior

During the COVID pandemic and related lockdowns, consumer behavior is ambiguous, and the composition of the consumer's market basket is affected.

First, a "cold" panic movement causes a rush on shops and an over-consumption of so-called "priority" goods for fear of shortages (food, medications). This behavior, even if it takes the form of panic that causes queues, is completely rational. Uncertainty as to the duration of the pandemic and the decisions that governments may take provoke a precautionary reflex among consumers to stockpile essential and even non-essential products. At that point, as a sudden increase in demand creates a scarcity of products or brings about rationing (toilet paper, gas, etc.), the fear of shortage can actually cause a shortage.

On the other hand, consumers become scarcer in some markets during the period of confinement, and restrictions on mobility (border closures, limitations on regional mobility) may materialize in a drop in demand for certain food products (fresh produce, fish products, agricultural, etc.). This reduction leads to an oversupply, which pushes some producers to organize special operations to dispose of stock. In some cases, producers of fresh meat, fruit, or vegetables may decide to destroy their production to avoid an excess of supply. The impact of all of these maneuvers on prices is therefore difficult to predict.

We must also expect a reduction in the consumption of so-called "non-essential" goods and services. Obviously, lockdowns and production stoppages greatly reduce the need for transportation of both goods and people. Spending for durable goods (household appliances, renovation, clothing, e.g.) will be postponed, as will consumption of leisure and entertainment services (restaurants, shows, tourist trips, etc.) because these services are no longer provided.

In the absence of more precise local information, we assumed in the CGE that the rush on necessities (in particular, food) is equivalent to two month's extra consumption (i.e., on average +17.0% of the annual budget for these products).

The consumption of non-essential goods is reduced proportionally to free up a budget sufficient to cover necessities. Finally, certain categories of expenditure are deemed to be incompressible, and their share in the budget cannot be changed (rents, fixed monthly fees, etc.).

## B.2. Transactions with Foreign Countries

For many developing and developed countries, foreign transactions play an important role in economic activity. As a result of the global nature of the COVID-19 crisis, measures to contain and reduce activity in neighboring or partner countries can have a significant impact on national activity.

In this respect, the computation of sector-based export intensities will give a precise idea of one channel of transmission of demand shock represented by a reduction in economic activity in the partner countries. Thus, even if local containment lasts only two months, the international effects of the pandemic could include reduced demand and lower prices for a much longer period.

The onset of the pandemic rapidly led to the imposition of significant restrictions and containment measures on travelers all over the world. These measures brought vacation travel to a standstill, and airports were emptied. The drop in tourist numbers produced a decline in activity in the hotel and restaurant sectors because travelers generally devote almost half of their budget to commercial services (hotels, restaurants, car rental, local transport, etc.).

## 3.3. Results

Comparison of the results between the two scenarios reveals that imposing lockdown within twenty-four hours of the onset of a pandemic drastically reduces the number of infections. According to the MAS, this is a decline from 117 agents to 54, a decrease of around 630,000 patients. A smaller effect on worker productivity is noted in the lockdown scenario compared to the laissez-faire model, given the lower number of patients.

Table 1: Variation of Patient Rate by Sector[1] (%)

| Product | Laissez-Faire | Lockdown |
|---|---|---|
| Cereal | -0.079 | -0.014 |
| Tubleg | -0.085 | -0.035 |
| Fruitpf | -0.029 | -0.043 |
| Araolea | -0.056 | -0.031 |
| Autag | -0.057 | -0.057 |
| Bovovcap | -0.106 | -0.041 |
| Volail | -0.083 | -0.017 |
| Autelev | -0.050 | -0.017 |
| Pechpaqua | -0.078 | -0.067 |
| Extract | -0.087 | -0.047 |
| Viandp | -0.083 | -0.033 |
| Gras | -0.050 | -0.033 |
| Grains | -0.100 | -0.014 |
| Cfruitleg | 0.000 | 0.000 |
| Indlaitgl | -0.080 | -0.020 |
| Autalim | -0.076 | -0.036 |
| Autindna | -0.069 | -0.032 |
| Autorout | -0.133 | -0.067 |
| Portaero | -1.000 | -0.700 |
| Autgcivil | -0.100 | -0.033 |
| Autconstruc | -0.062 | -0.031 |
| Hotel | -0.040 | -0.040 |
| Restau | -0.033 | -0.033 |
| Telecom | -0.067 | -0.052 |
| NTSER | -0.069 | -0.041 |
| SRP | -0.083 | -0.043 |
| Autserv | -0.077 | -0.031 |

***Source:*** Authors' calculations.

In the laissez-faire scenario, we assumed a government that was totally passive in the face of the pandemic. An increase in the number of infected cases reduced the number of people available to work, taking into account legal regulations that may make it unappealing or impossible to replace workers in the short term. Economic shock will depend upon the structure of the economic system, but absenteeism will globally reduce the number of available workers. The sectors suffering from a reduction in the number of workers increase pressure on available workers who become relatively scarce on the market (Table 2).

