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## Epidemics and Informality in Developing Countries

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# Epidemics and Informality in Developing Countries*

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**Abstract**

Developing countries are facing the Covid-19 epidemic with particular challenges, such as their economic and labor force composition. In this research I will extend the so-called SIR-macro model with demand and supply effects to study how the size of the informal sector impact the ability of these countries to respond to the epidemic. Lockdown policies are useful to control the health crisis but these are less effective in informal markets. As a result, infection and death rates will not decrease as expected, and since informal activities are not counted in the calculation of the GDP, this would exacerbate the size of the recession. Finally, in order to generate similar results to an economy with only formal markets, the economy with informal markets has to implement more severe containment policies.

**JEL Classification** : E26, E32, I12, H30.
**Keywords** : COVID-19, informality, recessions, SIR macro model.

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# 1 Introduction

The COVID-19 pandemic presents enormous challenges for societies as it spreads throughout the world. Governments are struggling with how to manage and understand the epidemic, and are imposing mitigation and lockdown policies that limit social interactions to control the disease. These lockdown policies have been effective in taming the spread of the disease in some countries, but not in all cases. This is the case of developing countries, where the epidemic is growing and leading to a large human cost. As of August 2020, the median number of official deaths across 25 emerging countries is over 15 per 100,000 people whereas this number was around 11 for developed economies. These countries are also confronting the epidemic with additional challenges, as documented by Alfaro, Becerra and Eslava (2020); Alon, Kim, Lagakos and VanVuren (2020); and Arellano, Bai and Mihalache (2020). For developing economies, the pandemic is a tremendous shock with collapsing export demand, tourism, remittances, and capital flows. Moreover, these countries face limited fiscal space due to the absence of unemployment insurance, debt crises, poverty and prevalence of informal markets.

In the economic front, the median decrease in real GDP the second quarter of 2020 was around -10.7% and -13% for developed and developing countries, respectively. Figure 1 panel (a) shows the economic performance of these economies in the second quarter of 2020 against the size of their informal sector in 2017 calculated by Medina and Schneider (2019). Although the sample data was restricted for emerging countries whose official numbers are publicly available at Eurostat or individual national statistics agencies, a negative correlation emerges implying that countries with high informality reported worse economic performance.

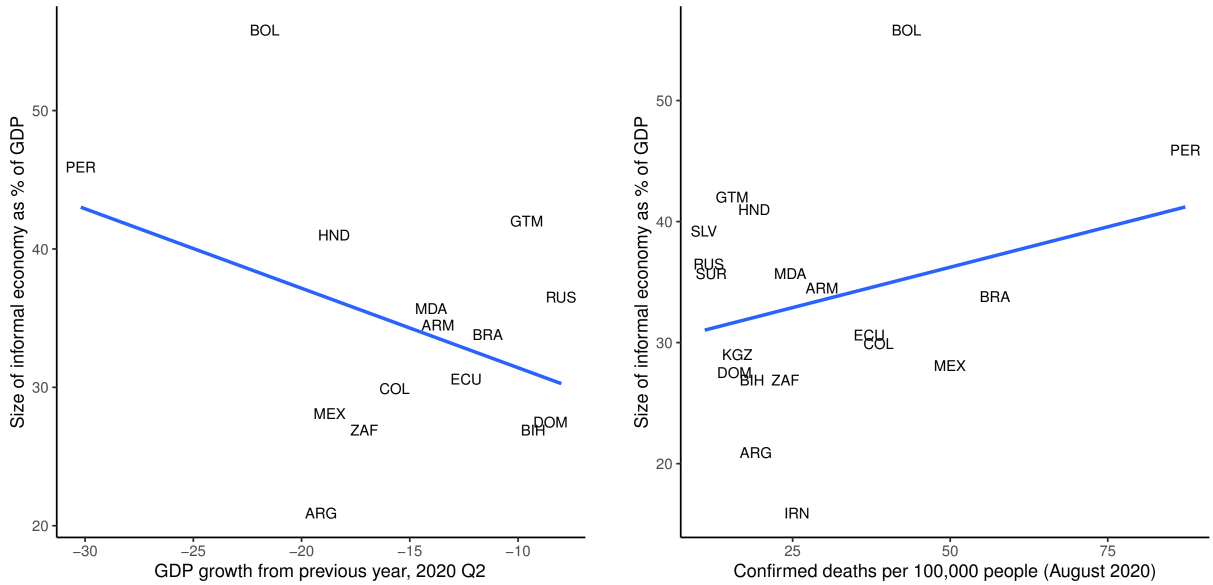
Panel (b) in figure 1 shows how this measure of informality is correlated with the cumulative confirmed deaths per 100,000 people for these countries in August 2020. Despite the preliminary nature of the data, there seems to be a positive correlation between the informality and the reported deaths in the current pandemic, especially for countries in Latin America such as Peru and Bolivia. So, it is evident that emerging markets are suffering both in the health and economic front.[1]

The SIR-macro model literature predicts a trade-off between the economics and death losses when containment measures are adopted (Eichenbaum, Rebelo and Trabandt, 2020*b*,*a*). However, in emerging markets these predictions seem to be not entirely accurate. Figure 2 shows the government response Stringency Index for three group of economies. Both, advanced and emerging countries started implementing containment measures at the middle of March, and some countries have not reduced the magnitude of these measures in the last months. The question is why these countries have negative results in terms of economic and health outcomes if they have adopted contingent measures similarly to developed countries in terms of magnitude and timing?

One explanation could be found in the production and labor structure of these economies, as discussed in figure 1. *Women and men in the informal economy : a statistical picture* (2018) found that informal workers are more likely to be poor and receive less income in comparison to

[1] In October, the New York Times reported large underreporting of cases and deaths in emerging markets; e.g., the ratio of excess deaths to official deaths is 3 in Mexico and 5 in Bolivia.

Figure 1. Economic decline, Informality and deaths due to COVID-19

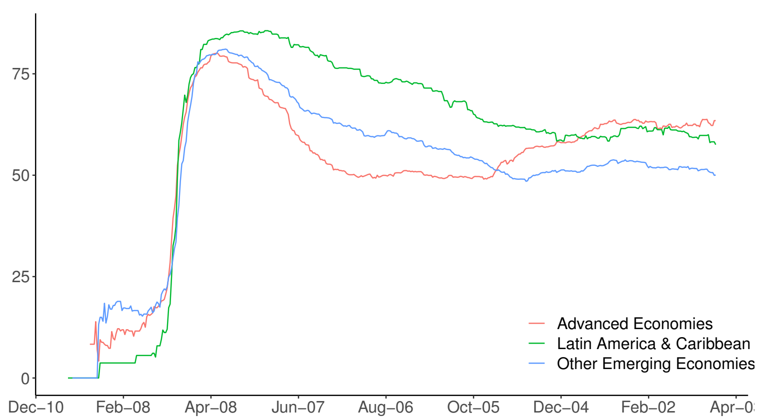



(a) Informality vs. GDP growth 2020 Q2

(b) Informality vs. Confirmed deaths

*Notes:* The sample was restricted to *low* and *middle* income economies according to the World Bank Atlas method. Limited testing and challenges in the attribution of the cause of death means that the number of confirmed deaths may not be an accurate count of the true number of deaths from COVID-19.
*Source:* Eurostat, individual national statistics agencies, Johns Hopkins Coronavirus Resource Center, World Bank and Medina and Schneider (2019).

