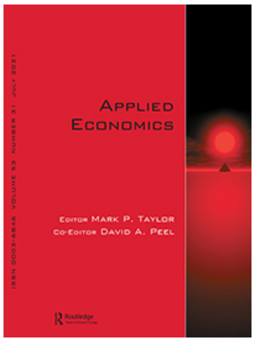

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Distributional impact of COVID-19: regional inequalities in cases and deaths in Spain during the first wave

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ABSTRACT
Spain is being hit hard by the COVID-19 pandemic. During the first wave, from mid-March to early June 2020, the disease caused nearly 30,000 deaths in a population of 47 million. This article quantifies the unevenness in the distribution of epidemiological variables across the Spanish territory. The study is relevant because Spain is divided into regions that hold devolved authority for providing health care services to their citizens. Using inequality metrics, the study shows: i) By mid-April inequality in the epidemiological variables reached a stationary value that changed little with the incorporation of new cases and deaths. At the end of the outbreak, cumulative cases and deaths were fairly unevenly distributed across Spanish provinces; ii) Inequality shows a monotonic downward trend throughout the outbreak showing a decrease from the onset to the end ranging from 22% to 49% in cases and between 17% and 42% in deaths; iii) Over 90% of the inequality observed can be attributed to differences between regions, while less than 10% is due to the differences across provinces within regions. Awareness of the existence and nature of the inequality observed in the epidemiological variables is needed to develop successful policies to improve health services in Spain.

KEYWORDS
COVID-19; regional inequality; Gini index; Theil index; regional decomposition; Spain

JEL CLASSIFICATION
JEL I12; I18; R50.

I. Introduction

The World Health Organization declared COVID-19 disease as a pandemic on 11 March 2020 (WHO 2020c) by which time there were 124,101 confirmed cases and 4,583 deaths, mostly in China. Since then, the virus spread very fast all around the world with more than 84 million confirmed cases and 1.8 million deaths as of 7 January 2021 (WHO 2020a).

Spain is one of the countries hardest hit by the pandemic, with 1,893,502 confirmed cases and 50,442 deaths (data reported on 7 January, WHO (2020a)), in a population of about 47 million. It was one of the countries most affected by the first wave. At the beginning of July 2020, when the first wave was considered controlled, figures ranked Spain as fifth in the world in terms of deaths by population behind San Marino, Belgium, Andorra and the United Kingdom (data reported on 7 July 2021, WHO (2020a)).

However, the effects of the pandemic have been felt very unevenly across Spain. The first significant outbreaks classified as non-imported cases appeared in early March in the capital, Madrid, which lies in the centre of the country, but also to a lesser extent in the provinces of Álava and La Rioja, which lie close to each other in the north. From 9 to 11 March, the regional governments of these regions imposed social isolation measures such as the suspension of school classes, the closure of universities, restrictions on visits to nursing homes and a ban on large-scale events.

By 11 March, the cumulative figures for cases in Spain were over 4400, more than 2900 of them in Madrid. The rest were distributed very differently across the other 51 provinces. Only in three provinces (Barcelona, La Rioja and Álava),the number of cases was slightly above 200, and 22 provinces had no cases at all. However, it was not until 14 March that the Spanish government enacted the State of Alarm (*Estado de Alarma*) (BOE 2020a). This legislation allowed the government to restrict the mobility of citizens and limit economic activity to essential sectors. In fact, during the first month of the State of Alarm, people remained in strict confinement at home, except for essential activities such as visiting doctor, basic shopping or work. The lockdown of the economy from 29 March to

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13 April, which restricted activities to essential sectors, had positive results in terms of flattening the epidemic curve (Saez et al. 2020; Tobías 2020). The initial State of Alarm was subsequently extended several times to Parliament ending on 21 June although some of the initial restrictions were lifted (BOE 2020b,c,d,e,f,g). Recent studies estimate that these measures prevented up to 450,000 deaths in Europe (Flaxman et al. 2020). In the case of Spain, the Spanish National Centre for Epidemiology (SNCE, Instituto de Salud Carlos III (2020)) considered that the peak of the first outbreak was under control by the end of May and established a new surveillance and control strategy of the disease.

Not surprisingly, most current studies on Covid-19 focus on the trends in the epidemiological variables such as confirmed cases, hospital admissions and deaths. Modelling and analysing trends helps to assess where the pandemic is and to predict its future evolution (Ceylan 2020; Liu et al. 2020). There are also studies that analyse the link between these variables and others of a socioeconomic nature, looking for significant links that may help to manage future pandemics. In this context, for the case of Spain, there are analyses focusing on the links between the propagation of Covid-19 and variables such as the mobility of citizens (Mazzoli et al. 2020; Aleta et al. 2020), local climate characteristics (Briz-Redón and Serrano-Aroca 2020; Ma et al. 2020; Oto-Peralías 2020; Paez et al. 2020), pollution concentration (Martorell-Marugán et al. 2021; Ogen 2020) and the implications of enforced isolation on the evolution of the disease (Henríquez et al. 2020; Siqueira et al. 2020; Moosa 2020; Casares and Khan 2020; Hyafil and Morina 2020; Flaxman et al. 2020; Zambrano-Monserrate, Ruano, and Sanchez-Alcalde 2020).

Despite the interest shown in trends in epidemiological variables, research literature has so far paid little attention to distributional issues associated with the evolution of the epidemic variables. Such analyses are also relevant in understanding how local characteristics and measures taken may affect the evolution of the pandemic. The Spanish National Health System is based on a universal coverage, publicly funded, with a free of charge provision and some co-payment of pharmaceuticals related to age and income (Mentzakis et al. 2019). However, Spain is divided into 17 regions, which hold devolved authority for organizing and providing health care services to their citizens. All regional governments have been responsible for health care planning, organization and management since 2002, and are thus politically accountable to their constituents (Costa-Font and Moscone 2009). In 2018, 92.6% of the public health expenditure were executed by the regions (Rodríguez Blas 2020).

This status quo was modified with the initial State of Alarm, which included measures to centralize health services at the national level (BOE 2020a). The subsequent extensions of the State of Alarm shifted towards a co-governance system, with the central government setting the benchmark for actions and the regional governments organizing those actions within their regions. Ensuring coordination between the national and regional governments was one of the key points for the resilience of the Spanish health system during the early weeks of the pandemic (Legido-Quigley et al. 2020).

Distributional concerns can be quantified using inequality metrics. This is a standard methodology that has been applied to several topics, especially in the social sciences. A non-exhaustive list includes studies on the distribution of variables as diverse as income (Ram 2015; Chongvilaivan and Kim 2016; Bui, Nguyen, and Pham 2017), health resources (De Maio 2007; Alcalde-Unzu, Ezcurra, and Pascual 2009; Morita et al. 2018; Saito et al. 2020), education facilities (Quadrado, Loman, and Folmer 2001), sports results (Borooah and Mangan 2012), demographic behaviour (Bleha and Ďurček 2019; Pagliacci 2019), natural resources use (Duro, Schaffartzik, and Krausmann 2018; Gutiérrez and Inguanzo 2019; Cetrulo et al. 2020; Tang et al. 2020) and pollutant emissions (Xia, Wang, and Ji 2019; Bolea, Duarte, and Sánchez-Chóliz 2020; Pakrooh et al. 2020).

Our research uses this methodology to study how unevenly epidemiological variables of the first wave of Covid-19 were distributed across the provinces and regions of Spain. We focus on two aspects in particular. First, the distribution of cumulative cases and deaths across Spain's provinces from March to June 2020 is quantified using inequality indices. Second, the analysis seeks to learn whether the inequality observed in the distribution of cases and deaths is due to differences between the Spain's regions, which hold devolved authority to manage their health systems, or to differences within regions, reflecting idiosyncrasies of provinces, which may be affected by their population density, city sizes, airports, ageing population, etc. This decomposition provides highly valuable information for policymakers. To address this second issue, we use the properties of the Theil index, which enables inequality to be decomposed into different levels (Shorrocks 1980; Shorrocks et al. 1984). The distributional analyses implemented in this study weight cases and deaths in provinces by their populations.

The rest of the article is structured as follows: Section 2 describes the Spanish National Health System and the role of the central and regional governments. Sections 3 and 4 detail the data and the methodology used in our analysis. Section 5 starts by looking at the main initial messages that can be drawn from the data. In particular, it overviews the trends in confirmed cases and deaths, their relationship with population figures and how they are distributed across the different regions and provinces. After the context is analysed, the trend in inequality indexes and the Theil decomposition are presented. Finally, Section 6 discusses the results and presents the conclusions.

II. The Spanish national health system

The Spanish National Health System (SNHS) is a publicly funded health system based on universal coverage with free access to health care for almost all citizens and some co-payment of pharmaceuticals related to age and income. All residents in Spain have the right to full health coverage, regardless of their nationality and legal status. This right was only limited during 2012–2018 when the legislation in force linked the right to the legal and employment situation of the people, excluding, in practice, only undocumented immigrants from coverage (RDL 16/2012 (BOE 2012) was repealed by RDL 7/2018 (BOE 2018)).

