THE EXISTENT HEALTH INFRASTRUCTURE AND ECONOMIC CONDITIONS IN REGIONS AND THE COVID-19 INFECTION IN ECUADOR

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ABSTRACT

To face the COVID-19 pandemic, governments established certain stringency measures as the lockdown and the traffic light system. However, the response to the pandemic also depends on the existent capacity and underlying conditions of regions. In this line, this study aims to determine the relationship between the COVID-19 pandemic and the underlying regional conditions, using two dependent variables: number of COVID-19 cases and the COVID-19 prevalence rate; for three phases: isolation, social distancing and contingency. Using daily COVID-19 data and cantonal level variables, a Negative Binomial model and a Tobit model were estimated to analyze the determinants of the number of COVID-19 cases and the prevalence rate, respectively. Our results show that the international connection and richness of cantons increased the level of COVID-19 cases but their health infrastructure reduced it. Stringency measures such as the traffic light system were effective to face the pandemic. The geographical proximity between cantons and the nature of economic activities (essential and non-essential) mattered for the spread of the pandemic.

Keywords: COVID-19, prevalence rate, health infrastructure, stringency, regions

JEL Codes: H70, P25

1. Introduction

The new type of coronavirus named SARS-CoV-2 detected at the end of 2019 in China has spread very rapidly around the world. To contain the spread of the COVID-19, subnational and national governments established restrictive measures to reduce the peak healthcare demand and mitigate the transmission of the virus. While the government policies aimed to contain the spread of the virus were important, the response to the pandemic depends to a larger extent on the existent capacity and underlying conditions. The fact that more developed countries record a higher life expectancy than developing countries indicates a reduction in infectious disease mortality promoted by improvements in sanitation, clean water, income, health system, among others (Anser et al. 2020). If a country with a historical low investment in health increases its expenditure in this sector, the results of this governmental policy could be exiguous or insufficient since their previous needs are not covered yet. On the contrary, a country with high historical investment in health would have better results with a further increase in this sector because it is filling the gap for the excess of demand of health services during the pandemic, given that the previous needs are already covered. In fact, Kapitsinis (2020) and Coccia (2021) obtain that the historical trend of health expenditure is associated with a lower COVID-19 lethality. Thus, the existent health infrastructure has determined the affectation of the pandemic across countries. Indeed, the COVID-19 pandemic has revealed an unequal access to basic services, health system and social protection not only across countries but also across regions within countries, especially in developing countries (ECLAC, 2020). Hence, the level of GDP is an important underlying characteristic that determines the effects of the pandemic. The COVID-19 affectation to lower income countries would be more severe as they account with less resources to face the pandemic (Winskill et al. 2020). In fact, Liang et al (2020) show that GDP per capita is associated with a reduction in the COVID-19 mortality only in high-income countries. However, Rodríguez-Pose and Burlina (2021) show empirical evidence of a positive correlation between the GDP per capita and COVID-19 deaths, indicating that high-income countries run more tests and report more transparently the COVID-19 death cases than low-income countries. Within countries, regions are also differently affected due to the spatially uneven expansion of the virus (Bailey et al. 2020) and also due to different reactive policies in each local government. One reason of the spatial uneven expansion is the international connection with China. Those countries that are more connected with China (generally main cities within countries) not only in terms of trade but also in terms of human mobility were more rapidly affected than others with less connection with it. Thus, high-income countries/cities had been more affected than countries/cities with weak economic conditions (Bhadra and Bhattacharya, 2021). The same occurred within countries, the main regions with high international interconnectivity and high income were first affected. Nevertheless, as aforementioned regions with more resources can face more adequately to the spread of the virus. For instance, if regions account with good infrastructure in terms of water and sanitation, its population will be safer. On the contrary, vulnerable people who lack access to water and sanitation in certain regions will be exposed to a higher risk of COVID-19 contagion.

Other characteristics of countries that influence the transmission of the virus are related to demographics (Matamoros et al. 2020; Bhadra and Bhattacharya, 2021). Since the COVID-19 virus, as other viruses (Freedman et al. 1975), spreads easily when people are close to each other, the population density of regions is an important spread factor due to a higher probability of interpersonal exchange. Gerritse (2020) obtained that the population density is associated with higher transmission rates, particularly at the onset of outbreaks. In many studies, the percentage of elderly people in the population is one of the main factors that increases the spread (Bhadra and Bhattacharya, 2021) and the lethality of the virus (Kapitsinis, 2020, Muniyappa & Gubbi, 2020; Richardson et al., 2020).

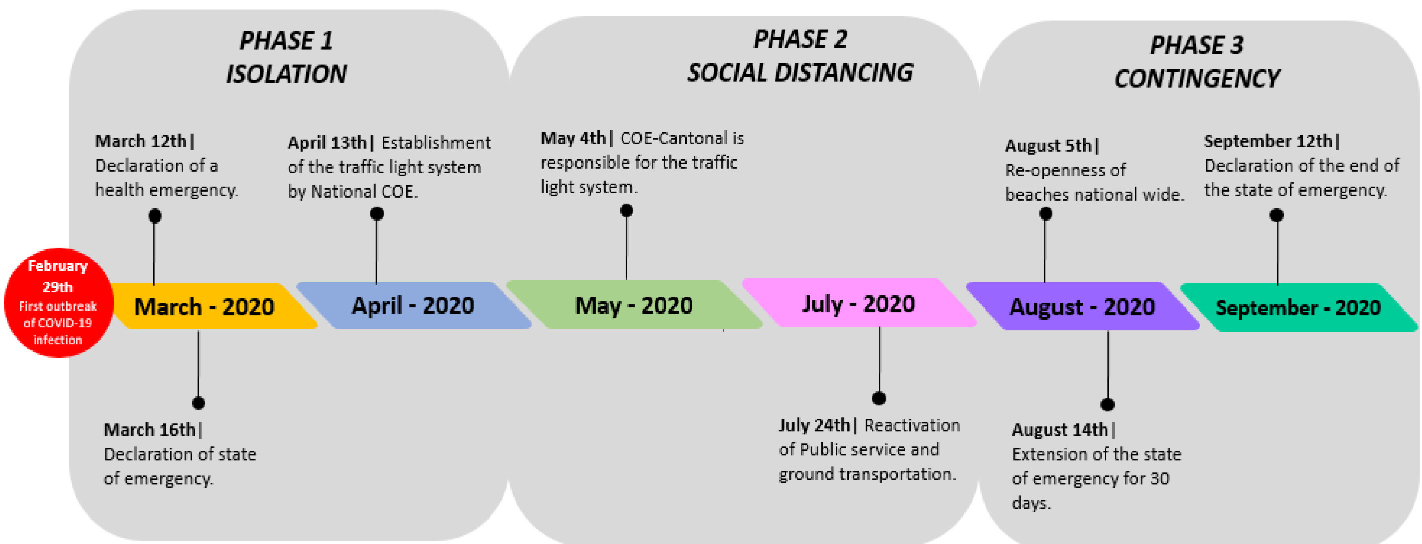
Therefore, the aim of this study is to determine the influence of underlying characteristics of regions in terms of health and transport infrastructure and demographic social and economic characteristics on the prevalence of the COVID-19 in the Ecuadorian cantons. Ecuador has become one of the countries with the highest number of people infected by COVID-19 in South America, despite being one of the first South American countries to close its borders, seaports and airports. As of September 21, 2020, Ecuador ranked seventh in Latin America with the highest level of confirmed cases (Muentes & Nicole, 2020). Besides, the Ecuadorian case is an interesting study case since it records a high regional income inequality which also could be a determinant of the spread of the coronavirus Sars-CoV-2 in the country. Not all regions in the country have adequate health infrastructure such that 189 out of 221 cantons do not account for Intensive Care Units. On average, cantons record 9 basic health centers (1st level) and 0.18 specialized health centers (3rd level). There are 152 and 206 out of 221 cantons that record less than the average in basic health centers and specialized centers, respectively. These differences might play an important role in the spread of the Sars-Cov-2 coronavirus since people in certain regions might not be able to get medical assistance opportunely and spread the virus to other people. Indeed, Ecuador has presented a considerable increase in the number of cases of COVID-19, which can be related to the collapse of the hospital system, with lack of hospital supplies for the care of chronic patients, such as intensive care units. Apart from the health infrastructure inequality, Ecuador also records inequality in terms of access to basic services. On average, there are 365 households have access to potable water and 691 access to electricity.

