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## Article

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# The role of informality in the economic growth, employment, and inflation during the COVID-19 crisis

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## ABSTRACT

The COVID-19 pandemic significantly impacted the global economy, with variable effects on economic growth, employment, and inflation rates in different countries and regions. Latin America and the Caribbean (LAC) region experienced the most severe consequences for economic growth and employment, while the change in inflation was relatively less affected. A notable characteristic of the LAC region is its high level of informality and its close relationship with inflation dynamics. A dynamic stochastic general equilibrium model was built and simulated to understand the role of informality in the COVID-19 crisis. The findings highlight that the informal sector exacerbates the negative impacts of the crisis on economic growth and employment rates but mitigates the inflationary effects resulting from the containment measures. In summary, the high rates of informality in the LAC region play an important role in shaping the consequences of restrictive measures to curb the pandemic on the economy.

## 1. Introduction

The COVID-19 pandemic in 2020 has caused the largest global economic contraction in the last 60 years. According to World Bank data, the world GDP per capita contracted by 4.0% from a year earlier, and the employment rate fell by 1.8 pp. In addition, one year later, global inflation increased by 3.5%, among the largest increases in the last decade. These increases in global prices are due to substantial interruptions in the global supply chain, changes in household consumption patterns, and frictions in the labor markets, which made it impossible to satisfy the demand derived from the progressive economic reopening (see [Kouvavas et al., 2020](#); [Boissay et al., 2021](#); [LaBelle and Santacreu, 2022](#)).

The pandemic has affected each country differently. The handling of the pandemic by the authorities, the stimulus policies of the governments, and some structural characteristics of the countries, such as economic diversification, the structure of the labor market, and the educational level, explain these differences (see [Galasso and Foucault, 2020](#); [Gimbel et al., 2020](#); [Niermann and Pitterle, 2021](#); [Leyva and Urrutia, 2022](#)). In particular, the Latin America and Caribbean (LAC) region was the most affected regarding economic growth and employment rate. Despite this, it was one of the regions with the least changes in the inflation rate.

Regarding the labor market structure, LAC countries stand out for their large informal sectors ([David et al., 2020](#)). This labor market structure is vital to its resilience during the COVID-19 pandemic. On the one hand, [Loayza \(2020\)](#) argues that informal employment is a characteristic of emerging and developing economies that makes them more vulnerable to the COVID-19 crisis. On the other hand, [Alberola and Urrutia \(2020\)](#) demonstrates that the informal sector acts as a buffer against inflationary pressures

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caused by various shocks, including those related to demand, technology, monetary policy, and financial markets, where the coronavirus crisis is a combination of these shocks.

In the pandemic crisis, the informality rate in the LAC region showed unprecedented procyclical behavior. [Leyva and Urrutia \(2022\)](#) documented and explained this fact. In particular, these authors found that labor supply and productivity shocks in the informal sector explain the procyclical informality rate and the large economic and employment losses during the pandemic. However, the [Leyva and Urrutia](#)'s (2022) model presents some limitations that prevent us from ascertaining the role of the informal sector during the COVID-19 crisis. First, productivity and labor supply shocks are treated as pandemic shocks. At the same time, recent works such as ([Busato et al., 2021](#)) introduce a richer pandemic environment that allows a better simulation of the COVID-19 crisis, including a lockdown policy based on active cases and economic activity instead of treating the pandemic shock as a combination of a productivity shock and a labor supply shock. Second, a framework of nominal rigidities, typical of a New Keynesian Dynamic Stochastic General Equilibrium (NK DSGE) model, is not considered, making it almost impossible to assess the inflationary effects of the pandemic crisis.

In this study, we explore the role of the informal sector in three main macroeconomic aggregates: the output growth rate, the employment rate, and the inflation rate, in the face of shocks that simulate the COVID-19 crisis. We use the framework of [Busato et al. \(2021\)](#), which provides a detailed pandemic block and endogenous lockdown policy. In addition, on the demand side, we add a factor that decreases both the marginal utility of consumption and labor supply with the severity of the disease, similar to [Chan \(2022\)](#). Finally, we introduce a rich labor market structure, and nominal rigidities, as in [Alberola and Urrutia \(2020\)](#). The exercise introduces an exogenous virus outbreak under two cases, an economy with mixed employment and another with the same characteristics but without informal employment. This counterfactual exercise allows us to determine the effect of the shadow economy on the pandemic crisis.

Following [Fernández and Meza \(2015\)](#), [Leyva and Urrutia \(2020\)](#), [Alberola and Urrutia \(2020\)](#), we calibrate the model for Mexico's economy as a potential representative of the informal economy in the LAC region, given its high rates of informality and the wide availability of data related to employment and the pandemic. First, we obtain the structural parameters from [Alberola and Urrutia's \(2020\)](#) model, the equivalent case to the pre-pandemic economy. Subsequently, we adjust the model to a fortnightly frequency. For this, we adjust the value of some parameters that allow us to simulate the dynamics under this frequency. Finally, we calibrate the parameters related to the COVID-19 block, using data on new cases and deaths from COVID-19 for the Mexican economy from the second half of February 2020 to the second half of June 2021. Even though the analysis focuses on the 2020–2021 period, to avoid distortions in the macroeconomic aggregates due to the Russian invasion of Ukraine, we take the most recent data from the pandemic, which allows us better to model the behavior of the virus outbreaks in Mexico.

The model operates as follows. First, there is an outbreak of an exogenous virus that spreads among individuals through consumption, labor, and non-economic activities. So, the active cases start to pile up as some recover and others die. At the same time, the government implements the lockdown policy by limiting the effective use of labor through a policy rule that depends on the mortality rate, preventing the further spread of the virus and human losses. Later, as the virus spread slows, the death rate begins to decline, allowing the government to relax lockdown measures and leading the economy into a recovery stage. Finally, households recover the path of consumption and rejoin the labor market.

In our simulations, a single virus wave (a pandemic shock) produces strong economic and job losses, large and persistent price increases, and a procyclical informality rate consistent with the dynamics observed during the COVID-19 crisis. By removing informal employment from the benchmark model, we find that the pandemic shock in this economic environment causes less economic and employment damage; however, it produces greater inflationary effects. In addition, the recovery of total employment is slower than when the labor market is mixed, and this is because informal employment is frictionless, allowing it greater resilience during the economic reopening.

We also break down the characteristics of the informal sector one by one to identify how they individually contribute to the impacts of the pandemic crisis. We find that the main features are free entry costs and tax evasion. On the one hand, free entry costs accelerate the flows into and out of informal employment, which produces greater falls in total employment and output at the time of the pandemic shock, and in the recovery phase, the economy does so faster. On the other hand, tax evasion prevents the government from alleviating the economy through lump-sum taxes since it reduces them less than in a scenario where informal employment is absent, which prevents households from smoothing their consumption. Therefore, a buffering effect over inflation arises.

Finally, through a welfare analysis, our results indicate that welfare loss in an economy without the informal sector is less than when there is mixed employment. This result highlights the consequences of lockdown policies in economies with large informal sectors and the challenges to labor market regulation in the Latin American and Caribbean region.

The rest of this document is organized as follows. Section 2 presents a review of the COVID-19 crisis in the world with an emphasis on the Latin American and Caribbean region and their labor market structure. The literature review is shown in Section 3. Next, Section 4 describes the structure of the model, while Section 5 details the calibration of the parameters. Section 6 discusses the research results, the impulse response functions, and the counterfactual exercise that eliminates informal employment. Section 7 concludes.

## 2. Background

The first human cases of COVID-19, the Coronavirus disease caused by SARS-CoV-2, occurred in Wuhan Province, China, in December 2019. During the first quarter of 2020, the virus spread to all continents, infecting over 850,000 people and causing 450,000 deaths. As a result, the World Health Organization declared the novel Coronavirus outbreak a global pandemic.

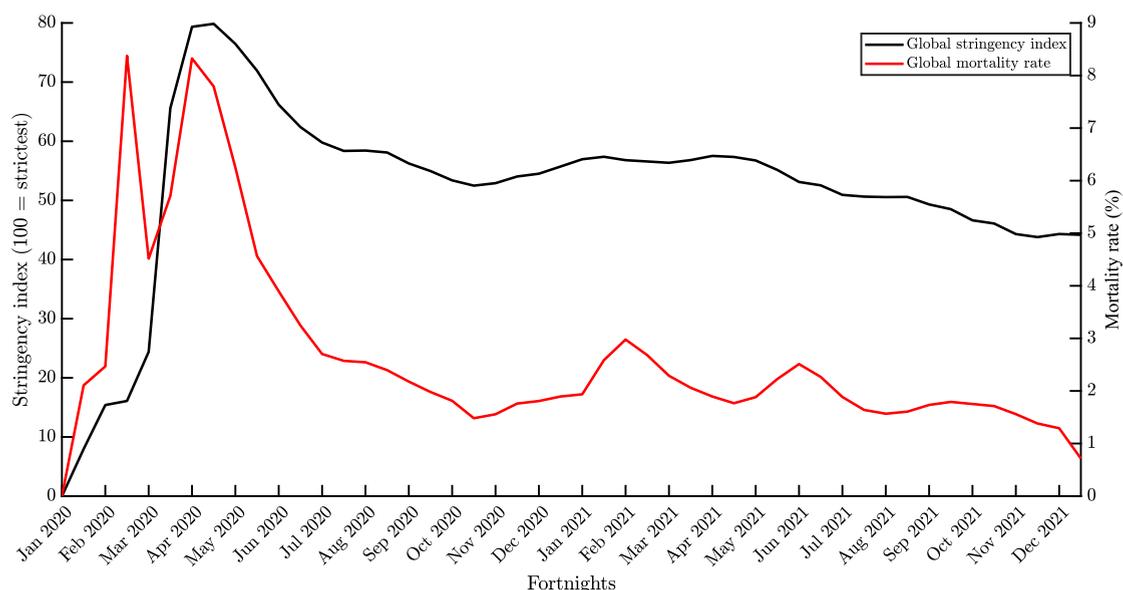


Fig. 1. Lockdown vs. Mortality rate.

