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DISCUSSION PAPER SERIES

IZA DP No. 14930

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ABSTRACT

Administrative Border Effects in COVID-19 Related Mortality

Does the organisation of healthcare systems affect health outcomes in a pandemic situation? To answer this question, we analysed the effects of the Covid-19 pandemic by focusing on mortality rate outcomes and exploited the heterogeneity of the healthcare organisational models among Italian regions, which makes Italy an ideal "laboratory". Within a common national healthcare system, Italian regions are allowed large autonomy to organise themselves as mixed-markets based on choice and competition, network or centralised leadership models, each delivering different responses to the Covid-19 emergency. Exploiting the discontinuity of healthcare organisational models across the Italian regional borders around Lombardy — the region that most convincingly embraced the mixed-market model fostering competition among health service providers — we applied a difference in geographic regression discontinuity design (DiD-GRDD) to compare mortality rates in 2020 of Lombardy's municipalities with that of neighbouring municipalities in other regions and also exploited the pre-crisis period (2017-2019). Our analysis shows that mortality rates in Lombardy during the first wave were higher by 1-2 percentage points among the population of residents aged 80 years or more, compared to the past, as opposed to regions adopting different organisational models. The mortality rate differential disappeared during the second wave following the implementation of a national policy based on risk zones, limiting mobility and taking stock of the experience developed during the first wave. Finally, by investigating the channels causing higher mortality during the first wave, we show that the role of organisational model differences vanishes, as differential mortality is mostly explained by the decision of the Lombardy regional government to use care homes for hosting Covid-19 patients and reduce the excess demand on the hospital system.

JEL Classification: I10, H12

Keywords: COVID-19, mortality, administrative borders, regions, Italy

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"Why Covid Caused Such Suffering in Italy's Wealthiest Region? Lombardy has been overwhelmed by the pandemic, in part because of a poorly executed medical privatization program" (Published Nov. 19, 2020; Updated Nov. 20, 2020)

– Peter S. Goodman and Gaia Pianigiani, *The New York Times*

"Fewer deaths in Veneto offer clues for fight against virus. Divergence of fortunes with nearby Lombardy stems from keeping more patients away from hospitals, experts say." (Rome, April 5 2020)

– Miles Johnson, *Financial Times*

1 Introduction

Comparing mortality rates in the first year of the Covid-19 pandemic, some countries appear to have been affected more severely than others. Eurostat, for instance, reported March (December) excess mortality rates for 2020 compared to 2016–2019 in the magnitude of 49.6% (27.1%) and 53.0% (9.4%) for Italy and Spain, respectively, against 15.5% (15.7%) and 2.5% (30.8%) for France and Germany, respectively.[1]

Although — in addition to the spread of the virus — demographic factors (e.g. the age structure of the population) are often advocated to explain differences in Covid-19 related mortality (Mesas et al., 2020; Onder et al., 2020), an important question remains unanswered: Are these differences partly attributable to the ways governments responded to the pandemic or the characteristics of their health systems? Recent papers have tried to answer this question by reporting evidence on the effectiveness of single or bundles of policies, such as stay-at-home orders, lockdowns or the use of protective masks on the diffusion of the pandemic and the level of mortality (Karaivanov et al., 2021; Hsiang et al., 2020; Chernozhukov et al., 2021). However, the adoption of some of these policies is unlikely to be exogenous and may depend on the spread of the virus and the capacity of the health systems (e.g. availability of intensive care unit [ICU] beds). In other words, to assess the relative merit of different health systems or regional governance, one should compare like with like, for instance, by considering the level of diffusion of the virus in the population. However, as to the latter, data especially in the first wave of the pandemic were not available due to non-existent or low amount of Covid-19 testing.

In this paper, we explore this issue focusing on the Italian case. Owing to the autonomy of Italian regions[2] in the management of their health systems,[3] Italy can be considered as an ideal "laboratory" to investigate the potential role played by different health systems and regional governments in the differential mortality rates they experienced. Pisano et al. (2020), for instance, stated, 'the fact that different policies resulted in different outcomes across otherwise similar regions should have been recognised as a powerful learning opportunity from the start'.[4] Our paper is related to two main strands of literature. The first is the recent literature on the correlates and determinants of Covid-19 related mortality (see Section 4 for a brief review). The second is the literature investigating the role of the characteristics of health systems, such the level of health

[1] Source: https://ec.europa.eu/eurostat/cache/metadata/en/demo_mexrt_esms.htm.

[2] In Italy *Regioni* (regions, hereafter) are the level 2 Nomenclature of Territorial Units for Statistics (NUTS-2) administrative units.

[3] See Section 2 for a detailed explanation of the regional autonomy in the INHS.

[4] https://hbr.org/2020/03/lessons-from-italys-response-to-coronavirus.

spending (Arcà et al., 2020; Mays and Smith, 2011), supply (Godøy and Huitfeldt, 2020) and their organization modes (van Lerberghe et al., 2014), on population's health outcomes and mortality.

Given the vastly different levels of diffusion of Covid-19 within Italy (Bertuzzo et al., 2020), we focus on Northern Italy, and in particular on Lombardy and its neighbouring regions. The Lombardy region in Italy was the first geographic area to be heavily affected by Covid-19 outside China, the country from which the pandemic originated. As the first Western region suffering a Covid-19 outbreak, Lombardy quickly was under the spotlight of international media. The dramatic evolution of the Covid-19 spread in Lombardy is effectively described in a newspaper article entitled, 'Two months that shook Lombardy' published by Il Post.[5] The immediate reaction to the first case diagnosed in Codogno (Lombardy region) was the establishment of a 'red zone' involving 50,000 citizens, which suspended all economic activities and residents' movements from and to this area. This action was a success demonstrated by the reduction of the spread of the epidemic in this area, but it was an exception in the Italian context. Indeed, a couple of days later, a new outbreak was discovered in the small hospital of Alzano in the municipality of Bergamo (Lombardy region). Alzano's hospital was not closed, and no red zone was declared in this area, resulting in a dramatic increase in the number of detected cases, hospitalisations and deaths within a few days. The decision to leave the hospital in Alzano open and not establish a red zone have become two of the most criticised decisions of the management of the Covid-19 crisis in Italy. At the time of writing, a legal inquiry is investigating the responsibility for these choices. What is clear is that both the national and Lombardy governments waited 8 days to quarantine the areas of Bergamo, Brescia, Cremona and the rest of the region. A legal inquiry is also investigating regional decisions about nursing homes. Indeed, during the worst period of the epidemic when the hospitals were collapsing, Lombardy's government asked some nursing homes to admit patients discharged by hospitals. These social and healthcare services host mainly elderly people affected by several illnesses, the most vulnerable of the population during the Covid-19 crisis. Nursing homes were not fully prepared for an epidemic, with limited numbers of protective masks and other protective equipment for the personnel working. First evidence shows that these hazardous choices may have had an impact on the increase of mortality in nursing homes (Alacevich et al., 2021). According to Il Post, in the nursing homes of Bergamo from January to April 1, 998 out of 6,100 residents died resulting in an increased mortality rate of 50% compared to 2019. In synthesis, the Lombardy region addressed the Covid-19 epidemic by letting the healthcare system be subject to excessive stress. In contrast to Lombardy's experience, the Veneto region appeared more ready to deal with the Covid-19 outbreak. Veneto responded to the Covid-19 epidemic by extensively testing symptomatic and asymptomatic citizens, engaging in broad contact tracing around positive cases, quarantining cases and suspected cases with daily telephone monitoring, publishing detailed practical guidelines on home isolation, minimising contact with physicians and nurses and limiting hospital admissions to patients with major healthcare needs (Binkin et al., 2020). A similar approach to the Covid-19 epidemic was adopted in Emilia-Romagna, which shifted to territorial and home management, thereby reducing the pressure on the hospital system. The vastly different levels of mortality between Lombardy and some neighbouring regions, such as Veneto and Emilia-Romagna, fed harsh criticism against the presumed incapacity of Lombardy's regional governance and the unpreparedness of its regional health system to deal with the pandemic. In particular, Lombardy was criticised for its hospital-centric management of the pandemic irrespective of the level of severity of patients, which partly contributed to the spread of the virus and the quick saturation of hospitals (Castaldi et al., 2021).

[5] https://www.ilpost.it/2020/05/07/two-months-that-shook-lombardy-to-the-core-coronavirus/

Veneto, on the other hand, was often praised for its policies based on a more diffused management of the emergence, with hospitals only representing the last resort for patients and the implementation of a tracking system based on high levels of Covid-19 testing.

However, such regional comparisons are flawed due to an important caveat: The diffusion of the pandemic was not even across regions (Bailey et al., 2020), and it is therefore not possible to observe how regions would have performed under the same conditions (counterfactual). Thus, to compare like with like, we focus on municipalities located in different regions but close to the regions' administrative borders by applying a Difference in Geographical Regression Discontinuity Design (DiD-GRDD). Comparing neighbouring municipalities, which are ruled by different regional governments, makes it likely that both observable and unobservable characteristics (e.g. the level of diffusion of the virus in the population) are similar.

Our results provide evidence of between 1 and 2 percentage points higher mortality in Lombardy in the first semester of 2020 compared to the neighbouring regions. The effect is limited to citizens over 80 years of age who were the most exposed to Covid-19 related mortality. In the second semester of 2020, however, Lombardy seems to have closed the mortality gap. This evidence unveils how Lombardy likely experienced poor emergency management especially at the epidemic onset and was able to recover later. Indeed, although the introduction of a national policy setting mobility and economic activity restrictions depending on risk zones may have partly contributed to the convergence in the second semester — since Lombardy was, on average, subject to stronger restrictions — a comparison with a region that experienced similar restrictions (Piedmont) shows clear relative improvement of Lombardy's performance.

Several stress tests for our analysis, such as a placebo analysis setting a fake border within the Lombardy region, a test to verify balancing of relevant covariates at the border as well as the classic parallel trend test (conducted with an event-study analysis), confirm our main results. We finally test the robustness of our findings to omitted time-invariant municipal variables and allow for the structural characteristics of the regional health systems to have time-varying effects (including in the model municipality fixed effects and time-varying interaction terms, respectively), and we obtain results that confirm our conclusions. Finally, when we allow for the relationship between the presence of care homes at the municipal level and mortality to vary before and after Covid-19 and across regions, they explain a large portion of the mortality gap between Lombardy and the other regions during the first wave of Covid-19.

At this point, we must caution the reader about what our analysis can and what cannot determine. First, using a DiD-GRDD design, we can assess whether, under similar observed conditions, different regions experienced different mortality rates. What our analysis cannot do is predict what would have been the decisions and the consequences on mortality of the different regional administrations under similar hypothetical situations. In other words, although we can observe how the Lombardy region responded when a severe Covid-19 outbreak appeared in Bergamo, we cannot say what the governments of Veneto or Piedmont would have done in similar conditions because outbreaks of such severity did not appear in those regions. Therefore, mistakes might have been made in Lombardy's first management of the Covid-19 outbreak, but we cannot exclude that under the same conditions other regions would have made similar choices. For this reason, we limit our comparison to municipalities close to the regional borders, which are likely to share similar conditions and virus diffusion. Second, our paper investigates differences in the capacity of regional health systems of facing a sudden and quite unpredictable health shock, such as a pandemic situation, and our findings are unlikely to be generalizable to "business as usual" situations (e.g. mortality due to chronic diseases).

The rest of the paper unfolds as follows: Section 2 provides background information on the Italian National Health System (INHS) and the main differences across the regions studied in this paper. Section 3 presents our empirical strategy, and Section 4 motivates the choice and describes the control variables. The main results are outlined in Section 5, and several robustness checks are reported in Section 6. The last section provides a summary and discussion of the main results and outlines our conclusions.

