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TRES ENSAYOS SOBRE ECONOMÍA DE LA SALUD

Por

CARLOS EMMANUEL SALDAÑA VILLANUEVA

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“TRES ENSAYOS SOBRE ECONOMÍA DE LA SALUD”

Carlos Emmanuel Saldaña Villanueva

Comité de Tesis:

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Director de la División de Estudios de Posgrado
Facultad de Economía, UANL
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Dedicatoria

A mi madre, mi hermana y mis dos hermosas sobrinas.

A mi compañera de vida, Bere.

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Three essays on health economics

1. Introduction

The health sector plays a crucial role in the overall functioning of an economy, impacting various aspects ranging from productivity to social well-being. As societies strive for economic growth and development, understanding the intricate relationship between health and the economy becomes paramount. This thesis aims to shed light on three distinct dimensions of this relationship, examining the influence of institutions, informality, and vaccination on health outcomes and economic growth.

Chapter 1 delves into the effect of institutions on the health returns to economic growth. Institutions, comprising a set of rules, norms, and organizations, shape the framework within which economic activities take place. Their impact on health outcomes has been acknowledged, but there is a need for a comprehensive analysis of their effect on the health-economic growth nexus. By exploring this relationship, Chapter 1 seeks to uncover the mechanisms through which institutions influence health outcomes, and subsequently, the long-term economic prosperity of a nation.

Moving forward, Chapter 2 focuses on the effect of informality on compliance with stay-at-home public policies during times of crisis. Informality, characterized by activities and employment outside the formal regulatory framework, poses unique challenges in implementing and enforcing public health measures. This chapter develops a methodology applicable to regions with heterogeneous characteristics of informality, providing insights into the dynamics between informality, compliance, and the effectiveness of stay-at-home policies. The findings of Chapter 2 will contribute to the development of targeted policy interventions and strategies to enhance compliance rates, particularly in regions with significant informal sectors.

In Chapter 3, the focus shifts to the evaluation of the effect of vaccination on COVID-19 mortality. With the global vaccination campaigns underway, it is essential to examine the impact of vaccination programs on reducing COVID-19-related deaths. This chapter utilizes a structural change cointegration methodology to investigate the effect of vaccination on the disappearance of cointegration between the time series of cases and deaths for the Mexican states. The analysis aims to provide empirical evidence regarding the effectiveness of vaccination in reducing the severity of the disease and the subsequent strain on the health system, ultimately contributing to improved health outcomes and economic recovery.

As we delve into these three distinct dimensions, this thesis seeks to deepen our understanding of the interplay between health and the economy. By examining the effect of institutions, informality, and vaccination on health outcomes and economic growth, we aim to contribute to the formulation of evidence-based policies that can foster improved health, societal well-being, and sustained economic development.

2. Can better institutions increase the performance of health in economic growth?

2.1. Abstract

The effect of health on economic growth has been extensively studied. The purpose of this article is to measure the effects in different institutional conditions. Using common data in the economic growth literature and adding worldwide governance indicators, it is observed that the main ways in which institutional quality increases the effect of health on economic growth are the countries with the best performance in citizen participation (voice and accountability of accounts) and control of corruption. This effect increases, on average, by 1.5% with respect to countries with low institutional quality. This suggests that it is not only important that governments allocate large amounts to the health sector, but also that citizens participate in their spending and that corruption practices are avoided.

2.2. Introduction

A country with health problems is one that will have difficulties to sustain its economic growth, reduce poverty and generate equal opportunities for its citizens. When workers are sick, their labor productivity is affected since they can work only for a shorter time and therefore receive a lower salary. Moreover, if people find themselves ill, they tend to spend part of their available time and income treating their medical conditions instead of working. As a result, workers show lower productivity during the activities associated with their jobs. In contrast, countries with less health problems tend to be more productive. Keeping workers healthy have several positive effects on labor supply and work productivity (D E Bloom & Canning, 2000; Schultz, 2002; Strauss & Thomas, 1998). For example, the healthier the workforce is, the longer it will be employed, the better its skills are used, and the greater its concentration and development capacities in education. Then, people will have a longer life expectancy, affecting the decisions they have to make in their life cycle. That is, they will increase their educational and productive stages (Weil, 2007).

The positive correlation between health and development is clear, however, this relation changes if we take into account the quality of each country's institutions. Societies with better institutions will enjoy better medical services and have more effective campaigns for preventing chronic degenerative conditions (Joumard et al., 2012). Likewise, the current pandemic faced by most countries has caused a resurgence of the importance of institutional quality not only in the health sector but also in other institutions. It is not easier for a country with weak institutions to confront and implement public policies against diabetes and hypertension than one with strong and solid institutions. This is evident in the face of the current pandemic caused by COVID-19 and the closure of economies, in which not only the medical equipment and the measures implemented to contain contagions matter, but also the state of the institutions, as shown by Ferraresi et al. (2020). Additionally, as far as we know, there are no other studies that consider the differences in the effects caused by the change in institutional quality environments. Previous literature has focused only on the effect of health on economic growth using an indicator of institutions as a control.

The purpose of this paper is to find the difference in health returns on economic growth induced by institutional quality. The strategy implemented in this paper is as follows. First of all, we obtained the average effect on economic growth without considering these differences, which is consistent with previous empirical evidence (Bloom et al., 2018; Weil, 2007). Secondly, we separated observations for each indicator of institutional quality based on macro data but using an adequate measure of the latent health variable and indicators of citizen participation, rule of law, regulatory quality, political stability of governments, control of corruption and government effectiveness as measures of characteristics of the institutional environment.

By using different indicators of the quality of institutions, our results indicated that institutional improvement increases the performance of health in economic growth. Particularly, for countries with high control of corruption, the effect of health on economic growth increased by 1.4% compared to those with a low level in this indicator. Similarly, countries with high citizen participation increased by 1.5% compared to those with low. In terms of public health policy, these results help to understand the type of institutions that society needs to boost economic growth. That is, if civil society participation is the key and has the biggest effect on economic performance, not only should more resources be allocated to the health sector, but also citizens should participate actively in the planning and implementation of the public health budget. Likewise, it is necessary to rigorously check that the planned expenditure in this sector is spent appropriately and where it is needed, since high control of corruption has a significant impact on economic growth.

The structure of the paper is as follows. In Section 2, we review various approaches where the performance of health in economic growth is discussed. In Section 3, we describe the theoretical and empirical methodology used in measuring the effect of health as a component of human capital and the differences of the methods given the quality of institutions. In Section 4, we discuss our findings and compare them with the previous literature. Finally, in the last section, we present our conclusions.

2.3. Literature review

Economic growth and human capital has been a subject of study for almost 30 years (Mankiw et al., 1992) and has been in force in recent years (Kraay, 2018). After Mankiw, Romer and Weil (1992) took the neoclassical growth model (Solow, 1956) and incorporated human capital, the first works that emerged considered the effect of health as a component of this capital measured by life expectancy (Barro & Lee, 1994; Caselli et al., 1996). However, these studies show endogeneity problems related to life expectancy since, on the one hand, populations that enjoy better levels of this indicator are more productive, and, on the other hand, the richest countries have better conditions to extend the life of their populations. To avoid the endogeneity problem, Bhargava et al., (2006) used the adult survival rate as an alternative variable to life expectancy.

In an attempt to obtain better estimates through aggregates, the exogenous approach which seeks to isolate the causal channel between economic growth and health through instrumental variables (Aghion et al., 2010; David E. Bloom et al., 2014; Cervellati et al., 2011; Lorentzen et al., 2008) was used. Unfortunately, the empirical evidence is mixed since, in some works such as Acemoglu & Johnson (2007), there is no evidence for a positive causal effect. On the other hand, Weil (2007b) used micro data to estimate returns to workers´ health through variables such as adult height, adult survival rate, and age at menarche.

More recent work has sought to reconcile both approaches (micro and macro) (Bloom et al., 2018), where their main findings show that micro strategies justify macro results using appropriate measures, such as the adult survival rate instead of life expectancy. Both the results of Weil (2007b) and David E Bloom et al., (2018) are compared with our global estimates.

The literature regarding institutional quality and economic growth is extensive. Several studies have used different indicators to measure the relationship between good institutions and economic growth. In the work of Esfahani & Ramírez (2003), they use the indicators of contract compliance, bureaucratic quality and absence of corruption from the International Country Risk Guide (ICRG) database. On the other hand, the works of Bhattacharyya (2009) and Nawaz (2015) make use of the World Governance Indicators database (The World Bank, 2015).

Other studies began to include variables that measure institutional differences to control these differences between countries. Among these studies, the one by Barro (1996), which uses indexes of the rule of law, stands out. Similarly, Barro & Sala-i-Martin (1995) incorporated political instability to measure the institutional quality of the countries. Also, in the study of health in economic growth, measures of institutional quality (David E. Bloom & Malaney, 1998; David E. Bloom & Sachs, 1998; David E Bloom et al., 2001; Hamoudi & Sachs, 1999; Sachs & Warner, 1997) and quality of public institutions (David E Bloom et al., 2001) have been used as controls.

Our main contribution to the literature focuses on adequate use of macroeconomic data to measure the effects of health on economic growth and to see the differences of these effects between countries through institutional quality. As mentioned, the institutions help the government and the population to combat, prevent and treat diseases that affect labor productivity and people's quality of life. That is why it is expected that the countries that enjoy the best levels in these indicators will also have the best effects since they enhance the channels in which health acts in the economy.