Table 1

Main macroeconomics aggregates during COVID-19 pandemic.

Source: Author's calculations with data from World Bank Data.

Group	GDP growth per capita (2020)	Employment rate change (2020)	Inflation rate (2021)
<b>Income level</b>			
High income	-4.6	-1.9	2.5
Upper middle income	-1.2	-2.2	3.5
Middle Income	-2.2	-1.9	4.1
Lower middle income	-4.5	-1.4	3.5
Low income	-2.7	-1.2	5.0
<b>Region</b>			
East Asia and Pacific	-0.6	-1.6	2.4
Europe and Central Asia	-5.7	-1.2	3.3
Latin America and Caribbean	-7.4	-5.0	3.9
Middle East and North Africa	-5.1	-1.7	2.3
North America	-3.9	-4.0	4.0
South Asia	-5.7	-1.3	5.5
Sub-Saharan Africa	-4.5	-1.0	4.3
<b>Other</b>			
OECD members	-4.7	-2.4	2.8
World	-4.0	-1.8	3.5

Note: The figures in the first and third columns represent percentages, while in the second, they represent percentage points.

Policymakers implemented restrictive lockdown measures to hold back the spread of the virus and prevent further human losses at the cost of stopping the world economy (Leyva and Urrutia, 2022). The main measures consisted of quarantines, travel restrictions, factory closures, limited personnel, and severe limitations in the service sector (Boone et al., 2020). Hence, the labor market suffered a major shock, leading to a deep global economic contraction. In return, the global mortality rate was reduced, which allowed the confinement measures to be relaxed (see Fig. 1). Subsequently, however, an inflationary worldwide phenomenon arose since the strong disruptions in the global supply chain and the lack of labor input made it impossible to satisfy the increase in demand resulting from the economic reopening.

The coronavirus crisis affected world regions unequally (see Table 1). The heterogeneity in the ravages of the crisis is explained by governments' different handling of the pandemic, both in terms of health, fiscal, and monetary policy (see, for example, König and Winkler (2021), Chen et al. (2021), Yilmazkuday (2022)). In addition, the economic characteristics of each country, such as the labor market structure and economic diversification, contribute to widening these differences (see Niermann and Pitterle, 2021; Leyva and Urrutia, 2022).

LAC region was the most affected group in terms of economic growth and employment rate; despite this, the price increase was not even among the three highest (see Table 1). Concerning the topics that highlight the difference in the impact of COVID-19 between countries, the LAC region stands out for its labor market structure, which, according to David et al. (2020), is characterized

**Table 2**

Informality rate in the Latin American and Caribbean countries during 2019.

Source: Author's calculations with data from the International Labor Organization.

Country	Informality rate	Country	Informality rate
Uruguay	24.5	Venezuela	58.3
Chile	29.3	Barbados	62.0
Saint Lucia	31.9	Colombia	62.1
Brazil	40.1	Ecuador	63.5
Costa Rica	41.2	Peru	68.4
Argentina	49.7	Paraguay	68.9
Guyana	50.0	El Salvador	69.1
Suriname	52.1	Guatemala	79.0
Panama	52.8	Bolivia	81.5
Dominican Republic	54.2	Nicaragua	81.8
Jamaica	56.4	Honduras	82.6
Mexico	57.6	Haiti	91.6

**Note:** We use the most recent informality rate available for Suriname, Venezuela, Barbados, Nicaragua, Honduras, and Haiti.

by large informal sectors and relatively rigid labor regulation. Furthermore, according to [Elgin et al. \(2022\)](#), the size of the informal economy is strongly related to the effectiveness and size of the fiscal stimulus, which contributes to the explanation of the differences in the impact of the COVID-19 crisis.

By 2019, in more than half of the LAC countries, informal employment represents more than half of the total employment (see [Table 2](#)). Moreover, according to [Medina and Schneider \(2019\)](#), LAC is the second region where the informal economy contributes a high percentage of GDP, behind Sub-Saharan Africa. In addition, [Leyva and Urrutia \(2022\)](#) mention that in previous downturns, Mexico, Colombia, Brazil, and Chile exhibited a countercyclical informality rate. However, during the pandemic slump, it had a procyclical behavior. Therefore, it is worth analyzing the effects of informal employment in the LAC region.

### 3. Literature review

The emergence of the COVID-19 pandemic attracted the attention of academics, who began investigating its impact on health and the economy. Among the first studies is the work of [Atkeson \(2020\)](#), which uses the SIR (Susceptible–Infected–Recovered) epidemiological model, initially proposed by [Kermack and McKendrick \(1927\)](#), to simulate the dynamics of COVID-19 and emphasizing the importance of social distancing, since this measure allows flattening the contagion curves.

The work of [Eichenbaum et al. \(2021\)](#) was one of the pioneers in embedding the SIR epidemiological model into a DSGE macroeconomic model, thus simulating the economic consequences of the COVID-19 pandemic. This model assumes that people can assimilate the disease risk and decide to cut their consumption and reduce the labor supply, causing great economic damage. On the other hand, [Busato et al. \(2021\)](#) uses a similar approach, assuming that the government induces a lockdown policy based on forcibly reducing firms' labor utilization, leading the economy into a recession. This analysis considers three scenarios: the government is more concerned about health, is indifferent between health and the economy, or is more concerned about the economy. Therefore, the government's preferences in dealing with the pandemic play an important role in the size of the recession.

The two studies above implicitly explain the differences in employment rates and economic growth between countries or regions through the differences in the disease risk perception and the lockdown policy's intensity. These two effects operate through reductions in aggregate demand (consumers react to risk by reducing consumption) and reductions in aggregate supply (workers react to risk by reducing their labor supply, and the government forces firms to quarantine their employees). However, these studies do not consider an environment with nominal rigidities that make it possible to assess the inflationary pressures of the pandemic crisis.

In line with the above ([Eichenbaum et al., 2022](#)) extend the model of [Eichenbaum et al. \(2021\)](#), introducing nominal rigidities. In the first place, they compare the model with flexible prices and those with sticky prices, which yield similar results except in the rate of inflation and investment. The model with sticky prices presents more of a moderate decrease in the inflation rate but a severer drop in investment. Second, they find that the inflation rate declines after the virus outbreak and levels off a year later in both models. However, as we have mentioned before, during the second year of the pandemic in most regions of the world, inflation did not stabilize; on the contrary, large price increases were observed.

[He and Wang \(2022\)](#) also feed their model with nominal rigidities. Still, unlike the previous models, they treat the pandemic crisis as a combination of a technological shock and a shock that affects the labor force, that is, from the aggregate supply side. The result they obtain in terms of the inflation rate is that it increases after the economy is disturbed by the pandemic shock since the labor force decreases and production costs increase. In addition, they mention that monetary and fiscal policy can alleviate job losses and increase production to some extent, but long-term inflationary pressures accompany monetary policy.

Therefore, the perceptions of contagion risk, the strictness of the lockdown policy, the fiscal packages, and the monetary policy play an important role in the impact of the pandemic on the economic growth rate, the employment rate, and the inflation rate. However, for the LAC region, [Niermann and Pitterle \(2021\)](#) mention that the restrictions were as severe as in many other regions; furthermore, fiscal incentives per capita represented 8% of GDP, a value that remains slightly below the average in the groups of

countries considered by the authors. On the monetary policy side, there are significant differences between advanced and emerging countries, according to Yilmazkuday (2022), since emerging countries were able to respond to reductions in economic activity by reducing interest rates more aggressively. In contrast, the advanced countries did not act similarly to the emerging countries since most of them have zero-bound on their interest rates. Despite these differences in monetary policy between advanced and emerging economies, we find no evidence that the countries of the LAC region have deployed expansionary monetary policies more aggressively to combat the pandemic crisis than the rest of the emerging economies.

One characteristic that stands out in the Latin American and Caribbean region is its high level of informality, whose role in the COVID-19 crisis has been explored very little. Loayza (2020) argues that informal employment makes economies more vulnerable to the coronavirus crisis. The study of Leyva and Urrutia (2022) seeks to replicate the procyclical behavior of the informality rate in the LAC region during the pandemic crisis through a DSGE model; they use technology and labor supply shocks to simulate the behavior of the crisis. However, the model lacks epidemiological modeling and nominal rigidities. In addition, the role of the informal economy in the main economic aggregates during the COVID-19 crisis is not investigated.

Alberola and Urrutia (2020), through a counterfactual exercise in a DSGE model, find that the presence of the informal sector facilitates price stabilization in the face of demand, technology, and monetary and financial shocks. Furthermore, employment and output contract less in the model with informality than in the model without because of productivity and financial shocks in the formal sector. In most cases, the informality rate acts countercyclically, except for aggregate demand and supply shocks. However, their analysis does not consider a pandemic shock that allows for addressing the role of informality in the COVID-19 crisis.

In this sense, the contribution of this work to the economic literature is to emphasize the role of the informal economy in the face of an economic crisis induced by forced confinement, paying special attention to the main macroeconomic aggregates. For this purpose, we use the Alberola and Urrutia's (2020) model, which presents a detailed environment of the labor market with frictions and rigidities in prices, and we embed epidemiological modeling similar to Busato et al. (2021). In addition, given the relationship between the lockdown policy and the mortality rate presented in the stylized facts, we add a lockdown policy rule that reacts to the virus mortality rate. In the next section, we present the model in detail.

#### 4. Model

This section presents a parsimonious DSGE model for a closed pandemic economy with a representative household, formal and informal productive sectors, labor market frictions, nominal rigidities, and a central government that oversees fiscal, monetary, and health policies.

The representative household may spend part of its time working in the formal sector. It may also be self-employed in the informal sector,<sup>1</sup> seek formal jobs as unemployed, or stay out of the labor force. Following Alberola and Urrutia (2020), we characterized the formal labor market as a sector with frictions in the hiring process, participation in the credit market, and contributing with taxes to the government; on the other hand, the informal sector operates with low productivity, is more flexible, evades taxes, and its members do not have access to the credit market.