Figure 2. Government response Stringency Index




*Notes:* This is a composite measure based on nine response indicators including school closures, workplace closures, and travel bans, rescaled to a value from 0 to 100 (100 = strictest). If policies vary at the subnational level, the index is shown as the response level of the strictest sub-region.
*Source:* Thomas Hale, Sam Webster, Anna Petherick, Toby Phillips, and Beatriz Kira (2020). Oxford COVID-19 Government Response Tracker.

formal workers. The current pandemic, where lockdows and containment measures were taken to mitigate the effects of the contagion, represents a huge challenge for these workers who need to be immersed in consumption and work activities to be able to survive. Moreover, over 70% of the informal employment is concentrated in the agriculture sector, which could be difficult to monitor

Table 1. Peruvian labor force by region and formal and informal employment (Thousands of people and percentage change)

| Category | | 2019q4 | 2020q1 (%) | 2020q2 (%) | 2020q3 (%) | 2020q4 (%) |
|---|---|---|---|---|---|---|
| | Informal | 12,429 | -6% | -33% | -17% | -7% |
| | Formal | 3,469 | -13% | -42% | -26% | -16% |
| | Urban | 9,587 | -13% | -48% | -22% | -13% |
| | Rural | 6,311 | 0% | -15% | -14% | -4% |
| Urban | Informal | 6,455 | -13% | -52% | -21% | -11% |
| | Formal | 3,132 | -14% | -41% | -25% | -17% |
| Rural | Informal | 5,974 | 1% | -13% | -13% | -3% |
| | Formal | 337 | -3% | -53% | -35% | -13% |
| Urban | 14-24 years old | 1,317 | -1% | -58% | -20% | -9% |
| | 25-44 years old | 4,014 | -21% | -50% | -20% | -10% |
| | > 44 years old | 4,256 | -9% | -43% | -25% | -17% |
| Rural | 14-24 years old | 989 | 24% | 12% | 10% | 14% |
| | 25-44 years old | 2,170 | -7% | -10% | -10% | -10% |
| | > 44 years old | 3,152 | -2% | -28% | -24% | -4% |
| Total employment | | 15,898 | 14,679 | 10,306 | 12,870 | 14,447 |

*Notes:* Percentages are calculated with respect to 2019q4. The quarterly household survey is representative at the national, urban and rural level. Numbers calculated using expansion factors.
*Source:* National Institute of Statistics and Informatics (INEI). Quarterly Household Survey (ENAHO) 2019-2020.

when blank containment measures are taken in order to reduce social and economic interactions.

This hypothesis is also supported at the micro-level. Using quarterly household survey data from Peru, I find that informal jobs were less affected by the containment measures taken in this country at the end of the first quarter in 2020.[2] Table 1 shows that informal employment represents more than 70% of the total employment in Peru. Moreover, this type of employment decreased less and is recovering faster than formal employment. This change is driven by rural areas where the total employment fell less (-15%) than urban employment (-48%).

Disaggregating the data by region, we can corroborate that both informal and formal urban employment were affected by the lockdown but this did not happen in rural areas, where the informal employment only decreased by 13% in the second quarter of 2020. In fact, the lower decrease of employment in rural areas is driven by workers between 14-24 and 25-44 years old who work in the informal sector (see the latest 3 rows). This is important, since most of the informal employment in rural areas is concentrated in the agricultural sector. Figure 8 shows that the percentage of informal employment in the agriculture, hunting, forestry and related service activities almost doubled in the second quarter of 2020, while that of formal employment remained constant. Dingel and Neiman (2020) found that a low share of jobs in this sector can be done at home, and lockdowns are difficult

[2] According to the survey, informal employment refers to the jobs that: (i) employers and self-employed workers whose productive unit belongs to the informal sector, (ii) employees without social security financed by their employer, or (iii) unpaid family workers, regardless of the formal or informal nature of the productive unit where they work.

to implement in this sector because of the nature of these jobs. Figure 9 shows a notorious increase in the number of people working as unpaid family workers in the second quarter of 2020.[3] At the end, the prevalence of informal employment increases the risk of infectious in the economy.

My research is related with the growing literature which connects the epidemiological literature with economic people's decisions (Eichenbaum et al., 2020*b*; Kaplan, Moll and Violante, 2020; Krueger, Uhlig and Xie, 2020). My paper question is also related with the literature studying the interactions between the current pandemic and developing economies. In this respect, Arellano et al. (2020) show how default risk impacts the ability of these economies to respond to the COVID-19 epidemic. The possibility of containment measures induced debt crises and results in less aggressive lockdowns and a more severe health crisis. On the other hand, Goldberg and Reed (2020) report how the evolution of the epidemic may be different in developing and developed economies in terms of poverty, health and education. Finally, Alon et al. (2020) show that age-specific lockdown policies may be more potent in developing countries than simple blank lockdowns. They arrive to this conclusion through the lens of an incomplete-markets macroeconomic model with epidemiological dynamics.

In this paper, I will extend the well-known SIR-macro model (with demand and supply effects) in a two sector economy: formal and informal markets. The government enacts containment measures to preserve lives. However, containment policies are less effective in informal markets since these economic activities are difficult to monitor when lockdowns are implemented in the economy. My main results are that the number of infections and deaths would increase even with containment policies, and since a large part of informal activities are not counted in the calculation of the GDP, this would exacerbate the size of the recession.

The paper is organized as follows. In section 2 I describe the SIR-macro model. Section 3 presents the calibrated parameters in the model using Peruvian data. Section 4 discusses the versions of the model without containment measures, with simple containment measures in both sectors, and simple containment measures in formal markets but no measures in informal markets (informal wedge). Section 5 compares the evolution of the aggregate variables in an economy with both markets and an economy with only formal markets. Finally, section 6 concludes.

## 2 The model

I first describe the SIR epidemiological model and the channels of disease transmission. The next section presents the decentralized economic environment.

### 2.1 The epidemic

The economy is initially in a steady state where all people are identical. The total population is normalized to unity. For simplicity, and given the short time horizon of interest, I abstract from

[3] Unpaid family workers are classified as informal workers according to the informal labor definition used by the National Institute of Statistics and Informatics (INEI) in Peru.

population growth and ignore aging. Agents can work in the formal and informal sector.

Individuals can be subdivided into four groups: susceptible (people who have not yet been exposed to the virus), infected (people who have been infected by the virus), recovered (people who survived the infection and acquired immunity), and deceased (people who died from the infection). The fraction of the population in each group is denoted by $(S_t)$, $(I_t)$, $(R_t)$ and $(D_t)$, respectively.

Social interactions occur at the beginning of the period (infected and susceptible people meet). Then, changes in health status related to social interactions (recovery or death) occur. At the end of the period, the consequences of social interactions materialize and $(T_t)$ susceptible people become infected. As in Eichenbaum et al. (2020*b*), I assume that susceptible people can become infected in three ways: purchasing consumer goods, working, and through random interactions unrelated to economic activity. The number of newly infected people is given by the transmission function

$$\begin{aligned} T_t = \pi_1^c(S_t C_{1t}^s)(I_t C_{1t}^i) + \pi_1^n(S_t N_{1t}^s)(I_t N_{1t}^i) + \pi_2^c(S_t C_{2t}^s)(I_t C_{2t}^i) + \cdots \\ \cdots + \pi_2^n(S_t N_{2t}^s)(I_t N_{2t}^i) + \pi_3(S_t)(I_t), \end{aligned} \tag{1}$$

where $(C_{mt}^s)$ and $(C_{mt}^i)$ represent the consumption in sector $m = \{1, 2\}$ of susceptible and infected people, respectively. The terms $(S_t C_{mt}^s)$ and $(I_t C_{mt}^i)$ represent total consumption in sector $m$ of susceptible and infected people. The number of newly infected people that results from consumption interactions in sector $m$ is given by $\pi_m^c(S_t C_{mt}^s)(I_t C_{mt}^i)$. The parameter $\pi_m^c$ reflects both the amount of time spent in consumption activities and the probability of becoming infected as a result of those activities in sector $m$.