2 The Italian National Healthcare Service (INHS) and heterogeneity across regions

The INHS was established in 1978 to provide free-of-charge, uniform and comprehensive care, replacing the existing system based on health insurance funds. The INHS is a typical Beveridge system financed through general taxation, which guarantees equitable access and a uniform provision of healthcare services to all citizens without any discrimination based on income, gender or age. Over the last 40 years, two major reforms were introduced, one in 1992/1993 and one in 1998/1999, aimed at containing costs and increasing the responsibility and autonomy of regional authorities (France et al., 2005). INHS is currently structured in three main levels: (i) the national state with the Ministry of Health; (ii) the regions with their health departments (21 regional governments, namely 19 regions and 2 autonomous provinces); and (iii) the Local Health Authorities (LHA), interacting with municipalities. LHAs are vertically integrated organisations funded by the region and are responsible for a wide range of hospital and community services in a given geographical area. LHAs directly manage most public hospitals, coordinate primary care and territorial services, assess the appropriateness of health services and their distribution and improve the integration of social and health services. A limited set of public hospitals (*Aziende ospedaliere*, AOs), including teaching hospitals (*Aziende Ospedaliere Universitarie*, AOU) and research hospitals (*Istituti di Ricovero e Cura a Carattere Scientifico*, IRCCS), are semi-independent public hospitals providing mostly tertiary and quaternary care with no responsibility of preventive medicine and territorial health and social services, similar to the British trust hospitals. Regions are allowed to adopt different strategies and governance models that ensure significant autonomy in organising their healthcare system under a balanced-budget constraint and the requirement of delivering the core and essential health benefits package (*Livelli Essenziali di Assistenza*, essential assistance level, LEA) to all citizens free-of-charge or upon a co-payment. The LEAs are set by the central government to preserve a core uniform set of services throughout the country. The recent reforms aimed at making the public sector more efficient, effective and accountable. However, this process produced large heterogeneity across regions that developed financial, administrative and political responsibility for the provision of healthcare, often employing different governance models and management tools (see Tediosi et al., 2009; Neri, 2011, among others).

In this paper, we focus on Lombardy,[6] the epicentre of the first wave of the Covid-19 crisis, and its neighbouring Italian regions, namely, from north-west to north-east, Piedmont, Emilia-Romagna, Veneto and the Autonomous Province of Trento (in the Trentino Alto Adige region). The five regions we consider in this paper account for over 40% of the Italian population (Table 1, column A) with an average income above the country's average.[7] Although relatively homogeneous from

[6] Lombardy shares its north border with Switzerland, for which we have no data.

[7] According to the Italian National Statistical Institute (ISTAT) data, in 2019 in Italy the per capita GDP was

an economic point of view, they are heterogeneous concerning the governance of their healthcare systems.

The complexities of defining health systems in terms of governance models and measures for governance in the health domain is well known in the literature, but often leading to a lack of consensus on nomenclature (for an extensive review, see Barbazza and Tello, 2014). Nuti et al. (2016), building on previous studies, identified five governance models in Italy: (i) the trust and altruism model, relying on the perspective that all public servants behave without personal interests or focusing on success and failure; (ii) the choice and competition model, based on the quasi-market system in which patients (or insurance companies) can choose the providers and the money follows the patients, introducing external incentives; (iii) the command and control model, based on the recourse to external incentives and the strong role of performance management, implying high monitoring costs and low acceptance by professionals; (iv) the transparent public ranking model, based on the lever of reputation, also known in England as the 'naming and shaming' model; and (v) the pay for performance (P4P) model, drawing upon economic incentives to direct the managers' behaviour, linking the rewarding scheme of their health authorities' CEOs to the performance they achieve on the assumption that financial payments can motivate people to achieve performance targets.

Complementing Nuti et al.'s taxonomy of the Italian governance models with data from key informants in the study by Bobini et al. (2020), Lombardy emerges as a stand-alone healthcare system in the Italian context. Lombardy is the only region that opted for the choice and competition model, stressing the role of patients' choices to boost competition by splitting purchasers and providers and including private institutions. The system is based on the assumption that, upon fulfilling the rules and standards set by the regional government, the market will regulate itself and promote competition between public and private health service providers. The model combines elements of the P4P model, as general managers of LHAs are rewarded according to the achievements of targets negotiated with the regional administration, though variability of managers' rewards and performance results is low with limited public information on hospitals' performances. Lombardy does not use a regional public ranking, which limits information available to the citizens and the possibility of hospitals to learn from their relative performance (Berta et al., 2013). Lombardy's governance structure is articulated and is the product of several reforms stratified over time. At the top of the Lombardy Regional Healthcare System (RHS) sits the organisational unit of the region's president that, jointly with the health department, is responsible for the financial balance and social and health service planning. Lombardy's RHS is characterised by the presence at the top by three agencies for the control of the social and health system (ACSS), innovation and purchases (ARIA) and training, education and research (PoliS). At the intermediate level are eight LHAs for the regional planning implementation without a direct supply of hospital or territorial services. At the bottom, are the suppliers that operate in a mixed-market setting with both public and accredited private suppliers. The public sector supplies services through 27 AOs, including 92 hospitals, and 4 research institutions (IRCCS). Lombardy is characterised by a large presence of private accredited suppliers, including 14 private IRCCSs out of a total of 30 private IRCCSs in the whole country.

The other four Italian regions bordering Lombardy opted for models in which the relevant role of the regional government is to plan activities and set standards and be implemented by LHAs

29,700 €, whereas among the five regions considered it ranged from a maximum of 39,700 €of Lombardy to a minimum of 31,700 €of Piedmont.

overseeing the service providers. In these regions, the presence of private providers is limited, and the percentage of beds in acute care supplied by accredited private institutions is well below Lombardy and the national average. Some specificity, however, applies. The Piedmont RHS is better described by a command and control model, following the recovery plan introduced in 2010 to access the national bailout fund. Although the central government specifies financial targets, no systematic benchmark of clinical results nor public disclosure of performance data exist. Following the recovery process, the number of LHAs was reduced to 12, with an average coverage of 360,700 people, which is still one of the lowest in Italy, with three AOUs and three AOs. Veneto, Emilia-Romagna and Trento Autonomous Province have adopted a mixed governance model that combines hierarchy and targets with transparent public ranking and P4P, however, specificities apply according to the governance models and the staff's managerial skills. Trento's RHS is relatively simple due to the small size of the resident population and with a local tradition of sound management. Veneto's RHS is characterised by a high level of centralisation aimed at rationalisation of the expenditures. Only one public enterprise (*Azienda Zero*) exists, which is in direct contact with the region's health and social department and is in charge of a large set of activities for the whole region, including purchases, hiring, logistics and budgeting. This centralisation allows service providers (i.e. nine LHAs, one IRCCS and two AOUs) to focus on their core activities, such as the organisation of the production of services, according to the territory's needs. Over time, Veneto's RHS has developed into a cohesive system based on strong legitimisation of the leadership of the RHS (Bobini et al., 2020).

In Emilia-Romagna's RHS, the department of health is supported by a regional health agency for technical and scientific matters, is responsible for the overall planning and coordination of activities and leaves large discretion to public service providers, including eight LHSs, four AOUs and three IRCCS. Emilia-Romagna was one of the first regions to increase the population coverage of LHAs, which currently count over 550,000 residents. The peculiarity of Emilia-Romagna's RHS is the strong interconnection with local administrative authorities, including municipalities, in a typical network model (Rhodes, 1997).

According to Bobini et al. (2020), Lombardy's system is flawed by an ambiguity of the effective role of the LHAs due to the partial overlapping of functions of the three levels of governance and their institutional role. It remains undetermined whether (i) LHAs, public hospitals and IRCCS share some planning and strategic functions, (ii) LHAs should coordinate hospitals or only supervise the competitive market involving both private and public providers and (iii) the scope of three agencies at the top of the governance structure (ACSS, ARIA, PoliS) is uniquely to centralise administrative activities or also to support the planning and governing activities of the RHS. 1 (column C) shows that the Lombardy's RHS spends the least for GPs services, which is a measure of primary care expenditure. The number of GPs and GPs performing out-of-hours services (respectively, 6.2 and 9.4 per 10,000 inhabitants, see columns D and E) are the smallest among the five regions considered as well as compared to Italy. Having pushed during the last decades towards a system of providers operating in a mixed-market structure with a pivotal role of hospital units, Lombardy shows a high rate of use of emergency rooms (column F) but small utilisation of GPs performing out-of-hours services (column G). Lombardy is also the region with the largest share in the whole country of beds in acute care provided by accredited private institutions (column H) and provides the largest share of ordinary-regime (column I) as well day-hospital discharges (column H) over the total.

According to Bobini et al. (2020), a distinguishing feature of Veneto's RHS is its top-down structure, with a centralised leadership by the health department and the Azienda Zero LHA. Although top-down systems are less flexible and prefer homogeneity to differentiation, Veneto's territory is relatively uniform, and the lack of flexibility is not an issue. The network feature of Emilia-Romagna's RHS guarantees a strong link with the territory's needs, allowing a strong differentiation depending on local needs. The system relies heavily on strong levels of trust among actors, allowing for prompt decision-making, especially during emergencies. In both these last two RHSs, as well as in the others neighbouring Lombardy and considered here, the share of public providers and the role of primary care is larger than in Lombardy.

Before the pandemic, the Lombardy region was considered one of the most capable Italian regions in dealing with an epidemic thanks to the quality and efficiency of its healthcare system. According to the quality evaluation provided by the Ministry of Health, Lombardy ranked among the top regional health systems.[8] Moreover, Lombardy attracts over 150,000 patients living in a different region each year, around 10% of its treated patients (Berta et al., 2013), revealing how many Italian citizens are willing to travel from other regions to Lombardy to receive their healthcare. A relevant feature of the Lombardy RHS is the central role of hospitals, which may turn out to be a weakness in situations such as during a pandemic.

The existing differences among the different RHSs, aimed at increasing the overall efficiency of the INHS, may represent a critical point when facing an unprecedented pandemic, such as Covid-19. Autonomy and independence in the organisation and delivery of healthcare services may be a problem when the response to an epidemic outbreak requires strong coordination among the different actors regardless of their local context. Such a scattered picture may be also reflected in subsequent substantial differences in the strategies adopted by the different regional governments to face the Covid-19 emergency (OECD, 2020).

During the first wave, when responding to the health emergency at the onset of the Covid-19 epidemic, Veneto largely relied on home care assistance, limiting hospital admissions to the most severe cases, and started early testing of healthcare workers operating in the community and hospitals. In Emilia-Romagna, the network model of the RHS helped them adapt promptly by relying on home care assistance and active surveillance systems on general practitioners with phone calls to patients to monitor their symptoms and strengthening primary care assistance, as suggested also in OECD (2021). On the contrary, Lombardy chose a hospital-centred approach at the expense of the community-based services with intensive use of emergency rooms as a consequence of reduced territorial services provided by GPs and GPs performing out-of-hours services. This might have contributed to exacerbating the stress to the health system generated by Covid-19 (Usuelli, 2020). The dramatic inflow of patients quickly saturated the intensive care units, forcing doctors to decide how to allocate resources (Rosenbaum, 2020). In the hospital setting, the virus was spread not only by patients but also by healthcare workers, who could not always rely on appropriate personal protective equipment and risked their lives while doing their job (Gibertoni et al., 2021).