The remainder of this article is structured as follows. Section 2 describes the COVID-19 situation in Ecuadorian regions and identifies phases according to specified landmarks. Section 4 details the data and methodology used in this study. Sections 5 and 6, respectively, discuss the results and concludes.

2. COVID-19 chronology in Ecuador

The chronology of the COVID-19 pandemic in Ecuador starts on February 29th, 2020. Until September 12th 2020, three time-intervals are identified. They are: i. isolation, ii. social distancing and iii. contingency. As shown in Figure 1, the first period goes from March 13th to May 3rd, 2020; the second period goes from May 4th to July 31th, and the last period goes from August 1st to September 12th, 2020. These periods respond to governmental measures to halt the pandemic. They show differences in the level of infection and the prevalence rate in Ecuadorian regions.

Figure 1*: Timeline of pandemic phases in Ecuador.*



Isolation

The first case of COVID-19 in Ecuador was reported on February 29th, 2020. This made Ecuador the third country in the region to report a positive COVID-19 case (SNGRE, 2020). Following the announcement of the first case of coronavirus in the country, governmental authorities activated sanitary measures in airports.

On March 12th 2020, the government declared a national health emergency for a period of 60 days and activated the National Emergency Operations Committee (COE-N, acronym in Spanish) to report about the epidemiological situation in the country. On March 16th, state of emergency was established throughout the Ecuadorian territory. From that moment on, a prolonged period of mandatory lockdown began, which lasted until May 4th. The lockdown included the closure of public services excepting health, security and basic services, curfew (from 9 p.m. to 5 a.m), suspension of domestic flights and suspension of interprovincial transportation. This period is then called “Isolation”. This phase goes from the beginning of the pandemic until May 3rd.

Table 1. *Descriptive statistic of the first phase.*

Independent Variables	Mean	Standard Deviation	Minimum	Maximum
Days that pass until the first infection.	28.59	29.29	0	144
Total Contagious	94.74	639.28	0	9291
Prevalence Rate	0.00062	0.00085	0	0.0064

Prepared by the author

Source: *National Risk and Emergency Management System (2020)*

As shown in Table 1, the average number of infected people per canton was 95. There were 27 cantons above the average number of infections and 194 below the average. The cantons with the highest number of infected people were Guayaquil (9291), Quito (1586), Daule (719), Milagro (717) and Samborondón (653). It is worth noting that Daule, Milagro and Samborondon are close regions to the epicentre, Guayaquil. By contrast, 36 cantons did not record any COVID-19 case. The mean of the prevalence rate, which considers the population, was 0.00062, indicating that on average, 0.06% of the population in each canton was infected in this phase. There were 62 cantons that recorded a higher prevalence rate and 159 cantons that recorded a lower prevalence rate than the national average. On average, cantons registered the first case of infected people with coronavirus 28.6 days after the first national reported case (March 13, 2020 in Guayaquil). Chinchipe was the last canton that registered a COVID-19 case. Only after 144 days, this canton registered new COVID-19 cases.

On March 28th, 2020, Guayaquil recorded 942 infected people, representing 51.34% of the total number of infected people nationwide, and by April 30th, 2020, it recorded 7528, representing 45.89% of the total number of confirmed cases of coronavirus in the country (SNGRE, 2020). At this stage, a lack of protocols to control infected people, an inefficient public service and the shortage of laboratories for testing (which in the beginning was concentrated in Quito) explain the increase in COVID-19 cases not only in Guayaquil but also in the rest of the country. The capital city, Quito was the second canton with the highest number of infected people with COVID-19 in the first phase. However, to contain the infection curve, drastic measures were imposed by the municipality, days before the Central Government, such as the implementation of the confinement of the population, restriction of inter-municipal mobility and closure of educational institutions since April 6th. As a result, Quito reported 1320 people infected until April 30th, 2020, that is, 8.05% of the total number of positive COVID-19 cases at the national level.

On April 13th, one month after the activation of the COE-N, the number of infected people by COVID-19 at the national level rose to 7,529 and, as of this date, the provincial traffic light system was established in Ecuador. As shown in Table 2, the traffic light system determines the activities that are allowed (SNGRE, 2020).

Table 2. *Characteristics of the traffic light system.*

Responsibilities	Traffic lights		
	Red	**Yellow**	**Green**
Commercial activity via online and telephone	Authorized	Authorized	Authorized

Commercial activities in local	Unauthorized, Online operation	Partially authorized, only 30% of the commercial capacity is permitted.	Partially authorized, only 50% of the commercial capacity is permitted.
Face-to-face work activities	No return to on-site work activities is authorized, only the essential activities are authorized.	Authorized with a maximum of 50% of the staff, the organization of shifts is necessary.	Authorized with a maximum of 60% of the staff, the shift organization is necessary.
Mobilization of private vehicles	Circulation of private vehicles once a week.	Circulation of private vehicles twice a week.	Circulation of private vehicles three times a week.
Public transport	Partially authorized circulation.	The circulation of urban transport is authorized.	Inter-parrish transportation circulation is authorized.
Curfew	From 6:00 p.m. to 5:00 a.m.	From 10:00 p.m. to 4:00 a.m.	From 00:00 to 05:00.

Prepared by the author

Source: *National Emergency Operations Committee (2020)*

Social Distancing

The period of social distancing goes from May 4th to July 31st, 2020. As of May 4th, 2020, the COE-N transferred responsibility to each cantonal COE for the management of the health crisis (SNGRE, 2020). As of May 16th, 2020, the Central government of Ecuador announced the extension of the Emergency State for 30 more days to stop the spread of COVID-19. Thus, the closure of public services except for health, security and basic services.