$(N_{mt}^s)$ and $(N_{mt}^i)$ represent hours worked in sector $m = \{1, 2\}$ of susceptible and infected people, respectively. The terms $(S_t N_{mt}^s)$ and $(I_t N_{mt}^i)$ represent total total hours worked in sector $m$ of susceptible and infected people. The number of newly infected people that results from interactions at work in sector $m$ is given by $\pi_m^n(S_t N_{mt}^s)(I_t N_{mt}^i)$. The parameter $\pi_m^n$ reflects the probability of becoming infected as a result of work interactions in sector $m$.

Susceptible and infected people can also meet in ways unrelated to consuming or working activities. The number of random meetings between infected and susceptible people is $(S_t)(I_t)$. These meetings result in $\pi_3(S_t)(I_t)$ newly infected people. The number of susceptible people at time $t + 1$ is given by

$$S_{t+1} = S_t - T_t. \tag{2}$$

The number of infected people at time $t + 1$ is equal to the number of infected people at time $t$ plus the number of newly infected people $(T_t)$ minus the number of infected people who recovered $(\pi_r I_t)$ and the number of infected people who died $(\pi_d I_t)$

$$I_{t+1} = I_t + T_t - (\pi_r + \pi_d)I_t, \tag{3}$$

where $\pi_r$ is the rate at which infected people recover from the infection and $\pi_d$ is the probability that an infected person dies.

The number of recovered people at time $t+1$ is the number of recovered people at time $t$ plus the number of infected people who just recovered ($\pi_r I_t$)

$$R_{t+1} = R_t + \pi_r I_t. \tag{4}$$

The number of deceased people at time $t+1$ is the number of deceased people at time $t$ plus the number of new deaths ($\pi_d I_t$)

$$D_{t+1} = D_t + \pi_d I_t. \tag{5}$$

Finally, the total population evolves according to

$$\text{Pop}_{t+1} = \text{Pop}_t - \pi_d I_t, \tag{6}$$

where $\text{Pop}_t$ denotes the mass of the total population at date $t$ and $\text{Pop}_0 = 1$. The dynamics of the four groups in the SIR epidemiological model evolves according to (2), (3), (4), and (5).

### 2.2 Economic model

The framework builds on Restrepo-Echavarria (2014) and Horvath (2018). It consists of a two-sector economy with a formal sector (sector 1) and an informal sector (sector 2). Households supply labor to both sectors. The formal labor income, in contrast to the informal labor income, is taxed since this activity is registered by the government. When the pandemic starts, the probability to find a formal job is lower than the probability to find an informal job. In addition, the government also collects taxes on consumption activities aimed at reducing social interactions. Government's revenue are used to provide lump-sum transfers to households. The size of the informal sector is given and is determined by the household's share of total time spent working in the informal sector.

**Formal sector (sector 1)** Perfectly competitive firms are registered by the government. Producers maximize profits by choosing the level of labor given the real wage. They operate using a linear production function

$$\max_{\{N_{1t}\}} A_1 N_{1t} - w_{1t} N_{1t}, \tag{7}$$

where ($N_{1t}$) is formal labor demand, and ($w_{1t}$) is the wage in the formal sector.

**Informal sector (sector 2)** Informal firms are unregistered by the government. In line with the informal economy literature, the informal production is labor intensive and face decreasing returns to scale (Restrepo-Echavarria, 2014; Horvath, 2018). These firms maximize their profits given by

$$\max_{\{N_{2t}\}} p_t A_2 (N_{2t})^{\nu} - w_{2t} N_{2t}, \tag{8}$$

where ($p_t$) reflects the relative price of informal to formal goods, ($N_{2t}$) is informal labor demand, and ($w_{2t}$) is the wage in the informal sector.

The optimization problem of the different types of people in the economy is similar to Eichenbaum et al. (2020$b$,$a$). The budget constraint of a type-$l$ person ($l = s, i, r$) is

$$(1+\mu_t)c^l_{1t} + (1+\mu_t\kappa)p_t c^l_{2t} = (1-\bar{\mu})w_{1t}\phi^l n^l_{1t} + w_{2t}\phi^l n^l_{2t} + \Gamma_t, \tag{9}$$

where $(c^l_t)$ and $(n^l_t)$ denote the consumption and hours worked, respectively. I will consider infected people are less productive than susceptible and recovered people. $\phi^l$ is the labor productivity parameter that is equal to one for susceptible and recovered people ($\phi^s = \phi^r = 1$) and less than one for infected people ($\phi^i < 1$).

Lockdowns constrain the economic activity through consumption taxes ($\mu_t$) in both sectors, and $\kappa$ captures the relative degree of effectiveness of these containment measures in the informal sector. This parameter can also be interpreted as the likelihood to consume or find a job in the informal sector relatively to the formal sector. In this sense, $\kappa$ is the wedge of containment measures in the informal sector which the government takes as given. Finally, $\Gamma_t$ is the sum of non-zero benefits in the informal market and government transfers from consumption and labor taxes.

**Susceptible** The lifetime utility of a susceptible person ($U^s_t$) is

$$U^s_t = u(c^s_{1t}, c^s_{2t}, n^s_{1t}, n^s_{2t}) + \beta\left[(1-\tau_t)U^s_{t+1} + \tau_t U^i_{t+1}\right], \tag{10}$$

subject to (9) and the probability that a susceptible person becomes infected given by:

$$\tau_t = \pi^c_1 c^s_{1t}(I_t C^i_{1t}) + \pi^n_1 n^s_{1t}(I_t N^i_{1t}) + \pi^c_2 c^s_{2t}(I_t C^i_{2t}) + \pi^n_2 n^s_{2t}(I_t N^i_{2t}) + \pi_3(I_t). \tag{11}$$

**Infected** The lifetime utility of an infected person ($U^i_t$) is

$$U^i_t = u(c^i_{1t}, c^i_{2t}, n^i_{1t}, n^i_{2t}) + \beta\left[(1-\pi_r-\pi_d)U^i_{t+1} + \pi_r U^r_{t+1}\right], \tag{12}$$

subject to (9) and using the fact that the cost of death is the foregone utility of life.

**Recovered** The lifetime utility of a recovered person ($U^r_t$) is

$$U^r_t = u(c^r_{1t}, c^r_{2t}, n^r_{1t}, n^r_{2t}) + \beta U^r_{t+1}, \tag{13}$$

subject to (9) and using the fact that recovered people acquired immunity.

**Transfers and profits** The government taxes formal labor income and at the end of the period rebates formal labor taxes to households as a lump sum transfer. The household also collects profits from informal firms. The total transfers budget constraint is

$$\mu_t(S_t c^s_{1t} + I_t c^i_{1t} + R_t c^r_{1t}) + \mu_t\kappa p_t(S_t c^s_{2t} + I_t c^i_{2t} + R_t c^r_{2t}) + \bar{\mu}w_{1t}(S_t n^s_{1t} + I_t\phi^i n^i_{1t} + R_t n^r_{1t}) + \cdots$$

$$\cdots + p_t A_2(S_t n^s_{1t} + I_t\phi^i n^i_{1t} + R_t n^r_{1t})^\nu - w_{2t}(S_t n^s_{1t} + I_t\phi^i n^i_{1t} + R_t n^r_{1t}) = \Gamma_t(S_t + I_t + R_t). \quad (14)$$

The informal labor activities are not registered by the government, so this labor income is not taxed.