Virus outbreaks occur exogenously, while their spread occurs through consumption, labor, and non-economic activity. In addition, the cases remain active for about a fortnight, some recover, and others die from the disease.

The government manages monetary policy by setting the interest rate according to a Taylor-type feedback rule on inflation and the output gap. The fiscal policy collects fixed and payroll taxes to finance public spending. Finally, health policy operates through restrictions on the use of labor following the mortality rate and the output gap.

##### 4.1. Population, occupation, and households

The total population is standardized to one and split into four occupational groups: individuals employed in the formal sector denoted by  $L_t^F$ , those who are self-employed represented by  $L_t^S$ , unemployed people indicated by  $U_t$ , and individuals who are not part of the labor force and denoted by  $O_t$ . The non-employed category is further classified into two groups: the unemployed, who incur job search costs, and those who are inactive. Finally, the total labor supply is the sum of individuals employed in the formal sector and those self-employed, represented by  $L_t$ .

The representative household derives utility from consumption and disutility from both labor and unemployment. Labor disutility is interpreted as the value of foregone leisure, while unemployment disutility is related to job search costs. The expected lifetime utility function is given by:

$$\mathbb{E}_t \sum_{\tau=0}^{\infty} \beta^{\tau} H_{t+\tau} \left[ \log \left( C_{t+\tau} - \psi \Phi_{t+\tau} \frac{L_{t+\tau}^{1+\phi}}{1+\phi} \right) - \frac{\zeta}{2} U_{t+\tau}^2 \right], \quad (1)$$

where  $\mathbb{E}_t$  denotes the mathematical operator of expectations conditional on the information available in period  $t$ ,  $C_t$  and  $L_t$  are consumption and labor supply at time  $t$ ,  $N_t$  are the new cases of the disease.  $\beta \in (0, 1)$  is the subjective discount factor,  $\psi \in [0, \infty)$  measures the labor disutility,  $\phi \in (0, \infty)$  is the inverse of Frisch elasticity,  $\zeta \in (0, \infty)$  measures the cost of searching

<sup>1</sup> Alberola and Urrutia (2020) assume that the informal sector is composed entirely of self-employed workers since, in Mexico, 41% of informal workers are self-employed. While in the formal sector, the self-employed represent 14%.

for unemployment. Following Chan (2022)  $H_t$  is a health-related variable that affects consumption desire, and the disutility of both labor and unemployment has the following behavior:

$$H_t = \left( \frac{N_t}{N_{ss}} \right)^{-\varphi_h} \tag{2}$$

where  $\varphi_{h,c} \in [0, \infty)$  denotes the percentage increase in  $H_t$  for a 1% increase in infected; therefore, higher infection rates elevate fear of contagion, leading households to reduce consumption and work hours as preventive measures. A deterministic shifter factor is introduced  $\Phi_t \equiv C_t^\omega \Phi_{t-1}^{1-\omega}$  that allows controlling the wealth effect on the labor supply by varying the parameter  $\omega \in [0, 1]$ .

Household expenses are distributed in consumption, physical capital investment, and the purchase of domestic bonds. At the same time, the sources of income are labor income from the formal and informal sectors, income from capital returns from holding bonds, profits from the firms they own, and direct taxes. Therefore, the household budget constraint in real terms is given by:

$$C_t + I_t + B_t \leq W_t^F \mu_t L_t^F + W_t^S \mu_t L_t^S + R_t K_t + \left( \frac{1 + i_{t-1}}{1 + \pi_t} \right) B_{t-1} + \Pi_t - T_t, \tag{3}$$

where  $I_t$  is the capital investment,  $B_t$  are domestic bonds,  $W_t^F$  is the wage per unit of effective labor in the formal sector,  $W_t^S$  is the wage per unit of effective labor in the informal sector,  $R_t$  represents the rate of rent for capital,  $K_t$  is the capital stock,  $i_t$  is the nominal interest rate,  $\pi_t$  denotes the inflation rate,  $\Pi_t$  represents profits from firms owned by the household,  $T_t$  is a lump-sum tax, and  $\mu_t$  denotes the labor effective utilization.

The latter is a time-varying parameter that seeks to capture the strength of social distancing measures. Higher values indicate minimal social distancing (e.g., a value of one implies no confinement measures), while values closer to zero represent stricter quarantine measures. We will delve deeper into this concept later.

Additionally, the investment decisions are affected by convex capital adjustment costs, and the physical capital is accumulated according to the following law of motion:

$$K_{t+1} = (1 - \delta) K_t + I_t - \frac{\vartheta}{2} \left( \frac{I_t}{K_t} - \delta \right)^2 K_t, \tag{4}$$

where  $\delta \in (0, 1)$  measures the capital depreciation rate, and  $\vartheta \in [0, \infty)$  captures the sensitivity parameter for the capital adjustment costs.

#### 4.2. Firms

##### 4.2.1. Final good firms

The final good is aggregated across varieties,  $z \in (0, 1)$ , of the intermediate goods using a Dixit–Stiglitz aggregator:

$$Y_t \equiv \left( \int_0^1 Y_t(z)^{\frac{\eta-1}{\eta}} dz \right)^{\frac{\eta}{\eta-1}}, \tag{5}$$

$\eta \in [0, \infty)$  is a parameter that measures the elasticity of substitution between varieties. The profits of the final good distributor are given by:

$$P_t Y_t - \int_0^1 P_t(z) Y_t(z) dz, \tag{6}$$

where  $P_t$  is the price of final good and  $P_t(z)$  is the price associated with the variety  $z$ . The distributor of the final good maximizes his profits by choosing the quantity of the final good while taking the price of the final good and the varieties as given.

##### 4.2.2. Intermediate goods firms

There are a continuum of intermediate good firms indexed by  $z \in (0, 1)$ . Each intermediate good firm  $z$  solves a two-step problem to produce a variety  $z$ . In the first step, it minimizes its cost by selecting capital stock  $K_t(z)$ , and the quantities of formal  $Q_t^F(z)$  and informal goods  $Q_t^S(z)$ ,

$$R_t K_t(z) + P_t^F Q_t^F(z) + P_t^S Q_t^S(z), \tag{7}$$

where  $P_t^F$  is the price of goods produced in the formal sector and  $P_t^S$  is the price of goods produced in the informal sector, taking prices as given subject to the production function:

$$Y_t(z) = A_t \left[ \alpha K_t(z)^{\frac{v-1}{v}} + (1 - \alpha) Q_t(z)^{\frac{v-1}{v}} \right]^{\frac{v}{v-1}}, \tag{8}$$

here  $A_t$  denotes total factor productivity (TFP),  $\alpha \in (0, 1)$  is a distribution parameter reflecting capital intensity in production. The composite good is defined as follows:

$$Q_t(z) = \left( Q_t^F(z)^{\frac{\epsilon-1}{\epsilon}} + Q_t^S(z)^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}}, \tag{9}$$

where  $\epsilon \in [0, \infty)$  is the elasticity of substitution between formal and informal goods. The formal good is produced using effective labor from the formal sector. In contrast, the informal output is produced using effective labor from the informal sector, that is,

$Q_t^F(z) \equiv A_t^F \mu_t L_t^F(z)$  and  $Q_t^S(z) \equiv \chi \mu_t L_t^S(z)$ , where  $A_t^F$  denotes the productivity of a worker in the formal sector, and  $\chi \in [0, 1]$  captures inefficiencies in informal sector productivity relative to formal sector productivity.

In the second step, only a random fraction  $1 - \theta$  of firms can reset their price; all other firms keep their prices unchanged. When firms reset their prices, they must consider that the price may be fixed for many periods. The following problem gives the optimal price selection. Each monopolistic firm  $z$  chooses its price  $P_t^*(z)$ , to maximize its nominal profits facing Calvo-type nominal rigidities and a common marginal cost  $MC_t$ :

$$\mathbb{E}_t \sum_{j=0}^{\infty} (\theta \beta)^j \frac{\lambda_{C,t+j}}{\lambda_{C,t}} \left( \frac{P_t^*(z)}{P_{t+j}} - \frac{MC_{t+j}}{P_{t+j}} \right) Y_{t+j}(z), \tag{10}$$

subject to the aggregate demand condition from the final good maximization problem:

$$Y_t(z) = \left( \frac{P_t(z)}{P_t} \right)^{-\eta} Y_t. \tag{11}$$

On the other hand, under the assumption of symmetry in which all firms follow the same pricing strategy, aggregating among retailers, the aggregate price index is given by:

$$P_t = \left[ (1 - \theta) P_t^*{}^{1-\eta} + \theta P_{t-1}^{1-\eta} \right]^{\frac{1}{1-\eta}}. \tag{12}$$

### 4.3. The labor market

There is a continuum of ex-ante equal formal entrepreneurs indexed by  $f \in (0, 1)$  with the potential to start a firm. Meanwhile, unemployed individuals  $U_t$  are looking for formal employment, and the entrepreneurs are creating job opportunities by posting formal job vacancies  $V_t^F$ . New formal matches are created through a standard constant return to scale matching function as follows:

$$M_t(f) = U_t(f)^\zeta V_t^F(f)^{1-\zeta}, \tag{13}$$

where  $\zeta \in (0, 1)$  is the matching function elasticity. A vacancy has a common cost  $\xi \in [0, \infty)$ , which lasts a period and is expressed in units of the final good for the entrepreneur.

At the beginning of the period, a group of workers  $L_{t-1}^F(f)$  are employed in the formal sector. A certain exogenous fraction  $s \in (0, 1)$  of the employed workers are laid off and unemployed. During the period, new formal matches between firms and workers are also created, so the number of formal employees at time  $t$  evolves by:

$$L_t^F(f) = (1 - s) L_{t-1}^F(f) + q_t^F(f) V_t^F(f), \tag{14}$$

where  $q_t^F(f)$  represents the probability that a vacancy is filled by a worker and is determined by the first-order condition of the matching function with respect to vacancies.