The SNHS is settled on the territorial organization of Spain established after the approval of the 1978 Constitution. Since then, Spain is divided administratively into 52 provinces grouped into 17 regions (called 'Autonomous Communities') and two autonomous cities located in the north of Africa. These regional and provincial divisions correspond to the NUTS 2 and NUTS 3 classifications, respectively, as used by the European Union for statistical matters (Eurostat 2020b). Figure 1 represents this territorial division.

From the organizational point of view, the SNHS is fully decentralized since 2002, with each of the 17 regional authorities being competent for the regulation, planning, budgeting, organization and

Figure 1. Territorial organization of Spain: regions. Source: Reproduced from the Minister of Health, 2020.

management of health care within its jurisdiction, including the implementation of public health policies. In this decentralized framework, the national Ministry of Health acts as the guarantor of the equitable functioning of health services throughout the country. However, its responsibilities are reduced to basic legislation and general coordinator in topics such as foreign health affairs (including those related to epidemiological control and fight against communicable diseases through the SNCE), pharmaceutical legislation, food safety and monitoring of health system performance. The national Ministry of Health is also responsible for the provision of services in the two autonomous cities located in the north of Africa, Ceuta and Melilla, representing 0.36% of the Spanish population. This provision is centrally managed through the Institute for Health Care Management (INGESA, in Spanish). Coordination between the national and regional public health administrations is carried out through the Inter-territorial Council of the national health system (CISNS) made up of 17 regional health ministers chaired by the national minister. Decisions of CISNS are expressed as recommendations that are adopted by consensus (see Bernal-Delgado et al. (2018)). Finally, provinces and municipalities do not play any relevant role in the decision-making of the SNHS. However, they do collaborate with regional health departments on public health programmes. Figure 2 synthetics the SNHS organizational framework.

The initial State of Alarm caused by Covid-19 altered the regular operation of the SNHS. To cope with the outbreak and contain its spread, the management of public health policies was centralized within the Ministry of Health. This centralization allowed a more efficient purchase of necessary goods and services in the international markets and organization of the production of these goods at national level. This was especially relevant to increase work safety because shortages in personal protective equipment have been deemed one of the reasons for the number of medical staff infected in Spain during the first days of the outbreak (Henríquez et al. 2020). After the relaxation of the lockdown measures imposed by the State of Alarm, the co-governance system between the national and regional public health administrations re-emerged, with the national Ministry setting the basic strategies to fight the pandemic and the regional governments in charge of implementing these strategies through the agreements reached within the CISNS.

Regarding financing, the SNHS is mainly funded by taxes. In general terms, the responsibility on tax collection is shared by the central and regional governments. The central government collects VAT, personal income tax and excise taxes, and

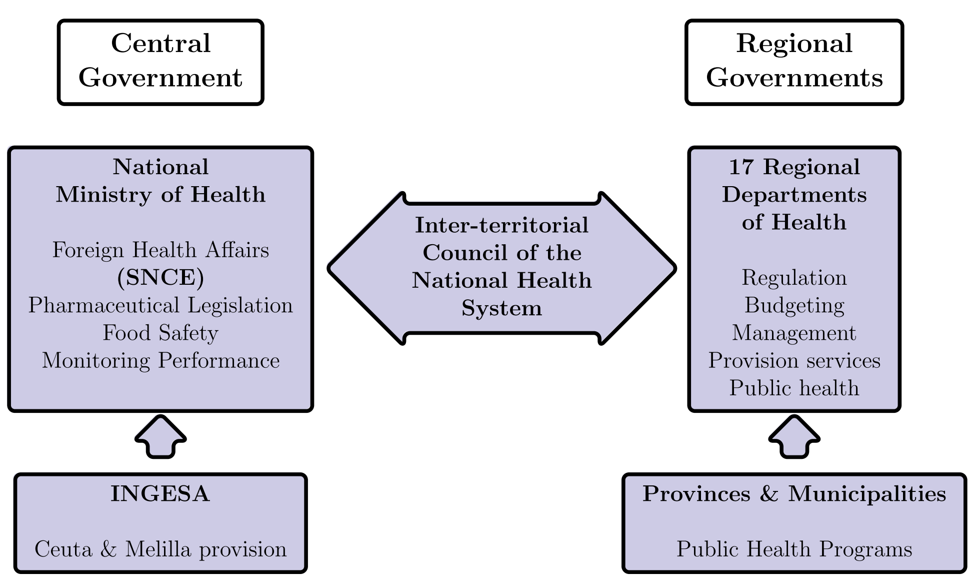


Figure 2. The decentralized approach of the Spanish National Health System.

afterwards, each regional government is assigned 50% of the personal income tax as well as 50% of the revenues generated within their territories by VAT and 58% of those yielded by selected excise taxes such as alcohol, tobacco and hydrocarbons. Tax rates for VAT and excise duties are common in all regions; however, the marginal rates of personal income tax can be revised by each region, within certain established limits. In addition, regional governments have full regulatory capacity on other taxes such as wealth, property, inheritance, gambling or car registration. Since Bernal-Delgado et al. (2018) point out, these resources grant the region significant fiscal autonomy. This fiscal autonomy is even greater in the case of the Basque Country and Navarre, which collect all the taxes within their jurisdiction and then transfer a part to the central government in payment for the services provided in those regions.

In addition to taxes, the regions are also financed through the so-called Fund for Basic Public Services, whose objective is to guarantee a minimum level of basic public health services throughout the country (as well as educational and social services). Each region contributes 75% of its tax revenues to the fund, and then the central administration distributes it among all the regions according to a formula that considers the characteristics of the population, geographic extension, density and insularity. The system is complemented by other funds that aim to reduce the funding imbalance across the regions.

It is worth mentioning that none of the revenues indicated are specifically earmarked for health spending, but rather for financing all the services provided by the regions. In practice, this means that regional health systems can become very different from each other due to the internal allocation that each region makes of its funds among the various services it offers to its citizens. As an example of these differences, Table 1 shows regional public expenditure on health as percentage of regional GDP and in euros per capita.

Table 1. Regional public expenditure on health (2018).

Region*	GDP	Euros
	Percentage	Per capita
Andalucía (Andalusia)	6.3	1212
Aragón	5.7	1601
Asturias [Principado de]	7.4	1676
Canarias (Canary Island)	6.7	1399
Cantabria	6.5	1543
Castilla y León	6.6	1577
Castilla-La Mancha	7.1	1438
Cataluña (Catalonia)	4.7	1432
Comunidad Valenciana	6.3	1415
Extremadura	8.7	1626
Galicia	6.4	1491
Islas Baleares (Balearic Islands)	5.1	1407
La Rioja	5.4	1477
Madrid [Comunidad de]	3.6	1274
Murcia [Región de]	7.4	1567
Navarra (Navarre)	5.3	1651
País Vasco (Basque Country)	5.3	1753

Source: Rodríguez Blas (2020).
*In brackets the full name and in parentheses the English name of the region (where applicable).

III. Data

During the pandemic, by delegation of the National Ministry of Health, the SCNE has been in charge of monitoring the COVID-19 epidemic (Instituto de Salud Carlos III 2020). For the follow-up to be successful, a proper and rapid data collection is considered essential. However, during the first wave, the SNCE reported data on epidemiological variables at the regional level but not at the provincial level.

In all cases, the confirmed cases and deaths reported correspond to patients with positive PCR tests. The definition of positive PCR test varied throughout the first wave. Until 10 May, all available laboratory techniques (PCR, ELISA serological test, rapid antibody test or antigen test) were considered. As of 11 May, confirmed cases diagnosed by PCR or antigen technique are counted according to the strategy for early detection, surveillance and control of COVID-19 of the Ministry of Health, which was agreed by the technicians of all regions in the CISNS (Instituto de Salud Carlos III 2020).

It is worth noting that many cases went undetected, especially at the onset of the outbreak, because either they were asymptomatic or the health system only tested more severely affected patients (Hyafil and Morina 2020). Similarly, the data may had undercounted the true number of deaths due to the lack of PCR test to all deaths (Alamo et al., 2020). On the other hand, recent literature has cast some doubts on the epidemiologic pertinence of using PCR test if individuals are positive but not contagious (Jefferson et al. 2020).

The data on epidemiological variables at provincial level used in this research come from the EScovid19data public repository (EScovid19data 2020) that was accessed on 3 August 2020. It runs under a Creative Commons Attribution 4.0 International licence (CC BY 4.0). This repository provides the data reported by the SNCE for single-provincial regions. For the rest of the regions, the repository was updated daily by volunteers during the pandemic, who extracted and homogenized data mostly from the official regional health services. In general terms, each region or province had a sponsor who was responsible for obtaining data that could be downloaded automatically or, if that was not possible, for uploading it to a common spreadsheet. More details on how the repository works are available on its own web page (https://github.com/montera34/escovid19data). This repository is one of the open-data resources considered as pertinent for studying COVID-19 in Spain (Alamo et al. 2020) and has been used for academic works such as Briz-Redón and Serrano-Aroca (2020), Martorell-Marugán et al. (2021) and Paez et al. (2020). Table A.1 in Appendix A lists the Spain's regions with the corresponding provinces and their main source of information used by the repository.