**Competitive equilibrium** A competitive equilibrium is a set of quantities $\{c^l_{1t}, c^l_{2t}, n^l_{1t}, n^l_{2t}, \Gamma_t\}$ and prices $\{w_{1t}, w_{2t}, p_t\}$ satisfying (7)-(14) such that (i) susceptible, infected, and recovered persons' decision rules solve households' maximization problem, (ii) formal firms solve formal firms' problem, (iii) informal firms' decision rules solve the informal firms' problem, and (iv) markets clear in every period:

$$\begin{aligned} N_{1t} &= S_t n^s_{1t} + I_t\phi^i n^i_{1t} + R_t n^r_{1t}, \\ N_{2t} &= S_t n^s_{2t} + I_t\phi^i n^i_{2t} + R_t n^r_{2t}, \\ Y_{1t} = A_1 N_{1t} &= S_t c^s_{1t} + I_t c^i_{1t} + R_t c^r_{1t}, \\ A_2(N_{2t})^\nu &= S_t c^s_{2t} + I_t c^i_{2t} + R_t c^r_{2t}. \end{aligned}$$

## 3 Calibration

Similar to Benhabib, Rogerson and Wright (1991), Horvath (2018), and Kaplan et al. (2020) preferences are represented by

$$u(c_{1t}, c_{2t}, n_{1t}, n_{2t}) = \ln\left[(a(c_{1t})^\rho + (1-a)(c_{2t})^\rho)^{\frac{1}{\rho}}\right] - \frac{1}{1+\eta}\left[b_1(n_{1t})^{1+\eta} + b_2(n_{2t})^{1+\eta}\right], \quad (15)$$

where $1/(1-\rho)$ denotes the elasticity of substitution in consumption. I will assume $\rho = 0$, so the elasticity of substitution between formal and informal consumption is equal to 1 and the composite consumption is a Cobb-Douglas function. I chose the values of $b_1$ and $b_2$ so that in the pre-epidemic state the representative household works 13 hours per week in the formal sector and 35 hours per week in the informal sector. So, the total hours worked per week is equal to 48, and 73% of this time is allocated to informal work and the rest to formal work. This share is consistent with the Peruvian data reported in the fourth quarter of 2019 in table 1.

I also chose the values of $A_1$ and $A_2$ so that the weekly income earned in the formal and informal sector are \$58,000/52 and \$26,100/52, respectively. This is also in line with the share of the informal economy as the percentage of the GDP reported by Medina and Schneider (2019) for Peru in 2017. The rest of the economic parameters are listed in table 2.

In the epidemiological side, I assume that the share of virus transmission not related to consumption or work activities ($\pi_3 S_t I_t$) represents 2/3 of the total infections in the economy. The share of virus transmission related to formal consumption activities (formal and informal) represents 1/6 of total infections, and the share of virus transmission related to work activities (formal and informal) represents 1/6 of total infections. The values of $(\pi^c_1, \pi^c_2, \pi^n_1, \pi^n_2, \pi_3)$ are chosen to satisfy these

Table 2. Parameters

| Parameter | Description | Value | Basis |
|---|---|---|---|
| $\beta$ | Household discount factor | 0.99 | |
| $1/(1-\rho)$ | Elasticity of substitution | 1 | |
| $1/\eta$ | Frisch elasticity of labor supply | 1 | Kaplan et al. (2020) |
| $a$ | Set relative prices in the informal sector | 0.7 | $p_{ss} < 1$ |
| $b_1, b_2$ | Set hours worked in formal and informal sector | 0.0029, 0.0002 | |
| $A_1, A_2$ | Productivity in formal/informal markets | 85.8, 20.46 | |
| $\bar{\mu}$ | Formal labor tax rate | 0.3 | Horvath (2018) |
| $\nu$ | Degree of decreasing returns in informal sector | 0.7 | |
| $\phi^i$ | Productivity of infected people | 0.8 | Eichenbaum et al. (2020*b*) |
| $\pi_d$ | Probability of dying | 0.0019 | Eichenbaum et al. (2020*b*) |
| $\pi_r$ | Probability of recovering | 0.3869 | Eichenbaum et al. (2020*b*) |
| $I_0$ | Initial infected people | 0.1% | Eichenbaum et al. (2020*b*) |

shares in the pre-infection steady state. Finally, I assume that in the model without containment measures 60 percent of the population either recovers or dies from the infection. The number of people that are initially infected is 0.1 percent.

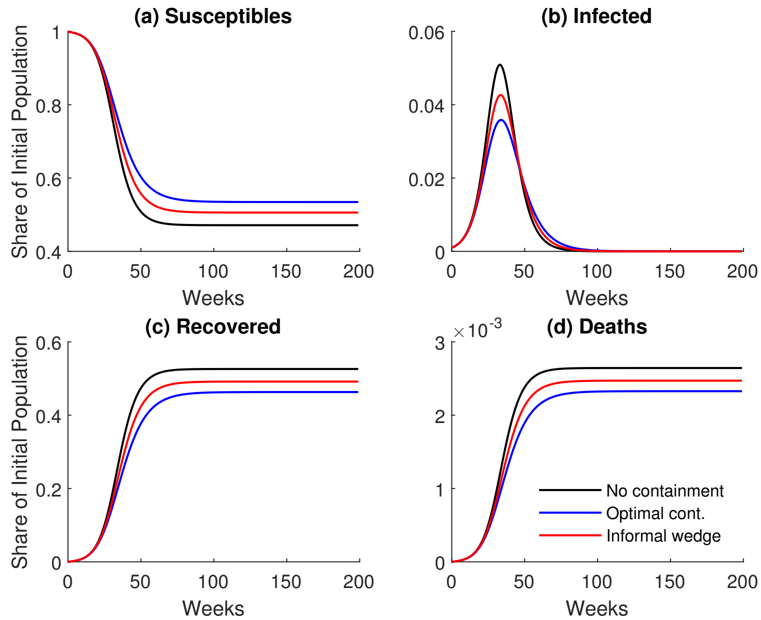
## 4 Importance of containment measures in informal markets

In order to gauge the importance of informal markets, I will solve the problem of the economy with three different scenarios: (i) No containment policies, which through the lens of the model implies ($\mu_t = 0$); (ii) The optimal containment policy in both, formal and informal markets, where ($\mu_t$) is chosen to maximize the social utility of susceptible, infected and recovered people in the economy; and (iii) simple containment policy with a *wedge* on informal markets. The optimal containment policy in points (ii) and (iii) is proportional to the aggregate level of infection rates, i.e. less severe containment rates when the number of infected people is low and the opposite when infections are high.

Finally, I assume there are no containment policies in informal markets in point (iii), so lockdowns are not effective in these markets and $\kappa = 0$, as opposed to the case (ii) where $\kappa = 1$. When $\kappa = 0$ the results can replicate the gap between formal and informal employment during 2020 in Peru (see table 1).