2.4. Methodology

2.4.1. Theoretical framework

From the neoclassical model of economic growth proposed by Solow (1956) and Mankiw et al., (1992), they propose a derivation of the neoclassical model, including human capital. The proposed production function is Cobb-Douglas type with physical capital, human capital in the form of health and education, labor and technology. It is assumed that both labor and technology grow at exogenous rates as well as the savings rates of the two types of capital, human and physical. The model describes the transitional dynamics with the growth of the product per unit of effective labor $\frac{\partial \ln y(t)}{\partial t}$ proportional to the gap with respect to the stationary equilibrium $[\ln(y^*) - \ln y(t)]$, that is:

$$\frac{\partial \ln y(t)}{\partial t} = \lambda[\ln(y^*) - \ln y(t)] \tag{1}$$

Solving the above equation for the per capita product and assuming that all the information for period t-1 is known, the trajectory of the product per worker is given by:

$$\ln\left[\frac{Y}{L}(t)\right] = e^{-\lambda} \ln\left[\frac{Y}{L}(t-1)\right] + \left(1 - e^{-\lambda}\right)[\ln(y^*) + \ln A(t)] \tag{2}$$

Where y^* is the output per unit of effective labor in the steady-state and $A(t)$ is the technology. The growth rate of output per worker, $g(t) = \ln\left[\frac{Y}{L}(t)\right] - \ln\left[\frac{Y}{L}(t-1)\right]$, is obtained by subtracting the element$\ln\left[\frac{Y}{L}(t-1)\right]$from both sides of the equation (2), then through simplifications:

$$g(t) = \left(1 - e^{-\lambda}\right)[\ln(y^*) + \ln A(t) - \ln\left[\frac{Y}{L}(t-1)\right] \tag{3}$$

The solution of income per unit of effective labor in the stationary equilibrium results in a linear relationship of the logarithms of the saving rates of physical and human capital and the growth rate of the labor force. In general, and using the proposed production function, the above is expressed as:

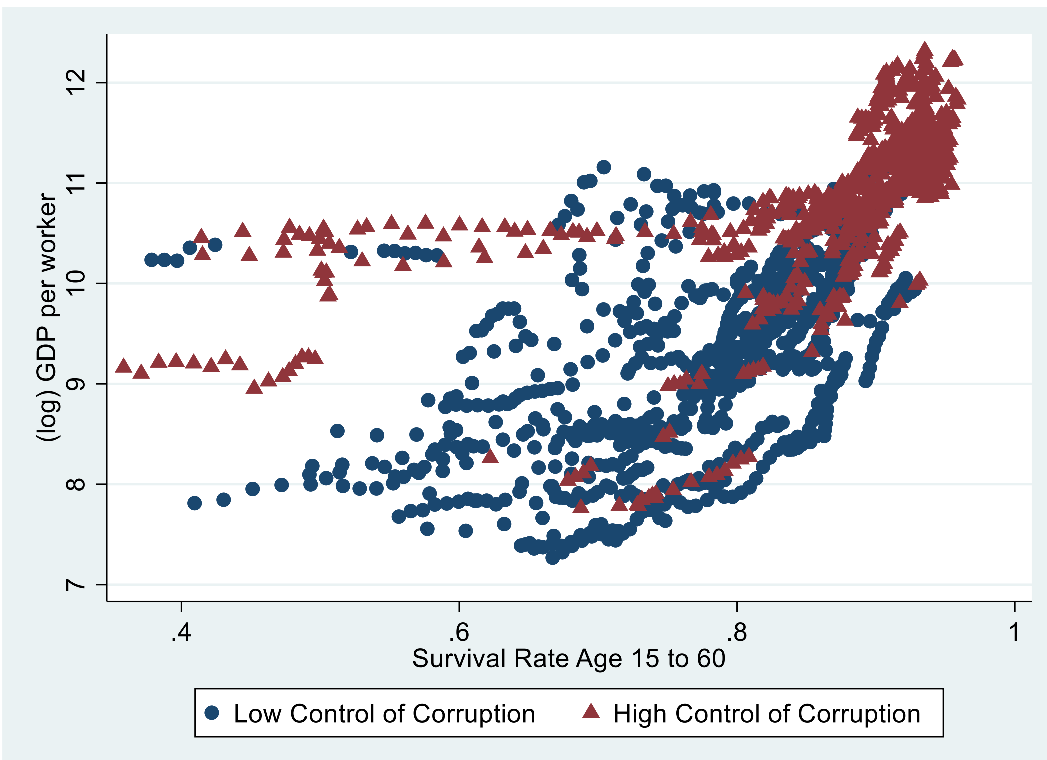
$$g(t) = \left(1 - e^{-\lambda}\right)\left[\phi_k \ln(k) + \phi_{he} \ln(h_e) + \phi_{hs} \ln(h_s) + \ln A(t) - \ln\left[\frac{Y}{L}(t-1)\right]\right] \tag{4}$$

Where k is the stock of physical capital, h_e y h_s are human capital in the form of education and health, respectively. According to equation 4, an increase in saving rates in the capital (physical and human) increases the product per unit of effective steady-state labor ($\phi_i > 0$ para i=k, he, hs). The increase in the population growth rate implies a reduction ($\phi_n < 0$) and that the economies furthest from their stationary equilibrium grow faster ($\lambda > 0$). It is important to mention that equation 4 is consistent with the approach of Bloom (2004), which adds the health status of workers as a form of human capital separable from education and is estimated in differences per worker.

2.4.2. Graphical Evidence and Data description

As illustrated in Figure 1, controlling for Rule of Law (High and Low), the difference between the relationship between the Adult Survival Rate (ASR) and the Gross Domestic Product per Worker (GDP per w) is not visible.

Figure 1: Unconditional correlation between ASR and GDP per worker in 2015. Source: Own elaboration with data from (Feenstra et al., 2015; The World Bank, 2015)



To carry out the estimates in this study, data from different sources were used for 118 countries for the period between 2003 and 2017. For example, the data on capital (such as growth rate) and the ASR were obtained from the World Bank (The World Bank, 2015). To measure human capital in the form of health, the Human Capital Index Project (HCIP) methodology (Kraay, 2018) was applied to use the available data from the ASR to calculate an indicator as a latent measure of health, given by:

$$HCI_{health} = e^{\gamma_{ASR} * ASR} \quad (5)$$

Where $\gamma_{ASR} = 0.35$, obtained through calibrations carried out in the *(HCIP)*[1]. This way of measuring health prevents infant mortality from inflating the indicator, as does life expectancy and has been used successfully to estimate the returns to health in economic growth (Bloom et al., 2018).

For the variables of production per worker and education, the data reported in Penn World Tables 9.1 (Feenstra et al., 2015) were used. Similarly, to measure institutional quality, the World Governance Indicators (World Bank, 2005) base was used, where it is measured: citizen participation in government, extreme changes in governments that may affect the quality of governance, the resources it has, the government to produce and implement good policies and provide public goods, the regulatory quality of government, the rule of law and the control of corruption.

To compare the indicators between countries, Kaufmann et al., (2010) standardized the variables since they were built with different databases. Likewise, it is assumed that there is an observed rating given by the inhabitants of country j, for the indicator k, y_{jk}, as a linear function of an unobservable variable g_j and an error term ε_{jk}, which is:

$$y_{jk} = \alpha_k + \beta_k (g_j + \varepsilon_{jk}) \quad (6)$$

Where α_k and β_k are parameters that map the unobserved governance in country j, g_j, in the observed indicator k, y_{jk}.

Furthermore, it is assumed that $g_j \sim N(0,1)$ and that $y_{jk} \in [-2.5, 2.5]$. This generates a confidence interval for each observation for each indicator. For example, one country can rate corruption from 1 to 100, another from 0 to 1, and another country from 1 to 6, standardizing results in values with different standard errors. However, this is not a problem for our work since the observations are separated by high and low institutional quality given by the median. The authors of the database (Kaufmann et al., 2010) and the studies consulted (Bhattacharyya, 2009; Nawaz, 2015) show that this separation avoids the problem of heterogeneity in standard errors.

[1] The methodology can be consulted at https://www.worldbank.org/en/publication/human-capital

Table 1 reports the descriptive statistics of the database built for 118 countries from 2003 to 2017. The first column shows the name of the variables while columns two, three, four and five show the mean, standard deviation (DE), the minimum value (Min) and the maximum value (Max). It can be seen that, for the period studied, the growth in production per worker was 3%.

Table1: Descriptive Statistics with the entire sample.

Variable	Mean	DE	Min	Max
GDP per worker	41059.30	37674.92	1434.52	223796.50
GDP growth per worker	0.03	0.08	-0.59	0.62
Capital	6.21	20.18	-223.09	435.62
Education	2.55	0.69	1.09	3.97
Adult Survival Rate (ASR)	0.83	0.11	0.36	0.96
Human Capital Index (Health)	0.89	0.06	0.66	0.97
Citizen Participation/ Voice and Accountability (VA)	0.06	0.94	-1.91	1.80
Rule of Law (RL)	0.09	1.00	-2.26	2.10
Regulatory Quality (RQ)	0.21	0.94	-2.00	2.26
Political Stability (PV)	-0.06	0.93	-2.50	1.76
Control of Corruption (CC)	0.08	1.04	-1.72	2.47
Government Effectiveness (GE)	0.17	0.99	-2.08	2.44
OBS		1888		

Source: Authors' elaboration

The descriptive statistics of the sample separated by institutional quality are found in Annex 1.