Table 3: *Descriptive statistic of the second phase.*

Independent Variables	Mean	Standard Deviations	Minimum	Maximum
Total Contagious	345.69	1249.72	0	13342
Prevalence Rate	0.0043	0.0049	0	0.0507

Prepared by the author

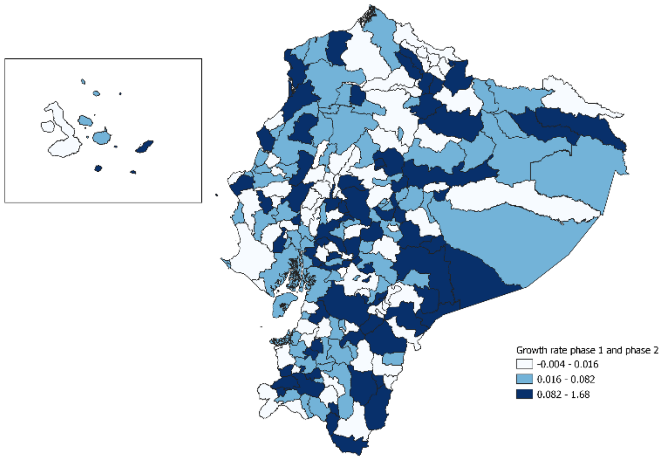
Source: *Infographics from the National Risk and Emergency Management System (2020)*

As shown in Table 3, on average, there were 346 infected people in cantons during the social distancing phase. Cantons that registered a high level of cumulate infected people at the end of such phase were Quito (13342), Guayaquil (11961) and Santo Domingo (3026). Quito recorded an increasing trend in the second phase, going from 1,619 infected on May 4th to 13,342 infected people on July 31st, 2020, becoming the canton with the highest number of infections (SNGRE, 2020). This increase could have taken place due to the early exit of the lockdown and the change of the traffic light from red to yellow: certain economic activities were partially reactivated in the capital from June 3rd. By contrast, Guayaquil remained among the 11,000 infected at the end of the "Social Distancing" phase. The minimum of 0 cases was registered in 3 cantons[1] (Chillanes, El Oro, Chilanga and Chinchipe). In addition, Table 3 shows that the national average of the prevalence rate during the social distancing phase was 0.43%. There were 78 cantons that recorded a higher prevalence rate and 143 cantons that recorded a lower prevalence rate than the national one. The canton with the highest proportion of infected people was Aguarico (0.05%).

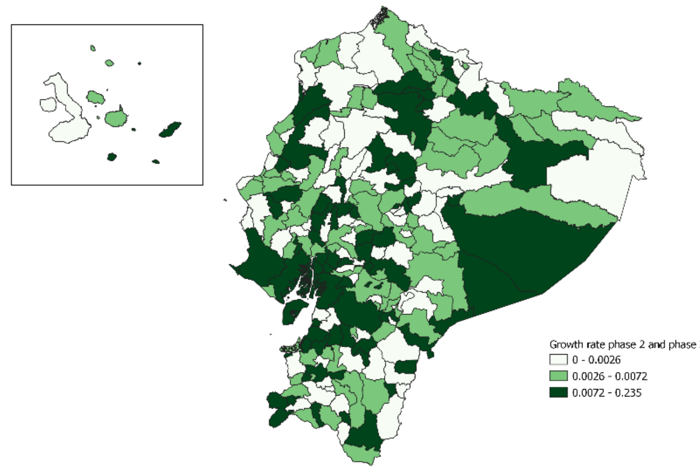
While the prevalence rate in level gives information, the growth of the prevalence rate between phases indicates how rapidly the virus spread and how effective the restrictive measures were in cantons. The growth of the prevalence rate between the isolation and the social distancing phase was on average 10.84%. There were 62 cantons that recorded a higher growth rate and 159 cantons that recorded a lower growth rate than the national average. In the context of an increase in the prevalence rate, some cantons in the country did not account for Intensive Care Units (ICU) and medical services reached their maximum capacity. In economically lagged cantons, patients infected by the coronavirus in critical condition, were transferred to public hospitals in other cities of the country or to private clinics in the canton. As shown in Figure 1, while at the beginning, richer cantons recorded higher growth rates of infected people, this situation was reverted and later, poorer cantons were those registering high growth rates of infected people. Indeed, the correlation coefficient between the GVA and the growth rate considering phase 1 and 2 was 0.0796, meanwhile the correlation coefficient between the GVA and the growth rate considering phase 2 and 3 was -0.1731. This indicates that as the pandemic advanced, cantons with less economic resources were more affected.

[1] In fact, a negative number of -4 was registered. This case is due to a reduction in infection at the national level presented by the National Risk Management System of Ecuador due to a cleaning of data because of duplications found in the epidemiological surveillance systems (SNGRE, 2020).

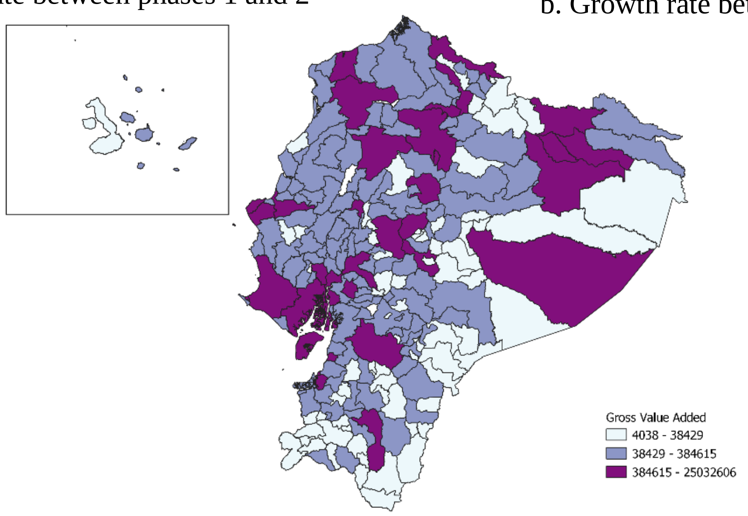
Figure 1. *Growth rate of COVID-19 infected people between phase 1 and phase 2, and between phase 2 and phase 3, and Gross Value Added by cantons*



a. Growth rate between phases 1 and 2



b. Growth rate between phases 2 and 3



c. Gross Value Added in thousand USD

From the second week of May, Ecuador began a process of relaxation of restrictive measures. Thus, by the end of May 2020, 2 cantons changed to green light and 72 cantons changed to yellow light, with a perspective of economic reactivation, while 147 cantons remain in red light (SNGRE, 2020).

Contingency

The contingency period goes from august 1st to September 12nd, 2020. During this period, in accordance to the Protocol for reactivation and operations of the commercial land transport service, the tourist transport service operated without any traffic restrictions. In addition, the COE-N authorized the reopening of beaches and the professional football championship at the national level with strict adherence to the rules and protocols issued on August 4, 2020 (SNGRE, 2020).

Table 4 shows that on average, a canton recorded 527 infected people by Sars-CoV-2 coronavirus. There were 37 cantons with more infected people and 184 cantons with less infected people than the national average. Quito reported the maximum number of infected persons during the "Contingency" phase which was 11,636 on September 12th, 2020, and reached a cumulative total of 24,978 patients with COVID-19 since the beginning of the pandemic, positioning itself as the canton with the highest number of infections at the national level. On the other hand, the canton of Guayaquil registered a cumulative total of 13,504 people infected by coronavirus, recording the second highest number of infected people in the country. However, Guayaquil was the canton with the highest number of deaths (SNGRE, 2020). In terms of the prevalence rate, on average a canton had 0.69% of its population infected at the end of this phase. There were 83 cantons with a higher prevalence rate and 138 cantons with a lower prevalence rate than the national average level. Aguarico (Orellana) was the canton with the highest prevalence rate (7.99%), and Olmedo, Simón Bolivar, Quilanga were the cantons with the lowest prevalence rate (0.04%, 0.06%, 0.07%, respectively). During this phase, there were cantons that did not have an increase in cases of infected people, such as Isabela (Galápagos), Coronel Marcelino Maridueña, Isidro Ayora (Guayas) and Pablo Sexto (Morona Santiago).