Figure 3 shows the evolution of the epidemic for these three scenarios. The share of the initial population that is infected peaks at 5.1 percent in week 34. This percentage lowers to 3.6 percent when the government enacts optimal containment measures in both formal and informal markets. With ineffective containment measures in the informal markets, this percentage is equal to 4.3. The lower fraction of infected people with containment policies imply more susceptible people and less recovered and death people at the end of the epidemic. For example, the mortality rate without

FIGURE 3. EVOLUTION OF THE EPIDEMIC



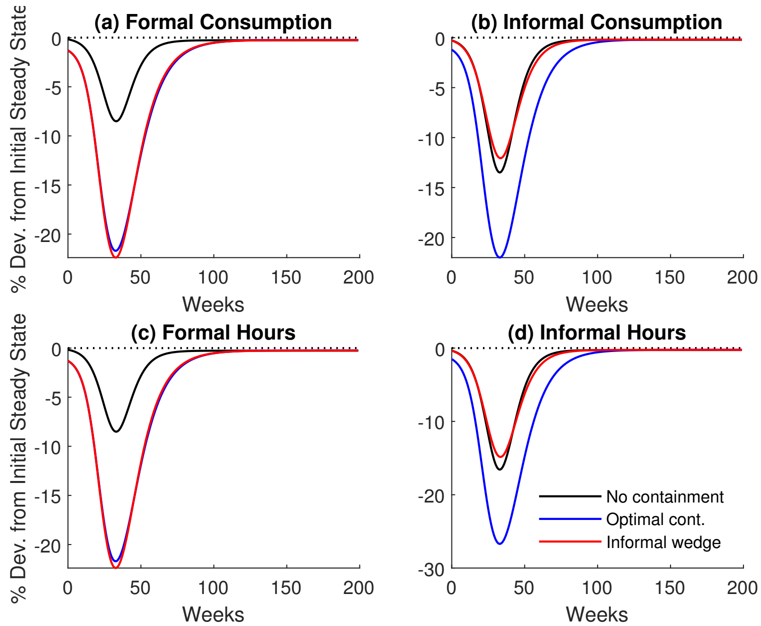

containment measures is equal to 0.26 percent at the end of the epidemic, but this rate is only equal to 0.23 percent and 0.25 in scenario (ii) and (iii), respectively. These findings suggest that even with ineffective containment measures in informal markets, more lives would be saved.

In the economic front, figure 4 shows the evolution of the aggregate consumption and hours for the formal and informal sector. With no containment measures, households will reduce their consumption and labor activities since they know the likelihood of becoming infected through these activities is not equal o zero. Formal consumption and formal hours will decrease to a maximum of 8.52 percent with respect to the initial steady state without containment measures. Informal consumption and informal hours will decrease to a maximum of 13.5 and 16.6, respectively. The decrease in economic activities in the informal sector is higher because the size of the labor informal activities in steady state is larger than labor formal activities, and informal consumption is less valuable compared to formal consumption in the calibrated utility function for households.

With simple containment policies (blue lines in figure 4), the drop in consumption and labor hours is deeper than the previous case. Formal consumption and formal hours worked decrease up to 21.71 percent, while informal consumption and hours worked decrease up to 22 and 26.7 percent, respectively. As discussed in figure 3, the cost of saving more lives during the pandemic is a recession where consumption and employment decline considerably.

On the other hand, the red lines in figure 4 show the evolution of aggregate variables with ineffective containment measures (informal wedge). Formal consumption and formal hours worked decrease up to 22.4 percent. Informal consumption and hours worked decrease up to 12.1 and 14.8 percent, respectively. That is, the drop in informal consumption (hours worked) will be 10 (12) percentage points lower than in the case where simple containment measures are taken in these markets. Moreover, the drop in these informal activities is lower than the drop of formal

FIGURE 4. EVOLUTION OF THE ECONOMY




consumption and hours worked (between 8-10 percentage points lower), similar to the Peruvian employment data.

As discussed in the introductory section, developing countries face accounting challenges in measuring the size of production, and to some extent employment, of the informal sector. Figure 10 shows the differences in aggregate consumption and employment when a developing economy can measure both formal and informal activities. When the government cannot measure the production in the informal sector (black line in panel a) the drop in aggregate consumption would be larger than when the government can incorporate informal production (red line in panel a). This accounting problem can represent up to 3 percentage points of the difference in aggregate consumption around the peak of the infections in the pandemic. Similarly, the difference in aggregate hours worked when the government can and can not account for the informal employment is important and the value of this gap is around 5 percentage points during the peak of the pandemic.

Finally, figures 11, 12, and 13 show the evolution of economic variables for susceptible, infected and recovered people. The drop in aggregate variables is mainly driven by the response of susceptible people in the economy as they will reduce their consumption and hours worked activities in a similar way as shown in figure 4. Recovered people will decrease their formal hours worked, but they will increase informal hours worked, in the case with no containment and informal wedge, because the relative wages in the informal sector is higher due to the drop in aggregate labor supply in this sector.[4] Because of this increase, they can smooth informal consumption with no containment measures in informal markets. A similar pattern emerges for infected people, but since they face a loss in labor productivity due to infection, both formal and informal consumption will drop by

[4]This happens since susceptible people strongly decrease informal hours worked and they represent the large size of the population in the economy.

Figure 5. Optimal containment policies

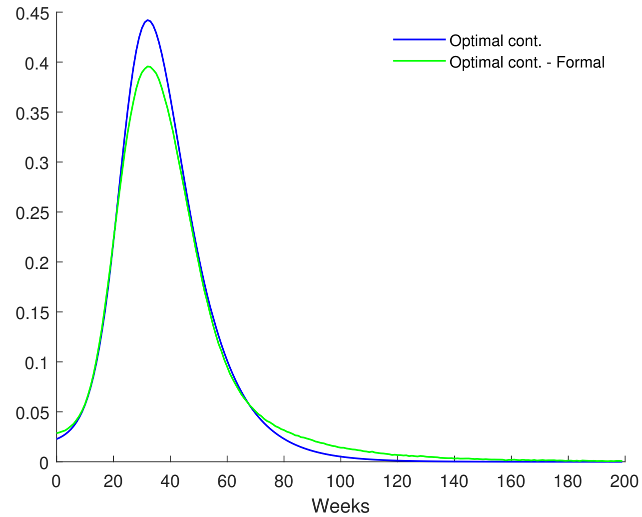
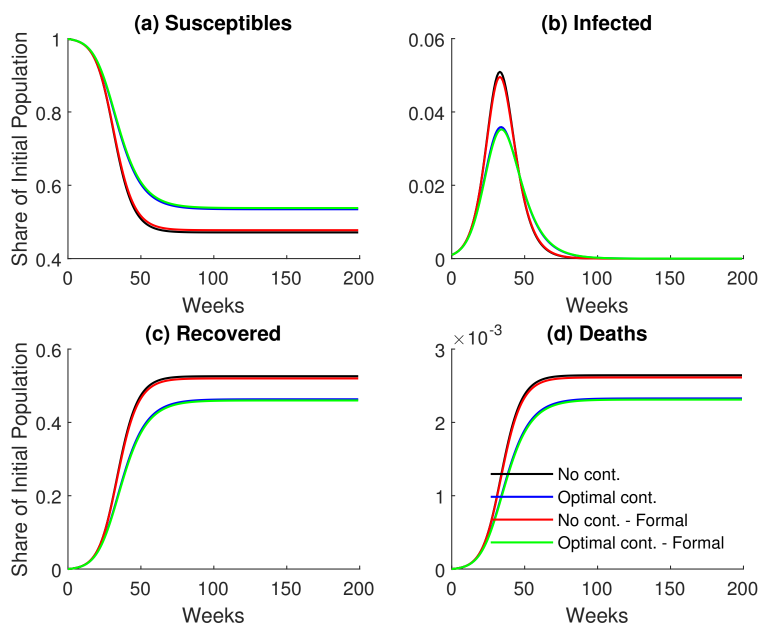