As for the second Covid-19 wave (starting from October 2020), the Italian government implemented several progressive restrictions initially applied homogeneously over the country. After November 6th 2020, they adopted a colour-labelled scheme with four different colours (coded as white, yellow, orange, and red indicating increasing levels of restrictions to mobility and economic activities), which were imposed on a regional basis to reflect existing regional heterogeneity in the

[8] instance, see the evaluation provided by the Ministry of Health concerning the LEA: `https://www.salute.gov.it/portale/lea/dettaglioContenutiLea.jsp?lingua=italiano&id=4747&area=Lea&menu=monitoraggioLea`

virus transmission and hospital stress.[9] Regional restrictions were automatically assigned centrally depending on the value of the reproduction number (Rt).

As described in detail in Manica et al. (2021), according to these measures, a stay-home mandate between 10 pm and 5 am (except for work, health and other certified reasons) was implemented in yellow and orange regions while the stay-home mandate plus a ban on movements between municipalities and to/from other regions was in place in the red ones. All but essential retail services and shopping malls were closed during weekends and holidays in both yellow and orange regions while all shops not selling essential goods were always closed (again except for essential retail and services) in red ones. Bars serving food, cafes and restaurants were allowed to be open until 6 pm while take-away activity only was allowed after 6 pm until 10 pm in yellow regions. In orange and red regions, only take-away activity until 10 pm was allowed. Distance learning in high schools and universities was mandatory in yellow and orange regions, including the second and third grades of lower secondary schools in red ones. For all colour-labelled restrictions, the public transports were reduced to 50% of their capacity (except for school service) and indoor recreational and cultural venues were closed. Gyms pools and leisure venues were closed except for outdoor sports centres in yellow and orange regions while, in red regions, individual outdoor training only was allowed (except for sports events of national interest, such as the national football league).

Differences of adopted colours among the five selected regions during the second wave may be summarised as follows: Lombardy and Piedmont were classified as red zones up to November 28, orange afterwards up until December 13 and yellow before Christmas; Emilia-Romagna spent the first week (up to November 14) in yellow then moved to orange for 14 days (December 5) and returned to yellow afterwards; Trento and Veneto remained yellow the entire time. During the Christmas period up to the end of the year, restrictions have been applied uniformly in all regions.

3 Difference in geographic discontinuity designs (DiD-GRDD)

Assessing the role of different healthcare systems in case of an unevenly spread shock is challenging, as several confounding factors might play a role in the outcome of interest (mortality). In this paper, we take advantage of the administrative border of regions. On the one hand, each region implements its healthcare governance model and is in charge of making timely decisions to respond to health emergencies, which only apply to its administrative territory. On the other hand, we posit that since virus diffusion mainly depends on individual mobility and contacts between people, the spread of the pandemic should have been remarkably similar in neighbouring municipalities located on each side of regional administrative borders. We focus on the administrative border of Lombardy with its four neighbouring regions and followed a difference in geographic regression discontinuity design (DiD-GRDD, hereafter). Figure 1 shows the administrative municipality borders in the five regions considered and highlights with different colours the set of municipalities used in the analysis for increasing distance to the border of Lombardy. The idea behind this research design is that by comparing a given outcome in administrative units (i.e. municipalities) that are geographically close during the same period, we can control for unobservable variables affecting an outcome of interest. This is the GRDD part of the estimator (see, for instance, Dell, 2010). By taking differences over time among these geographical regression discontinuity designs (RDD), we are then able to isolate the effect of Covid-19 on regional differences in the outcome variable. This is the difference-in-differences (DiD) part of the estimator (Grembi et al., 2016).

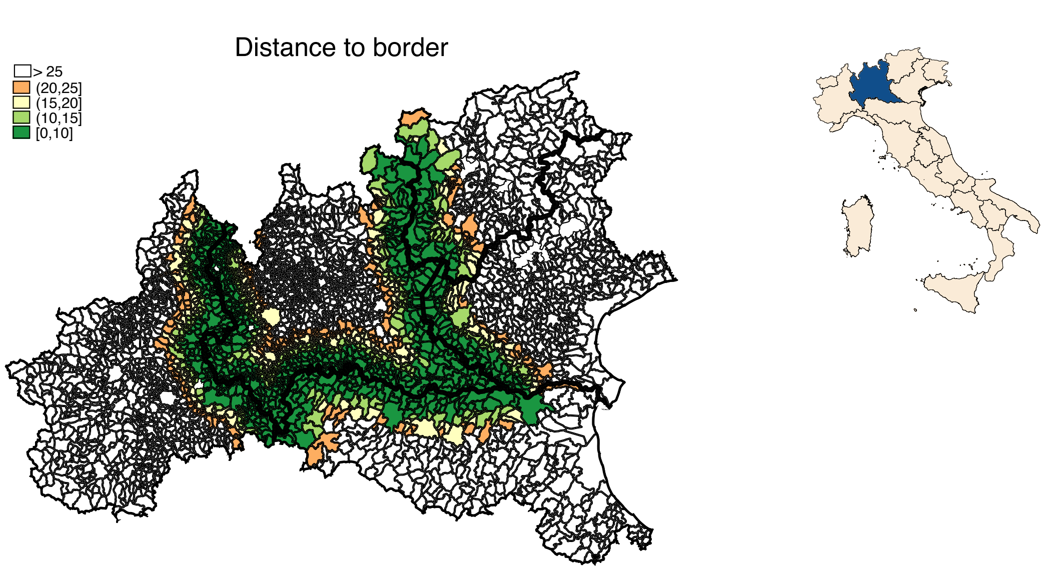
[9] For all details regarding the adopted measures see `https://www.agenas.gov.it/covid19/web/index.php`

Table 1: Regional descriptive statistics

	Population	Average number of residents covered by LHSs	RHSs' expenditures for GPs	Number of GPs	Numbe of GPs on out-of-hours services	People using ER within 3 months before interview	People using GPs out-of-hours services within 3 months before interview	beds in acute care, accredited private institutions	Accredited private in-ordinary-regime discharge	Accredited private day-hospital discharges over total discharges
	thousands	thousands	€	for 10,000 inhabitants	for 10,000 inhabitants	out of 1,000	out of 1,000	%	% over total	% over total
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(L)
Year	2019	2019	2019	2018	2018	2019	2019	2019	2019	2019
Piedmont	4,329	360.7	81.5	6.9	10.2	89	40.1	8.7%	19.3%	10.6%
Lombardy	10,011	370.8	64.6	6.2	9.4	96.7	28.1	36.5%	36.4%	42.8%
Trento, A. P.	544	543.7	76.0	6.6	11.6	82	51.1	14.5%	20.9%	14.1%
Veneto	4,885	542.7	82.7	6.5	14.4	87.4	36.5	12.4%	17.2%	27.8%
Emilia-Romagna	4,459	557.4	85.4	6.6	10.6	93.2	33.5	17.1%	19.3%	25.7%
ITALY	59,817	543.8	76.1	7.1	19.6	78.6	38.9	30.4%	26.0%	28.3%

Sources:
(A) Istat, resident population on Jan. 1st 2019
(B) Our calculations using Istat and Ministry of Health data
(C) Ministry of Health
(D-L) Istat, Healthcare sector data

Figure 1: Geographic regression discontinuity design



Note. This figure shows the location of Lombardy in Italy on the right, and the municipalities of the five regions we include in our analysis, depending on the bandwidth for the DiD-GRDD (i.e. distance from the border in kilometers), on the left. Lombardy's neighboring regions are counterclockwise: Piedmont (west), Emilia-Romagna (south), Veneto (east) and Trentino Alto Adige (east).

We claim that these differences, if any, can be attributed to how the pandemic was managed by regional governments or the capacity of different regional health systems to cope with the emergency. As an outcome, we chose excess mortality (i.e. Covid-19-related mortality). The identifying assumptions of this estimator are equivalent to those described in Grembi et al. (2016) for the *diff-in-disc* design, except for the fact that we exploit geographical thresholds represented by regional borders.[10]

We specify the DiD-GRDD model as follows:

$$\begin{aligned} y_{it} = \alpha_0 + \alpha_1 post_t + \alpha_2 Lombardy_i + \alpha_3 Lombardy_i \times post_t + f(d_i) + \\ + g(d_i) \times Lombardy_i + h(d_i) \times post_t + \\ + l(d_i) \times Lombardy_i \times post_t + \boldsymbol{\beta}\mathbf{X_{it}} + \epsilon_{it} \end{aligned} \tag{1}$$

where y_{it} are age-specific mortality rates (i.e. the number of deaths divided by the corresponding age group, multiplied by 100), $post_t$ is a dichotomous variable taking the value of 1 in 2020 (i.e. the period affected by Covid-19) and 0 before it (2017–2019), $Lombardy_i$ is another dichotomous variable taking the value of 1 for Lombardy's municipalities and 0 for all other municipalities; $f(d_i)$, $g(d_i)$, $h(d)$ and $l(d_i)$ are different first-degree polynomials in distance in kilometres (i.e. the running variable) from the administrative border, $\mathbf{X_{it}}$ is a vector of control variables and ϵ_{it} is an idiosyncratic error term.

As data on Covid-19-related deaths might be biased (Buonanno et al., 2020; Bartoszek et al., 2020) because no uniquely defined way to classify Covid-19-related deaths exists and testing of deceased people was not compulsory. Thus, we focused on age-specific total mortality rates (i.e. for any cause), which are correctly measured using administrative data collected regularly by municipal registry offices and are our dependent variables in the regression models. This allowed us to minimise the measurement error of the outcome variable and estimate the Covid-19-related deaths from the excess mortality at the municipality level before and after the onset of the pandemic crisis.[11]. In model (1), the main coefficient of interest is α_3, which captures the DiD-GRDD effect (i.e. the excess mortality of Lombardy's municipalities compared to those of close municipalities in a neighbouring region in 2020 compared to the years 2017-2019). We estimated equation (1) for four different samples, each one including Lombardy's municipalities and the municipalities of Piedmont, Emilia-Romagna, Veneto and Trentino Alto Adige regions, respectively. Moreover, we estimated several specifications applying various distance bandwidths from the regional border (from 10 km to 25 km for each 5 km bandwidth increment) and for several age groups.

To check the plausibility of the DiD-GRDD identifying assumptions, we estimated some placebo versions of equation (1) . In one spatial placebo, we only focused on mortality in Lombardy, and we set a fake border at different bandwidths from the real one. If the estimated effect in the specification of equation (1) was a genuine administrative border effect, we should not find any statistical difference in mortality rates between municipalities on each side of the fake border in this placebo specification. We also implement a time placebo in which we apply an event-study-like specification for which the $post_t$ and the $Lombardy_i \times post_t$ indicators are replaced with year dummies D_t and $Lombardy_i \times D_t$ i indicators, respectively. This specification enabled us to estimate a coefficient for each $Lombardy_i \times D_t$ interaction and check whether the emphparallel trend assumption holds.

[10] Grembi et al. (2016) in their article use municipalities' population cut-offs.

[11] See, for instance, Alacevich et al. (2021) for a similar approach.