2.5. Empirical Framework

Based on equation (4) the following regression is proposed:

$$\Delta Y_{i,t} = \alpha_i + \mu_t + \beta_k \Delta k_{i,t} + \beta_{he} \Delta hc^{e}{}_{i,t} + \beta_{hs} \Delta hc^{s}{}_{i,t} + \beta_y \ln(Y)_{i,t-1} + \epsilon_{i,t} \qquad (7)$$

Where $Y_{i,t}$ is the GDP per worker of country i in year t, $Y_{i,t-1}$ is its lag, $\Delta k_{i.t}$ is the gross capital formation as a share of GDP, $hc^{e}_{i,t}$ y $hc^{s}_{i,t}$ are the variables of human capital in the form of education and health by country i and year t, respectively. The regression is carried out with fixed effects by country and year.

Equation (7) is the base regression; however, the effects by institutional quality and their interactions will be controlled as suggested (Esfahani & Ramírez, 2003) and added to the regression as performed in Catrinescu et al., (2009). Bearing in mind the problem of standard errors in each indicator that we use, the database was separated by institutional quality as follows:

$$d_k = \begin{cases} High\ if\ y_{jk} \geq \widetilde{y_k} \\ Low\ if\ y_{jk} < \widetilde{y_k} \end{cases} \tag{7}$$

Where $\widetilde{y_k}$ is the median of indicator k. This form has been used by (Bhattacharyya, 2009; Nawaz, 2015), and only two levels of separation were used to have subsamples of adequate size. To test our hypothesis, the regression will be carried out, separating the database for each indicator of institutional quality into high and low.

Additionally, lags of the health and education variables are added as suggested (David E Bloom et al., 2018; Kotschy & Sunde, 2018) to control for population shocks in the growth of output per worker.

2.6. Results

Table 5 reports the results of the base model (equation 7). The first part is a comparison between the returns obtained by the previous literature and ours. Considering the 95% confidence interval, it is shown that our estimate is consistent with the micro and macro evidence. In the second part, the calculations are performed with the regressions separated by high and low institutional quality.

Table2: Base results and their comparisons

Returns with micro data (Weil, 2007a)	6.7%	
Returns with macro data (David E Bloom et al., 2018)	9.1%	
Our Estimation	7.55% (5.12% - 9.35%). [2]	
Separate Estimates[3]	Institutional Quality	
	Low	High
Citizen Participation[4]/ Voice and Accountability (VA)*	**2.2%**	**3.6%**
Rule of Law (RL)	2.9%	3.6%
Regulatory Quality (RQ)	2.7%	3.4%
Political Stability (PE)	1.4%	3.6%
Control of Corruption (CC)*	**2.4%**	**3.9%**
Government Effectiveness (GE)	2.7%	3.3%

Source: Authors' elaboration

Separating for each indicator, it can be observed that when there is a high institutional quality environment, health performance increases on average by 1.2%. The largest difference is found in the Political Stability indicator; however, the separate estimates were not significant for the regressions with a low level of this indicator.

In Annex 2, all the separate regressions are reported, as well as the base. As can be seen in Tables 9 to 14, no clear evidence was obtained from the effect of institutional quality on economic growth. This is because the appropriate empirical strategy to measure this effect would be separate regressions for each year (Kaufmann et al., 2009) and would establish more levels of separation. Our interest is focused on the effect of health on economic growth and the differences through institutional channels, so this strategy was not adopted. When comparing the standard errors to see if the coefficients were statistically different, only for the separations by Citizen Participation (Voice and Accountability) and Control of Corruption, it was thus: as shown in Table 2.

[2]Values in parentheses are the 95% confidence interval.
[3]The returns are lower because the capital coefficients were also changed.
[4]Voice and Accountability is close to citizen participation as it captures the way in which citizens participate in electing their government as well as the freedom of expression and association they have.

Another interesting result is found in the capital coefficients in the separate regressions. These have higher returns when the institutions are of better quality, which goes hand in hand with the idea that greater stability and governance help to promote investments. However, to obtain better conclusions in this regard, it is necessary to establish a theoretical and empirical framework that justifies the effects on public infrastructure and the factors that affect labor productivity (Esfahani & Ramírez, 2003).

In Annex 3, robustness tests are performed and compared with the base results. In this, the dynamic panel with the estimator of Arellano & Bond (1991) is used. The Human Capital Index (Health component) is also changed for life expectancy and additionally, the GDP per worker per GDP per capita. The results are maintained, although the coefficients are modified as indicated (Bloom et al., 2018).

2.7. Conclusions

The effect that capital in the health form has on economic growth has been widely studied using various approaches. However, this study focused on showing the difference (and measuring it) through institutions as a factor that favors better performance in the most developed economies in this area.

The results of the base model are consistent with those of the previous literature. As you might expect, the performance obtained with macro regressions is usually higher than that obtained with micro data. With a confidence level of 95%, it can be said that our results are consistent with those studies.

According to our results, a 10% increase in the Health index will be reflected in a 3.9% increase, on average, in economic growth for the countries with better institutions, separated by Corruption Control. On the other hand, if the country is in an unfavorable institutional environment, the performance is reduced, on average, by 2.4% of the same institutional indicator, which answers the main question that motivated this work. In effect, better institutions increase the performance of health in economic growth.

This indicates that the role that health plays in an economy is affected by institutional factors. This goes in the direction that policies concerning the public health sector should not only focus on making large expenditures on this indicator, but also that they be carried out in better institutional settings. That is, given that the two indicators in which the effect was increased to greater institutions, it is not only important that a considerable amount of resources be allocated to the health sector, but also that, to increase this effect, citizens must actively participate in government and resources must be exercised responsibly and transparently.

These elements have become vital points for the current management of the COVID-19 pandemic where measures of social distancing, hygiene and restrictions for events or circumstances of large crowds of people are relevant. Institutions play a fundamental role in the decisions that people make because if they are sound and trusted, they will better channel their human capital in the form of health to improve their productivity.

3. "Stay at Home (If You Can)": Informal Employment and COVID-19 in Mexico

3.1. Abstract

This paper explores the relationship between residential confinement to reduce the spread of the COVID-19 virus, seen as a public policy, and how it affects the informal labor sector, as well as the response of individuals to the pandemic in the states of Mexico. Forming panels for various levels of informality applied to panel vector auto-regressive (PVAR) shows that staying at home as public policy becomes more effective as informality decreases. In addition, the response of individuals to an increase in the spread of the pandemic depends on the level of informality: for states with lower rates of informality, individuals respond to a higher concentration of residential confinement. But for states with a higher level of informality, the evidence is not significant. The paper considers the role of informality in the development of an effective public policy.

3.2. Introduction

The onset of the COVID-19 pandemic led to a series of social distancing measures (closure of bars, restaurants, shopping centers and schools, suspension of mass events, and residential confinement) aimed at preventing an increase in the number of cases and, in the absence of accurate treatment, deaths in the vulnerable population. This series of measures, including residential confinement or better known as stay-at-home, implemented by the vast majority of countries around the world, are known as non-pharmaceutical interventions (NPIs). Several studies have analyzed the effectiveness of this policy (Andersen, 2020; Ferraresi et al., 2020; Kong & Prinz, 2020; Yilmazkuday, 2020), as well as the determinants that motivate people to residential confinement (Bargain & Aminjonov, 2020; Müller & Rau, 2020).

However, these public policy measures are also affected by the employment situation in each country. One of the main challenges, regarding the labor market, is the population with informal jobs. It is important to mention that informal employment is of particular concern when evaluating the impact of the economic and health crisis caused by the COVID-19 pandemic, as recent research and international organizations have shown (Altamirano et al., 2020; International Labour Organization ILO, 2020; OECD, 2020). On the public health side, informal workers lack social security, making them especially vulnerable to lack of access to medical services in case of infection. In addition, in terms of the health situation in countries with higher rates of informal labor, it is this lack of access to medical services that makes their populations less healthy and therefore more likely to have the co-morbidities that increase coronavirus mortality (hypertension, diabetes, obesity).

On the economic side, informal workers and their households are highly dependent on the income they generate on a daily basis, as their situation of informality deprives them of job stability and income. This is especially important in times of the coronavirus, since this sector depends on going out to work daily to cover the basic needs of the household (Loayza & Pennings, 2020). This makes it impossible for them to stay out of work for long periods of time and, since most of these jobs cannot be done at home (Dingel & Neiman, 2020), a public policy of staying at home puts their daily subsistence at risk.

Additionally, governments face another economic problem due to the large portion of informal workers. The fiscal and institutional capacity of these countries is less effective in responding to the pandemic. This is because informal employment does not pay taxes as much as formal employment does.

According to ILO's[5] estimates, the impact of the emergency closure of the economy during the first month of the confinement on the income of informal workers has been a 60% reduction globally. In sectors with higher rates of informality, such as Africa and Latin America, the estimated reduction is 81%. This is of enormous concern for countries in these regions, where poverty rates could increase considerably in the face of less social assistance and job security.