Figure 6. Evolution of the Epidemic with and without informal markets

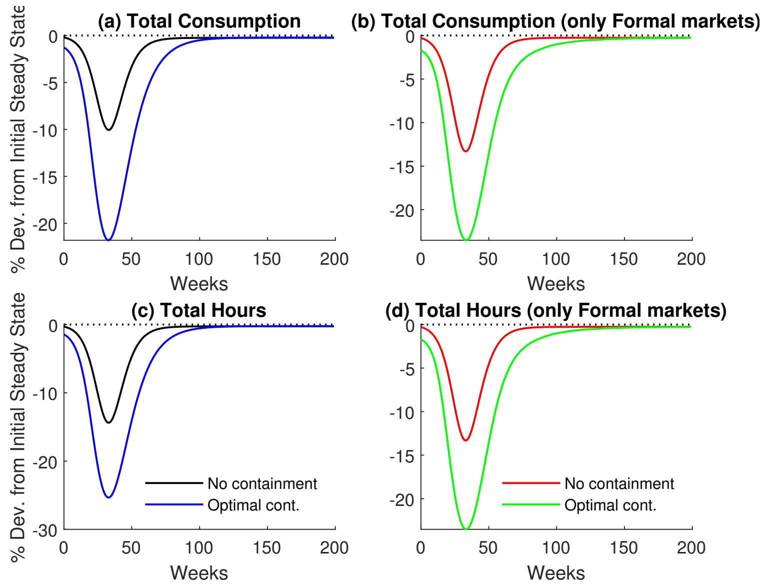



approximately 20 percent over the entire horizon of analysis.

## 5 Economy without informal markets

Due to the importance of informal markets in the previous section, it would be interesting to analyze what will happen to an economy where there are only formal activities. To perform this analysis, I will consider the utility function in (15) with $a = 1$ and $b_2 = 0$ and target consumption (labor) in the steady state as the sum of formal and informal consumption (labor) used in section 3. I will also recalibrate the values for $A_1$ and $b_1$ in order to guarantee consumption and labor are equal to

Figure 7. Evolution of the Economy with and without informal markets




targets in steady state, and recalculate the values of $\pi_1$ and $\pi_2$ in equation (1) to ensure the share of virus transmission related to consumption and labor represent 1/3 of new infections and the rest of 2/3 infections are unrelated with economic activities. The latter guarantees that the *'basic'* reproduction number in both experiments are similar.

Figure 5 shows the optimal containment measures in the economy with formal and informal markets (blue line) and the economy with only formal markets (green line). Without informal markets, the optimal containment measure is lower during the peak of the infections (5 percentage points lower) than the optimal measures in the economy with informal markets. This happens because in order to restrict economic activities in the economy with both markets, the supply effect of the containment measures is large (see discussion about figure 7 below).

The evolution of the epidemic for the four different groups of people in the economy is shown in figure 6. The red and green lines represent the evolution of the epidemic in the economy where only formal markets exist. The black and blue lines come from the analysis in the previous section. We can notice that without or with simple containment policies, the number of infected and dead people in the economy with only formal markets are slightly lower than the economy with both markets.

Figure 7 shows the evolution of consumption and hours worked for the economy with both markets (panels a and c) and with only formal markets (panels b and d). Total consumption and total hours are calculated as the sum of aggregate formal and informal consumption in panels (a) and (b), whereas total consumption and total hours in panels (b) and (d) represents only formal activities. Without containment measures, aggregate consumption drop less in the case of the two-sector economy (3 percentage points lower), but the total hours worked drop less in the case of the economy with only formal activities (1 percentage point lower). With containment measures the differences persist but they are smaller. At the end, in order to generate similar results to the economy with only formal markets, the two-sector economy needs to take larger containment measures.

## 6 Concluding remarks

In this paper I analyze the importance of the informal sector in a standard epidemiology model with aggregate demand and aggregate supply effects. In this sense, susceptible people become infected through consumption and labor interactions with infected people in formal and informal markets. Containment policies are less effective in informal markets because economic activities in this sector are difficult to monitor by their nature.

I found that infection and death rates increase with optimal containment measures applied only in formal markets. However, there are gains in terms of saving lives in this scenario with respect to an scenario where the economy does not impose containment measures. Moreover, if informal aggregate consumption is not counted in the calculation of the GDP, the calculated size of the recession would be larger. Finally, compared to an economy with only formal market, the economy with informal markets must face larger optimal containment policies, with slightly more infected and dead people and a deeper (shallower) decrease in total hours worked (total consumption).

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# Appendix A Calculating the Steady State

The decentralized problem in the pre-epidemic economy can be written as

$$\max \sum_{t=0}^{\infty} \beta^t \left\{ a \ln c_{1t} + (1-a) \ln c_{2t} - \frac{1}{2} \left[ b_1 n_{1t}^2 + b_2 n_{2t}^2 \right] \right\}$$

subject to

$$\begin{aligned}
c_{1t} + p_t c_{2t} = (1-\bar{\mu}) w_{1t} n_{1t} + w_{2t} n_{2t} + \Gamma_t \qquad (\lambda_{bt}),\\
w_{1t} = A_1 \qquad \text{(FOC firms 1)},\\
w_{2t} = \nu p_t A_2 (n_{2t})^{\nu-1} \qquad \text{(FOC firms 2)},\\
\Pi_t = (1-\nu) p_t A_2 (n_{2t})^{\nu} \qquad \text{(Profit firms 2)},\\
T_t = \bar{\mu} w_{1t} n_{1t} \qquad \text{(Government's budget)},\\
c_{1t} = A_1 n_{1t} \qquad \text{(Markets clear condition 1)},\\
c_{2t} = A_2 (n_{2t})^{\nu} \qquad \text{(Markets clear condition 2)},
\end{aligned}$$

where $\Gamma_t$ represents the sum of transfers ($T_t$) and benefits in the informal sector ($\Pi_t$).

In the pre-epidemic economy there are only susceptible agents and the optimal solution for the sequence $(c_{1t}, c_{2t}, n_{1t}, n_{2t}, \lambda_{bt}, p_t)$ can be found solving the system of equations given by the first order conditions, the implied utility function and the clear markets condition

$$\frac{a}{c_{1t}} = \lambda_{bt}, \tag{16}$$

$$\frac{1-a}{c_{2t}} = p_t \lambda_{bt}, \tag{17}$$

$$b_1 n_{1t} = (1-\bar{\mu}) A_1 \lambda_{bt}, \tag{18}$$

$$b_2 n_{2t} = \nu p_t A_2 (n_{2t})^{\nu-1} \lambda_{bt}, \tag{19}$$

$$c_{1t} = A_1 n_{1t}, \tag{20}$$

$$c_{2t} = A_2 (n_{2t})^{\nu}. \tag{21}$$

Equations (16), (18), and (20) imply that

$$n_{1t} = \sqrt{\frac{(1-\bar{\mu})a}{b_1}}.$$

Similarly working with equations (17), (19), and (21) we have that

$$n_{2t} = \sqrt{\frac{(1-a)\nu}{b_2}}.$$

Then, ($c_{1t}$) and ($c_{2t}$) can be calculated with (20) and (21), and ($p_t$) solves (16) and (17)

$$p_t = \left( \frac{1-a}{a} \right) \frac{c_{1t}}{c_{2t}}.$$

The values of $(b_1, b_2, A_1, A_2)$ will be chosen to target the values of $(n_{1t}, n_{2t}, c_{1t}, c_{2t})$ in steady state.