Table 4: *Descriptive statistics of the third phase.*

Independent Variables	Mean	Standard Deviation	Minimum	Maximum
Total Contagious	526.92	1987.47	2	24978
Prevalence Rate	0.0069	0.0071	0.00047	0.0799

Prepared by the author

Source: *Infographics from the National Risk and Emergency Management System (2020)*

On September 12th, 2020, the state of emergency that prevailed in Ecuador due to the COVID-19 pandemic finished. By September 12th, 2020, there were approximately 110,000 COVID-19 infected people and 6,400 dead people due to COVID-19. From September 13th, 2020, Ecuador faced the pandemic with new rules and fewer restrictions such as the elimination of curfew and allowance of social gatherings. In addition, decentralized autonomous governments would have the possibility to limit the use of parks, beaches and tourist sites (COE, 2020).

3. Methodology

3.1. Data

Data on daily and cumulative COVID-19 infections at the cantonal level was obtained from the Ministry of Public Health and the National System for Risk Management and Emergencies. The population projections at the cantonal level for the period 2020 based on the 2010 Population and Housing Census were obtained from the National Institute of Statistics and Census of Ecuador (INEC acronym in Spanish). Variables related to health facilities such as the Intensive Care Units and hospital beds were taken from the database of the Statistical Registry of Hospital Beds and Discharges. The information about health services by level was obtained from the GEOSALUD system of the Ministry of Public Health. The variable referring to the number of companies according to their economic activity was obtained from the Directory of Companies and Establishments (DIEE, acronym in Spanish). Finally, the Cantonal Gross Added Value was obtained from the Regional Accounts database of the Central Bank of Ecuador. Variables related to the population with refrigerator,

3.2. Variables

4.2.1 Dependent Variables

To analyze the effect of social, economic, and health characteristics on the COVID-19 spread in cantons, two dependent variables are considered: i. the number of COVID-19 infected people and ii. the prevalence rate, which is the proportion of the population infected by COVID-19. The models are estimated for three time-intervals: from March 13th to May 3rd (Isolation phase), from 4th May to 31st July 2020 (Social distancing phase) and 1st August to 12th September 2020 (Contingency phase).

Table 5 shows that the cumulative number of COVID-19 cases has increased along the three phases from 9291 cases at the end of the Isolation period to 24978 at the end of the Contingency period. It should be noted that during the phase of social distancing of 89 days, 4,051 additional cases were registered meanwhile during the phase of contingency of only 43 days, 11,636 new cases were registered. Therefore, in the "Contingency" phase there were more people infected in less time. Indeed, in the Isolation phase, 1.82 daily cases were registered in each canton whereas in the social distancing phase and in the contingency phase, on average 2.45 new cases and 2.86 new cases were daily registered, respectively. The average cantonal prevalence rate increased dramatically from 0.6% of the cantonal populations in the isolation phase, to 5% in the social distancing phase and to 7.9% in the contingency phase, registering growth rates of 733% and 58%, respectively.

Table 5: *Comparison between independent variables*

Dependent Variables	PHASES "Isolation" 52 days	"Social Distancing" 89 days	"Contingency" 43 days
Cumulative total Contagious	9291	13342	24978
Average Total Daily Cases during the phase	1.82	2.45	2.86
Cumulative Prevalence Rate	0.006	0.050	0.079

Prepared by the author

Source: *National Risk and Emergency Management System (2020).*

Table 6 presents descriptive statistics of independent variables by groups: sociodemographic variables, economic variables, health related variables, geographical variables, COVID-19 variables and household characteristics variables. These variables were chosen according to the literature review, summarized in Table 7. The average population density across cantons is 135 inhabitants/km2. The standard deviation of this variable shows that cantons are very heterogeneous. Some cantons are very densely populated whereas others have geographically dispersed population. In the latter, the probability to catch the coronavirus Sars-CoV-2 might be lower than in the former. On average, the Gross Value Added in logarithm is 11.29. Likewise, cantons are heterogeneous, which indicates that the level of response of municipalities to the COVID-19 pandemic varies across them. On average, a canton records a share of 8.4% of elderly population and a share of 63% of economically active population. Regarding the connectivity, there are 0.02 international airports in cantons, on average. Only 6 cantons out of 221 account for airports with permission for international flights and only 15 cantons account for national airports. Regarding the economic activity, on average, firms in essential sectors and in non-essential sectors represent 65% and 35%, respectively of the total number of firms in each canton.

Regarding health-related variables, the availability of health services of level 1 in cantons (8.8 units on average) is larger than level 2 and 3 health services (0.53 and 0.18, respectively). It should be noted that the 3rd level health facilities are those with intensive care units (ICU). There are cantons that do not have second and third level health facilities. Only 5 cantons out of 221 account for at least one 3rd level hospital. Quito record 13 3rd level hospitals, Guayaquil, 10, Portoviejo 3, Riobamba 2 and Santa Elena, 2. On average, each canton account for 4 intensive care beds. However, only 32 out of 221 cantons account intensive care beds. This implies that the population in the remaining 216 cantons do not have immediate access to ICUs to be treated in severe COVID-19 scenarios. This is the case of Galapagos, a province whose cantons do not have intensive care beds. People with severe COVID-19 conditions is Galapagos islands had to be transferred to hospitals in continental Ecuador. Regarding variables related to the infrastructure of households, on average 59% of households in each canton have access to potable water.

Table 6: *Descriptive statistics of the independent variables*

Independent Variables	Mean	Standard Deviation	Minimum	Maximum
Sociodemographic variables				
Population density	135.4329	351.2115	0.3195	4529.5
Share of Pop65	0.08418	0.0321	0.0242	0.2011
Share of Active population	0.632	0.034	0.5344	0.7012
Economic variables				
ln GVA	11.2956	1.5406	8.3034	17.0356
ln manuf. exports	4.3197	7.1575	0	21.2664
National airport	0.095	0.3503	0	1
International airport	0.0271	0.16288	0	3
Share of essential act.	0.6496	0.1388	0.0876	0.9216
Share of non-essential act.	0.3503	0.1388	0.0783	0.9123
Geographical variables				
Distance to GYE	199.803	151.735	0	1215.272
Distance to UIO	252.253	169.4129	0	1353.664
Health variables				
Level 1 health center	8.7918	12.8509	1	137
Level 2 health center	0.5294	0.671	0	5
Level 3 health center	0.1809	1.1456	0	13
Support health service	0.0995	0.392	0	3
Ambulatory health service	2.5746	4.5035	0	50
ICU beds	4.5475	28.4404	0	343
COVID-19 variables				
Days to the first case	28.5927	29.2901	0	144
Household variables				

Household with drinking water	0.5931	0.153	0.385	0.9568

As for COVID-19 traffic lights that municipalities established in their territory, as shown in Figure 2, 60.6% of them remain with red light-related constraints in the social distancing phase. The prevalence rate in this phase for cantons with red light constraints was on average 0.05% infected people out of the total population, whereas for cantons with yellow light and green light constraints, the prevalence rate was on average 0.08% and 0.21%, respectively. This indicates that some cantons relaxed constraints even though they record high prevalence rates. For the Contingency phase, 88.6% of cantons changed to yellow light, seeking for economic reactivation. In terms of COVID-19 measures, these cantons recorded on average 0.40% of prevalence rate. Cantons that changed to green light, recorded 0.68% of prevalence rate, and cantons that remain in red light, recorded 0.64% of prevalence rate.