With respect to population, 2019 data from the Spanish Statistical Institute (INE) are used.

IV. Methodology

Measuring inequality

The simplest way to analyse the extent to which the distribution of a variable within individuals from a sample (provinces in our case) deviates from a perfectly equal distribution is to draw a Lorenz curve (Lorenz 1905). In our case, this curve relates the cumulative proportion of provinces weighted by population to the cumulative proportion of cases (or deaths), assuming that provinces are arranged in increasing order of cases (or deaths). A completely uniform distribution is shown by a diagonal line that represents the situation in which all provinces have the same number of cases or deaths given their population. The nearer the curve of the distribution is to this diagonal line, the more uniform the distribution is. One advantage of using a Lorenz curve to assess evenness is that it enables the distribution of a variable to be compared over time. When the Lorenz curves of two distributions are displayed in the same graph and do not cross, it can be stated unequivocally that the curve closer to the diagonal represents a more egalitarian situation than the other.

Apart from the graphical analysis provided for the Lorenz curve, the evenness of a distribution can be measured via inequality indexes. In general terms, an inequality measure is a function that ascribes a value to a specific distribution such that directly quantified comparisons can be made across different distributions. An inequality index is considered appropriate if it satisfies four basic properties: anonymity, population invariance, scale invariance and the Pigou-Dalton Transfer (Cowell 2011). Among the inequality indices that hold these properties, for the purpose of this study, we use the Gini index (Gini 1911) and the Theil index (Theil 1967) which are some of the most widely used in social science.

The Gini index is inextricably linked to the Lorenz Curve because it quantifies the degree of inequality of a distribution as the normalized area between the Lorenz curve of the distribution and the 45-degree line (line of perfect equality). Formally, the Gini index for the distribution of an epidemiological variable e among M provinces can be calculated as

$$G = \frac{1}{2ep^2} \sum_{i=1}^{M} \sum_{j=1}^{M} p_i p_j \left| e_i - e_j \right|, \tag{1}$$

where e_i and p_i represent the epidemiological variable (cases or deaths) and population of province i for $i = 1, 2 \ldots, M$, respectively. $p = \sum_{i=1}^{M} p_i$ is the overall population, and $e = \sum_{i=1}^{M} \frac{p_i}{p} e_i$ denotes the total of the epidemiological variable. This index ranges between 0 (maximum equality) and 1 (maximum inequality).

The main drawback of the Gini index is that it is neither easily decomposable nor additive. In addition, it does not respond in the same way to income transfers between people at opposite tails of the income distribution as it does to transfers in the middle of the distribution (Atkinson 1970; Allison 1978).

The Theil index belongs to the General Entropy family of indices, which are based on the notion of entropy in information theory (Theil 1967). This family is expressed in terms of a parameter that expresses the sensitivity of the indicator to different parts of the distribution. The Theil index corresponds to the case in which this parameter takes a value of 1 meaning that all points in the distribution are treated equivalently. Formally, the Theil index is calculated as

$$T = \sum_{i=1}^{M} \frac{p_i}{p} \frac{e_i}{e} \ln\left(\frac{e_i}{e}\right). \tag{2}$$

The Theil index ranges between 0 (maximum equality) and $Ln(M)$, with M being the number of provinces in our study, (maximum inequality).

Note also that the Theil index requires logarithms to be applied to the epidemiological variables. This is an important point for our analysis since some provinces have zero cumulative cases and deaths in the early days of the outbreak. Following the advice of Bellù and Liberati (2006), we consider a value equal of 10^{-100} for these cases to solve this shortcoming.

Unlike the Gini index, the Theil index displays the property of additive decomposability, defined by Shorrocks et al. (1984), which enables inequality to be decomposed by population subgroups and expressed as a weighted sum of a within-group and a between-group component. This point is developed in the next subsection.

Regional decomposition of inequality

When a population can be partitioned into excluding subgroups, it is useful to decompose the dissimilarities observed by population sub-groups, expressed as a weighted sum of a within-group and a between-group component. The *within* component accounts for inequality inside each group and the *between* component accounts for inequality across groups. This is the case here, where data are available at provincial level and provinces can be classified by regions. Given that regions are in charge of the health services, we are interested in learning what part of the inequality observed is due to differences *within* and *between* regions.

The Theil index is one of the inequality measures that enables inequality to be decomposed additively between and within groups (Shorrocks 1980; Shorrocks et al. 1984). When applied to our study, the decomposition of the Theil index for the distribution of an epidemiological variable e among M provinces distributed among R regions can be formally expressed as

$$\mathrm{T} = \mathrm{T}_{\mathrm{within}} + \mathrm{T}_{\mathrm{between}}, \tag{3}$$

being

$$\mathrm{T}_{\mathrm{within}} = \sum_{r=1}^{R} \frac{\sum_{i=1}^{M_r} p_{i,r} \cdot e_{i,r}}{\sum_{i=1}^{M} p_i \cdot e_i} \cdot \mathrm{T_r}, \tag{4}$$

$$\mathrm{T}_{\mathrm{between}} = \sum_{r=1}^{R} \frac{\sum_{i=1}^{M_r} p_{i,r} \cdot e_{i,r}}{\sum_{i=1}^{M} p_i \cdot e_i} \cdot \left[\ln\left(\frac{p}{p_r} \cdot \frac{\sum_{i=1}^{M_r} p_{i,r} \cdot e_{i,r}}{\sum_{i=1}^{M} p_i \cdot e_i} \right) \right], \tag{5}$$

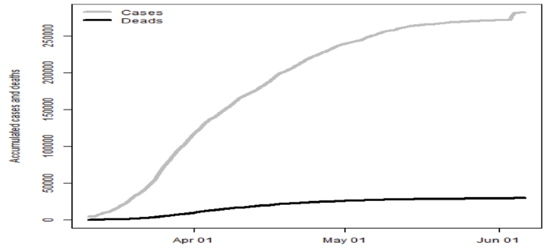
where M_r is the number of provinces in region r, $p_{i,r}$ is the population of province i in region r and T_r is the value of the Theil index calculated with the population of region r alone.

The term $T_{between}$ reflects inequality due to differences observed between regions, while the term T_{within} represents inequality due to differences observed within the provinces of those regions. It is worth noting that the contribution of region r to total inequality, T, is given by $(\sum_{i=1}^{M_r} p_{i,r} \cdot e_{i,r} / \sum_{i=1}^{M} p_i \cdot e_i) T_r$. This term refers to the inequality *within* region r.

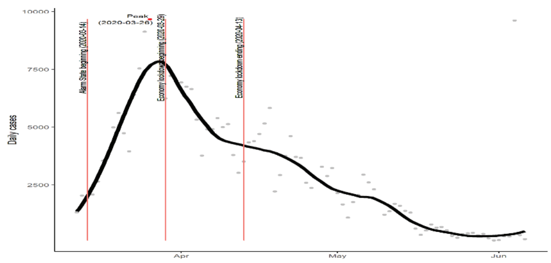
V. Results

Trend in cases and deaths

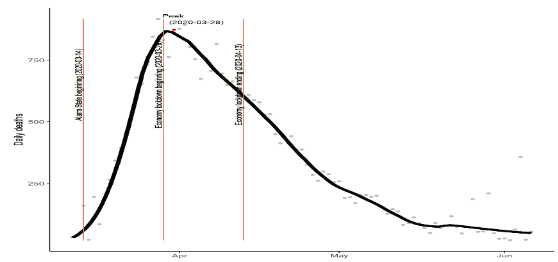
We focus our analysis on a period of interest determined by the curves of incidence and prevalence of the epidemic. In particular, the onset (ending) is set as the first (last) day on which the number of deaths was above 30, that is from 11 March to 6 June 2020. Choosing this study period ensures that the data



(a) Prevalence (Cumulative data)



(b) Cases per day (points). Line: Estimated trend with local regression (loess) for $\alpha = 0.3$ (smoothness parameter) and $\lambda = 2$ (degree of the local polynomial).



(c) Deaths per day (points). Line: Estimated trend with local regression (loess) for $\alpha = 0.3$ (smoothness parameter) and $\lambda = 2$ (degree of the local polynomial).