An active match produces one unit of formal intermediate input using one worker. The value of a match for a formal entrepreneur in terms of utility is defined recursively as follows:

$$J_t^F = \mu_t \left[ P_t^F A_t^F - (1 + \kappa_t + \tau) W_t^F \right] \lambda_t^C + \beta (1 - s) \mathbb{E}_t J_{t+1}^F, \tag{15}$$

where  $\kappa \in (0, \infty)$  represent the working capital requirement for the formal sector and  $\tau \in (0, 1)$  is a payroll tax.

On the other hand, the value that a worker assigns to being employed in the formal sector is represented by  $\lambda_t^F$  and is given recursively by:

$$\lambda_t^F = \mu_t W_t^F \lambda_t^C - \psi \Phi_t L_t^\phi \frac{\partial u_t}{\partial C_t} + \beta (1 - s) \mathbb{E}_t \lambda_{t+1}^F, \tag{16}$$

here  $\partial u_t / \partial C_t$  denotes the marginal utility of consumption and  $\lambda_t^C$  represents the Lagrange multiplier for consumption.

The Nash product is defined as the weighted product of the value of a single worker for a formal employer and the value of a formal job for a worker as follows:

$$(\lambda_t^F)^\gamma (J_t^F)^{1-\gamma}, \tag{17}$$

where  $\gamma \in (0, 1)$  represents workers' bargaining power. The wage in the formal sector is determined by the argument that maximizes the Nash product. Finally, vacancy postings in the formal sector satisfy the following zero profit condition:

$$q_t^F J_t^F = \xi \lambda_t^C. \tag{18}$$

The informal sector has no search frictions, taxes are evaded, and no access to working capital (see Eq. (25)), so the representative household determines wages and informal labor.

#### 4.4. COVID-19 pandemic

The transmission of virus  $V_t$  occurs in the workplace, consumer activities, and non-economic activities, so that the following expression gives the newly infected  $N_t$ :

$$\frac{N_t}{N_{ss}} = (\varpi_c C_t + \varpi_l \mu_t L_t + \varpi_o) V_t, \tag{19}$$

where  $\varpi_c, \varpi_l, \varpi_o \in [0, \infty)$  are the consumption, labor, and non-economic activity weight in epidemic propagation, respectively.

The size of the disease  $S_t$  is determined by the current patients, the new cases, less the recovered ones, and the deaths; this is expressed through the following accumulation rule:

$$S_{t+1} = (1 - r - m)S_t + N_t, \tag{20}$$

where  $r \in (0, 1)$  is the recovery rate and  $m \in (0, 1)$  denotes the mortality rate mean.

#### 4.5. Government

The government oversees the fiscal, monetary, and health policies. The monetary policy is executed by adjusting the nominal interest rate based on a Taylor-type feedback rule, which considers inflation and the output gap.

$$1 + i_t = \frac{1}{\beta} \left( \frac{P_t}{P_{t-1}} \right)^{\varphi_{i,\pi}} \left( \frac{Y_t}{Y_t^n} \right)^{\varphi_{i,y}}, \tag{21}$$

where  $\varphi_{i,\pi} \in [0, \infty)$  is the parameter that governs the reaction of the interest rate to inflation, and  $\varphi_{i,y} \in [0, \infty)$  captures the reaction of the interest rate to the output gap.

On the other hand, fiscal policy encompasses the collection of taxes and the exercise of public spending. Public spending  $G_t$  follows the output,<sup>2</sup> so the exercise of spending is carried out as a stochastic fraction  $g_t$  of the output  $G_t = g_t Y_t$ . The government budget constraint is given by:

$$G_t = \tau W_t^F \mu_t L_t^F + T_t, \tag{22}$$

Finally, on the health policy side, the government restricts the use of labor in the formal and informal sectors indiscriminately when there are sharp increases in the death rate from the disease, and at the same time, is concerned about the damage to the economy; therefore it also takes into account the output gap:

$$1 - \mu_t = (1 - \mu_{t-1})^{\rho_\mu} \left[ \left( \frac{S_{t+1}}{S_{ss}} \right)^{\varphi_{\mu,s}} \left( \frac{Y_t}{Y_t^n} \right)^{1 - \varphi_{\mu,s}} \right]^{1 - \rho_\mu}, \tag{23}$$

here the use of labor  $\mu_t$  is controlled by the government simulating the lockdown policy; this component reacts negatively to increases in active cases of the disease and to the output gap in an exchange between health and the economy, where  $\rho_\mu \in (0, 1)$  measures the persistence of lockdown policy, and  $\varphi_{\mu,s} \in [0, 1]$  is the elasticity of the lockdown policy to the active cases.

#### 4.6. Market clearing

The aggregate profits of formal entrepreneurs are given by the earnings from the sale of formal inputs minus the capital requirements of formal workers, wages, and the cost of posting vacancies, that is:

$$\Pi_t^F = P_t^F Q_t^F - (1 + \kappa i_t + \tau) W_t^F \mu_t L_t^F - \xi V_t^F, \tag{24}$$

On the other hand, the aggregate profits of self-employed workers are given by the earnings from the production of the informal good minus their salary, that is:

$$\Pi_t^S = P_t^S Q_t^S - W_t^S \mu_t L_t^S, \tag{25}$$

Therefore, the aggregate of profits is given by the sum of profits of the producers in the formal sector, profits of the producers in the informal sector, and profits of the producers of the final good, as follows:

$$\Pi_t = \Pi_t^F + \Pi_t^S + (1 - MC_t) Y_t, \tag{26}$$

The one-period bond market clears in a way that satisfies the working capital requirements of formal firms, that is:

$$B_{t+1} = \kappa W_t^F L_t^F, \tag{27}$$

Combining the representative household budget constraint (3), the government budget constraint (23), the aggregate benefits (27), and the one-period bond market clearing condition (28), we obtain the following market-clearing condition:

$$Y_t = C_t + G_t + I_t + \xi V_t^F. \tag{28}$$

<sup>2</sup> The assumption that public spending is a fraction of output supports a procyclical fiscal policy observed in countries with high rates of informality (see for example [Çiçek and Elgin, 2011](#))

#### 4.7. Stochastic processes

We assume that both aggregate TFP and the formal sector TFP follow an AR(1) process as shown below:

$$A_t = \rho_A A_{t-1} + \varepsilon_{A,t}, \quad A_t^F = \rho_A A_{t-1}^F + \varepsilon_{A^F,t}, \tag{29}$$

where  $\rho_A \in (0, 1)$  denotes the persistence of aggregate productivity and formal sector productivity shocks. Furthermore, productivity shocks are independent and identical distributed random variables, that is  $\varepsilon_{A,t} \stackrel{i.i.d.}{\sim} \mathcal{N}(0, \sigma_A^2)$  and  $\varepsilon_{A^F,t} \stackrel{i.i.d.}{\sim} \mathcal{N}(0, \sigma_{A^F}^2)$ .

The emergence of the virus  $V_t$  is assumed to follow an zero-mean *ARIMA*( $p, d, q$ ) process that is formally written by the following expression:

$$\left(1 - \sum_{m=1}^p \rho_{v,m} \mathbb{L}^m\right) V_t = \left(1 + \sum_{n=1}^q \varrho_{v,n} \mathbb{L}^n\right) \varepsilon_{v,t}, \tag{30}$$

where  $\mathbb{L}$  is the lag operator,  $\{\rho_{v,m}\}_{m=1}^p$  are the parameters of the autoregressive part of the model,  $\{\varrho_{v,n}\}_{n=1}^q$  are the parameters of the moving average part, and  $\varepsilon_{v,t} \stackrel{i.i.d.}{\sim} \mathcal{N}(0, \sigma_v^2)$  captures exogenous outbreaks of the virus.

Finally, we assume that the fraction of output that the government spends  $g_t$  follows an AR(1) process, that is:

$$g_t = (1 - \rho_g) g + \rho_g g_t + \varepsilon_{g,t}, \tag{31}$$

here  $g \in (0, 1)$  denotes the average of government expenditures to GDP ratio,  $\rho_g \in (0, 1)$  represents the government spending shocks persistence, where government spending shocks are independent and identical distributed random variables, that is  $\varepsilon_{g,t} \stackrel{i.i.d.}{\sim} \mathcal{N}(0, \sigma_g^2)$ .

### 5. Calibration

This section details the calibration strategy for the model parameters. First, we mute the virus outbreaks by simulating a pre-pandemic scenario in which we seek to match moments in the Mexican economy. Then, once the model's structural parameters have been obtained, we transform some key parameters to adapt the model to a fortnightly frequency. Finally, we calibrate the parameters related to the pandemic block.

#### 5.1. Pre-pandemic scenario

The base structure of our model in the pre-pandemic scenario is based on the [Alberola and Urrutia's \(2020\)](#) model, with the difference that we use a CES production function instead of the Cobb–Douglas production technology. The main reason for this change is that the lockdown policy totally or partially restricts the use of labor so that in the case of a complete closure with the Cobb–Douglas function, the output becomes zero due to the lack of substitution between inputs. Therefore, considering this change in the production function, we recalibrate the model parameters.

Model parameters in the pre-pandemic scenario are categorized into three groups. The first group includes commonly used Real Business Cycle (RBC) and New Keynesian (NK) literature parameters. The second group comprises parameters typically used in the Mexican economic literature or specific to the Mexican economy. The final group of parameters is selected to replicate some target values of the model in steady-state and to match key business cycle moments for Mexico.

For the first block of parameters, we choose the discount factor, the inverse of the Frisch labor supply elasticity, the capital share in producing the final good, and the capital depreciation rate according to the standard business cycle literature. The elasticity of substitution between capital and labor, the elasticity of substitution between varieties, and the parameters associated with the Taylor rule correspond to the prototype New Keynesian model.