The event-study DiD-GRDD specification reads as follows:

$$
\begin{aligned}
y_{it} = \alpha_0 + \sum_{\substack{t=2017\\ t\neq 2019}}^{2020} \alpha_{1j} D_t + \alpha_2 \times Lombardy_i + \sum_{\substack{t=2017\\ t\neq 2019}}^{2020} \alpha_{3j} Lombardy_i \times D_t + f(d_i) + \\
+ g(d_i) \times Lombardy_i + h(d_i) \times post_t + \\
+ l(d_i) \times Lombardy_i \times post_t + \boldsymbol{\beta}\mathbf{X_{it}} + \epsilon_{it} \qquad (2)
\end{aligned}
$$

where the polynomials in distance are allowed to vary between the pre- and post-2019 period and not be year specific. We set 2019 as the reference (omitted) year. Thus, the non-interacted Lombardy indicator captures the differential mortality of Lombardy compared to the other regions in 2019. If the parallel trend assumption holds, the $Lombardy_i \times D_t$ interaction coefficients should be zero for $t = 2017, 2018$ and be different from zero only in 2020.

4 The data

The empirical estimation of models described in Section 3 relies on extensive use of a range of administrative data. Administrative data, as opposed to survey data, have the advantage of being readily and publicly available, covering the whole population and being affected the least by measurement error. Our main outcome variable is the number of deaths (for any cause) in each municipality, and it is built by integrating various administrative data sets produced by the Italian Statistical Institute (ISTAT), namely the National Registry of Resident Population (*Anagrafe Nazionale della Popolazione Residente*, ANPS), municipalities' population registers and the tax register (*Anagrafe tributaria*).[12] At the time of writing, data were available for the period January 1–December 31, 2020 for all 7,903 Italian municipalities; however, to investigate the role of different healthcare systems on Covid-19 excess mortality, we selected only municipalities of Lombardy and the five Italian regions neighbouring it, Piedmont, Autonomous Province of Trento, Veneto and Emilia-Romagna, over the period 2017–2020.

4.1 Choice of the control variables

A rich body of work is becoming available as to the main determinants of Covid-19 diffusion and mortality. We started from this evidence to select (conditional on availability) the covariates to be included in our empirical analysis. For instance, the extant literature has identified a clear demographic profile for Covid-19 victims (Jordan et al., 2020; Zheng et al., 2020). Covid-19 infections are seen more often among the oldest citizens and proportionally affect fewer females than males. Underlying health conditions, such as respiratory and cardiovascular disease, diabetes, hypertension and cancer, are important predictors of Covid-19-related mortality (Robilotti et al., 2020).

Recent evidence from Sweden using individual-level registry data demonstrates that gender (being male), individual income, education, married status (being single) and being an immigrant from a low- or middle-income country all independently predict a higher risk of death from Covid-19 (Drefahl et al., 2020). Similar evidence of a disproportionate impact of Covid-19 on immigrant communities has been reported in the United States (Clark et al., 2020).

[12] These data are freely downloadable from https://www.istat.it/it/archivio/240401.

Moreover, environmental factors, such as air pollution, and weather conditions, such as temperature and humidity, are associated with mortality (Ma et al., 2020; Wu et al., 2020; Becchetti et al., 2020; Coker et al., 2020). Recent studies also demonstrate how hospitals' resource availability had an impact on Covid-19 mortality. In particular, geographic areas with fewer ICU beds, nurses and general medicine/surgical beds were statistically significantly associated with more deaths in the United States and the UK (Lin, 2021; Wood et al., 2020). Moreover, previous influenza-like illness in Covid-19 hospitalised patients and previous influenza vaccinations in 2019 are associated with larger Covid-19 incidence and reduced rates of Covid-19, respectively (see Green et al. (2021) and Ceccarelli et al. (2020) among others).

Accordingly, restrictions in economic activity and individual mobility (lockdown) contribute to reducing the diffusion of the virus and reducing mortality. This has been observed, *inter alia*, for China, Italy and Spain (Qiu et al., 2020; Lau et al., 2020; Ciminelli and Garcia-Mandicó, 2020; Tobías, 2020), which were among the first countries to be hit by the pandemic and to implement lockdown.[13] Mobility habits have been shown to explain the number of Covid-19 infections jointly with other factors and some environmental variables (i.e. PM pollution and temperature) (Cartenì et al., 2020). Thus, governments' emergency measures aimed at human-mobility containment have had a direct impact on the number of Covid-19 related deaths (Hadjidemetriou et al., 2020) and should be considered when studying Covid-19 mortality.

4.2 Description of control variables

We included in the $\mathbf{X_{it}}$ vector of equations (1) and (2) several controls at the municipal level that are likely to be associated with, or potential determinants of, mortality. In short, we collected data on the following groups of variables (data sources are reported in Table 3):

Demographic and socio-economic characteristics: population structure by age and gender; percentage of immigrants; population size; population density; average taxable income.

Infrastructure variables: distance to the closest airport, distance to the closest care home, distance from the closest early declared red zones (February–March 2020).

Healthcare system variables: number of beds per capita in public hospitals, number of beds per capita in private hospitals, number of beds in ICU public hospitals; closest distance from closest ICU in private/public hospital (two separate variables); closest distance from private/public hospital (two separate variables).

Environmental and climate variables: air quality (PM2.5 yearly average concentrations from 2014 to 2018), as derived from the Copernicus Atmosphere Monitoring Service Reanalysis product (Inness et al., 2019); weather/climate conditions (yearly average wind speed and components, temperature, relative humidity, surface pressure, precipitation, solar radiation), as derived from the Copernicus Climate Service ERA5 product (Hersbach et al., 2020).

Pulmonary diseases: COPD gross municipality rate and influenza gross municipality rate (obtained by National Outcomes Plan, PNE `https://pne.agenas.it`).

[13] However, evidence is not limited to this countries. Evidence on Europe has been reported in Flaxman et al. (2020).

The choice of these explanatory variables was motivated by factors that have been identified by the extant literature as potential drivers of both the pandemic spread and its mortality (see Section 4.1).

In addition to the explanatory variables included in the model, we used data on citizens' mobility to test the validity of the identifying assumptions of the proposed GRDD model in 2020, which requires citizens' mobility to be balanced at the border (confirmed especially in the first wave, see Appendix). Mobility data were provided by Mobile Network Operators, which offers information on collective mobility behaviours aggregated at the municipal level.[14] The mobility indicators provide a daily time series of mobility according to the direction of movements as internal (within the same municipality), inward (to a municipality), outward (from a municipality) and total. More information about the mobility indicators and their application to a European Commission JRC's live anomaly detection system to spot potential new outbreaks can be found in Santamaria et al. (2020) and Iacus et al. (2021).

Table 2 reports the age-specific mortality rates (per 100 individuals in the same age group) for the five regions we considered in the analysis and the two periods 2017–2019 and 2020 (i.e. pre- and post-Covid-19). The four last columns report the DiD contrasts in the mean mortality in 2020 vs. 2017–2019 between Lombardy and each other region. Three things stand out. First, mortality rates for any cause were higher in 2020 compared to the previous years in all regions, especially in the 81+ age group. In the first semester, for instance, the mortality rate in 2020 in the 80+ age bracket was 37%, 13%, 26%, 25% and 7% higher compared to the previous three years in Lombardy, Piedmont, Emilia-Romagna, Veneto and Trentino Alto Adige, respectively. Second, the excess mortality is higher in Lombardy than in the other regions. The DiD contrasts show, for instance, excess mortality of Lombardy of 4 percentage points compared to Emilia-Romagna for the 81+ age bracket. Last, a comparison between panel (a), which shows the descriptive statistics only for the municipalities included in our DiD-GRDD analysis, and panel (b), reporting the same statistics for all municipalities, shows that the DiD contrasts are comparable for Emilia-Romagna and Trentino Alto Adige. However, while focusing on the municipalities at the border, the positive excess mortality of Lombardy concerning Piedmont and Veneto is lower than when considering the entire regions.

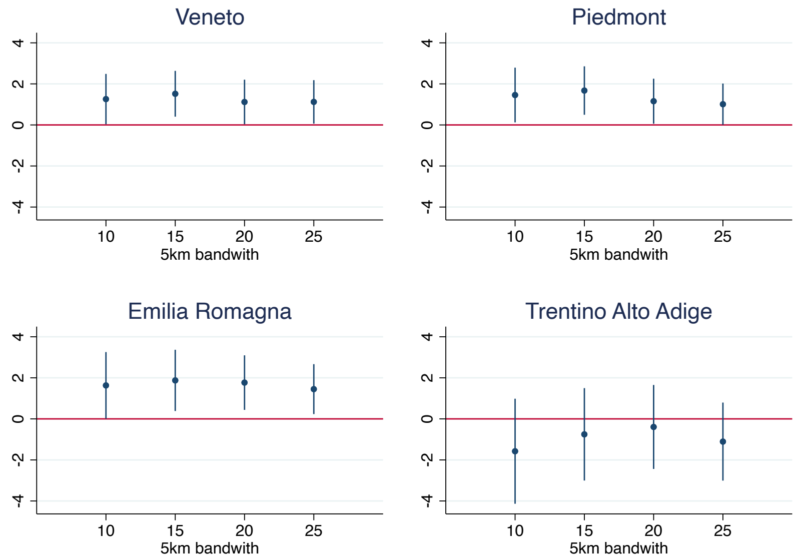
[14] Given that mobile phone subscribers represent about 65% of the population in EU, mobile data provide reliable information to capture the aggregate mobility patterns of the population (Iacus et al., 2021).

Table 2: Age-specific mortality rates (%)

Variable	Lombardy (L)		Piedmont (P)		Emilia-Romagna (ER)		Veneto (V)		Trentino Alto Adige (TAA)		DiD L vs. P	DiD L vs. ER	DiD L vs. V	DiD L vs. TAA
	2017-19	2020	2017-19	2020	2017-19	2020	2017-19	2020	2017-19	2020				
(a) DiD-GRDD sample														
First semester														
Mortality rate 0-50	0.026	0.029	0.028	0.024	0.025	0.049	0.025	0.026	0.026	0.019	0.007	0.002	-0.021	0.027
Mortality rate 51-70	0.286	0.371	0.327	0.326	0.238	0.265	0.282	0.393	0.251	0.267	0.086	0.173	0.058	0.068
Mortality rate 71-80	1.233	1.797	1.369	1.512	1.067	1.500	1.156	1.716	1.186	1.178	0.421	1.008	0.131	0.907
Mortality rate 81+	6.011	8.227	6.572	7.401	5.467	6.908	6.070	7.614	5.930	6.349	1.387	4.150	0.775	3.054
Second semester														
Mortality rate 0-50	0.023	0.026	0.027	0.035	0.026	0.022	0.027	0.023	0.022	0.022	-0.005	0.012	0.007	-0.002
Mortality rate 51-70	0.264	0.297	0.292	0.345	0.259	0.222	0.263	0.277	0.262	0.255	-0.020	0.118	0.070	-0.008
Mortality rate 71-80	1.139	1.289	1.183	1.368	1.055	1.149	1.086	1.164	1.018	1.265	-0.035	0.462	0.056	0.212
Mortality rate 81+	5.415	6.255	5.937	7.132	4.869	6.288	5.385	5.969	5.247	6.817	-0.354	3.103	-0.579	1.743
(b) All municipalities														
First semester														
Mortality rate 0-50	0.023	0.024	0.027	0.025	0.021	0.018	0.025	0.031	0.024	0.022	0.002	0.004	0.003	-0.006
Mortality rate 51-70	0.266	0.419	0.334	0.319	0.221	0.245	0.270	0.298	0.248	0.247	0.167	0.251	0.129	0.127
Mortality rate 71-80	1.169	2.060	1.315	1.360	1.044	1.251	1.120	1.286	1.125	1.121	0.846	1.207	0.683	1.022
Mortality rate 81+	5.813	9.026	6.345	6.507	5.662	6.255	6.083	6.704	5.727	5.899	3.050	4.059	2.620	3.385
Second semester														
Mortality rate 0-50	0.023	0.026	0.032	0.026	0.021	0.024	0.024	0.023	0.024	0.026	0.009	0.008	0.000	0.003
Mortality rate 51-70	0.249	0.265	0.301	0.315	0.228	0.231	0.263	0.272	0.244	0.266	0.002	0.104	0.013	-0.016
Mortality rate 71-80	1.136	1.210	1.227	1.563	0.935	1.119	1.062	1.127	1.031	1.223	-0.262	0.702	-0.110	0.132
Mortality rate 81+	5.254	5.943	6.154	7.781	4.794	6.117	5.513	6.189	5.221	6.490	-0.938	3.677	-0.633	1.293

Note. Average mortality rates by sub-period (pre- and post-Covid-19) for the five regions included in our analysis and DiD contrasts computed in the raw data. Panel (a) reports the descriptive statistics only for the municipalities included in our DiD-GRDD with a 25km bandwidth while panel (b) on all municipalities. (data source: ISTAT, https://www.istat.it/it/archivio/240401).