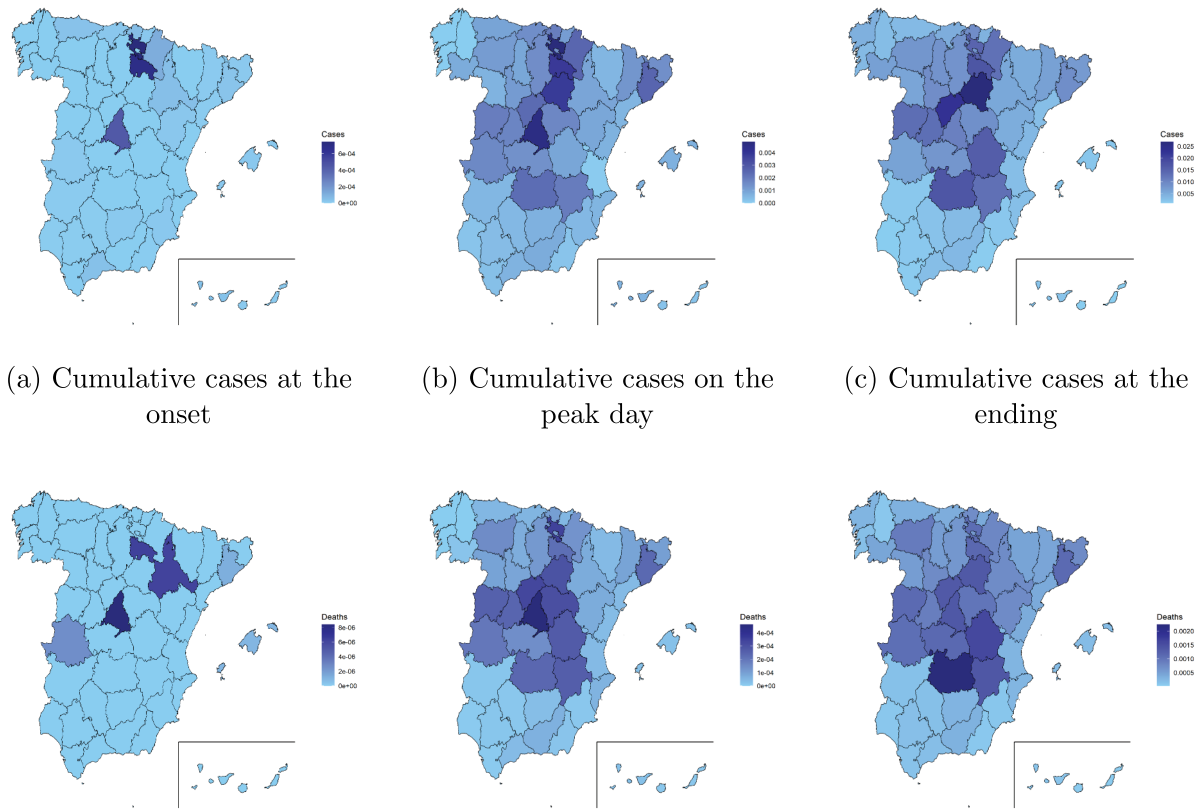
Figure 3. Epidemiological curves for the first COVID-19 wave in Spain.

represent homogeneous information for the entire first COVID-19 wave.

Time series for the epidemiological variables, cases and deaths are noisy, reflecting administrative lags in incorporating new information. In fact, weekend data show unreal reductions as data are reported at the start of the next week. Following Mazzoli et al. (2020), we eliminate this effect by smoothing the time series running average of 3 days, assigning the value to the mid point.

Figure 3 shows the cumulative and numbers of cases and deaths per day for the first Spanish wave. Cases per day are calculated as the inter-day variation of the cumulative data reported. At country level, daily cases and deaths peaked on 26 and 28 March 2020, respectively. These peaks are very close together, taking into account that, based on Chinese data, the WHO reported that the time between symptom onset and death ranged from about 2 to 8 weeks (WHO 2020b). This confirms the idea that during the first part of the outbreak in Spain, the fatality rate (deaths/cases) was significantly high, probably due to the pressure on health services (Verelst, Kuylen, and Beutels 2020).

At a first glance, the data shows epidemiological variables as heterogeneously distributed across Spain's provinces. Figure 4 shows the cumulative number of cases and deaths with respect to the population of each province on three key dates: at the onset of the disease, on the peak day and at the ending. Several facts deserve to be highlighted. First, except at the onset, a highly positive relationship is observed between the distribution of cases and the distribution of deaths across provinces. In fact, the Pearson correlation between cases and deaths across provinces is 0.89 for the peak day of cases, and 0.85 for the peak day of deaths. This means that the fatality rates between provinces are very similar over time. Second, there are differences in terms of rankings between provinces when the distributions are compared over the key dates. At the onset of the pandemic, the numbers of cases and deaths were low and concentrated in a few provinces reflecting local outbreaks in Madrid (in the centre) and La Rioja (in the north). By the peak days, the virus had already spread throughout the country, with Madrid and the surrounding provinces especially hard hit. By the ending, the virus had spread more evenly across the provinces, but



(a) Cumulative cases at the onset

(b) Cumulative cases on the peak day

(c) Cumulative cases at the ending

(d) Cumulative deaths at the onset

(e) Cumulative deaths on the peak day

(f) Cumulative deaths at the ending

Figure 4. Distribution across provinces of per capita epidemiological variables during the first COVID-19 wave in Spain on key dates.

cases and deaths were still concentrated in the provinces in the centre of the peninsula, while those on the coast were less affected. However, Madrid was no longer at the top of the ranking: it had been surpassed by Ciudad Real, one of its neighbouring provinces belonging to Castilla-La Mancha region, with a high percentage of elderly population. Third, the data trend also shows the role of Madrid in spreading the virus. Madrid was the main local outbreak at the onset of the pandemic. Later, local peaks of incidence and mortality appeared in other provinces with a high level of mobility from and to Madrid in the week before the onset of the local outbreaks (Mazzoli et al. 2020).

The data are completed with Table 2, which quantifies the cumulative cases and deaths per 100,000 heads of population at the end of the outbreak. It can be seen that the regions with most cases are those closest to the initial outbreaks: Comunidad de Madrid and its neighbouring regions, Castilla-La Mancha and Castilla y León, plus La Rioja and its neighbour Navarra. With respect to the deaths, the three regions with ratios

Table 2. Epidemiological variables for the first COVID-19 wave per 100,000 population in Spain's regions (29 May 2020).

Region*	Cases	Deaths
Andalucía (Andalusia)	209	17
Aragón	537	68
Asturias [Principado de]	328	32
Canarias (Canary Island)	110	7
Cantabria	495	36
Castilla y León	1077	84
Castilla-La Mancha	1190	147
Cataluña (Catalonia)	791	96
Ceuta	210	5
Comunidad Valenciana	281	29
Extremadura	327	48
Galicia	422	23
Islas Baleares (Balearic Islands)	185	20
La Rioja	1713	114
Madrid [Comunidad de]	1086	137
Melilla	155	2
Murcia [Región de]	175	10
Navarra (Navarre)	1277	79
País Vasco (Basque Country)	832	66

*In brackets the full name and in parentheses the English name of the region (where applicable).

above 100 are Castilla-La Mancha, Comunidad de Madrid and La Rioja. This figure contrasts with the lower ratios of less than 25 in Andalusia and Galicia (apart from the islands and autonomous cities).

In summary, descriptive data show that as time went, cases and deaths became more evenly distributed across provinces although the distribution at the end of the outbreak remained quite heterogeneous. Inequality indices can thus be expected to show a decreasing trend over the outbreak. In the next subsection, these indices are quantified.

Table 3. Inequality measures for the epidemiological variables of COVID-19 in Spain from provincial distributions with population weight.

Day	Cumulative cases		Cumulative deaths	
	Gini	Theil[a]	Gini	Theil[*]
Onset	0.83	1.60 (0.41)	0.82	1.58 (0.40)
Peak day	0.69	0.93 (0.24)	0.69	0.96 (0.24)
Ending	0.65	0.81 (0.21)	0.68	0.92 (0.23)

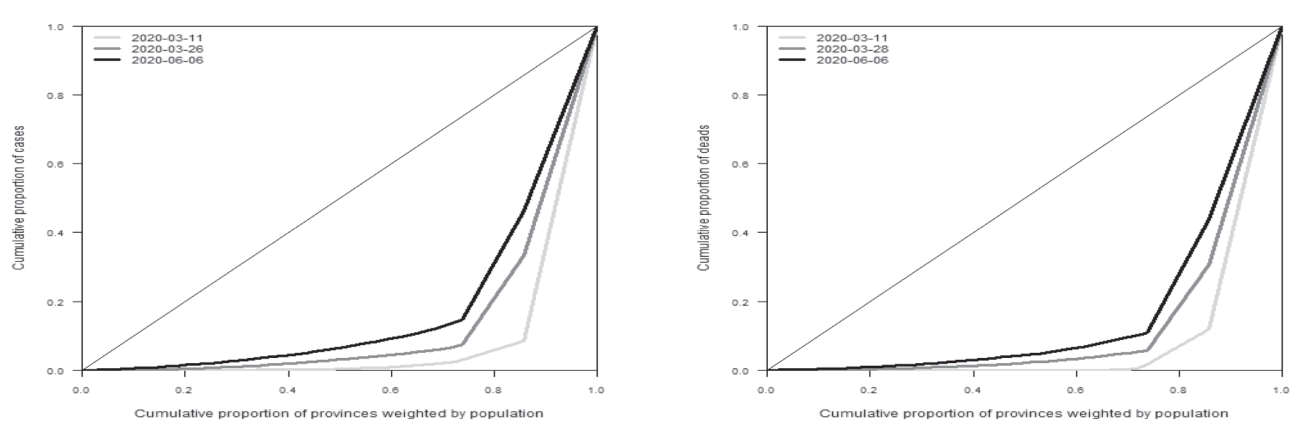
*In parentheses, the value normalized by the maximum level of the Theil index ($Ln(52) = 3.95$)

Figure 5 compares the Lorenz curves for cumulative cases and deaths on key dates. These comparisons show that provinces in the low and middle parts of the distribution increase their share of the total cumulative cases and deaths over time, bringing the curve closer to the diagonal though still far from it. Thus, it can be unambiguously claimed that the distributions of cumulative cases and deaths became more homogeneous as the Covid-19 disease evolved until the first wave ended.