For the second block, we obtain parameters widely used in literature and those characteristics of the Mexican economy. The elasticity of substitution between formal and informal inputs is obtained from [Restrepo-Echavarría \(2014\)](#). A standard value in literature for the elasticity of the matching function is the one obtained by [Blanchard and Diamond \(1989\)](#), which we will use in our calibration. The government expenditures to GDP ratio is obtained from [Alberola and Urrutia \(2020\)](#), which calculates its empirical mean. We set the payroll tax's value following the estimates of [Ordóñez \(2014\)](#). [Leyva and Urrutia \(2020\)](#) reported that, on average, a worker lasts 2.8 years in a formal job, so we set the quarterly separation rate consistent with this value. Finally, the requirement for working capital in the formal sector, which has no empirical counterpart, corresponds to the average of the total short-term credit to manufacturing GDP ratio calculated by [Meza et al. \(2019\)](#).

Finally, we calibrate labor disutility, informal sector productivity, search costs for the unemployed, workers' bargaining power, and the costs of posting vacancies to match Mexico's employment rate, informality rate, unemployment rate, formal sector wage premium, and hiring costs over the wage bill, respectively. While the standard deviation of TFP shocks, the persistence of productivity shocks, the strength of the wealth effect on labor supply, the standard deviation of formal TFP shocks, the fraction of firms that do not change prices, the standard deviation of demand shocks, the persistence of demand shocks, the capital adjustment costs, and the elasticity between formal and informal goods to match the Mexican economy's second moments, such as GDP volatility, the first autocorrelation of GDP, the relative volatility of employment to GDP, the volatility of the informality rate, the volatility of the inflation rate, the correlation between inflation and GDP, the relative volatility of consumption to GDP the relative volatility

**Table 3**  
Pre-pandemic structural parameters.

Parameter	Symbol	Value	Source/Target
Discount factor	$\beta$	0.990	
Inverse of Frisch labor supply elasticity	$\phi$	1.000	RBC literature
Capital share in production function	$\alpha$	0.333	
Capital depreciation rate	$\delta$	0.025	
Elasticity of substitution between capital and labor	$\nu$	0.500	
Elasticity of substitution between varieties	$\eta$	5.000	NK literature
Inflation feedback in Taylor rule	$\varphi_{i,\pi}$	1.500	
Output gap feedback in Taylor rule	$\varphi_{i,y}$	0.250	
Elasticity of substitution formal/informal	$\epsilon$	5.000	Restrepo-Echavarria (2014)
Elasticity of matching function	$\varphi$	0.400	Blanchard and Diamond (1989)
Average government expenditures to GDP ratio	$g$	0.090	Alberola and Urrutia (2020)
Payroll tax	$\tau$	0.250	Ordonez (2014)
Separation rate (formal turnover)	$s$	0.088	Leyva and Urrutia (2020)
Working capital requirement formal sector	$\kappa$	0.210	Meza et al. (2019)
Labor disutility	$\psi$	1.806	Employment rate: 55.7%
Informal sector productivity	$\chi$	0.662	Informality rate: 55.8%
Search cost for unemployed	$\zeta$	52.509	Unemployment rate: 4.75%
Workers' bargaining power	$\gamma$	0.754	Formal wage premium: 13.0%
Cost of posting a vacancy	$\xi$	0.383	Hiring costs over wage bill: 3.4%
Standard deviation of aggregate TFP shocks	$\sigma_A$	0.346	Volatility of GDP: 1.57
Persistence of TFP shocks	$\rho_A$	0.906	First autocorrelation of GDP: 0.92
Strength of wealth effect in labor supply	$\omega$	0.026	Relative volatility employment: 0.42
Standard deviation of formal TFP shocks	$\sigma_{A^f}$	0.435	Relative volatility informality: 0.53
Fraction of firms not changing prices	$\theta$	0.550	Volatility inflation: 0.48
Standard deviation of demand shocks	$\sigma_g$	0.688	Correlation inflation, GDP: -0.35
Persistence of demand shocks	$\rho_g$	0.736	Relative volatility consumption: 1.11
Capital adjustment costs	$\vartheta$	20.996	Relative volatility investment: 1.98

**Table 4**  
Theoretical and empirical moments.

	Data Mexico	Pre-pandemic scenario
$\sigma(Y_t)$	1.57	1.57
$\rho(Y_t, Y_{t-1})$	0.92	0.92
$\sigma(\pi_t)$	0.48	0.48
$\rho(\pi_t, Y_t)$	-0.35	-0.35
$\sigma(L_t)/\sigma(Y_t)$	0.42	0.42
$\rho(L_t, Y_t)$	<b>0.76</b>	<b>0.79</b>
$\sigma(I_t^S)/\sigma(Y_t)$	0.53	0.53
$\rho(I_t^S, Y_t)$	<b>-0.56</b>	<b>-0.48</b>
$\sigma(C_t)/\sigma(Y_t)$	1.11	1.11
$\sigma(I_t)/\sigma(Y_t)$	1.98	1.98

Note: The empirical moments were obtained from Alberola and Urrutia (2020).

of investment to GDP, and the correlation between employment and GDP respectively. The moments of the Mexican economy are obtained from the calculations by Alberola and Urrutia (2020).

Table 3 shows this section's calibrated parameters, grouped by blocks divided by a thicker line. The table's first column shows each parameter's name, the symbol that represents it in the second column, and the parameter's value in the third column. The fourth column shows the literature source or target calibration. Finally, the theoretical and empirical moments are shown in Table 4. We note that the model replicates a countercyclical informality rate close to its empirical value.

## 5.2. Adjustment to a fortnightly frequency

Different works that use epidemiological models to simulate the dynamics of COVID-19 use high-frequency data (see Atkeson, 2020; Busato et al., 2021; Eichenbaum et al., 2021, 2022, among others). The high-frequency data allows us to accumulate active cases of the disease since, following Atkeson (2020), when a person becomes ill with COVID-19, in 18 days, on average, they recover or die. Therefore, we adjust the parameters of our model to work on the biweekly frequency.

To adjust our model on a biweekly basis, we only need to adjust eight parameters: the discount factor  $\beta$ , the capital stock depreciation rate  $\delta$ , the fraction of firms that do not change their prices  $\theta$ , the formal sector working capital requirement  $\kappa$ , the capital adjustment costs  $\vartheta$ , the separation rate of the formal sector  $s$ , the Taylor rule coefficient associated with the output gap  $\varphi_{i,y}$  and the costs of posting a vacancy  $\xi$ . The adjustment of the parameters to biweekly frequency is detailed below.

We choose the discount factor so that the quarterly real interest rate is 1%, equivalent to a biweekly real interest rate of 0.17%; therefore, we adjust the discount factor as the biweekly gross interest rate inverse. The capital depreciation rate is assumed to

**Table 5**  
Augmented Dickey–Fuller test.

Variable	<i>t</i> -statistics	Critical value at 5%
log ( <i>V<sub>t</sub></i> )	0.003	−1.950
Δlog ( <i>V<sub>t</sub></i> )	−4.414	−1.950

**Table 6**  
AIC and BIC values.

Model	AIC criteria	BIC criteria
ARMA(0, 1)	99.25	117.08
ARMA(0, 2)	92.42	116.19
ARMA(1, 0)	91.10	108.94
ARMA(2, 0)	86.93	110.70
ARMA(2, 1)	86.39	116.11
ARMA(1, 1)*	84.41*	108.18*

depreciate at a quarterly rate of 2.5%, which implies that capital depreciates 0.42% every fortnight. In our calibration, we obtained that firms reset their prices every 2.1 quarters, equivalent to 12.6 fortnights; therefore, 92.1% of the firms do not change their prices. The formal sector working capital requirement is set so that the quarterly average empirical ratio between total short-term credit and manufacturing GDP is 21%. Since total short-term credit is a stock variable and manufacturing GDP is a flow variable, their relationship does not hold over different periods. Therefore, when multiplied by six, the parameter that measures the quarterly formal sector working capital requirement is equivalent to the biweekly formal sector working capital requirement. Similarly, the parameter that captures the capital adjustment costs is divided by six. The separation rate is set so that a worker lasts 2.8 years on average in a formal job, equivalent to 16.8 fortnights. Therefore, the biweekly separation rate is one-sixth of the quarterly separation rate. A standard value for the coefficient that measures the reaction of the interest rate to the output gap in the Taylor rule is 0.25; this value is divided by six to adjust to the biweekly frequency. Finally, the costs of posting vacancies are multiplied by six to adjust them to biweekly frequency. The parameters adjusted to the fortnightly basis are shown in the first block of Table 7.

5.3. Pandemic block parameter calibration

In this subsection, we calibrate the parameters associated with the pandemic block. For this purpose, we use new COVID-19 daily cases and new COVID-19 daily deaths from the CONACyT database. Subsequently, we aggregate the data on a fortnightly basis. The analysis period covers the second half of February 2020 to the second half of June 2022.

The pandemic block’s parameters to be calibrated are the sensitivity of household utility to new cases of the disease, the average mortality rate, the recovery rate, the weight of consumption in the spread of the epidemic, the weight of labor in the spread of the epidemic, the weight of non-economic activity in the spread of the epidemic, the intensity of the lockdown policy concerning active cases, the persistence of the lockdown policy, and the parameters related to the ARIMA(*p, d, q*) virus process.

We begin by obtaining the mortality rate mean in the period analyzed. For this purpose, we calculated the ratio between the biweekly series of COVID-19 deaths and the biweekly series of new COVID-19 cases. Following Atkeson (2020), the disease of COVID-19 lasts an average of 18 days. During this time, the infected person recovers or dies. Therefore, the total elimination rate of the virus on a fortnightly basis is set at 15/18. The recovery rate is obtained by subtracting the mortality rate mean from the total elimination rate.