Likewise, there have been several social implications due to characteristics such as resilience, flexibility and economic tensions within a country. For example, the short-term consequences for the informal labor market depend on the country's level of socioeconomic development. The lack of control over these jobs reduces the room for maneuver by federal and local governments in public budgets (Loayza & Pennings, 2020). Similarly, there is an additional issue to consider when segmenting labor force by gender. The informal employment sector has a larger portion of women than men. More than 60% of the women who work in countries with a low to medium income level do so in the informal sector (Gausman & Langer, 2020; Langer et al., 2015).

In a context of job instability, household cash flow becomes vital for survival during pandemic lockdowns. This is relevant because households that suddenly see their income drop try to smooth their consumption by using available savings. However, even in developed countries, there is evidence of a lack of savings for household expenses over very long periods (Catherine et al., 2020). Therefore, a public policy of emergency closure that doesn't consider the labor context of each region could aggravate the effects in the informal sector. This accentuates the economic impact of the pandemic as the informal sector is also integrated with formal employment, and it has been proposed to gradually incorporate both sectors (formal and informal) in order to record and plan short- and medium-term public policies that help, first, contain the effects of the lack of social protection of the informal sector and, second, improve the quality of the labor market (Narula, 2020).

Mexico is one of the 20 largest economies in the world. Despite this, it is also a developing country, with 41.9% of the population living below the national poverty line and more than half of the workers in the informal sector (INEGI, 2020b; The World Bank, 2015). Nevertheless, these informal workers are not homogeneous. In fact, at the income level there is

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[5] ILO, I. L. O. (2020). *COVID-19 and the world of work*. ILO Monitor Fourth Edition

also enormous heterogeneity. Additionally, it is important to mention that Bloomberg published a ranking of the 53 largest economies in the world ordered by level of resilience at the time of the current pandemic. Mexico is in the 53rd place, that is, the least resilient. This makes it, according to the study, the worst place to be during the coronavirus era (Bloomberg, 2020a, 2020b). This is of particular concern because, as discussed in other papers on COVID-19 (Tejedor Estupiñán, 2021), the problems related to pandemic and vaccination reveal the weaknesses of health care systems.

3.3. Literature Review

This paper is not the first to consider the effects of the current COVID-19 pandemic on Mexico. For example, the effects of COVID-19 on the Mexican economy have already been discussed (Esquivel, 2020). Similarly Esquivel and Campos-Vázquez (2020) calculated the effect of the crisis on the population in different ways, seeing as consumption has been affected by restrictions on urban mobility. Additionally, several studies have been conducted, using input-output matrices, on how different sectors, regions and vulnerable populations of the Mexican economy will be affected (Chapa, 2020). The effect of residential confinement has been studied in other papers for Mexico, such as Rangel et al. (2021) or for some other countries, such as in Testa et al. (2021). However, the latter does not consider the cross effects or the informality separations examined in our paper. We can also find in the literature other contributions looking for answers to similar questions, such as food security and the impacts it has on agriculture, as shown in Luque Zúñiga et al. (2021) and Moreno Salazar Calderón (2021), where these phenomena can be understood due to the link between food production and informality.

It has also been studied how the temporary closure of the construction, service and manufacturing industries leads to an increase in the number of economically active people joining the informal sector (Mendoza Cota, 2019). Furthermore, Mexican households that depend on informal labor income, coupled with low access to formal credit, are substantially less likely to work from home, which may contribute to increased inequality (Peluffo & Viollaz, 2020).

However, these studies have not considered the effect that residential confinement has on the growth of the number of confirmed COVID-19 cases and vice versa and the role of informality in how people have responded to public policy on staying at home and how people choose to isolate themselves residentially in the face of the rising pandemic.

The main contribution of this article to the literature is to evaluate, through the regions separated by levels of informality, the effect of the policies of social distancing, especially residential isolation, implemented to reduce the spread of the virus. In addition, our approach allows us to visualize whether the growing number of confirmed cases causes, within the employment possibilities of households, an increased need to stay at home.

3.4. Methodology

Residential confinement and the number of COVID-19 cases are closely related (Andersen, 2020; Engle et al., 2020; Yilmazkuday, 2020; Zhu et al., 2020). Among the first works to understand this relationship is that of Maloney and Taskin (Maloney & Taskin, 2020), who used a panel regression to identify the determinants of social distancing and economic activity. One of their main findings is that the greater the number of registered cases, the more people tend to stay at home, trying to reduce the probability of contagion. This suggests that, as cases and deaths increased during the COVID-19 pandemic, people perceived a greater risk of being infected and thus limited their outward movements.

Moreover, Milani (2020) shows the endogenous effects between these two variables by using GVARs (global autoregressive vectors). This is done mainly because obtaining a beta coefficient in the regressions does not consider the interdependence of these two variables. That is, an increase in effective residential confinement should decrease infections. While an increase in cases should generate incentivize staying at home to avoid infection.

Model

As mentioned above, each category (very low, low, high and very high) is made up of 8 states in the Mexican Republic. A PVAR system of order L is estimated for each category, represented by the following systems of equations:

$$Y_{it} = \sum_{l=1}^{L} Y_{it-l}A_l + X_{it}B + u_i + e_{it}$$

Where Y_{it} is a (1×3) vector of endogenous variables, viz.: change in residential confinement, daily growth in confirmed cases, the mood on Twitter. X_{it} is a (1×3) vector of exogenous variables made up of paydays, weekends, and weather alerts. u_i and e_{it} are (1×3) vectors representing the specific fixed effect of the endogenous variables and the idiosyncratic errors, respectively. The (3×3) A_l and B matrices are the parameters to be estimated.

Modeling the system using the VAR panel will allow us to capture the effect of the increase in confirmed daily cases on residential concentration and vice versa. In fact, the purpose is to identify an inverse effect. That is, while an increase in the number of cases of infection should alert people and increase their concentration in residential areas, the increase in concentration in residential areas should cut off the channels of spread of the pandemic and decrease the growth in daily cases. This will not be captured by a simple regression where one variable remains dependent on the other. For our case, having in the endogenous PVAR the variables that we want to calculate their effects, we expect to obtain these effects in different directions.

Additionally, separating the sample by informality for each PVAR will allow us to evaluate the average effect for each set. It is expected that, despite the level of informality, an increase in residential confinement will decrease the transmission of the virus. Conversely, in the face of an increase in the number of cases, states with less informality would have greater opportunities to react and stay at home.

For each PVAR, estimates were made using the library developed by Abrigo and Love (2016) and the selection of the model by Akaike's criteria (Akaike, 1969). In the generation of the impulse-response functions (IRF), it was verified that all the systems of equations complied with the stability condition, and the graphs for the orthogonal and accumulated IRF were generated to visualize the aggregate effect (Lütkepohl, 2005; Sims, 1980).

Also, consistent results must be obtained for the exogenous variables. Intuitively, it is expected that weekends and paydays will decrease the concentration in residential areas, and, on the other hand, storm warnings will increase it. The former is due to the fact that on weekends and paydays people go out to buy basic necessities, even when mobility restrictions exist. In addition, with these dummy variables, a large part of the seasonal effects is controlled on a weekly basis. The latter is expected even for regions with high informality, since storms generate rain and winds that make economic activity impossible.

3.5. Data

Three databases are used for the analysis. First, the daily confirmed cases by state (Gobierno de México & Secretaría de Salud, 2020). It is understood that Mexico only tested people with symptoms or who had contact with confirmed cases. This may substantially affect the true number of cases because of the number of asymptomatic infections not counted in this indicator. However, for the first objective of the analysis, which is to identify the reaction of staying at home due to the increasing number of infections, the indicator of daily cases per state is still useful because such data has been reported and socialized by federal and local governments. For our second objective, which is to evaluate the public policy implemented for the so-called "stay-at-home", it is expected that the population has socialized the symptoms, people respond by doubting that they have been infected, and therefore try to get the government to test them.

Our second source of information is Google's Mobility Reports (Google LLC, 2020). On the concern that the amount of people who have smartphones might not be enough to validate this statistic, Google assures that for the days and/or regions that do not have the necessary information to generate each indicator (due to the anonymization and privacy protection of the data), a lost value is reported. For the database used and the indicator of concentration of residential areas, we have complete panels. The residential zone indicator helps to evaluate the stay-at-home policy. It is not combined or entered into any model that includes another Google Mobility Reports indicator (retail, grocery, parks, transportations and workplaces) because it is noted that the residential indicator has a different measurement methodology.

For the first five indicators, the number of visitors recorded in the classification of these places is used, while for residences the main indicator used is the time people stay at home. This is helpful for this work because people already spent a considerable amount of time at home prior to the pandemic, mostly for rest and leisure, and, presenting the indicator differently, there would be no way to control for this effect of time spent at home with the data available for Mexico.

Third, the mood of the Mexican Twitter users is used (INEGI, 2020c). This indicator is provided and generated by the National Institute of Geographic and Statistics (INEGI) of Mexico for all states on a daily basis. This makes a perfect match between the level of frequency and disaggregation of the two previous databases. This indicator is used because it approximates the amount of news, ideas, and collective encouragement regarding the pandemic. All these three indicators are included in the Panel Vector Autoregression model (PVAR) as endogenous variables.