Figure 2: DiD-GRDD impact on mortality rates of age 81+ population — first semester



Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated on the horizontal axis.

Table 3 reports the definition for all variables, timing and sources.

5 DiD-GRDD: Main results

As it is well known that Covid-19-related mortality is higher in the older cohort than in the younger population, we examined age-specific mortality rates by age groups: 0–50, 51–70, 71–80 and 81 and over. Results are presented depicting the point estimate and the 95% confidence intervals of coefficient α_3 of equation (1) for different choices of bandwidth (i.e. using municipalities within 10 km, 15 km, 20 km and 25 km from the Lombardy administrative border). To examine differences between the first and second waves, models are estimated separately for each semester of 2020.

5.1 First semester (January—June 2020)

We start observing differences in mortality for the eldest age groups. Figure 2 shows the results for the oldest age group (81+). Lombardy has an excess of mortality concerning all neighbouring regions but Trentino Alto Adige, for which mortality is not statistically different. The point estimates are precise and stable, varying the bandwidths around the border. Estimates of Lombardy's mortality premia range between 1.13–1.48 percentage points (pp, hereafter), 1.46–1.86 pp and 1.07–1.74 pp for Piedmont, Veneto and Emilia- Romagna, respectively. Overall, Lombardy appears to have experienced higher mortality in the population above 80 years of age of between 1 and 2 percentage points.

Table 3: Control variables description and sources

Description	**Year**	**Source**
Percentage of population in age class 51-60	2017-2020	ISTAT
Percentage of population in age class 61-70	2017-2020	ISTAT
Percentage of population in age class 71-80	2017-2020	ISTAT
Percentage of population in age class 81+	2017-2020	ISTAT
Percentage of migrant citizens	2017-2020	ISTAT
Population density	2017-2020	ISTAT
Hospitalization rate for COPD	2017-2020	AGENAS
Hospitalization rate for influenza	2017-2020	AGENAS
Relative Humidity	2017-2020	Copernicus Climate Service
Temperature at 2mt	2017-2020	Copernicus Climate Service
Total precipitations	2017-2020	Copernicus Climate Service
Wind Speed	2017-2020	Copernicus Climate Service
Particulate matter 2.5	2017-2020	Copernicus Atmosphere Service
Number of beds (per capita) in public hospital	2017-2019	Ministry of Health
Number of beds (per capita) in ICU in public hospital	2017-2019	Ministry of Health
Number of beds (per capita) in private hospital	2017-2019	Ministry of Health
Per capita taxable income	2017-2019	ISTAT
Number of care homes	2019	Regional Healthcare Directorate
Distance from airport	Time invariant	Google Maps
Distance from care homes	Time invariant	Google Maps
Distance from red zone	Time invariant	Google Maps
Size ICU in private hospitals	2017-2019	Ministry of Health
Size ICU in public hospitals	2017-2019	Ministry of Health
Size private hospitals	2017-2019	Ministry of Health
Size public hospitals	2017-2019	Ministry of Health
Distance from ICU in private hospital	Time invariant	Google Maps
Distance from ICU in public hospital	Time invariant	Google Maps
Distance from private hospital	Time invariant	Google Maps
Distance from public hospital	Time invariant	Google Maps
Mobility index (inward, outward, internal)	2020	Mobile Network Operators

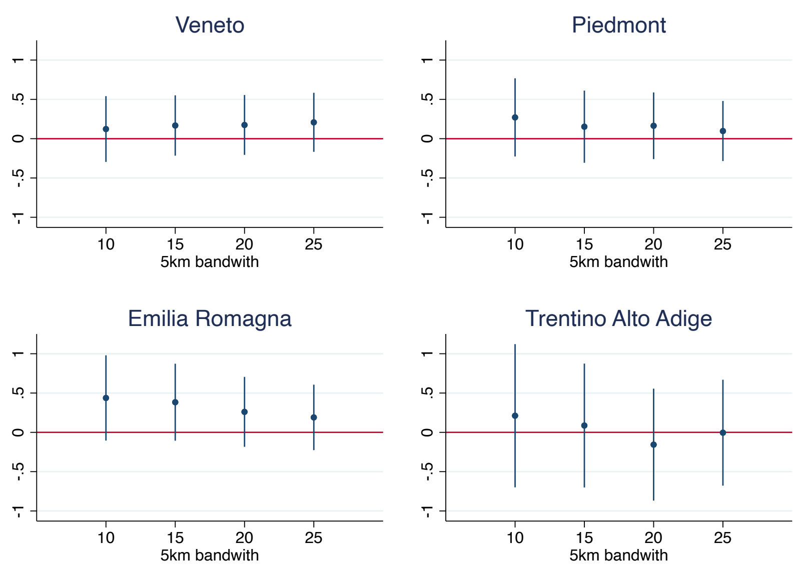
Note. This table reports the description, year in which they are measured and source of the control variables included in the DiD-GRDD regression models. ISTAT is the Italian National Statistical Office (*Istituto Nazionale di Statistica*) and AGENAS is the National Agency for the Regional Health Services (*Agenzia Nazionale per i Servizi Sanitari Regionali*.

Table 4: DiD-GRDD main results—age class 81+

	First Wave				Second Wave			
Bandwidth	10km	15km	20km	25km	10km	15km	20km	25km
Piedmont								
Lomb#Post	1.458**	1.675***	1.156**	1.012**	-0.0313	-0.211	-0.0182	0.245
	(0.680)	(0.602)	(0.559)	(0.512)	(0.652)	(0.573)	(0.530)	(0.494)
Trentino Alto Adige								
Lomb#Post	-1.576	-0.753	-0.394	-1.107	-1.818	-2.112*	-1.918*	-1.536*
	(1.305)	(1.148)	(1.043)	(0.970)	(1.164)	(1.087)	(0.982)	(0.895)
Veneto								
Lomb#Post	1.260**	1.518***	1.119**	1.123**	-1.733***	-1.334**	-1.475***	-1.321***
	(0.625)	(0.569)	(0.554)	(0.540)	(0.577)	(0.542)	(0.521)	(0.489)
Emilia-Romagna								
Lomb#Post	1.630**	1.875**	1.767***	1.450**	0.124	0.491	0.353	0.128
	(0.829)	(0.761)	(0.678)	(0.620)	(0.650)	(0.626)	(0.580)	(0.531)

The table reports the coefficients on the $Lombardy_i \times Post_t$ (Lomb#Post) indicator, obtained using the DiD-GRDD models estimated on samples including Lombardy and each other region at the time. Estimates are presented for municipalities within different bandwidths around the Lombardy's border.

Figure 3: DiD-GRDD impact on mortality rates of age 71-80 population — first semester



Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated on the horizontal axis.

Figure 3 shows the estimates for the 71–80 age bracket. In this case, Lombardy's excess mortality with respect to the near regions is much less generalised and only limited to the case of Emilia-Romagna, with excess mortality in the range of 0.5–0.6 pp. The latter is, however, statistically significant at least at 10% only within 15 km from the border. Thus, the higher mortality of the elderly for Lombardy, compared to its neighbouring regions, appears to have occurred only for the over-80 population.

As shown in the Appendix, excess mortality in Lombardy is not statistically different from neighbouring regions in younger age groups (namely in the 0–50 and 51–70 groups). In some cases, Lombardy performed better (e.g. with respect to Trentino Alto Adige in the 0–50 age group). Even in the few cases in which the estimates are statistically significant, their point-wise estimate is negligible. This is consistent with younger age groups being only marginally exposed to Covid-19-related mortality (Onder et al., 2020).

5.2 Second semester (July–December, 2020)

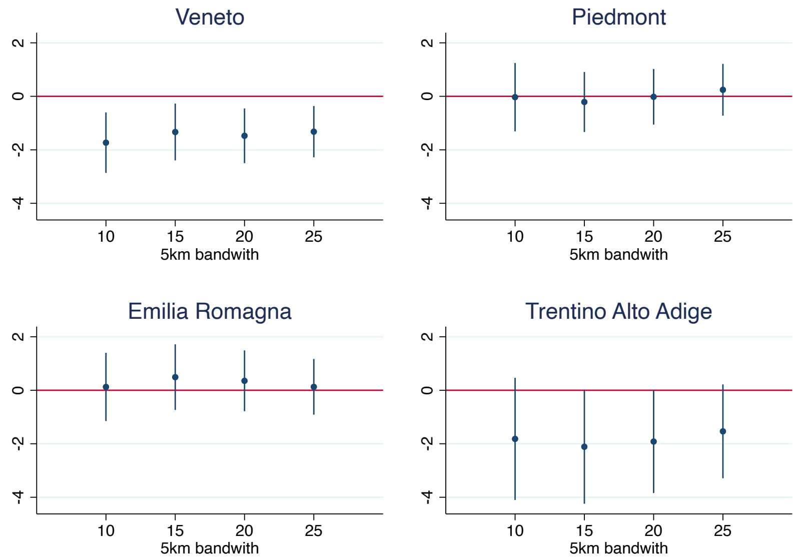
Figure 4 shows the regional differences in mortality for the oldest age group in the second semester of 2020. As described in Section 2 and well documented in Vespe et al. (2021), during the last part of the second semester (November 6—December 31), a system of colour-labelled restrictions was implemented by the national government. This system produced heterogeneous consequences in mobility restrictions as well as in teleworking, distance-learning activities and the opening of restaurants and bars. This implies that differences in mortality at the border in the second semester not only reflect the action of regional governments but also the consequences of the centrally mandated policy on the colour zones. Differences in mobility and economic activity around the border related (e.g. the implementation of yellow versus orange/red zones) may have impacted mortality rates. Notably, this heterogeneous set of restrictions was implemented at the regional level for a limited period of 6 weeks over the 26 weeks of the second semester and no difference at the border were found for some region pairs, as they were classified with the same colour. Piedmont and Lombardy, for example, are fully comparable because they spent similar times in the same colour zones.

Our results show that Lombardy seems to have closed the mortality gap among the 81+ population with respect to Veneto in the second semester. Indeed, Lombardy experienced lower mortality by about 1.31 and 1.71 pp, depending on the bandwidth. However, Veneto spent the entire second semester as a yellow region. This result should be, therefore, taken with caution given the huge differences in the levels of restrictions to normal activity between the yellow zone (in Veneto) and the red and orange zones (in Lombardy). The same cautionary note applies with Trentino Alto Adige, compared to which lower mortality by 1.51 and 2.05 pp, respectively, is observed in Lombardy.