In the lockdown scenario, the effects of absenteeism are more important for most sectors because of the shocks related to confinement (see below).

[1] See the Appendix for the meaning of product names.

**Table 2: Variation of Composite Labor Demand (%)**

| Product | Laissez-Faire | Lockdown |
|---|---|---|
| **Cereal** | -10.885 | -11.366 |
| **Araolea** | -5.979 | -10.064 |
| **Volail** | -7.787 | -4.812 |
| **Extract** | -34.475 | -25.101 |
| **Grains** | -31.402 | -7.234 |
| **Autalim** | -27.656 | -22.517 |
| **Portaero** | -100.000 | -46.351 |
| **Hotel** | -16.262 | -27.464 |
| **NTSER** | -19.160 | -23.155 |
| **Tubleg** | -11.590 | -14.926 |
| **Autag** | -6.534 | -14.370 |
| **Autelev** | -3.897 | -1.090 |
| **Viandp** | -28.433 | -17.309 |
| **Cfruitleg** | 9.909 | 2.315 |
| **Autindna** | -26.528 | -15.386 |
| **Autgcivil** | -18.954 | -46.725 |
| **Restau** | -16.027 | -39.364 |
| **SRP** | -28.241 | 15.753 |
| **Fruitpf** | -2.143 | -15.649 |
| **Bovovcap** | -9.131 | -10.027 |
| **Pechpaqua** | -8.488 | -13.233 |
| **Gras** | -14.365 | -11.088 |
| **Indlaitgl** | -29.123 | -17.404 |
| **Autorout** | -23.389 | -46.721 |
| **Autconstruc** | -7.779 | -21.072 |
| **Telecom** | -29.306 | -34.459 |
| **Autserv** | -19.835 | -31.245 |

***Source:*** Authors' calculations.

The drop in labor demand will generate a drop in sector-based output (Table 3), but the results are of a different magnitude. In the laissez-faire scenario, more absenteeism leads to reduced economic activity compared to the lockdown scenario. In the latter scenario, however, economic activity is affected by a cessation of non-priority activities (supply shock) and by a reduction in household consumption because individuals are confined (demand shock).

**Table 3: Variation in SectorB-based Production (%)**

| Product | Laissez-Faire | Lockdown |
|---|---|---|
| Cereal | -7.609 | -7.977 |
| Araolea | -3.746 | -6.559 |
| Volail | -3.691 | -2.186 |
| Extract | -13.214 | -9.364 |
| Grains | -6.348 | -1.352 |
| Autalim | -10.052 | -8.068 |
| Portaero | -68.733 | -17.000 |
| Hotel | -9.902 | -17.037 |
| NTSER | -14.002 | -17.000 |
| Tubleg | -8.127 | -10.752 |
| Autag | -4.139 | -9.796 |
| Autelev | -1.747 | -0.469 |
| Viandp | -2.413 | -1.408 |
| Cfruitleg | 2.397 | 0.570 |
| Autindna | -8.898 | -5.004 |
| Autgcivil | -6.317 | -17.000 |
| Restau | -6.507 | -17.000 |
| SRP | -6.745 | 3.330 |
| Fruitpf | -1.311 | -10.863 |
| Bovovcap | -4.412 | -4.907 |
| Pechpaqua | -5.382 | -8.784 |
| Gras | -5.931 | -4.544 |
| Indlaitgl | -6.228 | -3.580 |
| Autorout | -7.893 | -17.000 |
| Autconstruc | -6.210 | -17.000 |
| Telecom | -5.999 | -7.188 |
| Autserv | -10.540 | -17.000 |

***Source:*** Authors' calculations.

Table 3 shows the complex effect of the supply and demand shocks. In the laissez-faire scenario, lower worker productivity tends to raise product prices. On the contrary in the lockdown scenario, lower consumer demand tends to further reduce the price of goods (Table 4).