Along with this graphical result, an inequality in the provincial distribution of the epidemiological variables is quantified using the Gini and Theil indices defined in expressions (1) and (2), respectively. Table 3 shows the indices for cumulative cases and deaths on key dates. Given that the Theil index is unbounded above, it is normalized by the maximum level that it can reach ($Ln(M)$ with M being the number of provinces); this normalization can be called the Relative Theil Index (Bellù and Liberati 2006). It enables the Gini and Theil indices to be compared since both ranged from 0 to 1.

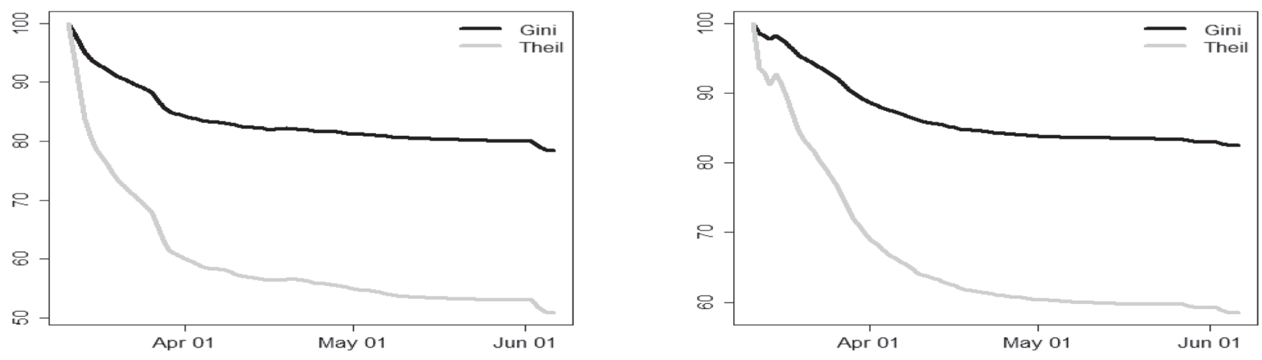
The results in Table 3 highlight two important facts. First, at the end of the Covid-19 wave, it can be stated that the numbers of cumulative cases and deaths are fairly unevenly distributed among the Spain's provinces. The Gini index shows similar inequality for cases and deaths, ranging at the ending of the wave from 0.65 to 0.68. It is worth noting that this figure is twice the Gini index for the distribution of disposable income among the Spanish population which was 0.33 in 2018 (Eurostat 2020a). Second, as the Lorenz curves show in Figure 5, the level of inequality quantified for both indices decreases over time as the virus spreads.

This last result is illustrated in more detail in Figure 6 where the trend in the indices for the full period studied (11 March to 6 June 2020) is displayed. The trend is shown with both indices normalized to 100 for the onset day. Positive and



(a) Cumulative cases (b) Cumulative deaths

Figure 5. Lorenz Curves for the epidemiological variables of COVID-19 with population weight in Spain on key dates.



(a) Cumulative cases (b) Cumulative deaths

Figure 6. Trend in inequality for the epidemiological variables of COVID-19 in Spain. From provincial distributions with population weight.

negative fluctuations in inequality place indices above and below 100, respectively. This enables the scale of the changes in the Gini and Theil indices to be easily compared in time and with each other.

As expected, Figure 6 shows a monotonic downward trend in the inequality in both cumulative cases and deaths. The only exception appears for 15 March when inequality in deaths increases slightly, probably because the daily deaths reported were abnormally low. It can be observed that inequality in the distribution of cases decreased by between 22% and 49% from the onset to the ending, depending on the index. Likewise, inequality in the distribution of deaths decreased by between 17% and 42% in the same period.

Decomposition of inequality by regions

Although the trend is monotonically decreasing, two different periods are observed. In the first part of the wave, in March, inequality decreases very fast as the disease spreads from the initial outbreaks, located mainly in Madrid, to the rest of the country, reaching the surrounding provinces very rapidly. As pointed out by Mazzoli et al. (2020), the emergence of local peaks of incidence and mortality was closely correlated with mobility from and to Madrid in the early-stage weeks. This spread leads to accumulate new cases and deaths more homogeneously across provinces. From mid-April onwards, inequality decreases at very low rates, until a stationary level is reached. Note that a stationary inequality level does not necessarily mean that the number of cases or deaths is stationary, but that those which occur are distributed maintaining the same unevenness across the provinces. In fact, the number of cases and deaths falls significantly from mid-April to late May (see Figure 3).

Another noteworthy feature illustrated in Table 3 and Figure 6 is that the Gini and Theil indices show similar trends, but the differences between them are significant in quantitative terms. The Theil index shows a greater variation in inequality over time because it is more sensitive to changes in the tails of the distribution, while the Gini index is more sensitive to changes in the middle of the distribution than at the top and bottom (Atkinson 1970; Allison 1978). In our case, the spread of the virus affected provinces at the tails, especially in March. In those days new cases and deaths emerged in Madrid (upper tail), while many provinces had hardly any (low tail). This explains why the Theil index decreased more sharply than the Gini index in the first part of the wave.

The decomposability property of the Theil index enables it to be calculated how much of the inequality observed in the epidemiological variables can be explained by differences *between* regions and how much by differences across provinces *within* those regions. Given that in Spain authority for planning and management of health services is devolved to regional authorities, the *between* component may reflect differences between regional health services (investment, human resources, governance, etc.) among other things. The *within* component represents the differences across provinces *within* each region. These differences may reflect idiosyncratic characteristics of provinces that belong to the same region (population density, ageing population, big cities, airports, etc.).

The *between* and the *within* inequality components of the Theil index for epidemiological variables in Spain are calculated according to expressions (3)–(5). Figure 7 shows their trend for the full period studied (11 March to 6 June 2020). Table 4 supplements this information by showing the contribution of each component in quantitative terms on the key days.

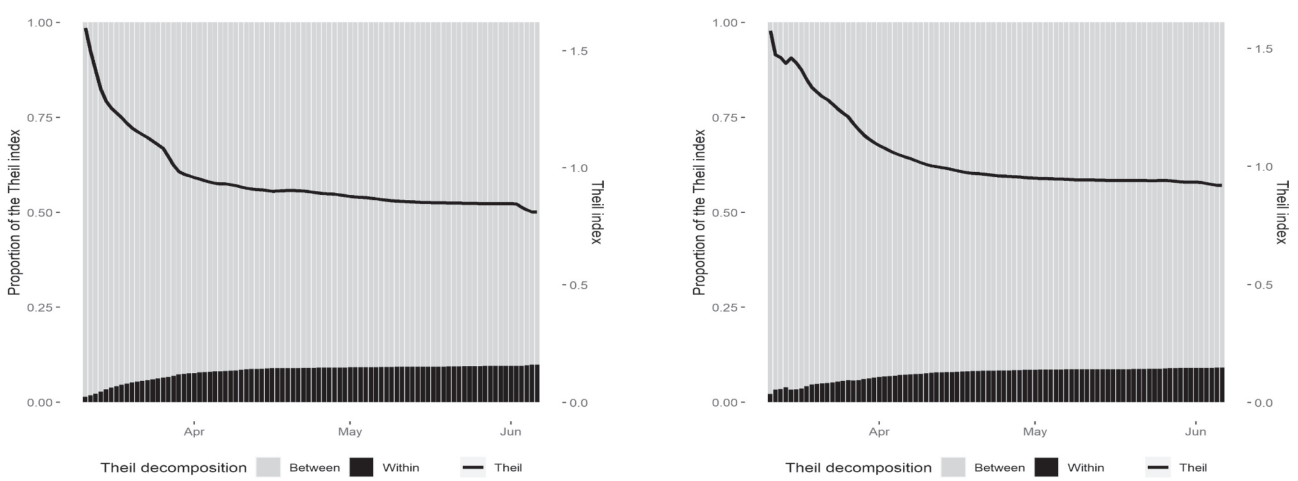
Table 4. Proportion of inequality from *between* and *within* for the epidemiological variables of COVID-19 in the regions of Spain with population weight.