Figure 2. *Number of cantons by COVID-19 pandemic traffic lights in Ecuador*

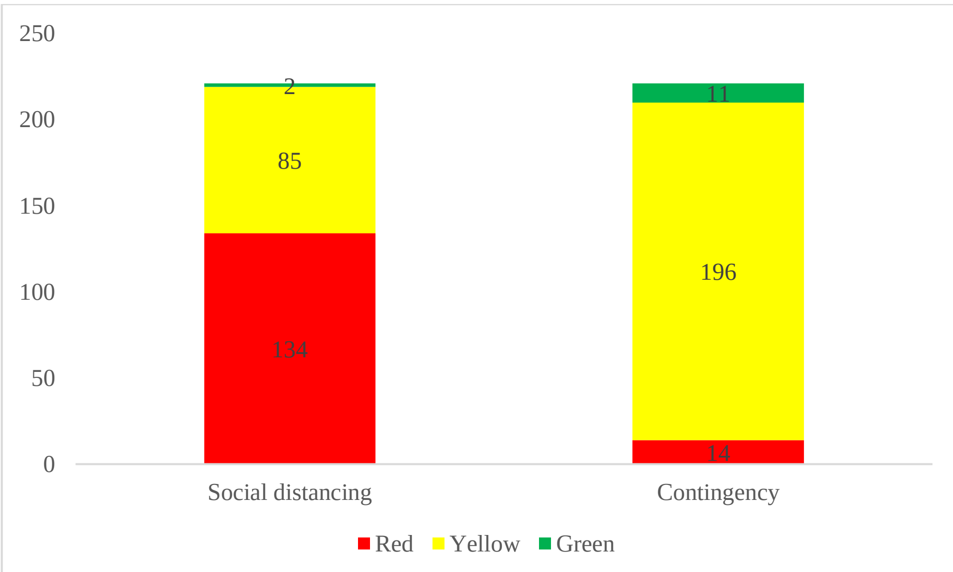


Table 7: *Expected sign of independent variables.*

Independent Variables	Description	Expected Sign	Author
Population density	Population density of each canton	+	Freedman (1975)
Ln GVA	Natural logarithm of the Gross Value Added.	+	World Bank (2020)
Ln manuf. exports	Natural logarithm of the manufacturing exports.	+	Bhadra & Bhattacharya, 2021
Share of Pop65	Percentage of the cantonal population over 65 years of age.	+	Xie et al. (2020)
Share of Active population	Percentage of cantonal population of working age.	+	Leung, Bulterys, & Bulterys (2020).

National airport	Number of airports in each canton.	+	Lin et al. (2020)
International airport	Number of international airports in each canton.	+	Anser et al. (2020)
Distance to GYE	Distance from Guayaquil to the other canton.	+	Cecilia (2014) Jin et al. (2020)
Distance to UIO	Distance from Quito to the other canton.	-	Cecilia (2014) Jin et al. (2020)
Level 1 health centers	Number of health facilities closest to the population over the total population of the canton.	-	Lin et al. (2020); Anser et al. (2020)
Level 2 health centers	Number of health facilities that provide services in four basic specializations: internal medicine, gynecology, general surgery, anesthesiology and hospitalization of patients referred from the fist level over the total population of the canton.	-	Lin et al. (2020); Anser et al. (2020)
Level 3 health centers	Number of regional health facilities providing all health care services out of the total population of the canton.	-	Lin et al. (2020); Anser et al. (2020)
Support health services	Number of health facilities located inside and outside a health facility out of the total population of the canton.	-	Lin et al. (2020); Anser et al. (2020)
Ambulatory health services	Number of health units that have mobility as a principle over the total population of the canton.	-	Lin et al. (2020); Anser et al. (2020)
ICU beds	Number of adult intensive care beds over the total population of the canton.	-	Anser et al. (2020)
Share of essential act.	Share of businesses that remained open during the pandemic.	+	
No essentials	Number of businesses in different economic sector that remained close during the pandemic.	-	

Prepared by the author

3.3. Method

To estimate the effect of cantonal underlying characteristics on the COVID-19 infections, two estimation models are employed. For the discrete dependent variable, the number of COVID-19 infected people, a count data model, the negative binomial regression is conducted. For the continuous dependent variable, the prevalence rate, a Tobit model is employed.

A negative binomial regression is employed to explain the COVID-19 cases in a canton i. This model is used because the assumption of a simple Poisson model that $E(y_i) = V(y_i) = \mu$ is not fulfilled. Our data shows over-dispersion: the empirical variance is larger than the mean (see Table 8).

Table 8. *Descriptive statistics of the discrete dependent variables by periods*

	Mean	Std. dev.
Isolation Cumulative contagion level	94.74	639.28
Social distancing Cumulative contagion level	345.70	1249.72
Contingency Cumulative contagion level	526.93	1987.46

To get rid of this assumption of the Poisson model, the Poisson model with random coefficients introduces into the average of the Poisson model a term of individual heterogeneity. Precisely, we have:

$$\mu_i^* = e^{X_i\beta + u_i}$$

Where u_i is an independent and identically distributed error term. The conditional distribution of y_i is a Poisson distribution:

$$y_i|X_i, u_i \rightarrow P(e^{X_i\beta + u_i})$$

$$P(y_i|X_i, u_i) = \frac{e^{-e^{X_i\beta + u_i}}(e^{X_i\beta + u_i})^{y_i}}{y_i!}$$

If e^{u_i} follows a Gamma law with mean 1 and variance α, $y_i|X_i$ follows a negative binomial law with α as the parameter of over-dispersion.

$$f(u) = \frac{\theta^\theta}{\Gamma(\theta)} e^{-\theta u_i} {u_i}^{\theta - 1}$$

$$P(y_i|X_i) = \frac{\Gamma(y_i + \theta)}{\Gamma(\theta) y_i!} (\frac{\theta}{\theta + u_i})^\theta (\frac{u_i}{\theta + u_i})^{y_i}$$

Regarding the second dependent variable, the prevalence rate in canton i, a Tobit model is employed. This model is used because the prevalence rate is zero for a nontrivial fraction of the cases, especially for the initial periods of study (Wooldridge. 2009). This model involves non-negative predicted values that have sensible partial effects on the range of independent variables. The observed response is expressed in terms of an underlying latent variable as follows:

$$y^* = \beta_0 + x\beta + u, u|x \sim Normal(0, \sigma^2) \qquad (3)$$

$$\mathrm{y} = \max{(0, y^*)}$$

Where y^* satisfies the assumptions of the classical linear model of normality in the residuals and homoscedasticity with a linear conditional mean.