Lombardy did not perform significantly worse or better than Piedmont in the second semester. In light of the worse performance of Lombardy in the first semester and the fact that the two regions fell in the same colour zones for most of the time, this lends support to the ability of the Lombardy health management system to adapt in the second wave and close the gap with Piedmont. For all the other comparisons, the national colour system – which greatly limited regional autonomy in the management of the pandemic – seems to have produced convergence in mortality between the most and the least affected regions of the first wave.

Figure 5 shows instead a remarkably similar situation across regions as to mortality of the 71–80 age group. The same is true for younger age brackets (Figures A3 and A4).

Figure 4: DiD-GRDD impact on mortality rates of age 81+ population — second semester



Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated on the horizontal axis.

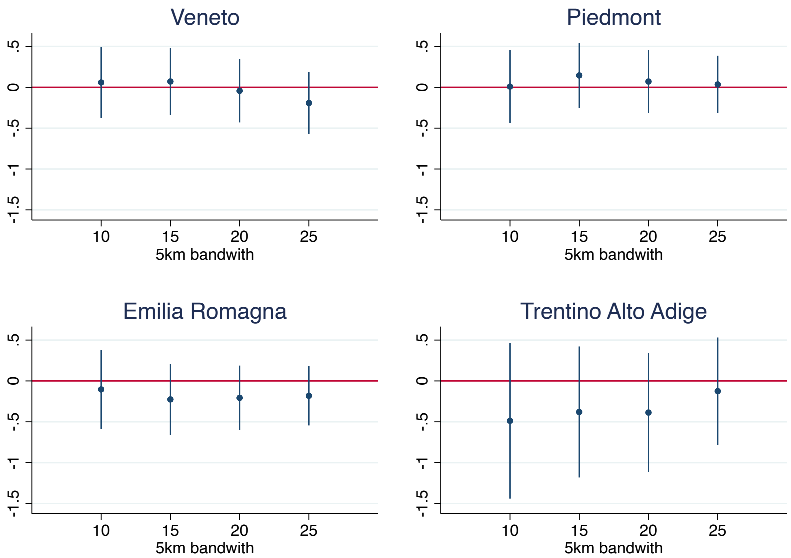
6 Placebo analysis, parallel trend assumption and balancing of covariates

In this section, we report two placebo analyses and other robustness checks. In the first placebo analysis, we set a fake border within Lombardy's regional territory and compared municipalities on each side of this border. Since the latter is ruled by the same regional administration and subject to the same RHS, we did not expect significant differences in mortality among them. In the second placebo, by adopting an event-study-like setting, we tested whether the excess mortality across the Lombardy administrative border differed also before the Covid-19 crisis outbreak. If this is the case, we can be reassured that excess mortality changes were a consequence of the Covid-19 crisis. Similar to DiD designs, this is a test of the so-called 'parallel trend assumption'. Last, we checked the effect of potential differences in the covariates at the border on predicted mortality following the test proposed by Carrell et al. (2018). In short, we tested whether covariates that strongly predict mortality rates change sharply at the border and spuriously produced the significant estimates obtained in our DiD-GRDD analysis.

6.1 Spatial placebo: Fake border analysis

As well known, an important identification assumption in RDD is the absence of manipulation of the running variable (distance from the border in our case). In principle, there is little room for differential manipulation of the treatment between the geographic areas around each shared border,

Figure 5: DiD-GRDD impact on mortality rates of age 71-80 population — second semester

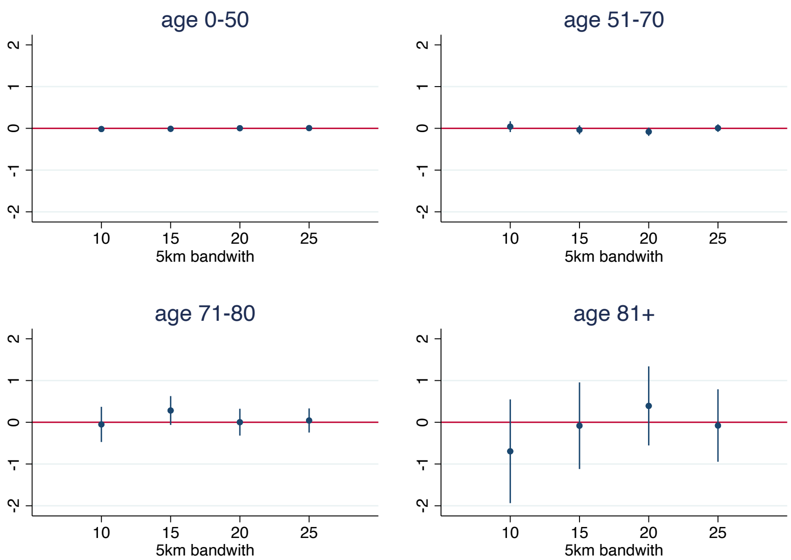


Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated on the horizontal axis.

especially during the first wave of the Covid-19 pandemic. A possible form of manipulation of the treatment (i.e. being exposed to a given regional health system or rules) in the context of our study could take place in the case a patient in a close-to-the border municipality would have been free to choose a region from which to receive healthcare. However, given the tight national restrictions imposed by the confinement measures suddenly implemented from the 9th of March (2020) onward in Italy, this event should be very rare (at least during the first Covid-19 wave) and only for highly severe and critically ill patients (namely patients to be transferred to ICU) upon saturation of both the specific hospital's ICU department where the patient is hospitalised and the overall availability of ICU beds in the whole region.

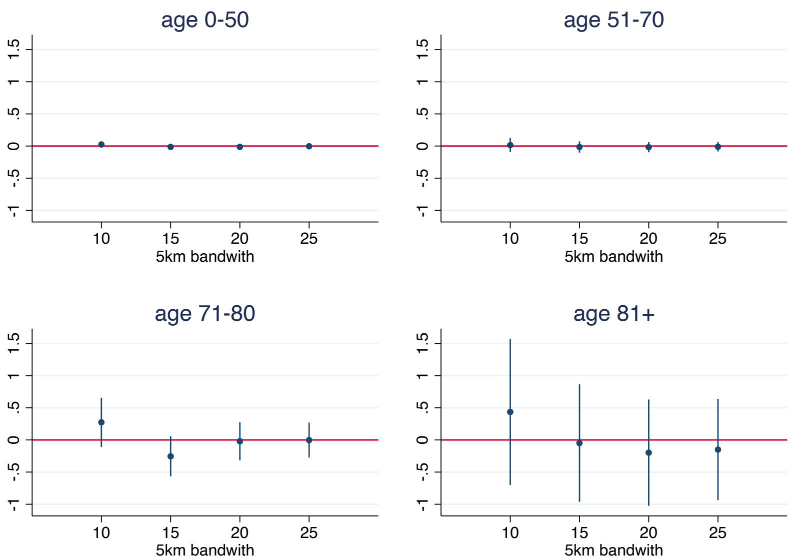
It is worth noting that this kind of confounder potentially runs against us, making our estimates lower bound. In the extreme situation in which patients close to the border randomly switch regions to look for care, we should not find any statistical difference for municipalities close to the border but in different regions. However, this threat to identification can be investigated by carrying out a spatial falsification check: to attribute the geographic differences in mortality detected with the DiD-GRDD analysis to differences in RHS or in how the Covid-19 crisis was managed, we must check that similar differences do not emerge between near municipalities belonging to the same region. To test for this, we implemented a spatial placebo where we only focused on mortality (separately by age group) among clusters of municipalities around a fake border, which was set within the Lombardy territory. We artificially created a new fake border within the region at different bandwidths from the real one. We then estimated again our preferred specification (equation (1)). The fake border was set by moving the real border towards the interior of the Lombardy region and

Figure 6: Fake border DiD-GRDD impact on mortality rates – first semester



Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from a “fake” administrative border — set within the Lombardy region — indicated on the horizontal axis.

Figure 7: Fake border DiD-GRDD impact on mortality rates – second semester



Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from a "fake" administrative border — set within the Lombardy region — indicated on the horizontal axis.

retaining all Lombardy's municipalities within a given distance bandwidth from the new border in the analysis. Just to take an example, if we set a bandwidth of 10 km, the border was moved by 20 km from the original one (meaning we could consider municipalities within 10 km on each side of the border). So, *de facto*, in this analysis the fake border changes with the bandwidth.

The spatial placebo estimates did not show any statistical difference between the average mortality rates of the clusters of municipalities lying on each side of the fake border. This result, which was confirmed both for the first wave (Figure 6) and the second wave (Figure 7), is particularly reassuring given that the two groups of municipalities – standing at the two sides of the fake border – were under the same regional administration and subject to the same RHS during the pandemic. It is also worth noting that the fake border estimates for the second wave did not suffer from the caveat discussed above (related to differences in colour-labelled restrictions among some pairs of regions) given the artificial nature of the new border lying within the very same region. On the contrary, restrictions in choosing to be hospitalised in a specific region were less strict than during the first wave, which may have introduced some bias in our estimates.

6.2 Event-study analysis and the parallel trend assumption

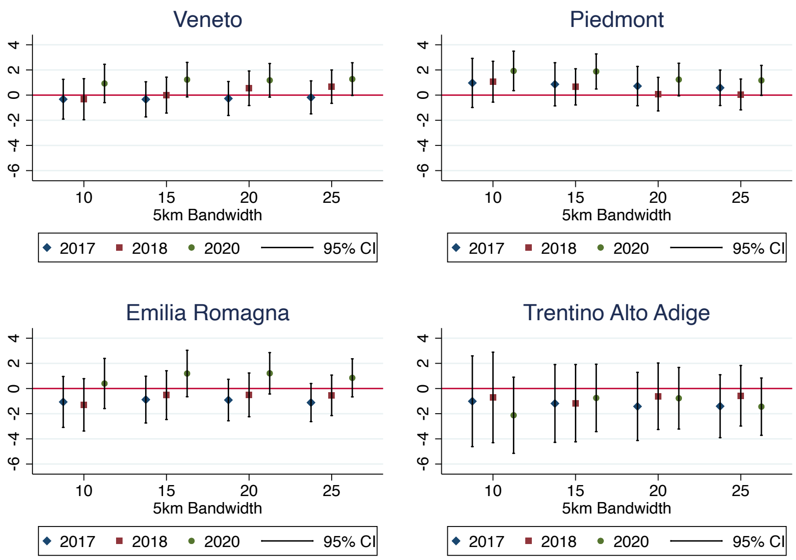
This section describes the results of the event-study DiD-GRDD analysis. For the sake of brevity, we only comment on the results for the 80+ age group, for which our baseline DiD-GRDD analysis detected statistically significant differences.

The red line in the graph of Figure 8 indicates the DiD-GRDD coefficient (the interaction between Lombardy and the year indicator) for the year 2019 (i.e. the omitted year). In principle, in the presence of the parallel trend assumption, we should observe differences in mortality at the border across regions (e.g. due to the higher quality of a health system of a region compared to the other), but these differences should remain constant over time. This entails that, for the years 2017 and 2018, the $Lombardy_i \times D_t$ interactions should be zero (implying the same difference in mortality as of 2019). Indeed, in 2017–2019, municipalities were not affected by the Covid-19 health shock. In this regard, Figure 8 is quite reassuring. The 2017 and 2018 estimates are often close to the red line, while the coefficient for 2020 is significantly above it in all the cases in which the DiD-GRDD detected excess mortality for Lombardy compared to neighbouring regions (namely with respect to Veneto, Piedmont and Emilia-Romagna). In some cases, owing to the addition of new parameters to be estimated, estimates for 2020 are not very precise but the graph shows quite clearly that their magnitude is above the pre-2020 interactions. Only in the case of Trentino Alto Adige does 2019 seem to be a peculiar year; that is, Lombardy seems to have experienced lower mortality both before 2019 and after 2019 but similar mortality to Trentino Alto Adige in 2019. For Trentino Alto Adige, therefore, our results are to be taken with caution given a potential violation of the parallel trend assumption.