Table 4: Variation of Price by Market (%)

| Product | Laissez-Faire | Lockdown |
|---|---|---|
| **Volail** | 5.073 | -8.537 |
| **Ble** | 4.469 | -5.910 |
| **Rizpaddy** | 6.691 | -12.814 |
| **Melonp** | 8.426 | -19.006 |
| **Agrum** | 2.750 | -19.600 |
| **Acajou** | 8.950 | -2.105 |
| **Ovin** | 7.683 | -11.017 |
| **Laitbrut** | 8.168 | -14.059 |
| **Viandovcap** | 5.351 | -7.321 |
| **Rizdecort** | 6.046 | -4.685 |
| **Laitass** | 5.948 | -4.404 |
| **Autpext** | 7.530 | 1.880 |
| **Autpchim** | 4.986 | -1.472 |
| **Pportaero** | 201.657 | 505.126 |
| **Peau** | 7.779 | -2.052 |
| **Srestau** | 5.212 | -9.032 |
| **NTSER** | 16.282 | 4.952 |
| **Milsorg** | 7.524 | -12.498 |
| **Oignon** | 7.834 | -9.613 |
| **Mangue** | 5.975 | -11.919 |
| **Ara** | 5.328 | -8.027 |
| **Autprodag** | 5.972 | -7.791 |
| **Bovin** | 8.636 | -11.415 |
| **Autpelev** | 4.540 | 1.287 |
| **Viandvolail** | 5.878 | -6.286 |
| **Farinmils** | 7.386 | -6.343 |
| **Autpalim** | 7.364 | -1.531 |
| **Tabac** | 9.109 | -2.876 |
| **Pmanuf** | 6.442 | 2.970 |
| **Pautgcivil** | 8.045 | -3.861 |
| **Pelec** | 7.481 | -1.616 |
| **Stelecom** | 5.132 | -5.340 |
| **SRP** | 8.542 | 22.051 |
| **Mais** | 4.736 | -11.609 |
| **Tomat** | 7.702 | -12.395 |
| **Banane** | 3.584 | -15.342 |
| **Pech** | **7.590** | **-3.054** |
| **Caprin** | 8.396 | -16.751 |
| **Viandbov** | 5.667 | -6.365 |
| **Huilbara** | 9.338 | -2.552 |
| **Tomatcons** | 3.236 | -5.989 |
| **Zircon** | 16.442 | 5.914 |
| **Azengrais** | 6.368 | -0.284 |
| **Pautorout** | 10.189 | -2.128 |
| **Paconstr** | 8.192 | 1.506 |

| | | |
|---|---|---|
| **Shotel** | 8.249 | -1.585 |
| **Autserv** | 16.711 | -3.407 |

***Source:*** Authors' calculations.

In the laissez-faire scenario, as the market prices of local goods rise, agents are shifted to relatively cheaper imported goods. In the lockdown scenario, the fall in household consumption demand concerns both local and imported goods (Table 5).

**Table 5: Variation in Imported Goods (%)**

| Product | Laissez-Faire | Lockdown |
|---|---|---|
| **Volail** | 3.567 | -20.025 |
| **Milsorg** | 4.700 | -26.930 |
| **Oignon** | 4.980 | -23.958 |
| **Ara** | 3.945 | -17.790 |
| **Ovin** | 6.209 | -18.573 |
| **Viandbov** | 4.337 | -15.205 |
| **Tomatcons** | 1.941 | -13.448 |
| **Autpext** | -4.705 | -4.720 |
| **Autpchim** | -4.632 | -10.460 |
| **Pelec** | 3.539 | -10.917 |
| **SRP** | 5.454 | 39.329 |
| **Mais** | -4.496 | -24.297 |
| **Banane** | 1.331 | -36.679 |
| **Autprodag** | 1.682 | -17.906 |
| **Bovin** | 9.536 | -19.842 |
| **Viandovcap** | 3.248 | -18.197 |
| **Laitass** | 1.679 | -11.336 |
| **Tabac** | 6.176 | -13.827 |
| **Pmanuf** | 0.078 | 4.482 |
| **Stelecom** | 1.468 | -14.992 |
| **Ble** | -5.348 | -5.795 |
| **Rizpaddy** | 1.888 | -27.848 |
| **Agrum** | -1.497 | -47.145 |
| **Pech** | 7.937 | -10.863 |
| **Autpelev** | 3.184 | 7.399 |
| **Rizdecort** | 1.087 | -10.095 |
| **Autpalim** | 3.536 | -6.083 |
| **Azengrais** | -0.166 | -6.625 |
| **Peau** | 4.546 | -12.294 |
| **Autserv** | 13.696 | -21.973 |

***Source:*** Authors' calculations.

The end result is a decrease in real GDP (-9.173 % in laissez-faire and-11.159% in the other) and an increase in unemployment (Table 6).