Additionally, three exogenous variables are added in the form of dummy variables: weekends, paydays, and weather alert days (for each state and day that the National Weather Service issued hurricane, storm or tropical depression warnings) (CONAGUA, 2020).

These indicators are used not only because they are appropriate for our analysis, but also because they have been used in other articles with similar objectives and have been reviewed nationally and internationally by experts in the field. For example, the number of COVID-19 cases in Mexico has already been used to frame discussions on the effects of certain population behaviors on them. In the case of Gasca et al. (2022), for example, statistical inferences are made about vaccination against COVID-19. The Google mobility reports indicator has also been used in other studies to understand economic phenomena, as seen in Milani (2021) and Yilmazkuday (2020). Moreover, it has been shown that the use of the indicator "Mood of Twitter" for Mexico is useful for identifying how information is transmitted through social networks, as shown in Leyva (2020).

Table 1 shows Mexican states separated by their level of informality (Very Low, Low, High & Very High). For each panel, the first column shows the state, the second column shows the proportion of workers who are in the informal sector, the third column shows the state's GDP per capita in international dollars in 2019, and the fourth column gives an international comparison (with respect to GDP per capita in 2019). The last two columns are intended to show the heterogeneity of wealth across states. At the end of each panel the mean and standard deviation of each group is reported, and at the end of the table these two descriptive statistics are also reported for the 32 states. It is important to mention that Campeche has those values for oil production.

Table 1. Mexican States by Groups of Informality

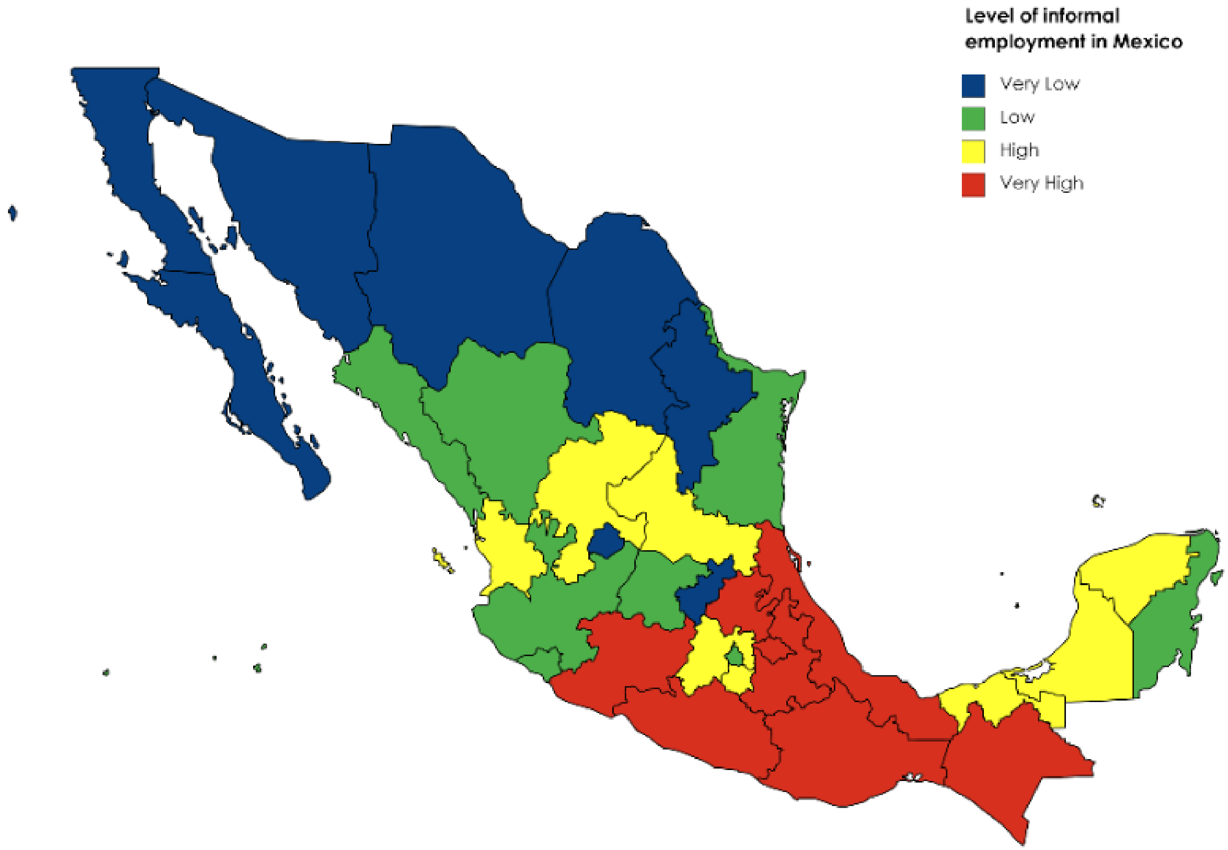
Panel: Very Low					**Panel: Low**			
State	*Informal employment ratio*	*GDP pc*	*International benchmark*		*State*	*Informal employment ratio*	*GDP pc*	*International benchmark*
Aguascalientes	40.94	23,390	Argentina		Colima	50.94	19,146	Costa Rica
Baja California	38.31	23,723	Argentina		Durango	51.5	15,531	China
Baja California Sur	38.85	32,954	Slovakia		Guanajuato	54.18	17,206	Grenada
Chihuahua	36.23	22,318	Uruguay		Jalisco	48.92	20,849	Mexico
Coahuila de Zaragoza	34.65	28,894	Russia		Ciudad de México	47.17	43,713	Italy
Nuevo León	36.51	35,031	Lithuania		Quintana Roo	47.08	23,890	Chile
Querétaro	41.81	25,782	Kazakhstan		Sinaloa	51.13	17,029	Suriname
Sonora	45.54	27,840	Croatia		Tamaulipas	46.08	20,408	Mexico
Mean	38.19	27,442			Mean	50.13	22,481	
SD	3.54	4,621			SD	2.77	9,073	
Panel: High					**Panel: Very High**			
State	*Informal employment ratio*	*GDP pc*	*International. benchmark*		*State*	*Informal employment ratio*	*GDP pc*	*International. benchmark*
Campeche*	62.02	62,311	Hong Kong		Chiapas	73.11	6,546	India
Morelos	65.97	13,699	Albania		Guerrero	77.63	9,161	Bolivia
Nayarit	61.88	13,576	Sri Lanka		Hidalgo	74.13	13,916	Albania
San Luis Potosí	55.83	19,444	Belarus		Michoacán de Ocampo	67.87	12,611	Ukraine
Mexico (State)	57.80	12,891	South Africa		Oaxaca	78.98	9,448	Guyana
Tabasco	63.09	21,700	Antigua and Barbuda		Puebla	70.98	12,570	Mongolia
Yucatán	60.65	16,333	Barbados		Tlaxcala	72.66	10,272	Namibia
Zacatecas	60.95	13,725	Fiji		Veracruz de Ignacio de la Llave	67.61	12,772	Moldavia
Mean	61.03	22,851			Mean	73.62	10,646	
SD	3.12	16,709			SD	4.10	2,473	
All sample	**Mean**	**SD**						
Informality	55.65	13.00						
GDP pc	20584	11,194						

Source: Authors' own elaboration with INEGI (2020b) and World Bank (2015) *data*.

For example, Aguascalientes is a Mexican state with an informality ratio of 40.94% and a GDP per capita of $23,390 international dollars per year, matching that of Argentina. On the other hand, Guerrero has an informality ratio of 77.63% and a GDP per capita of $6,546 international dollars, which makes it comparable to India. In terms of production per person and informality, Mexico is highly heterogeneous.

Figure 1 shows on the map of Mexico the groups of states by level of informality described in Table 1. It can be seen that the northern region of Mexico is home to a large number of states in the Very Low informality group. The greater number of formal jobs with respect to the total labor market is largely due to the presence of the manufacturing sector in the region. On the other hand, the south and southeast of Mexico have a greater number of informal jobs than the other regions. This is due to the fact that there is more informal trade and tourism-related activities in the region.

Figure 1. Level of Informal Employment Across Mexican States.



Source: Authors' own elaboration with INEGI (2020a) data.

For the southern states, it is important to note that, in the presence of their informal sector, they also have a greater primary activity than the northern states with less informality. For example, according to the Economic Information Bank (INEGI, 2020a), Nuevo León is a northern state with 36.51% of informal workers with respect to its total labor market, and the primary activity sector (which includes agriculture, animal husbandry, forestry, fishing and hunting) represents 0.46% of its gross state domestic production.

On the other hand, Oaxaca, being a southern state with a 78.98% rate of informality, has a primary activity sector that represents 6.05% of its total gross domestic product. In the case of tourism, it has been reported that the southern states, where the most informal activities are concentrated, have been the most affected by the pandemic in this sector (Banxico, 2020).