The independent variables include sociodemographic, economic and health characteristics of cantons. Sociodemographic variables are the population density, percentage of the population older than 65 years old and the percentage of economically active population. The economic characteristics of cantons include the quantity of national and international airports, the Cantonal Gross Value Added and the number of businesses in essential sectors and in non-essential sectors[2]. The health characteristics include the number of health facilities at three levels, mobile care and support services, and the number of intensive care beds. As the spread of the virus is reinforced with the social contact, the distances from the main cities of Ecuador (Quito and Guayaquil) were included. Finally, two variables related to the pandemic are included: the number of days that elapsed until the first COVID-19 case appeared in a canton j and the traffic light, reflecting the level of constraints in each canton. For the prevalence rate model, the health services by levels, ICU beds, essential and non-essential activities were transformed into relative variables, dividing them by the total cantonal population.

To obtain unbiased and efficient estimators, normality, homoscedasticity and multicollinearity were tested. To analyze the assumption of normality, the Shapiro-Wilk test was used. The null hypothesis that the data come from a normal distribution was rejected in all models. To solve the normality problem, outlier observations, identified through an analysis of studentized residuals, were eliminated. The Breusch-Pagan test for heteroscedasticity indicates that the variance is not constant. This implies that the size of the residuals is independent of that of the values that have been predicted. (Wooldridge, 2010). To correct this problem, the multiple linear regression model adjusted by robust standard errors was estimated (Wooldridge, 2010). This method allows automatic consideration of heteroscedasticity. The Variance Inflationary Factor (VIF) was used to test the multicollinearity (see Appendix 1). The VIF values do not exceed 10, demonstrating there is no linear dependence between independent variables.

4. Results

Results regarding factors that influence on the number of COVID-19 infected people and on the COVID-19 prevalence rate are shown in Table 9 and Table 10, respectively. As dynamics of the pandemic changed over time, three phases are studied: i. isolation phase (column 1) ii. Social distancing phase (column 2) and iii. Contingency phase (column 3). Previous to discuss the results, negative binomial models, presented in Table 9, are adequate according to the likelihood-ratio chi-square test (shown at the bottom of Table 9), which shows that the number of infected people is over-dispersed.

Table 9. *Estimation results of the Number of COVID-19 infected people*

Dependent variable	Isolation phase		Social Distancing phase		Contingency phase	
Number of COVID-19 infected people	**Coefficient**	**Average marginal effect**	**Coefficient**	**Average marginal effect**	**Coefficient**	**Average marginal effect**

[2] Essential sectors include Agriculture, forestry and fishing (A), Water supply; sewerage, waste management and remediation activities (E), Wholesale and retail trade; repair of motor vehicles and motorcycles (G), Transportation and storage (H) and Human health and social work activities (Q).
Non-essential sectors include Mining and quarrying (B), Manufacturing (C), Electricity, gas, steam and air conditioning supply (D), Construction (F), Accommodation and food service activities (I), Financial and insurance activities (K), Real estate activities (L), Professional, scientific and technical activities (M), Administrative and support service activities (N), Public administration and defense, compulsory social security (O), Education (P), Arts, entertainment and recreation (R), Other service activities (S), Activities of households as employers, undifferentiated goods- and services-producing activities of households for own use (T) and Activities of extraterritorial organizations and bodies (U).

Population density	0.0004**	0.0421**	0.0001	0.0449	0.0001	0.093
	(0.000)	(0.0225)	(0.000)	(0.0611)	(0.000)	0.105
ln GVA	0.247***	365.414**	0.291***	1745.674***	0.279***	2947.978***
	(0.091)	(197.618)	(0.075)	(639.554)	(0.070)	(1218.313)
ln manuf. exports	0.018*	30.386*	0.018*	107.1343*	0.016*	173.337*
	(0.011)	(21.731)	(0.010)	(70.10526)	(0.009)	(125.139)
Share of Pop65	-4.512	-436.756	-11.465***	-4674.5***	-6.535***	-4589.247***
	(2.789)	(309.965)	(1.949)	(1465.349)	(1.840)	(2039.582)
Share of Active population	6.802***	658.371**	2.771	1130.018	5.385***	3781.182***
	(2.454)	(321.673)	(1.892)	(832.176)	(1.805)	(1821.149)
National airport	-0.129	-12.473	-0.053	-21.497	0.033	22.939
	(0.193)	(19.114)	(0.181)	(74.096)	(0.171)	(120.067)
International airport	0.158	15.243	0.044	18.124	-0.208	-146.369
	(0.424)	(41.491)	(0.390)	(158.859)	(0.360)	(261.253)
Distance to GYE	-0.002***	-0.192***	-0.0001	-0.043	0.0006	0.435
	(0.000)	(0.081)	(0.000)	(0.170)	(0.000)	(0.319)
Distance to UIO	0.001***	0.128**	-0.001***	-0.499***	-0.001***	-0.927***
	(0.000)	(0.062)	(0.000)	(0.193)	(0.000)	(0.396)
Level 1 health centers	0.016	1.533	0.048***	19.696***	0.050***	35.422***
	(0.015)	(1.511)	(0.013)	(7.661)	(0.012)	(15.287)
Level 2 health centers	0.3**	29.052*	0.214*	87.039*	0.258**	181.406**
	(0.130)	(16.329)	(0.114)	(51.772)	(0.106)	(95.848)
Level 3 health centers	-0.136	-13.174	-0.289**	-117.779**	-0.266**	-187.001**
	(0.134)	(14.018)	(0.127)	(51.541)	(0.116)	(80.464)
Support health services	-0.113	-10.931	-0.215	-87.652	-0.206*	-144.558
	(0.181)	(18.291)	(0.146)	(62.849)	(0.123)	(96.674)
Ambulatory health services	-0.023	-2.194	-0.005	-2.013	-0.002	-1.129
	(0.030)	(3.074)	(0.027)	(10.871)	(0.026)	(18.089)
ICU beds	0.007	0.649	-0.0000	-0.010	-0.002	-1.181
	(0.004)	(0.572)	(0.004)	(1.595)	(0.004)	(2.788)
Share of essential act.	-0.208	-20.107	-0.563	-229.462	-0.384	-269.973
	(0.494)	(48.247)	(0.411)	(176.229)	(0.371)	(272.108)
Days to the first case	-0.063***	-6.14***	-0.014***	-5.863***	-0.007***	-4.714***
	(0.005)	(2.188)	(0.002)	(1.775)	(0.002)	(2.062)
Households with drinking water	-1.189**	-115.081**	-0.646*	-263.564*	-0.554	-389.048
	(0.497)	(62.486)	(0.408)	(180.364)	(0.380)	(297.243)
Ref. cat. Green in Distancing phase						
Red in Distancing phase			-1.064**	-433.935**		
			(0.499)	(236.089)		
Yellow in Distancing phase			-1.044**	-425.673**		
			(0.503)	(236.896)		