Overall, strong violations of the parallel trend assumption did not emerge also for the second wave (Figure 9), for which significantly worse mortality for Lombardy was estimated with respect to Veneto and Trentino Alto Adige. However, the usual caveat related to the implementation of the colour system during the second wave applies in interpreting these results.

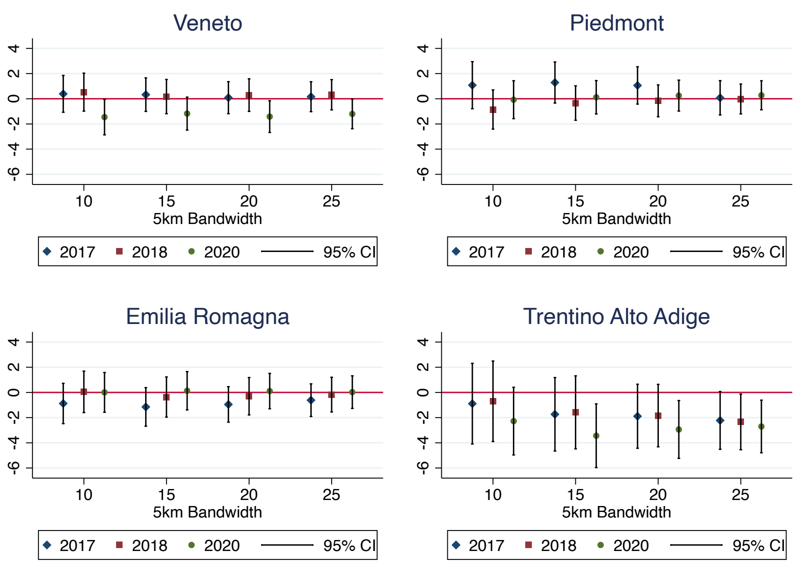
The analysis in this section broadly supports the validity of our research design and shows that excess mortality for Lombardy at the border, compared to its neighbouring regions, only appeared in 2020. A thorough discussion of our results is included in the next section.

Figure 8: Event-study DiD-GRDD impact on mortality rates of age 81+ population — first semester



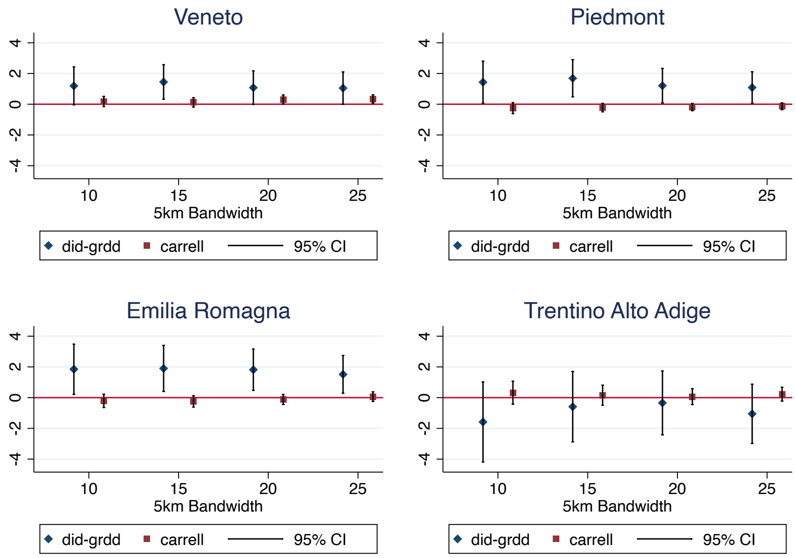
Note. Plots of the year-specific coefficients (points) and confidence intervals (bars) of the event-study DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated on the horizontal axis.

Figure 9: Event-study DiD-GRDD impact on mortality rates of age 81+ population — second semester



Note. Plots of the year-specific coefficients (points) and confidence intervals (bars) of the event-study DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated on the horizontal axis.

Figure 10: Balancing of covariates test for age 81+ population — first semester



Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated in the horizontal axis using as dependent variables predicted mortality rates from a linear regression on the covariates (Carrell et al., 2018).

6.3 Balancing of covariates at the border and the effect on mortality

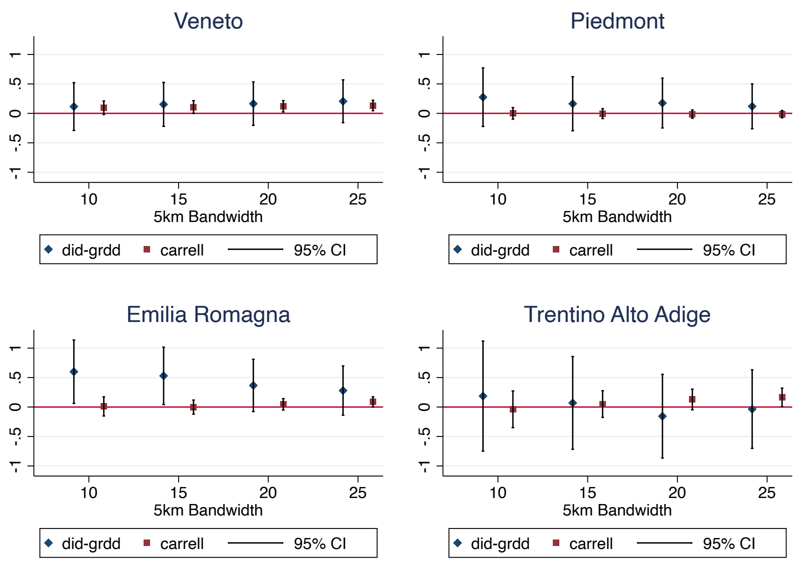
In this section, we outline how we carried out the test proposed by Carrell et al. (2018) to check for the balancing of covariates, which are potentially important predictors of mortality rates. We first estimated predicted mortality through linear regressions of observed mortality rates on the control variables (see Section 4.1), after which we estimated equation (1) using predicted mortality rates instead of the observed mortality rates as the dependent variables. The results are shown in Figures 10 and 11 for the age groups 81+ and 71–80, respectively, in the first wave, and Figures 12 and 13 for the age groups 81+ and 71–80, respectively, in the second wave.

The DiD-GRDD coefficient shown in the graph is much smaller than in our baseline estimates, generally close to zero, and statistically non-significant. This confirms that different covariates alone are not able to explain differences in mortality at the border, especially when one focuses on quite narrow bandwidths, for which the assumption of municipalities' similar observable and unobservable characteristics is more credible.

6.4 Omitted variables, characteristics of regional health systems and time-varying effects of covariates

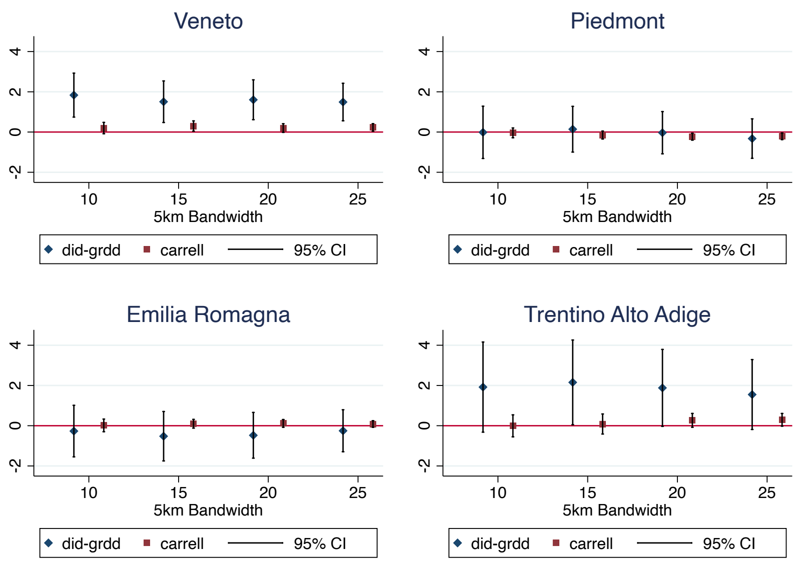
Two potential caveats with the specification of equation (1) are that (i) we do not control for covariates for which we have measures only for 2019 (e.g. regional health system websites often provide only current information and not past data, such as ICU units and care homes) and (ii)

Figure 11: Balancing of covariates test for age 71-80 population — first semester



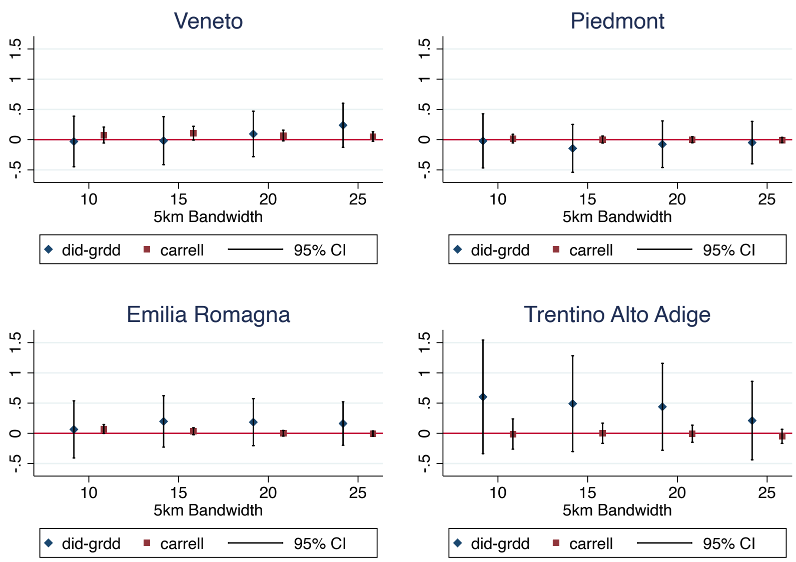
Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated in the horizontal axis using as dependent variables predicted mortality rates from a linear regression on the covariates (Carrell et al., 2018).

Figure 12: Balancing of covariates test for age 81+ population — second semester



Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated in the horizontal axis using as dependent variables predicted mortality rates from a linear regression on the covariates (Carrell et al., 2018).

Figure 13: Balancing of covariates test for age 71-80 population — first semester



Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated in the horizontal axis using as dependent variables predicted mortality rates from a linear regression on the covariates (Carrell et al., 2018).

we do not control for municipality level time-invariant unobservable variables through municipality fixed effects.

In this section, we review how we checked the sensitivity to the first issue by including the time-invariant covariates but also an interaction between all covariates with the post-2019 indicator ($x\#\#post$ specification) in the regression. These interactions serve two goals. First, they account for the fact that measures for 2019 might be partly different from the previous years (measurement error), and second, they allow for all factors to have differential effects at the baseline and in the Covid-19 period. The age structure of the population or the prevalence of ICU, for instance, may impact mortality differently before vs. after the onset of the pandemic.[15]

We sought instead to address the second issue (unobservable municipal characteristics) by including municipal fixed effects (FE specification). As to the latter, if the assumptions underlying the DiD-GRDD are correct – near municipalities are comparable in terms of observable and unobservable variables – including these FEs should not significantly impact the estimates.