# Appendix B Computing the Equilibrium

Guess sequences $(n^s_{2t}, n^i_{2t}, n^r_{2t}, p_t, \lambda^*_{\tau t}, S^*_t, I^*_t, R^*_t)$ for a given sequence of containment rates $(\mu_t)$ for some large horizon $H$. In practice, I solve the model for $H = 250$ weeks. From the first order conditions of formal and informal firms:

$$w_{1t} = A_1,$$
$$w_{2t} = \nu p_t A_2 (S^*_t n^s_{2t} + I^*_t \phi^i n^i_{2t} + R^*_t n^r_{2t})^{\nu-1}.$$

First, compute the sequence of the unknown variables in each of the following equilibrium equations:

$$\frac{a}{c^r_{1t}} = (1+\mu_t)\lambda^r_{bt},$$
$$\frac{1-a}{c^r_{2t}} = (1+\mu_t\kappa)p_t\lambda^r_{bt},$$
$$b_1 n^r_{1t} = (1-\bar{\mu})w_{1t}\lambda^r_{bt},$$
$$b_2 n^r_{2t} = w_{2t}\lambda^r_{bt},$$
$$u^r_t = a\ln c^r_{1t} + (1-a)\ln c^r_{2t} - \frac{1}{2}\left[b_1(n^r_{1t})^2 + b_2(n^r_{2t})^2\right].$$

Iterate backwards from the post-epidemic steady-state values of $U^r_t$

$$U^r_t = u(c^r_{1t}, c^r_{2t}, n^r_{1t}, n^r_{2t}, ) + \beta U^r_{t+1}.$$

Then, calculate the sequence for the remaining unknowns in the following equations

$$(1+\mu_t)c^r_{1t} + (1+\mu_t\kappa)p_t c^r_{2t} = (1-\bar{\mu})w_{1t}n^r_{1t} + w_{2t}n^r_{2t} + \Gamma_t,$$
$$\frac{a}{c^i_{1t}} = (1+\mu_t)\lambda^i_{bt},$$
$$\frac{1-a}{c^i_{2t}} = (1+\mu_t\kappa)p_t\lambda^i_{bt},$$
$$b_1 n^i_{1t} = (1-\bar{\mu})w_{1t}\phi^i\lambda^i_{bt},$$
$$b_2 n^i_{2t} = w_{2t}\phi^i\lambda^i_{bt},$$
$$u^i_t = a\ln c^i_{1t} + (1-a)\ln c^i_{2t} - \frac{1}{2}\left[b_1(n^i_{1t})^2 + b_2(n^i_{2t})^2\right],$$
$$\frac{a}{c^s_{1t}} - (1+\mu_t)\lambda^s_{bt} + \pi^c_1\lambda^*_{\tau t}I^*_t c^i_{1t} = 0,$$
$$\frac{1-a}{c^s_{2t}} - (1+\mu_t\kappa)p_t\lambda^s_{bt} + \pi^c_2\lambda^*_{\tau t}I^*_t c^i_{2t} = 0,$$
$$-b_1 n^s_{1t} + (1-\bar{\mu})w_{1t}\lambda^s_{bt} + \pi^n_1\lambda^*_{\tau t}I^*_t n^i_{1t} = 0,$$
$$-b_2 n^s_{2t} + w_{2t}\lambda^s_{bt} + \pi^n_2\lambda^*_{\tau t}I^*_t n^i_{2t} = 0,$$
$$u^s_t = a\ln c^s_{1t} + (1-a)\ln c^s_{2t} - \frac{1}{2}\left[b_1(n^s_{1t})^2 + b_2(n^s_{2t})^2\right].$$

Given the initial values $\text{Pop}_0, S_0, I_0, R_0$ and $D_0$, iterate forward using the following equations

$$
\begin{gathered}
T_t = \pi_1^c(S_t C_{1t}^s)(I_t C_{1t}^i) + \pi_1^n(S_t N_{1t}^s)(I_t N_{1t}^i) + \pi_2^c(S_t C_{2t}^s)(I_t C_{2t}^i) + \pi_2^n(S_t N_{2t}^s)(I_t N_{2t}^i) + \pi_3(S_t)(I_t), \\
\text{Pop}_{t+1} = \text{Pop}_t - \pi_d I_t, \\
S_{t+1} = S_t - T_t, \\
I_{t+1} = I_t + T_t - (\pi_r + \pi_d) I_t, \\
R_{t+1} = R_t + \pi_r I_t, \\
D_{t+1} = D_t + \pi_d I_t.
\end{gathered}
$$

Iterate backwards from the post-epidemic steady-state values of $(U_t^s)$ and $(U_t^i)$

$$
\begin{gathered}
U_t^i = u(c_{1t}^i, c_{2t}^i, n_{1t}^i, n_{2t}^i) + \beta\left[(1 - \pi_r - \pi_d)U_{t+1}^i + \pi_r U_{t+1}^r\right], \\
\tau_t = \frac{T_t}{S_t}, \\
U_t^s = u(c_{1t}^s, c_{2t}^s, n_{1t}^s, n_{2t}^s) + \beta\left[(1 - \tau_t)U_{t+1}^s + \tau_t U_{t+1}^i\right].
\end{gathered}
$$

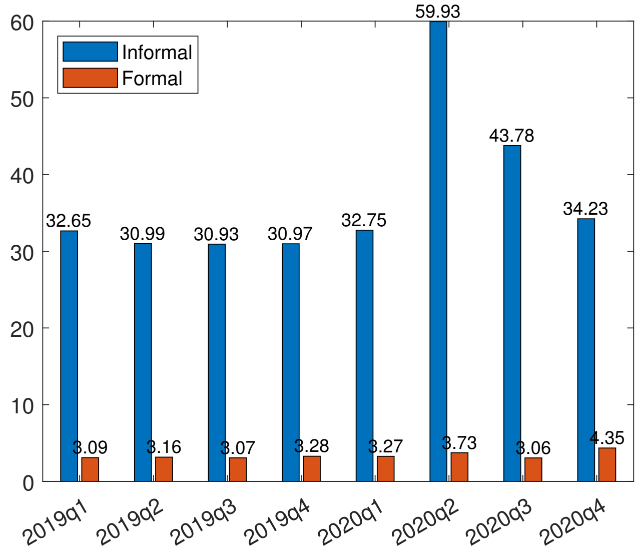
Calculate the sequence of the lagrange multiplier of the probability of becoming infected for susceptible people

$$
\lambda_{\tau t} = \beta(U_{t+1}^i - U_{t+1}^s).
$$

Finally, use a gradient-base method to adjust the initial guesses $(n_{2t}^s, n_{2t}^i, n_{2t}^r, p_t, \lambda_{\tau t}^*, S_t^*, I_t^*, R_t^*)$ so that the following equations hold with arbitrary precision:

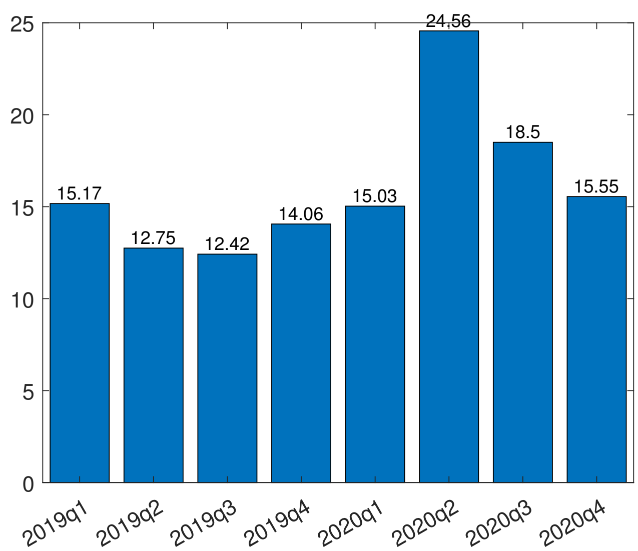
$$
\begin{gathered}
(1 + \mu_t)c_{1t}^i + (1 + \mu_t\kappa)p_t c_{2t}^i = (1 - \bar{\mu})w_{1t}\phi^i n_{1t}^i + w_{2t}\phi^i n_{2t}^i + \Gamma_t, \\
(1 + \mu_t)c_{1t}^s + (1 + \mu_t\kappa)p_t c_{2t}^s = (1 - \bar{\mu})w_{1t} n_{1t}^s + w_{2t} n_{2t}^s + \Gamma_t, \\
\lambda_{\tau t}^* = \lambda_{\tau t}, \\
S_t^* = S_t, \\
I_t^* = I_t, \\
R_t^* = R_t, \\
\mu_t(S_t c_{1t}^s + I_t c_{1t}^i + R_t c_{1t}^r) + \mu_t\kappa p_t(S_t c_{2t}^s + I_t c_{2t}^i + R_t c_{2t}^r) + \bar{\mu}A_1(S_t n_{1t}^s + I_t\phi^i n_{1t}^i + R_t n_{1t}^r) + \cdots \\
\cdots + p_t A_2[S_t n_{2t}^s + I_t\phi^i n_{2t}^i + R_t n_{2t}^r]^\nu - w_{2t}[S_t n_{2t}^s + I_t\phi^i n_{2t}^i + R_t n_{2t}^r] = \Gamma_t(S_t + I_t + R_t), \\
S_t c_{1t}^s + I_t c_{1t}^i + R_t c_{1t}^r = A_1(S_t n_{1t}^s + I_t\phi^i n_{1t}^i + R_t n_{1t}^r).
\end{gathered}
$$

Figure 8. Percentage of informal and formal workers in the agriculture, hunting, forestry and related service activities




*Source:* National Institute of Statistics and Informatics (INEI). Quarterly Household Survey (ENAHO) 2019-2020.

Figure 9. Unpaid family workers




*Notes:* Unpaid family workers are categorized as informal workers according to the informal labor definition in Peru.
*Source:* National Institute of Statistics and Informatics (INEI). Quarterly Household Survey (ENAHO) 2019-2020.

Figure 10. Aggregate variables with and without informal markets

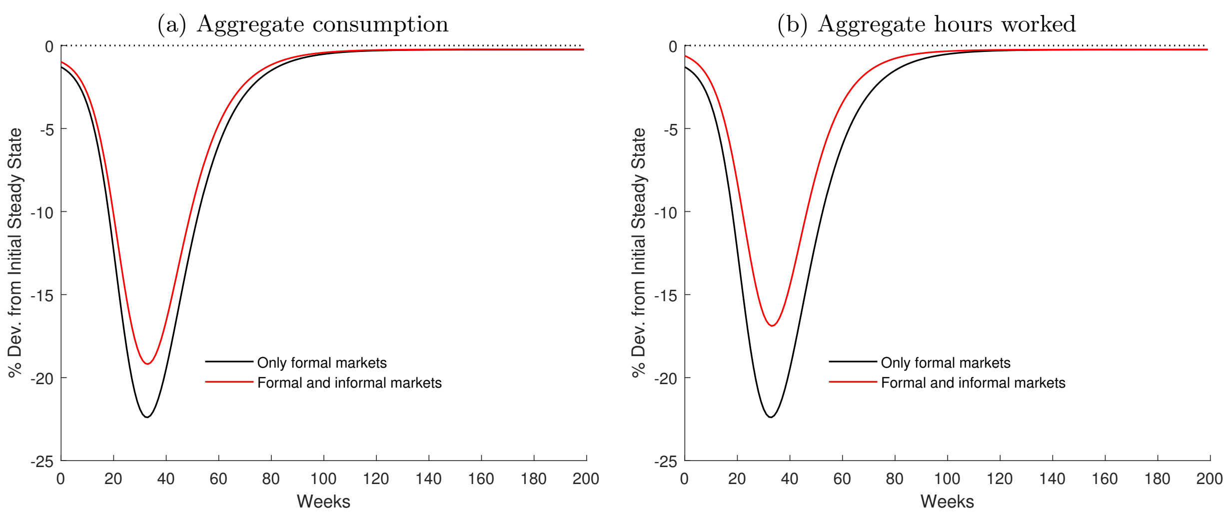


FIGURE 11. EVOLUTION OF THE ECONOMIC VARIABLES FOR SUSCEPTIBLE PEOPLE

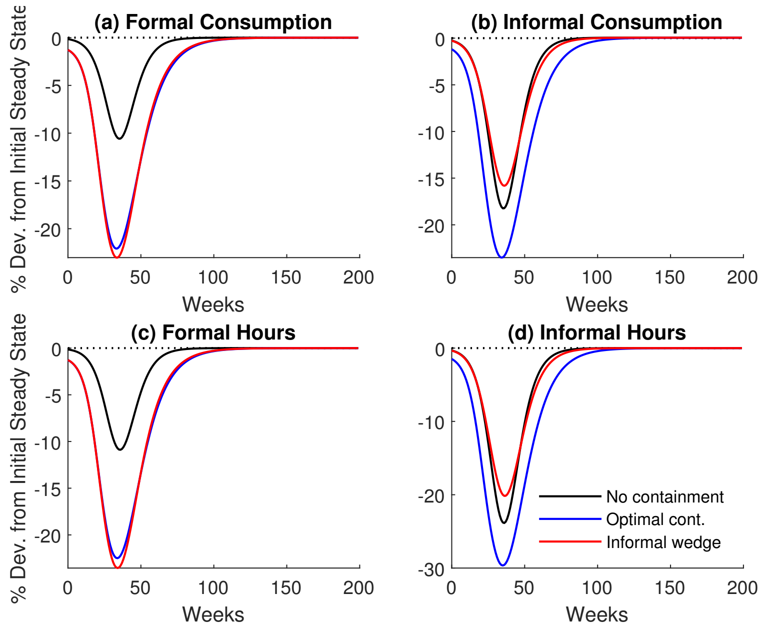



FIGURE 12. EVOLUTION OF THE ECONOMIC VARIABLES FOR INFECTED PEOPLE

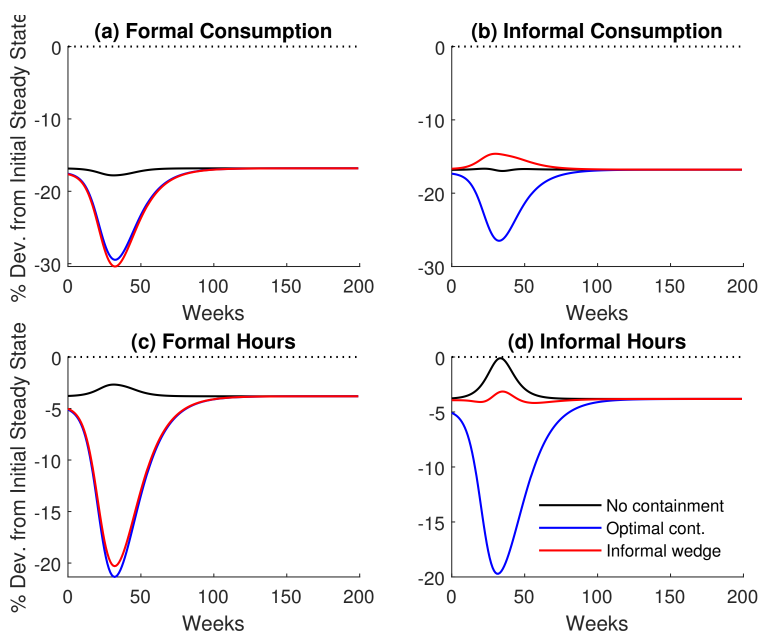


Figure 13. Evolution of the economic variables for recovered people