Remember that, in the labor market, wages are presumed to be rigid. The effect of cumulative absenteeism as a result of confinement has a stronger impact on the labor market in the lockdown scenario.

**Table 6: Variation in the Unemployment Rate (%)**

| Qualification | Laissez-Faire | Lockdown |
|---|---|---|
| **LTQH** | 4.005 | 37.312 |
| **LMQH** | -0.293 | 103.810 |
| **LTQF** | 2.449 | 49.062 |
| **LMQF** | 0.089 | 112.479 |

***Source:*** Authors' calculations.

Finally, the effects in terms of losses to the country's economy are greater if there is no containment (-25,347 in laissez-faire compared to -17,585 in lockdown). To cancel losses to the economy, the GDP would have to increase by 20.65% in laissez-faire and 9% in lockdown

# IV. Conclusions and Policy Implications

- A pandemic model can be associated with an economic model to evaluate the effects of a pandemic on production/consumption and, consequently, on the objective function of government.
- Our results show that, in the case of an imported pandemic, the exogenous increase of imported infected individuals could have significant negative impacts on the economy. Lockdown improves the health situation but generates more negative effects on the economy while, at the same time, reducing the function loss of government.
- Because of the function loss, a threshold could be introduced to trigger the lockdown of the economy, implying an economic cost that can be evaluated.

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# Appendix

**Activities**

| Code | Names |
|---|---|
| Cereal | Cereal cultivation |
| Tubleg | Cultivation of tubers; dry pod vegetables and spices |
| Fruitpf | Fruit, plant and flower crops, nurseries |
| Araolea | Peanuts and other oilseed products (except cotton grains) |
| Autag | Other agricultural crops and support activities |
| Bovovcap | Cattle, sheep and goat farms |
| Volail | Poultry farm |
| Autelev | Hunting; livestock-support activities, and other related activities |
| Pechpaqua | Fishing, fish farming, and aquaculture |
| Extract | Extractive activities |
| Viandp | Slaughter, processing, and conservation |
| Gras | Manufacture of edible fats |
| Grains | Grain work |
| Cfruitleg | Preserved fruits and vegetables |
| Indlaitgl | Manufacture of dairy products and ice cream |
| Autalim | Other food industries |
| Autindna | Other non-food industries |
| Autorout | Construction of roads and highways |
| Portaero | Ports and airports |
| Autgcivil | Other civil engineering |
| Autconstruc | Other construction activities |
| Hotel | Hotel and accommodation |
| Restau | Eating and drinking places |
| Telecom | Telecommunications |
| NTSER | Non-market services |
| SRP | Research and prospecting services |
| Autserv | Other market services |

**Products**

| Code | Names |
|---|---|
| Ble | Corn |
| Milsorg | Millet-Sorghum |
| Mais | Corn |
| Rizpaddy | Paddy rice |
| Oignon | Onions |
| Tomat | Tomatoes |
| Melonp | Melons and watermelons |
| Mangue | Mangoes |
| Banane | Bananas |
| Agrum | Citrus |
| Ara | Peanuts |
| Cotgrain | Seed cotton |
| Acajou | Cashew nuts |
| Autprodag | Other agricultural products |
| Pech | Peaches |

| | |
|---|---|
| Ovin | Sheep |
| Bovin | Cattle |
| Caprin | Goats |
| Laitbrut | Raw cows' milk |
| Volail | Poultry |
| Autpelev | Other livestock products |
| Viandbov | Beef meat |
| Viandovcap | Sheep and goat meat |
| Viandvolail | Poultry meat |
| Huilbara | Crude peanut oils |
| Rizdecort | Husked rice |
| Farinmils | Millet flour and sorghum |
| Tomatcons | Tomato preserves |
| Laitass | Milk and the like |
| Autpalim | Other food products |
| Zircon | Zircon |
| Autpext | Other mining products |
| Tabac | Cigarettes and other manufactured tobacco |
| Azengrais | Nitrogen products and fertilizers |
| Autpchim | Other basic chemicals |
| Pmanuf | Non-food manufacturing products |
| Pautorout | Road and highway products |
| Pportaero | Ports and airport |
| Pautgcivil | Other civil engineering works |
| Paconstr | Other constructions |
| Peau | Water |
| Pelec | Electricity |
| Shotel | Hotel and restaurant services |
| Srestau | Eating and drinking places |
| Stelecom | Telecommunications services |
| NTSER | Non-market services |
| SRP | Research and prospecting services |
| Autser | Other services |