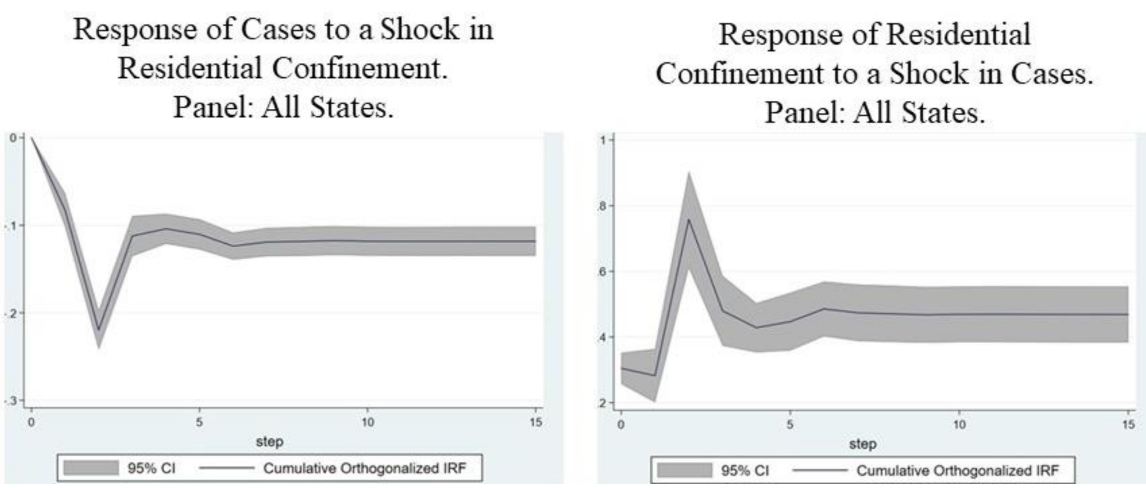
3.6. Results[6]

Effects on the aggregate for the 32 states of Mexico

Figures 2, 3, and 4 show the cumulative orthogonalized impulse response functions (COIRF) for the panels referred to in each figure. For each graph, the x-axis represents 15 periods (in this case, days) forward from the unexpected shock known as impulse. The blue line is the response to an unanticipated impulse of one variable over another. The gray region of the graph is the 95% confidence intervals.

For the first graph in Figure 2, the COIRFs were made by including all 32 states in the panel. We can see that the unanticipated momentum of residential concentration causes a negative response in cases that stabilizes in the seventh period. It is important to note that, for this graph, the response starts from zero, indicating that a higher concentration in residential areas does not have immediate effects, but rather they tend to appear and stabilize after one week. On the other hand, the second graph in Figure 2 represents the response of the residential concentration to an unanticipated surge of cases. In this case, the response is positive and different from zero since the beginning of the shock. This confirms the importance of clearly communicating the surge in cases so that people can become aware of the pandemic. Importantly, for the COIRFs to be statistically significant, the confidence interval must exclude zero over the estimated time horizon. This confirms that staying at home has combated the spread of the virus, and for an increase in the number of cases, people respond by staying more in residential areas. Modeling with PVAR the relationships between infections and residential isolation offers the possibility of verifying the direction of the effects, while a linear model would not be clear about causality.

Figure 2. COIRFs on the Aggregate for the 32 States of Mexico.



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[6] Causality tests of Granger, stability of the models and stationarity of the series were carried out. The periods of the calculations were also divided and no significant differences were presented.

Source: Authors' own elaboration.

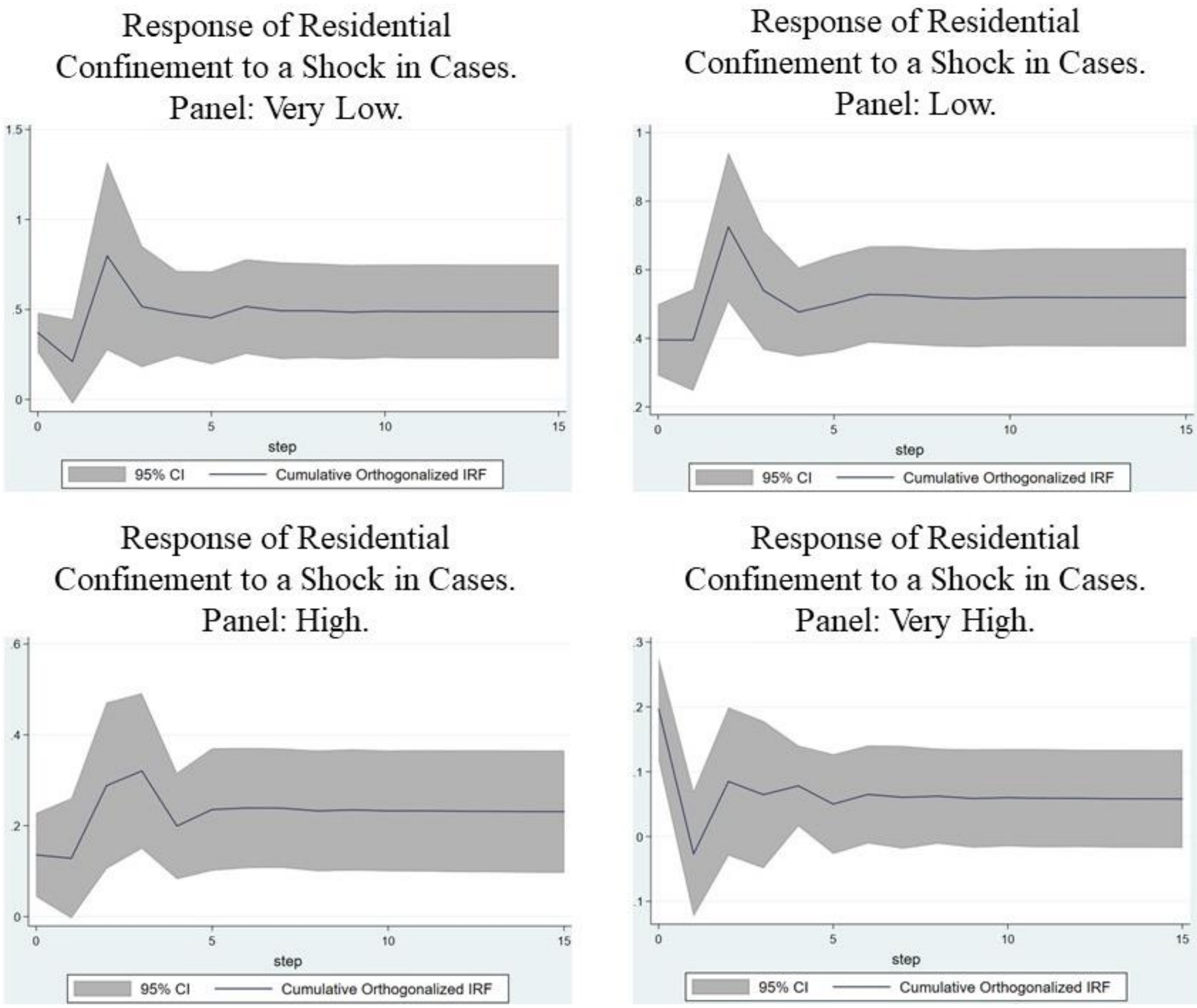
Effects on groups of states by informality

Separating states by groups of informality produces heterogeneous results. Figure 3 shows the impulse response functions of the growth in cases of residential isolation shock.

It can be seen that, although for all groups this response is negative, for states with less informality this response is greater than for those with greater informality. As the group's informality increases, the response is even smaller. This indicates that the "stay home" public policy has been effective, as also shown in the PVAR with all states. However, staying home has been more effective for those states with less informality.

This result is in line with the fact that states with a large informal labor market have fewer people who are likely to stay home and that efforts by people who have been able to isolate themselves residentially have had less effects in terms of mitigating contagion.

Figure 3 Response of Residential Confinement to a Shock in Cases by Group of Informality