The parameters that measure the weighting of consumption, employment, and non-economic activity in the spread of the virus are calibrated following Eichenbaum et al. (2021), where it is mentioned that the transmissions related to consumption and employment are around 1/6 of the total time each. Hence, the transmissions related to the non-economic activity are the remaining 2/3 of the time. Therefore, the following 2 × 2 system is solved:

$$\frac{\varpi_c C_{ss}}{\varpi_c C_{ss} + \varpi_l \mu_{ss} L_{ss} + \varpi_o} = \frac{1}{6},$$

$$\frac{\varpi_l \mu_{ss} L_{ss}}{\varpi_c C_{ss} + \varpi_l \mu_{ss} L_{ss} + \varpi_o} = \frac{1}{6}.$$

Next, we estimate the parameters of the ARIMA(*p, d, q*) virus process. For this purpose, we use data on new daily COVID-19 cases obtained from the CONACyT database and aggregate them fortnightly. Subsequently, we obtain the logarithm of the series and determine the order of integration of the process. To do this, we apply the augmented Dickey–Fuller test. Table 5 shows the results of this test. In the first row, we can see that the series in logarithms has at least one unit root. In the second row, we show the test results for the series in the first differences, where the test statistically rejects the existence of unit roots; this implies that the process is first-order integrated. Once we identify the order of integration of the process, we estimate the ARMA(*p, q*) process on the series in the first differences using the lowest Akaike and Bayesian information criteria to determine the best model. Table 6 shows the outputs of the model’s Akaike and Bayesian information criteria, where the lowest values for the Akaike and Bayesian information criteria correspond to the ARMA(1, 1) model.

**Table 7**  
Parameters adjusted to biweekly model and pandemic block parameters.

Parameter	Symbol	Value	Source/Target
Discount factor	$\beta$	0.990 <sup>1/6</sup>	Quarterly real interest rate: 1%
Capital depreciation rate	$\delta$	0.025/6	Quarterly capital depreciation rate: 2.5%
Fraction of firms that not changing prices	$\theta$	$1 - [6/(1 - 0.525)]^{-1}$	Firms reset prices every: 2.1 quarters
Working capital requirement formal sector	$\kappa$	$6 \times 0.21$	Quarterly short-term credit to GDP ratio: 21%
Capital adjustment costs	$\theta$	20.996/6	Quarterly capital adjustment costs 20.996
Separation rate (formal turnover)	$s$	0.088/6	Avg. Duration of a worker in formality: 11.2 quarters
Output gap feedback in Taylor rule	$\varphi_{i,y}$	0.250/6	Quarterly output gap Taylor rule: 0.250
Costs of posting a vacancy	$\xi$	0.383 $\times$ 6	Quarterly posting vacancy costs: 0.383
Household sensitivity to new cases	$\varphi_h$	0.250	Quarterly inflation rate (YoY) dynamics.
Mortality rate	$m$	0.063	Average mortality rate: 6.3%
Recovery rate	$r$	0.770	Disease duration 18 days
Consumption weight in virus propagation	$\varpi_c$	0.240	Transmission related to consumption: 1/6
Labor weight in virus propagation	$\varpi_l$	0.300	Transmission related to labor: 1/6
Non-economic weight in virus propagation	$\varpi_o$	0.667	Transmission related to non-economic activity: 2/3
AR(1) pandemic shock coefficient	$\rho_v$	0.743	Estimation ARMA(1,1) process
MA(1) pandemic shock coefficient	$\rho_v$	0.519	Estimation ARMA(1,1) process
Standard deviation of pandemic shock	$\sigma_v$	0.222	Estimation ARMA(1,1) process
Lockdown policy persistence	$\rho_\mu$	0.800	Quarterly GDP persistence
Lockdown elasticity to active cases	$\varphi_{\mu,s}$	0.500	Minimum QGDP growth (YoY): -21.9%

Once we have the parameters associated with the autoregressive process of the virus, we proceed to carry out simulations with different values of trial and error in the parameters related to the confinement policy and the sensitivity of household utility to new cases of the disease to replicate the dynamics of the pandemic in Mexico. First, we obtain the GDP, the population aged 15 and over, and the CPI from the INEGI database. Using this information, we construct the annualized growth rate of GDP per capita and the inflation rate, both demeaned by the average from 2019/Q1 to 2020/Q1. Subsequently, we carry out simulations varying the parameters related to the confinement policy. Finally, we compare our model's GDP and inflation behavior with the data. For this, we aggregate the artificial biweekly GDP and the annualized inflation rate data from our model at a quarterly frequency using the following expressions,<sup>3</sup> respectively:

$$Y_t^Q = \frac{1}{6} \left[ Y_t + \sum_{i=1}^5 \frac{Y_{t-i}}{\prod_{j=0}^{i-1} (1 + \pi_{t-j})} \right]$$

$$\pi_t^{Q,Ann} = \frac{1}{6} \sum_{i=0}^5 \pi_{t-i}^{Ann}, \quad 1 + \pi_t^{Ann} = \prod_{j=0}^{23} (1 + \pi_{t-j})$$

Finally, we calibrate household sensitivity to new disease cases to replicate the observed dynamics of the inflation rate during the pandemic period. This is a key parameter in this process since it influences the curvature of inflation. Inflation is contained at the time of the pandemic outbreak; as economic restrictions are released, a gradual increase occurs (see Fig. 3). Therefore, a higher parameter value cause consumption to be reduced more than output, so inflation will be contained at the beginning of the pandemic shock. The details of pandemic block parameters are shown in the second block of Table 7.

## 6. Results

In this section, we show the model's results and the performance to mimic the cyclical movements during the pandemic. Finally, we perform a counterfactual, removing informal employment from the model and comparing the dynamics of the output growth rate, the employment rate, and the inflation rate with the full model.

### 6.1. Impulse-response analysis

First, we induce the economy to face a pandemic shock, estimate the dynamics of the variables related to the pandemic and the macroeconomic variables of interest, and describe the behavior of the impulse-response functions (IRFs). Subsequently, we aggregate the data at a quarterly frequency and compare the variables of economic growth, employment rate, inflation rate, and informality rate with the data from Mexico to assess the model's ability to mimic the dynamics of these variables in the face of the pandemic shock.

<sup>3</sup> The superscript *Q* indicates the variables in quarterly frequency, while the superscript *Ann* indicates the annualized variables.

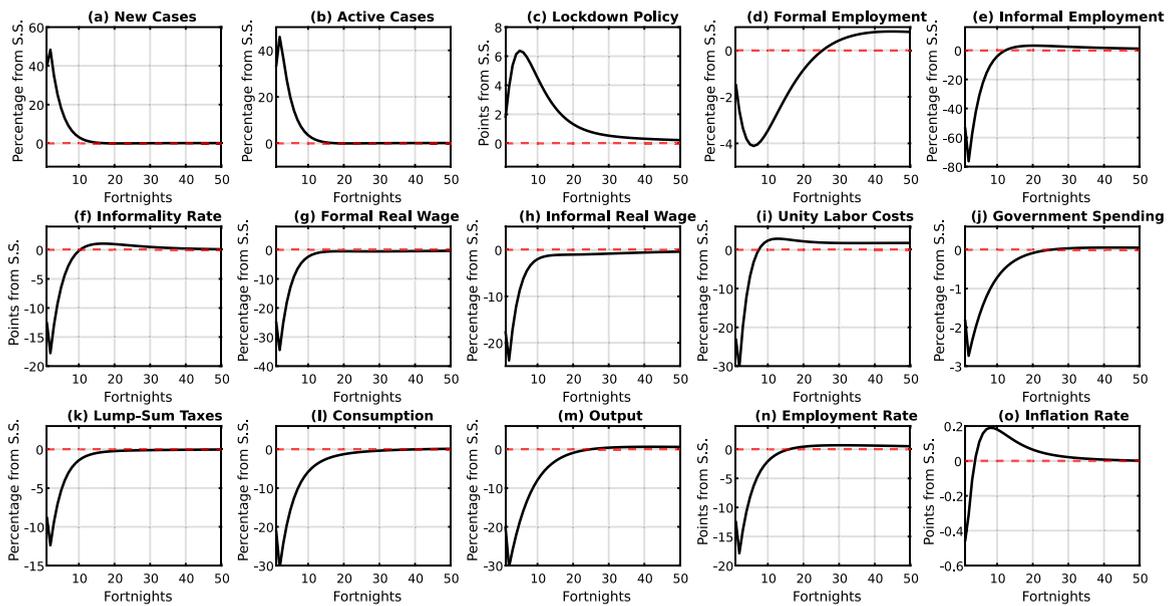


Fig. 2. Impulse-response to a pandemic shock.

### 6.1.1. Pandemic shock

In Fig. 2, we show the IRFs of inducing a shock of size equal to the estimated variance of the virus's  $ARMA(1, 1)$  process. Panel (a) shows the spread of new infections, which increases up to 48.3% compared to the initial infected population. With the increase in the number of active cases of the disease, the government deployed a lockdown policy restricting employed personnel use by 63.7% of total employment (see panel (c)), causing some workers to be quarantined.

Both the forced quarantine and the decreased desire to work due to the risk of contagion led to sharp reductions in the employment rate by 17.9 points of its average, as shown in panel (n); however, the impact across sectors is different. On the one hand, in panels (d) and (e), we can see that informal employment is more affected than formal employment since informal employment saw a contraction of 76.3%, while formal employment only contracted 4.1%; this wide difference leads to a procyclical informality rate. On the other hand, informal employment recovers faster since it approaches its steady-state value around ten fortnights, while formal employment takes more than twenty fortnights to recover.

In our model, the lockdown policy indiscriminately restricts employment use in both sectors. However, given the frictions in the formal sector, most of the response to the pandemic shock is driven by the informal sector. At the same time, this feature allows the informal sector to recover faster since there are no entry costs.

Real wages in the formal sector experience steeper declines than in the informal sector. This disparity stems from the differing levels of flexibility within each sector. The informal sector's inherent flexibility increases labor demand, preserving workers' bargaining power. Conversely, the formal sector's rigidity leads to sharper reductions in labor demand, weakening workers' positions and translating into deeper salary cuts.

Government spending is linked to output, so the dynamics between them are proportional (see panels (j) and (m)). Lump-sum taxes are reduced to alleviate the economy and maintain household consumption patterns as much as possible. However, the informal sector makes government spending more dependent on lump-sum taxes since it does not pay payroll taxes, making the government's fiscal policies to alleviate consumption difficult. This is discussed further in Section 6.2.