Day	Cumulative cases (%)		Cumulative deaths (%)	
	Between	*Within*	*Between*	*within*
Onset	98.57	1.43	97.76	2.24
Peak day	93.47	6.53	94.13	5.87
Ending	90.11	9.89	90.84	9.16

The most striking finding is that inequality in both epidemiological variables can be attributed mostly to differences between regions in the period analysed. Indeed, there are hardly any differences in the percentage contribution of each component to total inequality when cases and deaths are compared. Furthermore, the gap between the *between* and *within* components widens over time. The *between* component can be asserted to account for over 90% of the inequality while the *within* accounted for less than 10% while the outbreak was active.

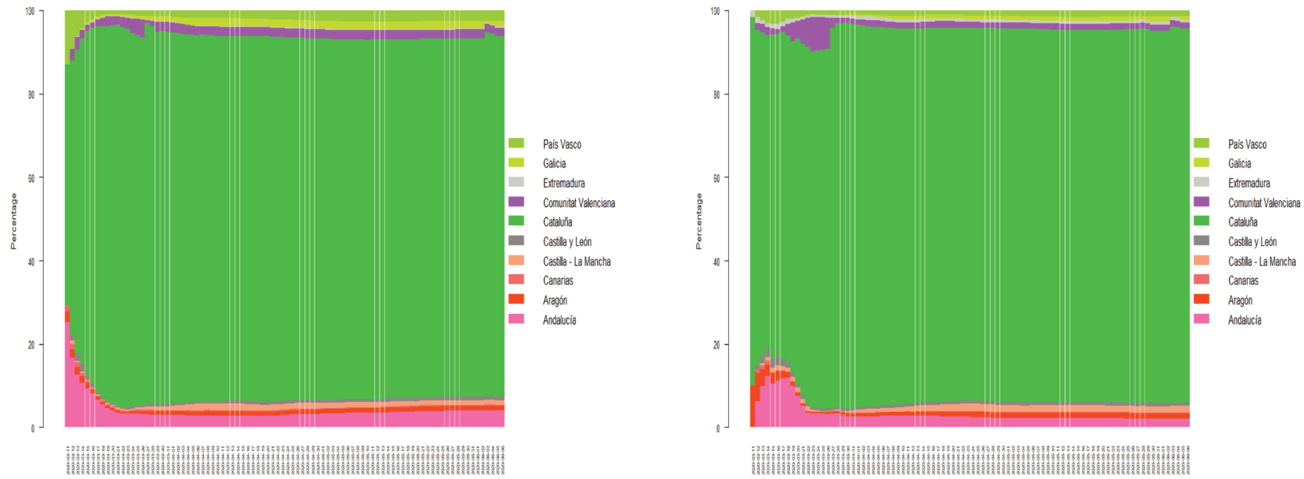
The Theil decomposition also enables the contribution of each region to the *within* inequality to be computed using expression (4). In this case, the *within* component accounts for just a small part of the total inequality, but it is still useful to analyse the role played by each region in the contribution to this component. Figure 8 shows the trend in the contributions by the regions to the *within* component throughout the wave for cumulative cases and deaths. Note that single-province regions do not appear in Figure 8 because intra-provincial inequality is meaningless when there is only one province. The most significant finding shown in Figure 8 is that Catalonia accounts for over 86% of the *within* inequality at the end of the wave. This occurs for both epidemiological variables and persists throughout most of the wave.

The expression that defines the *within* component of inequality, (4), reveals that the two elements determine the contribution of each region to that component. The first is the proportion of the epidemiological variables of each region in



(a) Cumulative cases (b) Cumulative deaths

Figure 7. *Between* regions and *within* regions inequality decomposition of the Theil index for the epidemiological variables of COVID-19 in Spain with population weight.



(a) Cumulative cases (b) Cumulative deaths

Figure 8. Contributions of regions to the within inequality distribution for the epidemiological variables of COVID-19 in Spain with population weight.

terms of that variable for the whole country weighted at provincial level ($\sum_{i=1}^{M_r} p_{i,r} \cdot e_{i,r} / \sum_{i=1}^{M} p_i e_i$). The second is the inequality of the distribution of the variable within each region (T_r). Both items are shown to be multiplying in expression (4). This means that the contribution of a particular region is high only when both components are high, as in the case for Catalonia. On the one hand, cumulative cases and deaths in Catalonia are over-represented given the populations of its provinces. At the end of the wave, cumulative cases and deaths in Catalonia counted for around 33% of the total when weighted at the provincial level, while its population represents 16% of the Spanish population. On the other hand, the four provinces of Catalonia were hit very unevenly by COVID-19. Cumulative deaths in the province of Barcelona at the end of the wave were 11 percentage points higher than those corresponding to its population, while those of Tarragona were 6 percentage points lower. This means there was high inequality within Catalonia. These two elements explain the high contribution of Catalonia to the *within* inequality.

Other regions also show high levels of intra-regional inequality. This is the case of Extremadura and Aragón for cumulative deaths and Aragón and Andalusia for cumulative cases. However, none of these regions has numbers of cumulative cases or deaths that are over-represented given their populations at provincial level. This is shown in Table 5, which summarizes the contribution of each region to the *within* component at the end of the wave (6 June 2020) distinguishing between the two elements involved.

VI. Discussion and conclusions

The COVID-19 pandemic is leaving a huge number of infected persons and deaths throughout the world. However, the disease has not spread homogeneously across or within countries. Pending the arrival of data on the effects of the virus worldwide, this study analyses the distribution of epidemiological variables in Spain, a country where the first wave can be considered to have developed from early March 2020 to early June 2020.

An awareness of the existence and the nature of inequalities observed in epidemiological variables is necessary to develop successful policies for improving and homogenizing the planning and management of health services in future waves. This issue is especially relevant in Spain, where the health system is decentralized, with regions responsible for health care planning, organization and management and thus are politically accountable to their constituents (Costa-Font and Moscone 2009).

Table 5. Contributions of Spain's regions to *within* inequality for the epidemiological variables of COVID-19 with population weight at the end of the wave (6 June 2020).

	Cumulative cases				Cumulative deaths			
	T_{within}				T_{within}			
Regions*	Value	Share	T_r	*Weights***	Value	Share	T_r	*Weights***
Andalucía	0.00323	4.02%	0.1309	2.47%	0,00178	2.11%	0.1093	1.63%
Aragón	0.00088	1.09%	0.1446	0.61%	0.00107	1.27%	0.1650	0.65%
Canarias	0.00026	0.32%	0.0914	0.28%	0.00017	0.20%	0.1092	0.16%
Castilla-La Mancha	0.00088	1.10%	0.0714	1.23%	0.00127	1.50%	0.0959	1.32%
Castilla y León	0.00063	0.78%	0.0697	0.90%	0.00068	0.81%	0.1096	0.63%
Cataluña	0.06947	86.50%	0.2141	32.44%	0.07564	89.71%	0.2245	33.69%
Comunidad Valenciana	0.00166	2.07%	0.0521	3.19%	0.00123	1.46%	0.0458	2.69%
Extremadura	0.00015	0.19%	0.0812	0.19%	0.00053	0.63%	0.2518	0.21%
Galicia	0.00108	1.34%	0.0987	1.09%	0.00071	0.84%	0.1437	0.49%
País Vasco	0.00209	2.60%	0.1182	1.76%	0.00123	1.46%	0.1055	1.16%
TOTAL	0.08031				0.08431			

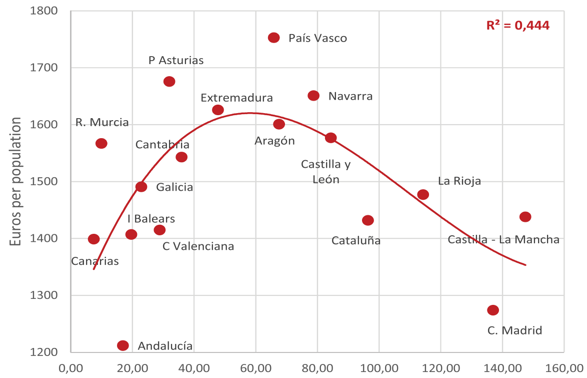
*Single-province regions do not appear because they do not contribute to the within inequality.

** $\left(\sum_{i=1}^{M_r} p_{i,r} \cdot e_{i,r}\right) / \left(\sum_{i=1}^{M} p_i \cdot e_i\right)$, where *e* represents cases or deaths.