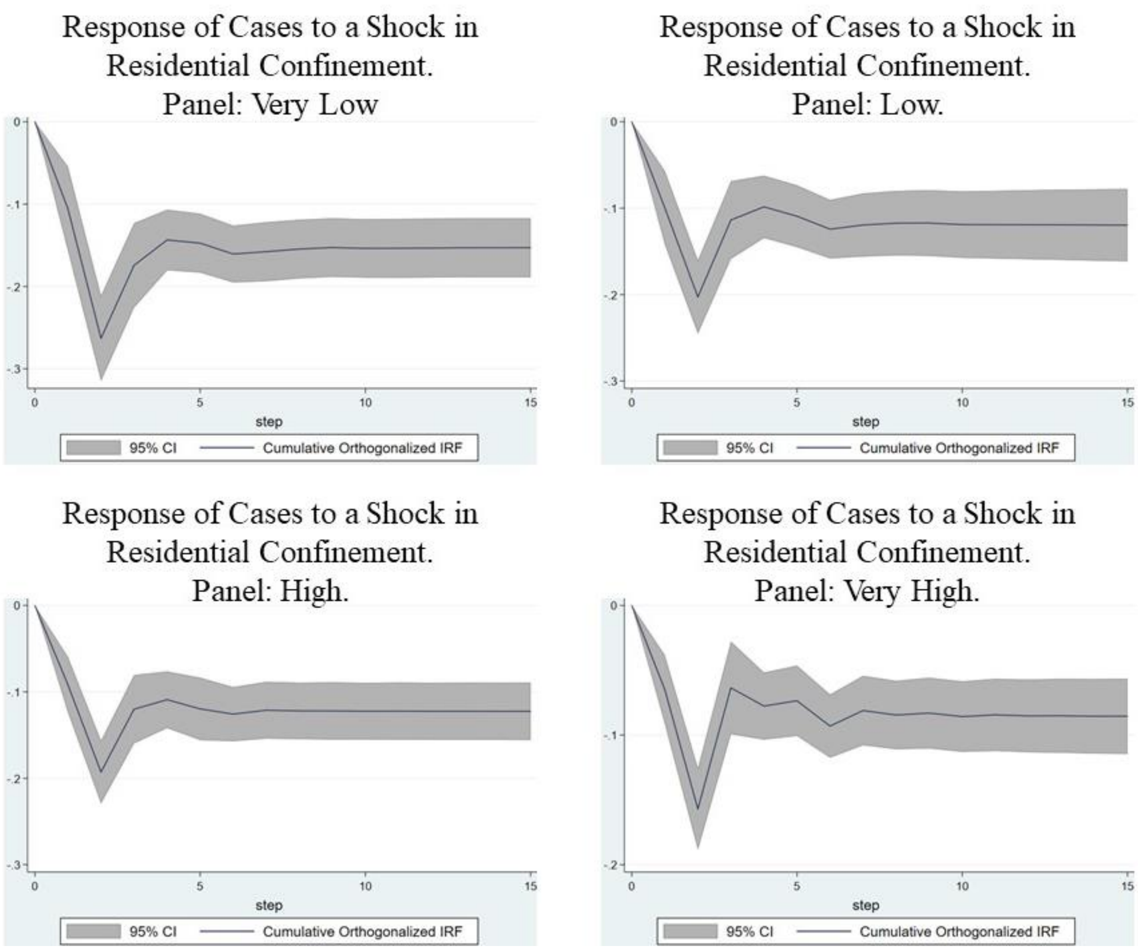


Source: Authors own elaboration.

As noted in Figure 3, where staying at home helps combat the spread of the virus, it is important to assess the possibilities of sheltering at home where there is a large informal sector.

In this direction, when evaluating how the impulse to residential confinement responds to a growth shock in the confirmed cases of COVID-19, Figure 4 shows that only the groups of high, low, and very low informality register a positive effect. That is, as the spread of the virus increases, people tend to stay more at home. Again, it can be seen that as informality decreases in the groups, the effect is greater. That is, the lesser the informality, the greater the possibility of staying at home to avoid infection. Unfortunately, for the group with very high informality there is no clear evidence. Although the response is positive, which is expected, this cumulative effect is not statistically significant.

Figure 4 Response of Cases to a Shock in Residential Confinement by Group of Informality



Source: Authors own elaboration.

Although the indicator of daily confirmed cases could be underreported due to the low amount of testing done by the Mexican government, the main idea of the work holds since the objective is to identify the immediate effects on the spread of the virus and residential isolation. It is also important to mention that, as of March 17, 2020, actions were taken by the federal government to reduce urban mobility by suspending formal education (Estados Unidos Mexicanos, 2020a) and, as of early April, also suspending non-essential activities (Estados Unidos Mexicanos, 2020b). This dynamic approach by the government is largely solved with the PVAR approach, which evaluates the model dynamically and controls for exogenous variations such as paydays, weekends, and weather alerts to avoid biases due to leaving the home because of these causes.

Finally, it is also important to understand the lack of response to an impulse to stay at home in the face of a growth shock in confirmed cases for the group with the highest informality.

The above analysis does not allow us to identify the characteristics that prevent the informal sector from staying at home. These could be, but are not limited to, the impossibility of working from home, the lack of savings to survive long periods without working and earning daily incomes, and the lack of access to job security and stability or unemployment insurance[7]. In any case, the study has provided evidence for the states where the average rate of labor informality in the group is 73.62%, which is comparable to the labor market situation in less developed economies. Something important to emphasize is how the effect of the cases is dissipated with residential confinement. As informality grows in the group of states, this effect becomes smaller and smaller. This shows the key role that informality plays in the labor market's ability to adapt to confinement conditions. It was also expected that in the middle groups, i.e., high and low informality, these effects would not change abruptly, or the trend would reverse. Hence, the results are consistent with our hypotheses.

3.7. Conclusions

The "stay-at-home" policy in Mexico has slowed the spread of the pandemic and, as the number of cases increased, people stayed home more. However, the effect is heterogeneous among states grouped by levels of informality.

While for states with lower rates of informality, "stay-at-home" has had a greater effect and more people have been able to stay home as the pandemic spread, for states with higher rates of informality, staying at home has had a lesser effect and the people have been unable to increase their residential isolation, even though measures to suspend formal education and non-essential activities have been adopted since the onset of the pandemic in the country. Some public policy alternatives focused on populations with a higher rate of informality are income transfers and support to households that depend on this type of activity. This should be done taking into account two important points. The first is to provide resources and public policies that encourage the informal population to stay at home and, above all, provide them with that possibility. The second is to provide effective hygiene measures to prevent the spread of the virus, such as the use of masks and the recommendation of their use, access to public washing facilities, and efficient remote care lines for suspected cases of infection to isolate them from the rest of the population.

"Stay-at-home" is important (if you can) because, in the present work, it has been shown that even when the informal labor market is large, it helps slow the spread of the pandemic. On the other hand, the heterogeneity shown in the results suggests that the context of each region and its labor market has to be taken into account when designing health policies to mitigate the spread of diseases as in the current pandemic. Other ways of attacking the pandemic under these circumstances could by the adoption of heterogeneous policies by age groups (Brotherhood et al., 2020), such as policies focused on mass testing and limiting the mobility of young people, since their age group takes more risks and the mortality rate of older people

[7] In fact, both formal and informal employment do not have unemployment insurance

is way higher. The exposure of younger people to the virus generates a negative externality to older people. Something similar happens between formal and informal employees. The states with high levels of informality face two problems: not receiving income because their work activities are informal and not having a constant source of income. Therefore, being confined at home means not earning that day's pay or suffering the ravages of the pandemic, getting sick from COVID-19, and facing it without social security, given the condition of informality.

In addition, this work provides insight into how to design public policies in regions where informality is very high. There is a growing concern that, in informal employment, the jobs and income of young workers could be the most affected. Also, the application of mass testing to effectively detect first cases at an early stage of the spread of the virus has been seen as a substitute for quarantine and succeeds in reducing the economic impacts of generalized quarantine public policies (Piguillem & Shi, 2020). The consideration of the informal labor market has been relevant in the discussion surrounding the damage caused by the COVID-19 disease. Field (Acevedo et al., 2021) shows that the labor dynamics and the economic impact of the closure of activities are strongly associated with informality, where alternative sources of information, such as surveys, have been used. Also, as discussed in Busso et al. (2021), public policies aimed at protecting the most vulnerable households have been, for the most part, insufficient. This has prompted organizations such as the World Bank (Ohnsorge & Yu, 2022) to focus their efforts on understanding the problem of informality during the pandemic. All these studies admit that there are still phenomena associated with these issues that we do not know about, so the results of this article contribute to the discussion.

Finally, this study provides a framework for various countries to assess whether their populations have responded to "stay-at-home" policies, especially where informality is of major concern and has similar characteristics to Mexico's in terms of its heterogeneity.

4. Has the covid-19 vaccine functioned in Mexico? Evidence of cointegration with structural change in Federal States.

4.1. Introduction

Mexico initiated its vaccination campaign in 2021. However, throughout the year, the Federal Entities recorded varying progress concerning the population receiving at least one dose. The objective of this study is to analyze the link between COVID-19 infections and deaths for the Federal Entities of Mexico, focusing on the structural changes caused by the Vaccination Program implemented by the Mexican government during 2021 compared to 2020. COVID-19 vaccines were in demand globally, necessitating a strategy to determine the priority groups for vaccination. The central idea behind the stages of vaccination in Mexico was to prioritize the population most susceptible to medical complications and, consequently, death.

4.2. Literature Review

Mourtgos & Adams (2021) studied the effect of COVID-19 vaccination on law enforcement officials in the United States, where daily testing was conducted. Time series data were treated using a Bayesian structural approach. Evaluating vaccine effectiveness using time series analysis has been conducted for diseases other than COVID-19. For example, Du et al. (2020) examined the vaccine against enterovirus in China, employing regressions while controlling for sociodemographic and environmental variables. For the pneumonia vaccine, Suarez et al. (2016) conducted a similar exercise to Du et al. but focused on Peru, comparing regressions before and after several applications using weekly data. Hungerford et al. (2018) evaluated the effects of the rotavirus vaccine from 2001 to 2016 using monthly data sets, comparing age groups and vaccinated versus unvaccinated individuals. Lavine & Rohani (2012) conducted a comparative analysis of clinical evaluations and ecological models for pertussis vaccines, including time series analysis. Additionally, Höhle et al. (2011) evaluated the application of the varicella vaccine in Germany, adjusting the infection data series prior to the extensive vaccination program using ARMA models and calculating hypothetical reductions based on generated forecasts.

4.3. Data

Time series data on daily COVID-19 cases and deaths per Federal Entity were obtained from the Ministry of Health of the Federal Government, available on the CONACYT dashboard from March 17, 2020, to October 21, 2021. This period was chosen to include a pre-vaccination period and a period with advancements. Additionally, for 2021, data up until October were considered to avoid seasonal problems that could arise due to temperature fluctuations.