Both formal and informal employment contribute strongly to production. Hence, the sharp reduction in personnel in both sectors produced by the harsh confinement policy to contain the virus and the reduction in household labor supply leads to biweekly GDP contracting up to 30.4%, as shown in panel (j). Furthermore, in panel (l), we can see that the inflation rate falls about 0.46 points below the inflation target in the face of the pandemic; however, it rises rapidly and remains very persistently above the objective for more than 30 fortnights.

The fear of becoming infected through consumer activities causes households to reduce consumption by 0.86 percentage points more than output (see panels (l) and (m)), dropping an initial inflation rate as Eichenbaum et al. (2022). Meanwhile, in the recovery period, wage increases outpace job growth due to frictions in the formal sector; this has a two-fold impact on the inflation rate: on the one hand, it raises firms' costs faster than output, pushing unit labor costs upwards and fueling inflation (see panel (i)). On the other hand, it boosts government payroll tax collection, allowing for a quicker reduction in lump-sum taxes that tend to stimulate consumption (see panel (k)). As a result, consumption rebounds faster than production, causing inflationary pressures. On the other hand, in the Eichenbaum et al. (2022)'s model, the labor market lacks frictions and no government entity, which explains the differences in inflation dynamics.

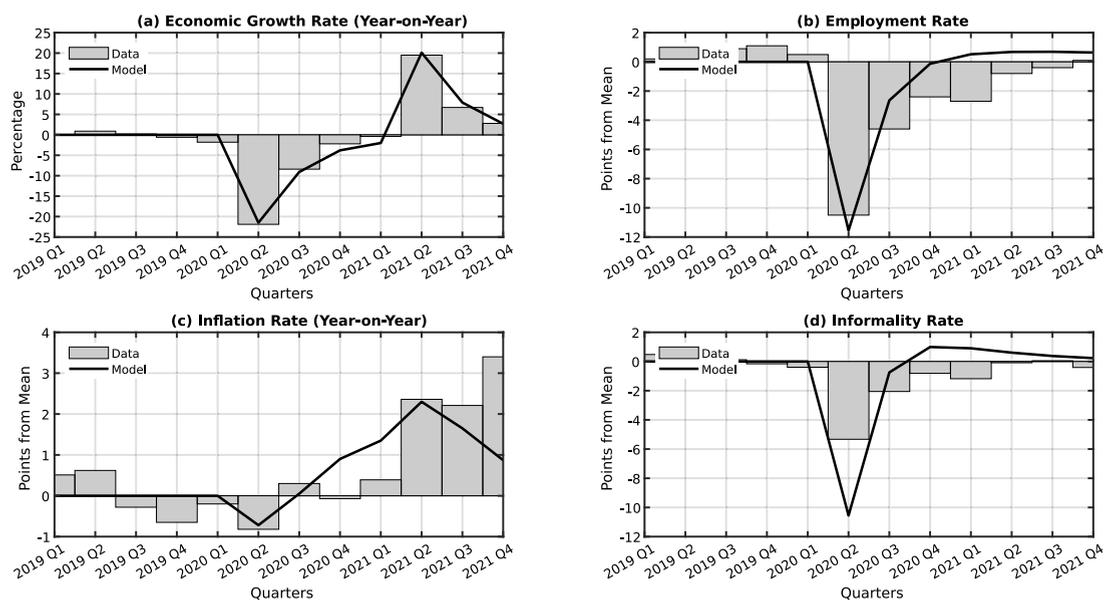


Fig. 3. Model vs. Data.

### 6.1.2. Model vs. Data

Now, we analyze the model's performance in replicating the data of our interest during the first two years of the pandemic. For this purpose, we work with the demeaned series for the annual GDP growth rate, the annual inflation rate, the employment rate, and the informality rate<sup>4</sup> to compare with the model's variables in response to a pandemic shock.

In Fig. 3, we show the data compared to the model's IRFs aggregated quarterly. We induce a shock of the size equal to the variance of the estimated process of the virus, and then we match the initial period of the shock with the second quarter of 2020. In each panel, the bars represent the demeaned data corresponding to each variable, while the solid lines represent the model's IRFs to the pandemic shock.

It is not surprising that GDP adjusted well, at least in the first two quarters after the shock, since the parameters that govern the behavior of the lockdown policy were adjusted to replicate the size of the fall and persistence of GDP during the pandemic, however for the rest of variables the model fit the data well, our model reacts with similar dynamics and magnitudes. The main details to note between the model and the data are that the employment rate in our model is less persistent, the informality rate falls more and less persistent than in the data, and the inflation rate falls harder at the start of the pandemic shock.

More accurate results could be obtained by relaxing the assumption that the informal sector is composed entirely of self-employed workers since this assumption allows individuals to move freely between inactivity and the informal sector. Furthermore, by adding the search for a job and matching environment to the informal sector, informal employment would not be as volatile as shown in the IRFs. Furthermore, the appearance of new variants of the virus, the resilience of economic agents and the labor market in the face of the pandemic, mass vaccination, the disruption in the global supply chain, and the effects of the rest of the world on the domestic economy, among other things, cause differences with our simulations.

## 6.2. The role of informal employment

In this section, we assess the role of the informal sector in the main macroeconomic aggregates in the face of a pandemic shock. For this purpose, we perform a counterfactual exercise comparing the IRFs of the GDP growth rate, the employment rate, and the inflation rate, considering two cases. The first is the benchmark model; in this case, the labor market comprises formal and informal sectors. In the second case, employment is completely formal. We eliminated all informal sector variables from the benchmark model to achieve this. At the same time, the rest of the parameters remain unchanged.

Fig. 4 shows the dynamics of this comparison. The black line of each panel in the graph represents the IRFs to the pandemic shock of the full model. In contrast, the blue line is the IRFs to the pandemic shock of the model without informality. We note that GDP falls by about 5 pp less in the model without informality than in the full model. The main reason is that total employment in the model without informality contracted less than in the model with mixed employment, specifically 3.8 pp less. As we can see in

<sup>4</sup> The employment rate is constructed as the ratio of the employed population and the population aged 15 and over. The employed population, the population aged 15 and over, and the informality rate are obtained from the INEGI database.

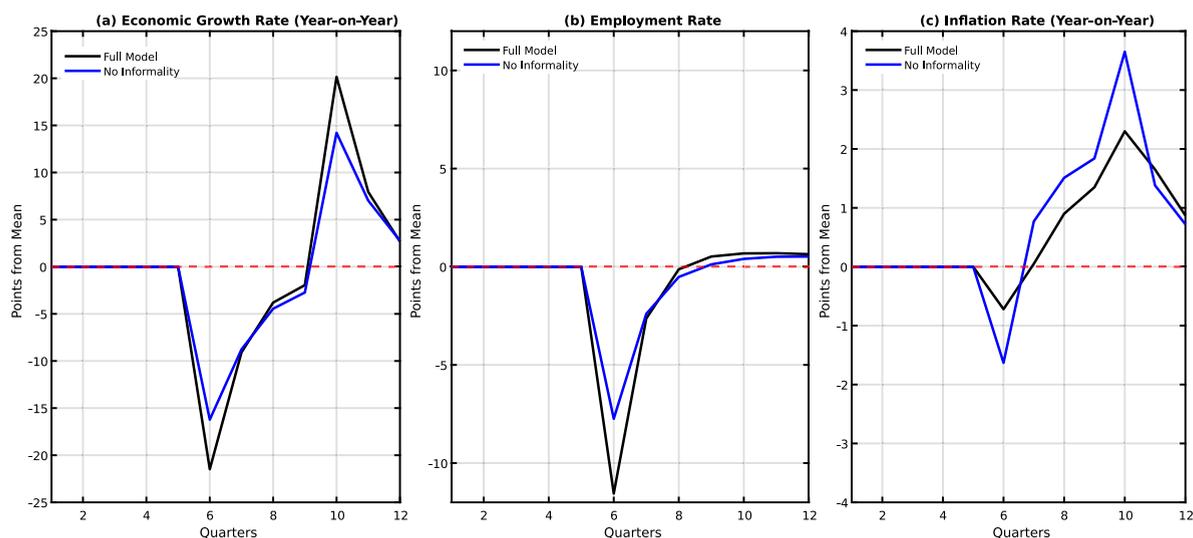


Fig. 4. Counterfactual exercise.

Fig. 2, formal employment is less affected by the pandemic shock than formal employment, but it takes longer to recover. Therefore, in the model without informality, total employment has the same characteristics as the formal sector.

One of the most striking differences between the two models is the inflation rate IRF. The full model's inflation rate fluctuates between  $-0.7$  pp and  $2.3$  pp. However, in the model without informality, the inflation rate is more volatile, ranging from  $-1.6$  to  $3.5$  pp. This stark contrast underscores the significant impact of the informal sector on the pandemic crisis. It exacerbates the effects on economic growth and employment rates while mitigating inflationary pressures. To understand the underlying reasons for these differences, we conducted a sensitivity analysis of the parameters that differentiate the formal and informal sectors.

In our model, the informal sector is characterized by low productivity, limited access to working capital, tax evasion, and no entry costs. To ensure the robustness of our findings, we allow the formal sector to resemble the informal sector by gradually acquiring these characteristics and comparing the effects with the benchmark model. We meticulously vary the parameters associated with the characteristics that distinguish the formal sector from the informal sector, setting the values of these parameters to zero, except for the parameter associated with productivity. This rigorous approach allows us to identify the specific characteristics of the informal sector that drive the results observed in the face of the pandemic shock.

Fig. 5 shows the IRF to the pandemic shock in the model without informality, varying the parameters that characterize the formal sector, resembling it to the informal sector characteristics. In each panel, the bars represent the model without informality, with the parameters unchanged. At the same time, the lines represent the modifications of this model by varying each of the parameters. For example, the black IRFs represent the model without informality with  $\chi = 0.666$  when the formal sector is less productive. In this case, there is no significant difference in the dynamics of GDP growth and employment rates concerning the model without informality. However, the inflation rate is the most volatile. The main reason is that producing the same amount of formal goods is more expensive, producing inflationary pressures when the output behaves similarly to a more productive economy.