Ref. cat. Green in Contingency phase						
Red in Contingency phase					0.289	203.216
					(0.266)	(196.558)
Yellow in Contingency phase					0.117	82.214
					(0.215)	(151.791)
Constant	-2.168		2.613**		-0.525	
	(1.433)		(1.191)		(1.058)	
N. obs.	221	221	221	221	221	221
LR test alpha=0	1938.16 (0.000)		1.1e+04 (0.000)		1.6e+04(0.000)	

Table 10. *Estimation results of the COVID-19 prevalence rate*

Dependent variable **COVID-19 prevalence rate**	**Isolation phase** **Coefficient**	**Distancing phase** **Coefficient**	**Contingency phase** **Coefficient**
Population density	0.0000*	0.0000	0.0000
	(0.000)	(0.000)	(0.000)
ln GVA	-0.0001	-0.0015***	-0.0020***
	(0.000)	(0.000)	(0.001)
ln manuf. exports	0.0000	0.0001	0.0001
	(0.000)	(0.000)	(0.000)
Share of Pop65	-0.0007	-0.0302***	-0.0087
	(0.002)	(0.010)	(0.018)
Share of Active population	0.0033	0.0166*	0.0432**
	(0.002)	(0.010)	(0.017)
National airport	-0.0001	0.0006	0.0009
	(0.000)	(0.001)	(0.002)
International airport	-0.0000	0.0001	-0.0015
	(0.000)	(0.002)	(0.004)
Distance to GYE	-0.0000	0.0000***	0.0000***
	(0.000)	(0.000)	(0.000)
Distance to UIO	0.0000**	-0.0000***	-0.0000***
	(0.000)	(0.000)	(0.000)
Level 1 health centers	-0.0000	0.0001*	0.0002**
	(0.000)	(0.000)	(0.000)
Level 2 health centers	-0.0000	-0.0003	-0.0004
	(0.000)	(0.001)	(0.001)
Level 3 health centers	0.0000	-0.0008	-0.0013
	(0.000)	(0.001)	(0.001)
Support health services	0.0000	-0.0007	-0.0008
	(0.000)	(0.001)	(0.001)
Ambulatory health services	-0.0000	0.0001	0.0000
	(0.000)	(0.000)	(0.000)
ICU beds	0.0000***	0.0000	0.0000
	(0.000)	(0.000)	(0.000)

Share of essential act.	-0.0010**	-0.0080***	-0.0143***
	(0.000)	(0.002)	(0.004)
Days to the first case	-0.0000***	-0.0000**	-0.0000
	(0.000)	(0.000)	(0.000)
Household with drinking water	-0.0008*	-0.0060***	-0.0085**
	(0.000)	(0.002)	(0.004)
Ref. cat. Green in Distancing phase			
Red in Distancing phase		-0.0206***	
		(0.003)	
Yellow in Distancing phase		-0.0195***	
		(0.003)	
Ref. cat. Green in Contingency phase			
Red in Contingency phase			-0.0017
			(0.003)
Yellow in Contingency phase			-0.0040**
			(0.002)
Constant	0.0011	0.0416***	0.0192*
	(0.001)	(0.006)	(0.010)
N. obs.	221	221	221

The quantity of infected people is positively related to the cantonal Gross Value Added. A 1% increase of cantonal GVA is associated to 365 more COVID-19 infected people in the isolation phase, to 1746 more COVID-19 cases in the social distancing phase and 2948 more COVID-19 cases in the contingency phase. This result is logical since more cases are more likely in richer cantons with more population. Using relative terms, i.e. the prevalence rate instead of the number of infected people, the cantonal GVA is negatively associated to the COVID-19 prevalence rate, especially in the two last phases. A 1% increase in the cantonal GVA is associated to a reduction of 0.0015 and 0.0020 of the prevalence rate in the social distancing phase and in the contingency phase, respectively. While richer cantons recorded more cases, the proportion of infected people with respect to their population was lower than in cantons with low levels of GVA. Underlying economic conditions of cantons are relevant to face the COVID-19 pandemic since therein better infrastructure and complementary services exist, which help people to be treated and be less exposed to the virus Sars-CoV-2. Our results confirm that more connected regions are more affected by the COVID-19 pandemic. An 1% increase in exports in canton i leads to 30.4 more infected people in the isolation phase, to 107 more infected people in the social distancing phase and to 173 more infected people in the contingency phase. Other variables related to the international connection of cantons such as national and international airports are not significant to explain the COVID-19 pandemic dynamics. This non-significant effect might be related to the fact that the number of airports does not indicate the level of international mobility of people, which would be a more appropriate measure. Moreover, essential and non-essential activities operating in cantons is an important predictor of their COVID-19 prevalence rate (not of the number of infected people). Essential activities are those that stay operating during the lockdown derived from the COVID-19 pandemic such as health, agriculture, water-related activities, wholesale and retail trade and transportation and storage. Non-essential activities are those that had to close during the lockdown such as mining, manufacturing, construction, accommodation and food service activities, financial and real estate activities, entertainment, among others. When only non-essential activities were operating, the spread of the Sars-CoV-2 virus was better controlled. Accordingly, our results show that a 1% increase of essential activities leads to a decrease of 0.1% in the prevalence rate in the isolation phase, 0.8% in the social distancing phase and 1.4% in the contingency phase. In the isolation phase, all economic activities closed except for essential ones. When firms of non-essential sectors such as entertainment, accommodation, construction, among others, reopened, more people got infected due to the face-to-face nature of these activities. Therefore, cantons with a higher (lower) proportion of firms operating in non-essential sectors reported more (less) COVID-19 cases and prevalence rate than cantons with a lower (higher) proportion of firms operating in these sectors.

Regarding cantonal demographic variables, contrary to the expected result (Muniyappa & Gubbi, 2020; Richardson et al., 2020), the proportion of elderly population in Ecuador is negatively associated to the COVID-19 infected people and to the prevalence rate. While older people were more vulnerable to the Sars-Cov-2 virus because of more likely health complications, they were not more exposed to the virus as family and close community protected them. More exposed people are those who work. Indeed, our results show that a 1 percentage point increase in the proportion of active population is associated with an increase of 658 more infected people in the isolation phase and of 3781 more infected people in the contingency phase. This result reflects the fact that the Sars-Cov-2 virus was more exposed to working people moving from one place to another having contact with many people in different situations. The existent population density had a statistically positive, although little effect in dimension (possibly explained by the presence of the working population variable), on both the level of infected people and the COVID-19 prevalence rate in Ecuadorian cantons during the isolation phase. An unit increase of the population density in an average canton with 135 inhab./km2 is associated to an expected increase of 0.04% of number of infected people and a null increase of the prevalence rate. In the isolation phase, the correlation coefficient between the population density and the level of infected people was 0.199 and the prevalence rate was 0.254. The positive correlation in this isolation phase indicates that the spread of the virus occurred before the declaration of health emergency in March, 12th 2020. It is worth noting that population density is no longer significant in the estimations for the social distance phase and the contingency phase on the level of infection and prevalence rate, indicating that their directly proportional relationship weakened for next phases. The correlation coefficient between population density and the level of infected people (prevalence rate) for the social distancing phase reduced to -0.0532 and for the contingency phase, it reduced to -0.0830. This could have been due to stringency measures implemented during the isolation phase. As in Chinese cities (World Bank, 2020), the most populated cities recorded less COVID-19 cases per inhabitant in the last phases.