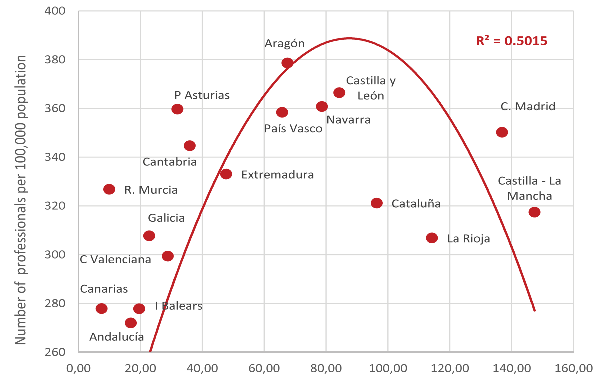
This article analyses epidemiological variables during the first wave of COVID-19 in Spain to assess how evenly they were distributed throughout the provinces of Spain. Using standard inequality metrics, the study shows that by the end of the first wave cumulative cases and deaths were fairly unevenly distributed across Spain's provinces, with a level of inequality twice that observed for the distribution of disposable income across the Spanish population during the last 10 years. Moreover, the study also shows that over 90% of the inequality observed in COVID-19 epidemiological variables can be attributed to differences between regions.

It is worth noting that our analysis is straitened to the quantification of the unevenness. The lack of data prevents a more in-depth statistical analysis that allows establishing, in terms of causality, which factors behind the unevenness observed in the distribution of the epidemiological variables across regions and provinces. Technically, once the wave is over, there is only one observation on the distribution of the variables of interest in the territory. Due to this small sample size, it is not possible to analyse seriously causality between the distribution of these variables and the potential determining factors. Thus, correlation and goodness-of-fit measures must be taken into account with caution. Nonetheless, signals from descriptive statistical analysis of the Spanish regions help to discern what factors that may have led to an uneven distribution of cases and deaths.

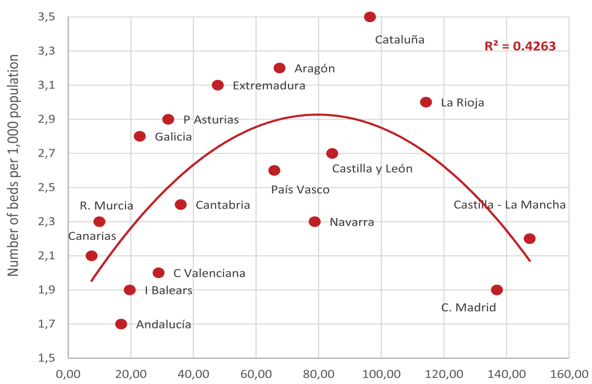
The fact that most of the inequality observed in COVID-19 epidemiological variables can be attributed to differences between regions could be seen as due, among other things, to the response of the regional health authorities to the pandemic being very diverse and ending up generating differentiated effects. There are still no data on these responses at regional level. However, data prior to the outbreak glimpse great differences in the management of the health system at regional level that may have affected incidence unevenly. Figure 9 shows the empirical relation between the COVID-19 deaths and some indicators that measures the health effort made by the regions. We see that there is no clear negative relationship between health effort and deaths. Indicators such as the per capita public health expenditure financed with the



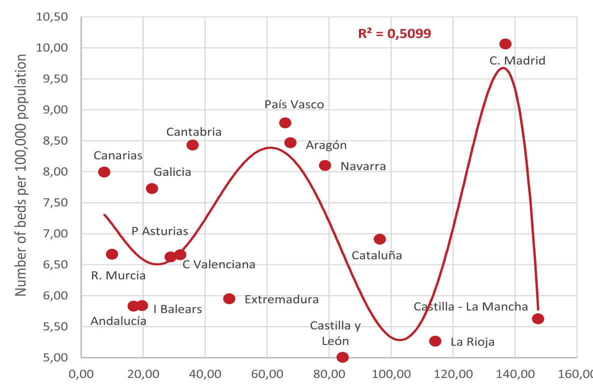
(a) Public health expenditures financed by regions, 2018.



(b) Healthcare professionals hired by the public system, 2018.



(c) Hospital Beds in the public system, 2018.

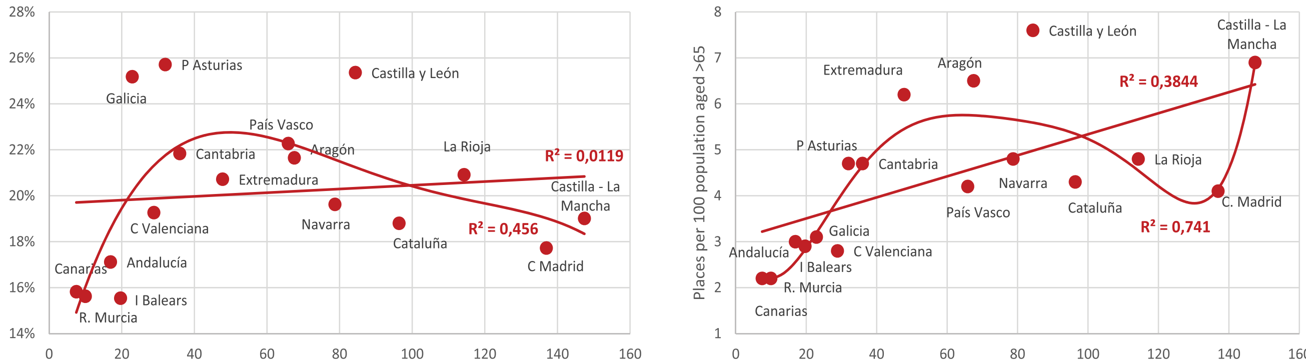


(d) Intensive Care Beds, 2011.

Figure 9. Health effort versus cumulative deaths. X-axis: COVID-19 Deaths per 100,000 population. Red line: polynomial adjustment. Data source: (a) and (b) Spanish Health Ministry (Rodríguez Blas 2020), (c) Spanish Health Ministry (2020) and (d) Martín et al. (2013).

regions' own funds (panel 9a), the number of healthcare professionals hired by the public system (panel 9b) or the number of hospital beds available (panel 9 c) show a bell shape when they are plotted against the number of deaths. Only if we focus on the regions hardest hit by the virus, we see that there is a clear negative relationship between health effort and the number of deaths. It seems that the regional health systems are prepared to serve a certain number of patients. In those regions where the virus was particularly virulent, health capacity was saturated and, given this limitation, regions with fewer resources suffered a higher incidence of deaths. Notice however that the relationship between deaths and the number of intensive care beds is more complex (panel 9d) although it must be taken into account that this indicator has not been officially collected since 2002, and the data used come from a study carried out by means of a questionnaire answered by hospitals (Martín et al. 2013).

There are many other factors that may have led to an uneven distribution of cases and deaths. Recent studies have shown that people with some health and socioeconomic personal characteristics are more likely to develop a severe form of Covid-19. In particular, age has been confirmed as a critical factor related to COVID-19 deaths (Williamson et al. 2020; Moosa and Khatatbeh, in press). There are still no official data on deaths from the disease per age group in Spain. Figure 10a illustrates the positive correlation between the deaths and the proportion of population aged 65 years and more for the Spanish regions. The correlation is weak over the whole sample (0.10) although more relevant between the regions less affected by the virus (0.85 for regions with less than 40 deaths per 100,000 population). In



(a) Population aged 65 and over, 2019. (b) Nursing home places, 2019.

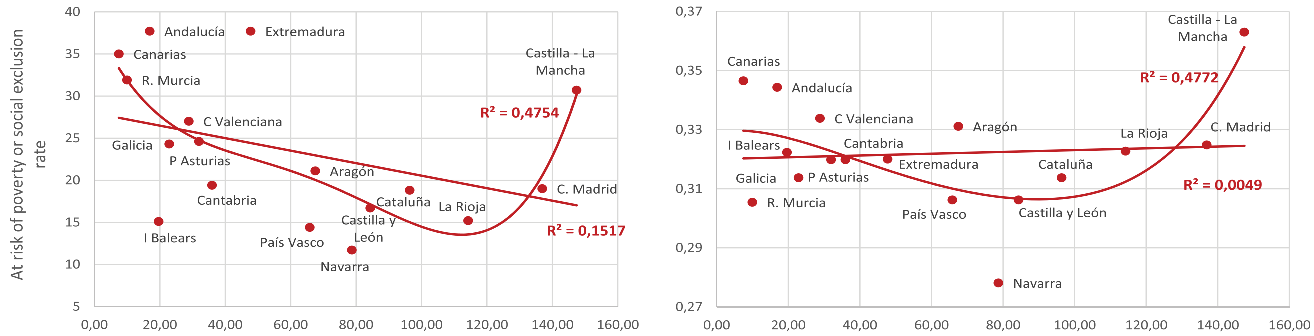
Figure 10. Ageing factors versus cumulative deaths. X-axis: COVID-19 Deaths per 100,000 population. Red lines: linear and polynomial adjustment. Data source: (a) INE (2019a) and (b) Abellán García, Aceituno Nieto, and Ramiro Fariñas (2019).

fact, regions such as Galicia or Asturias with over 25% of their population classed as elderly show death numbers under 40 per 100,000 population. However, this positive relation is not observed at this aggregate level with other medical risk factors as obesity or diabetes which have been also shown as determinants in progressing to severe forms of COVID-19 (Guo et al. 2020; Cai et al. 2020; Simonnet et al. 2020; Williamson et al. 2020).