4.4. Methodology

The structural change cointegration model proposed by Gregory-Hansen has established itself as an effective methodological tool for evaluating the effectiveness of vaccination in reducing COVID-19 mortality. Its application in the analysis of time series data on cases and deaths offers numerous advantages that support its utility in the field of health. The following are the most compelling reasons why medical and health professionals should consider this model as a solid option:

Capturing significant structural changes: The structural change cointegration model allows for addressing fundamental changes in the behavior of the variables under analysis. Given that mass vaccination against COVID-19 represents a crucial structural change in the dynamics of cases and deaths, this model is capable of accurately capturing and modeling the effects of such changes. This is essential for obtaining an accurate assessment of vaccination effectiveness.

Long-term relationship analysis: Cointegration is based on the concept of long-term relationships between variables. In the case of vaccination and COVID-19 mortality, it is crucial to consider that the effectiveness of vaccines may take time to fully manifest. The structural change cointegration model has the ability to capture and analyze these long-term relationships, allowing for evaluating whether there is a solid and significant association between vaccination and the reduction of mortality.

Control of confounding variables: By using the structural change cointegration model, it is possible to control and take into account other factors that could influence COVID-19 cases and deaths but are not directly related to vaccination. Variables such as social distancing measures, mask usage, and the availability of medical resources can be considered and controlled in the analysis. This ensures that the observed effects are mainly attributable to vaccination, providing a more accurate evaluation of its effectiveness.

Causality assessment: The structural change cointegration model also allows for evaluating the causal relationship between vaccination and the reduction of mortality. Through additional statistical tests, it is possible to determine whether vaccination has a causal impact on decreasing COVID-19 deaths. This ability to assess causality provides solid and rigorous evidence of the effectiveness of vaccination as a preventive measure.

Therefore, the structural change cointegration model proposed by Gregory-Hansen offers a solid and reliable methodological approach to evaluate the effectiveness of vaccination in reducing COVID-19 mortality. Its ability to capture structural changes, analyze long-term relationships, control confounding variables, and assess causality provides medical and health professionals with a valuable tool to support their decisions and actions in the fight against the pandemic. By employing this model, a more precise and informed evaluation of vaccination effectiveness can be obtained, thus contributing to informed decision-making and the implementation of effective strategies in the prevention and control of COVID-19.

The treatment of data series for each Federal Entity was conducted separately due to heterogeneity in COVID-19 healthcare infrastructure across states in Mexico. In the initial stage, the series were smoothed using 7-day moving averages, and the natural logarithm was applied to ensure comparability in levels, a necessary requirement for cointegration tests. It was expected that the cointegration structure would change as progress was made in the percentage of the population receiving at least one dose, or in the best-case scenario, cointegration would disappear from the series. This means that the coefficients accompanying the dummy variable would be statistically insignificant. To assess this, breakpoint estimates (τ) proposed by statistical tests were obtained, and cointegration tests were conducted before and after the breakpoints. Finally, Federal Entities with breakpoints (breaks) were compared using a significance level greater than 5%, and the percentage of the population with at least one dose, as reported by the Ministry of Health of the Mexican Government, was compared.

4.5. Results

Then, using the cointegration test with structural change with the four models proposed by Gregory-Hansen. These models are:

Model baseline:

$$\ln(d_{it}) = \mu_{1i} + \beta_{1i}\ln(c_{it}) + e_{it}$$

Where d_{it} and c_{it} are the deaths and cases respectably, i y t are the subindex of Federal States and days of the observations in this order, μ_{1i} is the intercept, β_{1i} is the elasticity of deaths and cases and e_{it} is a white noise.

To model the structural changes, we will define a dummy variable as:

$$\varphi_{it\tau} = \begin{cases} 0 & si\ t \leq [n\tau] \\ 1 & si\ t > [n\tau] \end{cases}$$

Where the unknown parameter $\tau \in (0,1)$ is the portion of data prior to the breakpoint appearing and [ ] denotes the integer part of that fraction.

Model 1 (M1): Change in level

$$\ln(d_{it}) = \mu_{1i} + \mu_{2i}\varphi_{it\tau} + \beta_{1i}\ln(c_{it}) + e_{it}$$

Model 2 (M2): Change in level with trend

$$\ln(d_{it}) = \mu_{1i} + \mu_{2i}\varphi_{it\tau} + \beta_{2i}t + \beta_{1i}\ln(c_{it}) + e_{it}$$

Where t is the variable of the day of the observations and which numerically increases by one unit on each day up to the n days of the sample.

Model 3 (M3): Regime change

$$\ln(d_{it}) = \mu_{1i} + \mu_{2i}\varphi_{it\tau} + \beta_2 t + \beta_{1i}\ln(c_{it}) + \beta_{3i}\ln(c_{it})\,\varphi_{it\tau} + e_{it}$$

Model 4 (M4): Regime change with trend

$$\ln(d_{it}) = \mu_{1i} + \mu_{2i}\varphi_{it\tau} + \beta_{2i}t + \beta_{4i}t\varphi_{it\tau} + \beta_{1i}\ln(c_{it}) + \beta_{3i}\ln(c_{it})\,\varphi_{it\tau} + e_{it}$$

Table 1: Cointegration tests with structural change

Federal States	Cointegration test with structural breaks							
	M1	Break	M2	Break	M3	Break	M4	Break
AGUASCALIENTES	*	29-jun-21	*	29-jun-21	*	29-jun-21	*	29-jun-21
CAMPECHE	*	09-sep-20						
CDMX	*	11-may-21						
DURANGO	*	26-may-21						
MORELOS							*	10-jul-21
NAYARIT	*	06-apr-21	*	06-apr-21				
QUERETARO							*	18-jun-21
QUINTANA ROO	*	06-oct-20	*	06-oct-20				
TAMAULIPAS	*	21-apr-21	*	09-apr-21	*	09-apr-21	*	09-apr-21

Source: Own elaboration using Gregory-Hansen tests implemented in STATA by Jorge Pérez-Pérez (2013)

The table provides information on the Federal States (or regions) being analyzed and their results from a cointegration test with structural breaks. The cointegration test is a statistical technique used to determine the long-term relationship between variables.

The table has several columns. "Federal States": This column lists the names of the different regions or states being examined. "M1, M2, M3, M4": These columns represent different models or variations of the cointegration test that were conducted. "Break": This column indicates the occurrence of a structural break, which refers to a significant change or shift in the relationship being analyzed. The dates specified in this column indicate when the structural break was detected in the respective model.

Based on the provided information, it can be observed that some states, such as Aguascalientes, Campeche, CDMX (Mexico City), Durango, Nayarit, Quintana Roo, and Tamaulipas, had structural breaks detected in multiple models (M1, M2, M3, M4), as indicated by the asterisks and the corresponding dates. On the other hand, some states, such as Morelos and Queretaro, had structural breaks identified in only specific models.

The presence of structural breaks suggests that there have been significant changes in the relationship between variables in these regions, which may impact the analysis and interpretation of the data. Further examination of the paper's content would provide more context and details about the variables, models used, and the implications of these structural breaks in understanding the relationships being studied.

Table 2: Vaccination by Federal Entity and evidence of cointegration.

Federal States	**% vac.**	**Evidence of cointegration**		
		All time	Before break	After break
AGUASCALIENTES	78	Yes	Yes	No
CAMPECHE	53	No	No	Yes
CDMX	92	No	yes	No
DURANGO	69	No	Yes	No
NAYARIT	71	No	Yes	No
QUERETARO	86	No	Yes	No
QUINTANA ROO	86	No	Yes	No
TAMAULIPAS	74	No	Yes	No
National Average	65			

Source: Own elaboration. Engle-Granger tests were applied to evaluate the complete cointegration structure in each subset of observations. % vac: Percentage of the population with at least one dose of the COVID-19 vaccine.

The table provides information on different Federal States and their vaccination rates (% vac.) along with evidence of cointegration before and after a structural break. "% vac." represents the vaccination rates, indicating the percentage of the population in each state that has been vaccinated against a certain condition or disease. "Evidence of cointegration" assesses whether there is evidence of cointegration, which indicates a long-term relationship between variables, in this case. "All time" represents whether there is evidence of cointegration when considering the entire time period analyzed. "Before break" and "After break" indicate whether evidence of cointegration is present before and after a detected structural break, respectively.

Based on the information provided, it can be observed that in Aguascalientes, there is evidence of cointegration when considering the entire time period, but after the structural break, there is no evidence of cointegration. In Campeche, there is no evidence of cointegration when considering the entire time period, but after the structural break, there is evidence of cointegration. For Mexico City (CDMX), there is no evidence of cointegration when considering the entire time period, but before the structural break, there is evidence of cointegration. On the other hand, in Durango, Nayarit, Queretaro, and Quintana Roo, there is no evidence of cointegration when considering the entire time period, but there is evidence of cointegration before the structural break. And in Tamaulipas, there is no evidence of cointegration when considering the entire time period, but there is evidence of cointegration before the structural break.

4.6. Conclusions

In the Federal Entities where structural change cointegration was observed between daily COVID-19 deaths and cases, it can be observed that these are the entities with the most advanced vaccination progress. Additionally, structural breakpoints represented actual losses in the cointegration structure. This implies that despite experiencing new waves of COVID-19 and a significant increase in the number of new cases, a vaccinated population counteracts the growth of deaths. This was evident in early 2022, where the new wave of the Omicron variant considerably increased the number of cases without significant increases in daily deaths.

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