The distance to the epicenters (Guayaquil and Quito) in Ecuador is also important to explain the contagion levels in neighboring cantons. As detailed in the chronology of the pandemic in Ecuador in Section 2, Guayaquil was the first epicenter of the COVID-19 pandemic. For this reason, at the beginning of the pandemic, the estimation results for the isolation phase show that distant cantons with respect to Guayaquil, record a lower number of infected people. By complement, cantons near Guayaquil (the epicenter) recorded high contagion rates due to their interconnectivity and mobility of population between them and Guayaquil. However, for the social distancing and contingency phases, distance to Guayaquil is no longer significant, instead the distance to Quito plays an important role explaining the contagion levels in neighboring cantons during these phases. As the distance to Quito increases by 1 kilometer, the number of COVID-19 infected people decreases in 0.49 and 0.93 in the social distancing and the contingency phases, respectively. Geography matters for the spread of the COVID-19 pandemic. In the global epicenter of China, this geographical pattern also exists as the contagion level reduced with the distance to the province of Hubei (Wuhan) (World Bank, 2020). The effects of distance to Quito and Guayaquil, although statistically significant, are null for the prevalence rates in any phase.

As for variables related to the health infrastructure, it should be noted that health facilities are classified in levels: i. a 1st level health center is a primary and basic center, ii. A 2nd health center accounts for more services and iii. a 3rd level health center accounts for intensive care units (ICU). Results show that 1rst and 2nd level health centers are related to increases in the contagion level in cantons in all phases. By contrast, 3rd level health centers are associated to the reduction in the contagion levels in 118 infected people in the social distancing phase and 187 infected people in the contingency phase. This result indicates that in cantons with less 3rd level health centers, infected people are less likely to be medically assisted and therefore more contagious. Support services reduce the level of contagion in the contingency phase. Health-related variables are not significant to explain the prevalence rates by phases.

The course of the COVID-19 pandemic in regions was also determined by the time when it arrived to their territory. Thus, regions that reported confirmed cases more rapidly registered higher number of contagious. In quantitative terms, one day of delay with respect to the first confirmed case in Ecuador implied a decrease of 6 infected people in the isolation phase, a decrease of 5.9 of infected people in the social distancing phase and 4.7 less COVID-19 cases in the contingency phase. More importantly, the constraints to halt the pandemic proved to be effective during the social distancing phase. Municipalities that imposed stricter measures registered fewer COVID-19 cases than municipalities that changed to green light. In quantitative terms, our results show that municipalities in red light and yellow light, respectively, are associated with 434 and 426 fewer COVID-19 cases than municipalities in green light. The same qualitative result is obtained when studying the prevalence rate. Municipalities in red light and yellow light, respectively, registered a decrease of 2% and 1.9% in the prevalence rate than municipalities in green light. By contrast, in the contingency phase, the effect of stringency weakens as the number of COVID-cases is not statistically different between cantons in red and in yellow light with respect to those in green light.

As one of the main suggestions to face the pandemic given by the World Health Organization (WHO, 2020) was to wash our hands constantly, the existent infrastructure of potable water is a key factor to explain the dynamics of the COVID-19 pandemic. Contrary to developed countries, in developing countries, there are many people that lack access to potable water, therefore, they were more vulnerable to the pandemic. Our results show that as the proportion of households with access to potable water in cantons increases 1%, the number of COVID-19 cases reduces in 115 and 264 during the isolation phase and social distancing phase, respectively. As for the prevalence rate, a 1% increase in the proportion of households with access to potable water reduced the prevalence rate by 0.08%, 0.6% and 0.9% in the isolation phase, social distancing phase and contingency phase, respectively.

5. Conclusions

The contribution of this study is a sound analysis about the COVID-19 pandemic by phases from isolation to contingency phase. By the means of the econometric analysis, the relation between the pandemic and the underlying characteristics of cantons in terms of their economic structure, sociodemographic characteristics is identified, controlling for COVID-19 related variables. This study was conducted using statistical and econometric analysis. From the statistical analysis, we conclude that the arrival and later spread of the COVID-19 pandemic was not uniform across the Ecuadorian territory. Big cities rapidly registered COVID-19 confirmed cases in March 2020. Small cities did not register or registered a low number of COVID-19 cases until the second phase of social distancing. While at the beginning, richer cantons recorded higher growth rates of infected people, this situation was reverted and later, poorer cantons were those registering high growth rates of infected people, indicating that as the pandemic advanced, cantons with less economic resources were more affected.

From the econometric analysis, we conclude that underlying economic conditions of cantons are relevant to explain the COVID-19 pandemic, both the number of cases and the prevalence rate. For instance, richer and more internationally connected cantons registered more cases than poor and less internationally connected cantons. In the same line, cantons with a higher proportion of working population were more affected, indicating negative effects in the labor market. In addition, our results indicate that geographical proximity to pandemic epicenters such as Guayaquil and Quito mattered for the pandemic dynamics in Ecuadorian cantons. Although richer cantons were rapidly affected, their health infrastructure helped them to alleviate the increase of the pandemic as their higher capacity in terms of health centers of 3rd level is associated with a reduction of COVID-19 cases. Better infrastructure and complementary services allow people to be treated and less exposed to the virus Sars-CoV-2. Results show that not only health infrastructure was important to face the COVID-19 pandemic but also the sanitary infrastructure, especially the availability of potable water. Moreover, the economic structure of cantons is an important predictor of their level of COVID-19 contagion and their prevalence rate. Cantons with a higher (lower) proportion of firms operating in non-essential sectors reported more (less) COVID-19 cases and prevalence rate than cantons with a lower (higher) proportion of firms operating in these sectors. Interestingly, the constraints to halt the pandemic proved to be effective during the social distancing phase.

Although this study advances in the analysis of the COVID-19 pandemic in Ecuador, a further analysis could be focused on the relation between underlying conditions of cantons and the COVID-19 lethality rate. In addition, variables related to the habits of population can be considered in an analysis at the individual level.

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Appendix 1: *Variance inflation factor of independent variables*

COVID-19 CONTAGION MODEL		**PREVALENCE MODEL BY COVID-19**	
Variables	**VIF**	**Variables**	**VIF**
nivel_aten_1	12.80	lnVAB	3.47
nivel_aten_3	9.56	nivel_aten_1*	2.11
aten_movil	7.92	Aerp_nacional*	1.83
CIUadultos	6.14	Primer_contagio	1.79
lnVAB	4.32	aten_movil*	1.68
nivel_aten_2	2.74	CIUadultos*	1.68
Pob_activa	2.14	Pob_activa	1.68
Aerp_nacional	1.90	Dist_GYE	1.67
ln_act_abiertas	1.65	act_abiertas*	1.65
Primer_contagio	1.62	Dist_UIO	1.62
Aerp_internac	1.61	nivel_aten_2*	1.61
ln_act_cerradas	1.61	Porc_pob_65	1.57
Dist_UIO	1.58	Aerp_internac*	1.45
Dist_GYE	1.58	aten_apoyo*	1.28
Pob_adulto_mayor	1.55	densidad	1.21
aten_apoyo	1.36		

Densidad	1.24	nivel_aten_3*	1.11
Media VIF	**3.61**	**Media VIF**	**1.71**