The red lines represent the IRFs of the model without informality when access to working capital is limited, that is when  $\kappa = 0.000$ . The IRFs colored in blue represent the case when the formal sector is exempt from taxes. Again, as in the previous case, there is no significant difference in the GDP and employment growth rate dynamics. However, in this case, there is less inflation. First, it is assumed that the spending behavior is procyclical. Hence, decreases follow falls in GDP in government purchases, which has a greater impact on aggregate demand, resulting in lower inflation. Second, when the payroll tax is zero, public spending is financed solely with lump-sum taxes. Finally, lump-sum taxes to finance government expenditures increase significantly when the economy enters recovery, reducing inflationary pressures.

Finally, the green IRFs represent the case when there are no entry costs in the formal sector; this is the most similar case to when there is mixed employment since the GDP and the employment rate contract to a greater extent while the behavior of the inflation rate softens. First, near-zero entry costs provide greater labor market flexibility, allowing households to be employed or unemployed quickly. Therefore, in the face of forced quarantine, workers leave their work more easily, further reducing the employment rate. Given the above, there are further falls in GDP. However, this flexibility allows workers to be reinstated quickly, making the pandemic shock to the employment rate less persistent. At the same time, labor market flexibility allows firms to expand output without increasing wages, buffering inflation.

In summary, the two key features of the informal sector, tax exemption and low entry costs, significantly impact economic aggregates during a pandemic shock. In a scenario with negligible entry costs for formal businesses, the initial job losses due to a pandemic would be more severe, leading to a sharper decline in output. However, during recovery, low entry costs allow workers to swiftly re-enter the formal job market, facilitating a faster economic rebound.

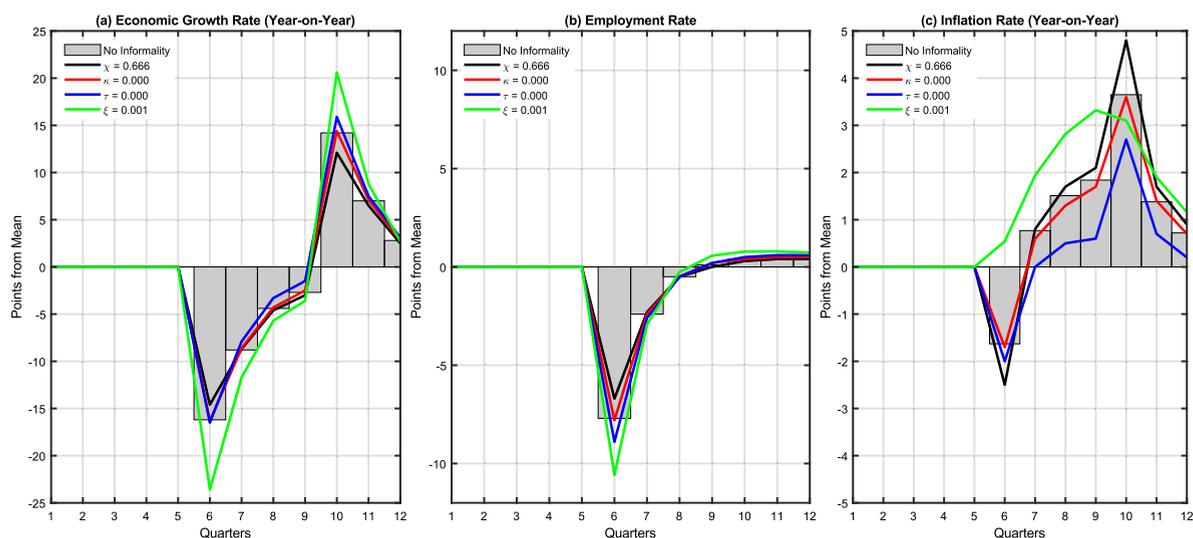


Fig. 5. Parameter sensitivity.

In the scenario where the formal sector adopts a zero-payroll tax policy, like the informal sector, government revenue relies solely on lump-sum taxes. This reduces the impact on inflation compared to a scenario with payroll taxes. This difference arises because, as in the model without informality, employment contracts less than output (see Fig. 4), causes payroll tax revenue to be reduced in a smaller proportion than output and to follow the government spending rule, it must reduce lump-sum taxes more strongly. By sharply reducing lump-sum taxes, the representative household will have greater disposable income, smoothing the effect on consumption and generating inflationary pressures. On the contrary, when government revenue depends exclusively on lump-sum taxes, these fluctuate along with output and are not reduced as much as in the previous case, which prevents greater consumption in an economy hit by confinement policies, which cushions the inflationary effect.

### 6.3. A note on welfare

In this section, we compare the households' welfare in the full model against the model without informality in the face of the pandemic shock. The households' welfare loss is greater in the model with mixed employment. The difference between the maximum welfare loss between the two cases is 6 pp, favoring the case of the economy without informal employment. However, the rapid recovery of informal employment makes it possible to reduce the gap in the loss of well-being during the two years of the pandemic. However, the economy is still 0.6 pp lower without informal employment. The above results imply that the representative household would prefer to live in an economy without informal employment during the pandemic shock. That is, they prefer a lower loss of output and employment at the cost of higher price increases.

Our results support the arguments of Loayza (2020), which state that the informal economy makes economies more vulnerable to the COVID-19 crisis. Furthermore, it is consistent with the results obtained by Alberola and Urrutia (2020), who submit a similar model to different shocks that perturb the economy, where households prefer that informality is absent. Therefore, it is worth paying attention to policies that reduce informal activity in emerging and developing countries to prevent technological, demand, monetary, financial, and pandemic shocks from causing further economic losses.

## 7. Conclusion

The COVID-19 health crisis caused the greatest economic damage in the last 60 years. However, the effects between the regions were differentiated. Economic growth and employment affected Latin America and the Caribbean region most; however, other regions suffered greater price changes. In addition, the LAC region is characterized by large informal sectors, so studying the role of the informal sector during the pandemic is of utmost importance to understand the impact of the crisis in this region.

In this paper, we have presented a DSGE model with labor market frictions and pandemic dynamics simulating the behavior of the COVID-19 crisis to analyze the role of the informal sector during the pandemic. We characterize the informal sector as a sector that does not face entry costs, does not pay taxes, is excluded from the credit market, and is less productive than the formal sector. On the other hand, we include a detailed pandemic block with a stochastic emergence of the virus that spreads through economic activities such as consumption and labor and non-economic activities, producing new cases. When new cases accumulate, they generate active cases, while others recover or die. As a result, the government imposes a lockdown policy restricting the use of labor in both sectors to prevent further spread and mortality. In addition, as disease cases increase, households decrease their desire to consume and to be employed to reduce the risk of contagion.

We first calibrate the model for Mexico's economy as a potential representative of the informal economy in the Latin American and Caribbean region. Our simulations show that employment is falling in both sectors, although the dynamics differ. On the one hand, the restrictions due to the pandemic shock significantly reduce informal employment more than formal employment. This prevents households from making up for formal job losses by becoming informal employees, producing a procyclical informality rate. On the other hand, the impact on formal employment is more persistent, so informal employment recovers more quickly, given the high flexibility of the informal sector. As a result, job losses due to confinement produce a sharp drop in output. In addition, households' repressed desire for consumption at the beginning of the pandemic produced reductions in aggregate demand that caused the inflation rate to fall. However, in the recovery phase, the persistence of the lockdown policy means that the aggregate supply does not recover at the rate of the aggregate demand, leading to strong price increases.

Subsequently, to assess the role of the informal sector in the COVID-19 health crisis, we carry out a counterfactual exercise eliminating informal employment from the economy, paying special attention to the economic growth rate, the employment rate, and the inflation rate. Finally, we modify the model's characteristics without informality one by one to resemble the informal sector. We find that the presence of the informal sector aggravates the damage to output and employment but cushions the inflationary pressures derived from the crisis. The channel through which the informal sector operates in causing the effects on economic growth, employment, and inflation mentioned above is due to its low entry costs, i.e., high flexibility, and that it is payroll tax-free. The high flexibility allows for greater employment outflows at the time of impact and greater inflows in the recovery phase. As a result, the strong job losses driven by the confinement policy cause greater contractions in GDP. On the other hand, the informal sector's ability to evade taxes means that the government has less room to alleviate the economy, so it does not reduce lump-sum taxes as much as when informality is absent. This further reduces households' disposable income, which prevents them from smoothing their consumption and, therefore, generates a buffer effect on inflation.

Lastly, we compare the welfare loss of the model with mixed employment and the model without informal employment in the face of the pandemic shock. We find that the greatest welfare loss occurs where there is informality, which implies that the representative household prefers to face the pandemic shock when there is no informal employment.

In this sense, public policies must adopt a focused approach to promote formal employment in Latin American and Caribbean countries. This approach mainly aims to reduce the prevalence of labor informality, which will help mitigate the negative impacts on GDP and employment during upcoming crises like the one we recently faced due to the COVID-19 pandemic. At the same time, this strategy will ensure workers and households a safer work environment backed by safeguards and protections.

Our results partly explain the differentiated effects of the crisis in terms of the main macroeconomic aggregates. However, the model can be improved if some extensions are considered. First, consider the effects of the rest of the world on the global supply chain in a two-country environment. Secondly, the confinement policy was directed towards non-essential economic sectors, mainly in the service sector, so the high economic dependence of this sector is important for the analysis. Finally, consider the risk perception with vaccination since households may feel safer and increase demand with a repressed supply, causing strong inflationary pressures.

### CRedit authorship contribution statement

**Manuel Torres-Favela:** Conceptualization, Formal analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. **Edgar M. Luna:** Conceptualization, Project administration, Resources, Supervision, Validation, Visualization.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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