Moreover, the COVID-19 pandemic revealed the precarious position of nursing homes in Spain (Rada 2020). Most nursing homes do not have doctors or nurses on staff. During the peak days of the pandemic, nursing homes in Madrid received guidelines from the Health Department indicating that residents with respiratory infection symptoms should not be sent to hospital. There are no official records for mortality in nursing homes, but Comas-Herrera and Zalakain (2020) estimate that between 8 March and 8 April there may have been 9756 deaths, which would account for 57% of the total deaths due to COVID-19 in Spain to that date. A recent study by Abellán García, Aceituno Nieto, and Ramiro Fariñas (2019) has established the number of places in Spanish nursing homes at regional level. Castilla-La Mancha, the most affected region by the virus in terms of cases and deaths per population, is the region with the second highest ratio of places by population over 65. Crossing these data with those of deaths from Covid-19 during the first wave, a moderate linear correlation of 0.67 is observed (see Figure 10b).

Additionally, the diffusion of the virus does depend not only on medical individual characteristics but also on their socio-economic situation (Williamson et al. 2020). In this context, the Spanish regions also show large disparities. The AROPE indicator, which measures the percentage of population at risk of poverty or social exclusion (Eurostat, EU 2012), shows substantial differences between the Spanish regions. There is a difference of 26 percentage points between the best and worst positioned regions (Navarre, 12% and Andalusia, 38%, respectively). These disparities, however, do not show a positive correlation with deaths caused by COVID-19 at the regional level. On the contrary, when both variables are crossed, a negative correlation emerges from the whole sample (Pearson coefficient −0.39). The correlation becomes strongly positive when the sample is limited to the regions more affected by the virus (0.78 for regions with more than 70 deaths per 100,000 population), which supports the highly non-linear relationship shown by the data (see Figure 11a). A similar U-type relationship is seen when deaths are crossed with the regional Gini index that measures how unevenly income is distributed within each region (see Figure 11b).

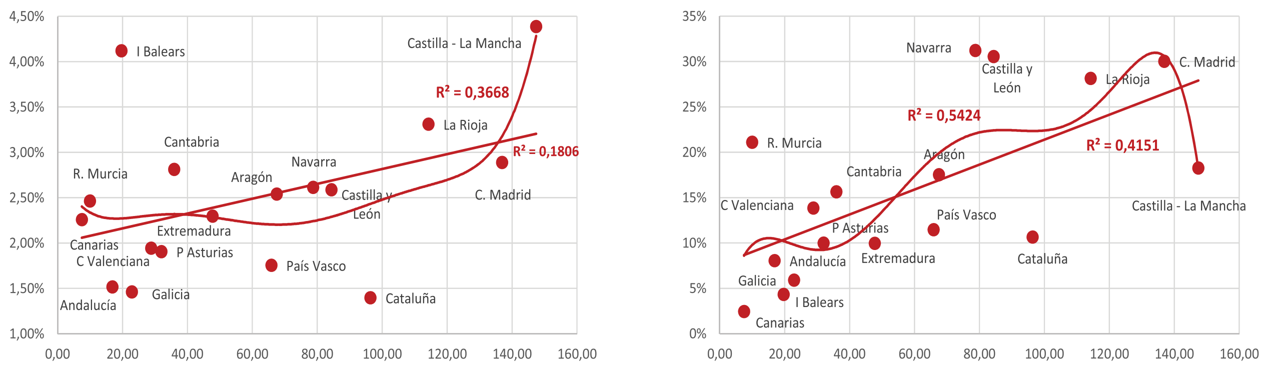
Another factor that may have led to an uneven distribution of cases and deaths was the mobility (Henríquez et al. 2020; Siqueira et al. 2020). Some studies point out that the virus arose mainly in Madrid and spread rapidly to the closest provinces during the early-stage weeks because of mobility from and to Madrid (Mazzoli et al. 2020). In this sense, regions furthest from Madrid, such as Galicia, Murcia and the islands, were less affected by the disease in the onset of the outbreak. Figure 12 shows the empirical regional relationship



(a) AROPE indicator, 2019.

(b) Gini coeficient for regional income, 2012.

Figure 11. Deprivation and income inequality versus cumulative deaths. X-axis: COVID-19 Deaths per 100,000 population. Red lines: linear and polynomial adjustment. Data source: (a) INE (2019a) and (b) Jurado Málaga and Perez-Mayo (2014).



(a) Population moved inter-regionally, 2019.

(b) Undergraduate students residing in other regions, 2018-19.

Figure 12. Mobility indicators vesus cumulative deaths. X-axis: COVID-19 deaths per 100,000 population. Red lines: linear and polynomial adjustment. Data source: (a) INE (2019b) and (b) Ministerio de Universidades (2019).

between deaths from COVID-19 and two variables that can be considered mobility proxies: percentage of the population that has moved inter-regionally during the last year (Figure 12a) and percentage of the undergraduate students residing in other regions (Figure 12b). Both variables can indicate the mobility of a part of the population that frequently moves from their workplaces to their homely places. This type of movement was very generalized during the days before the State of the Alarm in which schools closed and teleworking was encouraged by many companies. We see that both variables show a positive correlation with the deaths at regional level (0.43 and 0.64, respectively), which allows us to surmise that mobility plays a relevant role in the distribution of deaths.

Figure 12 also shows remarkably low mobility levels for Catalonia, especially when compared to other regions with a similar population and economic level. Notice, for instance, that inter-regional mobility in Catalonia is less than 1.5% (the lowest level among all regions) versus almost 3% in Madrid; in the same sense, 10% of undergraduate students in Catalonia come from other regions versus more than 30% of those in Madrid. These figures probably reflect that issues such as the widespread use of Catalan as the spoken language or the turbulent political moment experienced after the unilateral declaration of the Catalan Republic in 2017 may be discouraging Catalonia inter-regional mobility both from and to other regions. However, mobility in Catalonia is higher when inter-provincial mobility is considered. In fact, more than 7% of the population of each of the four provinces in Catalonia moved their residence to or from other provinces in the last year, which is substantially higher than the 3% shown by Madrid (which is a uni-provincial region). These high levels of the inter-provincial mobility in Catalonia may be one of the causes behind the high results obtained for inequality within Catalonia (see Figure 8).

Notwithstanding all the empirical evidence just mentioned, more comprehensive studies should be carried out to determine the underlying causes of the uneven distribution of the COVID-19 epidemiological variables observed. Likewise, there is a perceived need to analyse the distribution of the impact of COVID-19 worldwide, taking into account the subsequent waves that are taking place. At the present time, the first half of January 2021, the disease seems to be far from being controlled mainly in Europe and America. An analysis of the distribution of epidemiological variables across countries will complete the picture in a more understandable way.

Finally, we must not lose sight that an accurate metrics on how the prevalence of COVID-19 is distributed territoriality may enable good practices developed by regions against the epidemic to be identified, so that more efficient responses can be provided in current and future outbreaks.

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A Appendix

Table A.1 Spanish regions and provinces

Region*	Provinces	Main data source
Andalucía (Andalusia)	8: Almería, Cádiz, Códoba, Granada, Huelva, Jaén, Málaga, Sevilla	Junta de Andalucía (press release)
Aragón	3: Huesca, Zaragoza y Teruel	Gobierno de Aragón (website)
Canarias (Canary Island)	2: Las Palmas y Santa Cruz de Tenerife	Consejería de Sanidad del Gobierno de Canarias (press release)
Cantabria	1: Cantabria	Instituto de Salud Carlos III
Castilla y León	9: Ávila, Burgos, León, Palencia, Salamanca, Segovia, Soria, Valladolid, Zamora	Junta de Castilla y León (website)
Castilla-La Mancha	5: Albacete, Ciudad Real, Cuenca, Guadalajara, Toledo	Gobierno de Castilla-La Mancha (press release)
Cataluña (Catalonia)	4: Barcelona, Gerona, Lérida, Tarragona	Generalitat de Cataluña and Portal de Transparència Catalunya
Ceuta	1: Ceuta	Instituto de Salud Carlos III
Comunidad de Madrid	1: Madrid	Instituto de Salud Carlos III
Comunidad Valenciana	3: Alicante, Castellón, Valencia	Generalitat Valenciana (website)
Extremadura	2: Badajoz, Caceres	Junta de Extremadura
Galicia	4: La Coruña, Lugo, Orense, Pontevedra	Sergas: Servicio Gallego de Salud (press release)
Islas Baleares (Balearic Islands)	1: Baleares	Instituto de Salud Carlos III
La Rioja	1: La Rioja	Instituto de Salud Carlos III
Melilla	1: Melilla	Instituto de Salud Carlos III
Navarra (Navarre)	1: Navarra	Instituto de Salud Carlos III
País Vasco (Basque Country)	3: Álava, Bizkaia, Gipuzkoa	Gobierno Vasco. Osakidetza (dashboard, press release)
Principado de Asturias	1: Asturias	Instituto de Salud Carlos III
Región de Murcia	1: Murcia	Instituto de Salud Carlos III

*In parentheses, the English name of the region (where applicable).