Figures 15-16 show that the estimates of our baseline DiD-GRDD specification and those allowing for time-varying effects for the covariates (depending on the pre- vs. post-2019 period) or municipal FEs generally lead to the same conclusion. Indeed, accounting for municipality FEs did not make much difference while controlling for additional covariates related to the characteristics of the health system, and allowing for all covariates to have time-varying coefficients in the pre- and post-2019 periods generally widened the gap between Lombardy and the neighbouring regions. The estimates using covariates $\times post_t$ interactions are generally much less precise than our baseline estimates (as shown by the wider confidence intervals in the graphs) but still point to excess mortality of Lombardy in the first semester and convergence in mortality rates in the second semester. Lombardy's differences in mortality with respect to Piedmont, Trentino Alto Adige and Emilia-Romagna are 2.2 pp, between 3.4 and 4.2 pp and 2.7 pp, respectively. In the second semester, Lombardy exhibited lower mortality compared to both Trentino Alto Adige and Veneto, between 1.7 pp and 2.2 pp and between 1.1 and 1.5 pp, respectively, indicating the region did not perform significantly different from all other regions.

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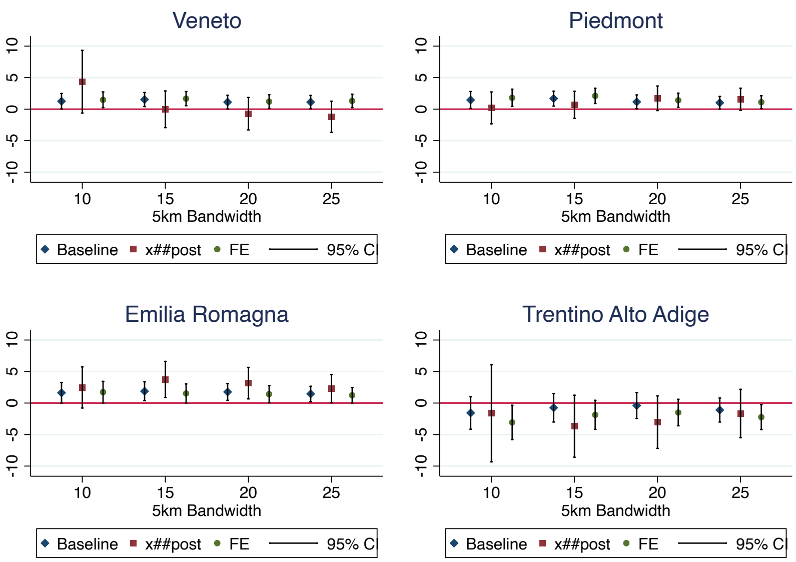
6.5 What went wrong?

In general, it is difficult to determine all the factors that may be responsible for the differences in mortality observed at the border. Here, we limit our analysis to one factor that has been already stressed in the literature, namely the presence in a municipality of nursing and care home facilities. Alacevich et al. (2021) reported in their analysis for Lombardy that hosting care homes was associated with significantly higher excess mortality rates during the first Covid-19 wave. The increased mortality appears to be driven by individuals above the age of 70 and is robust to controlling for the number of hosts in the care homes, suggesting that the latter may have contributed to spreading the virus. In this section, we report a similar test at the border that not

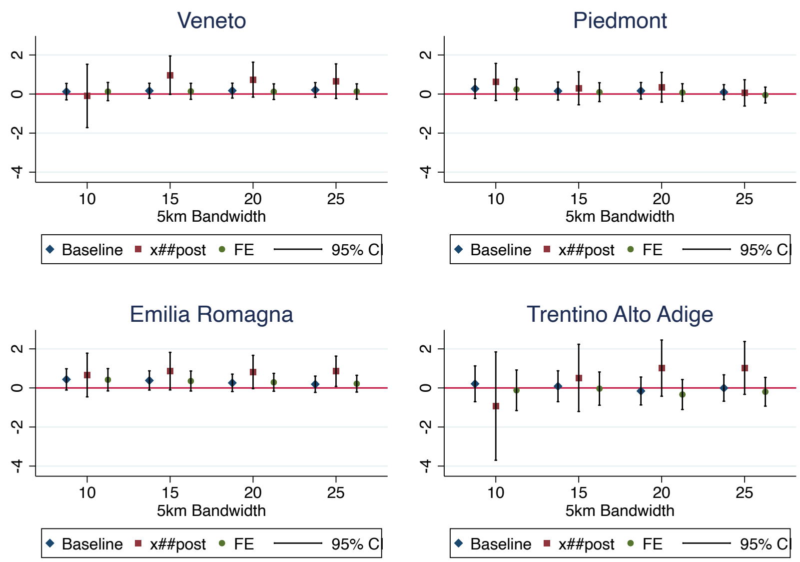
[15] This is the implicit assumption of studies which use as the dependent variable the excess mortality of 2020 compared to the 2015-2019 average and regress it on covariates measured in 2020 or 2019 (e.g. Alacevich et al., 2021). Indeed if we specify baseline average (2015-2019) mortality as $y_b = \boldsymbol{\beta_b}\mathbf{X} + \epsilon_b$ and the mortality in 2020 as $y_{2020} = \boldsymbol{\beta_{2020}}\mathbf{X} + \epsilon_{2020}$, where the covariates X are measured in 2020 (or assumed time-invariant), after taking the difference we gets $\Delta y_{2020,b} = (\boldsymbol{\beta_{2020}} - \boldsymbol{\beta_b})\mathbf{X} + (\epsilon_{2020} - \epsilon_b)$. Thus, the coefficients of the time-differenced regression measure the change in the effect of the regressors on mortality compared to the baseline period (not affected by Covid-19). It is worth noting the time differencing removes any time-invariant unobservable, a point which we address below.

Figure 14: Sensitivity to time variant covariates' effects and inclusion of Municipality FEs for 81+ population—first semester



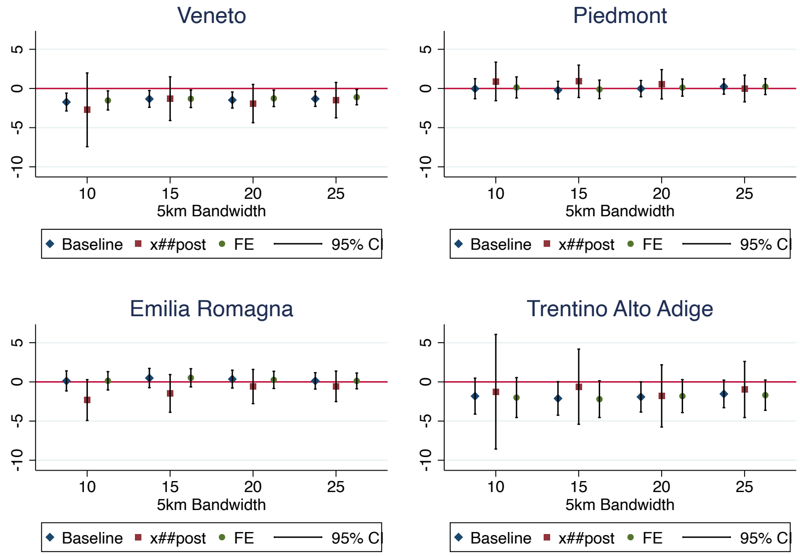
Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated on the horizontal axis allowing for time-varying covariates' effects or including municipality fixed effects..

Figure 15: Sensitivity to time variant covariates' effects and inclusion of Municipality FEs for 71-80 population — first semester



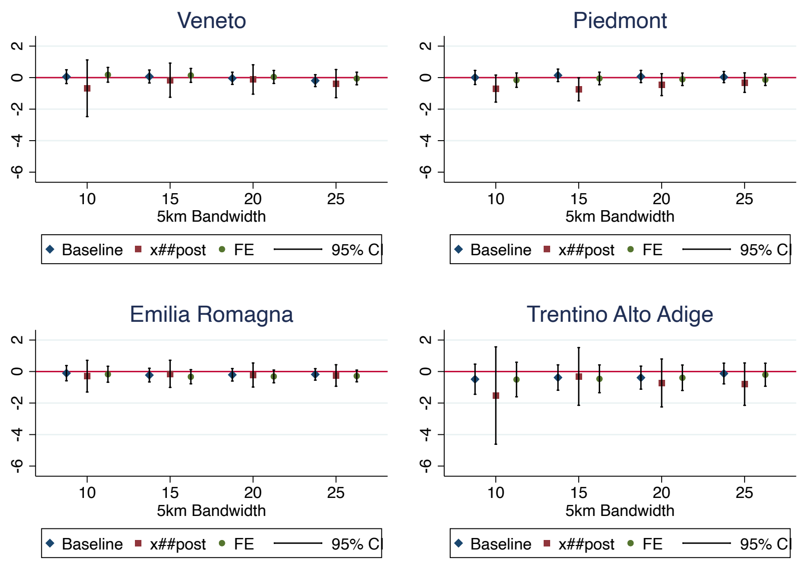
Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated on the horizontal axis allowing for time-varying covariates' effects or including municipality fixed effects..

Figure 16: Sensitivity to time variant covariates' effects and inclusion of Municipality FEs for 81+ population — second semester



Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated on the horizontal axis allowing for time-varying covariates' effects or including municipality fixed effects..

Figure 17: Sensitivity to time variant covariates' effects and inclusion of Municipality FEs for 71-80 population — second semester



Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated on the horizontal axis allowing for time-varying covariates' effects or including municipality fixed effects..

only focused on Lombardy but all five regions included in our analysis. Consistently with our DiD-GRDD strategy, we included in the estimated model of equation (1) an interaction term between a dummy for hosting nursing and care homes and the $Lombardy_i$, $post_t$, and the $Lombardy_i \times post_t$ indicators. The first and the second interactions capture potential underlying regional differences in mortality related to the presence of nursing and care homes in Lombardy at the baseline, or for all regions in the post-Covid-19 period, respectively, while the last interaction captures differential mortality in Lombardy's municipalities hosting nursing and care homes in the post-Covid-19 period. Table 5 reports the baseline DiD-GRDD coefficient ($Lombardy_i \times post_t$) along with its interaction with the nursing and care homes indicator.

As for the first wave, we observed differential mortality in Lombardy for municipalities hosting nursing and care homes in the post-Covid-19 period concerning Emilia-Romagna. The mortality premium ranges between 1.8 and 2.5 pp depending on the distance bandwidth. Interestingly enough, after including the nursing and care homes interaction, the baseline $Lombardy_i \times post_t$ coefficient, albeit positive, ceases to be statistically significant. We found similar results for the Lombardy vs. Veneto comparison: a positive interaction between nursing and care homes and the DiD-GRDD coefficient was estimated, ranging between 1.3 and 1.5 pp. while the baseline coefficient was not statistically significant. By contrast, the same was not observed when comparing Lombardy with Piedmont: the interaction between $Lombardy_i \times post_t$ and nursing and care homes was never statistically significant while the baseline coefficient remained virtually unchanged. Last, comparing Lombardy with Trentino Alto Adige, the interaction term with nursing and care homes appears to be negative. Overall, these results point to better management of care homes in the first Covid-19 wave for Emilia-Romagna and Veneto compared to Lombardy. After we accounted for such differences, the mortality gap at the border was explained away. By contrast, Piedmont seems to have had similar problems to Lombardy and Trentino Alto Adige to have performed worse.

As for the second wave, nursing and care homes did not play the same role observed in the first wave. Table 5, in the last four columns, shows that coefficients for the triple interaction are non-significant regardless of the bandwidth choice. We put forward that the dramatic experience of the first wave led to several improvements in the management of the health emergency (e.g. avoiding any transfer of Covid-19 patients from hospitals), in particular in the nursing and care homes with massive adoption of individual protection devices and a clear separation of care home patients affected by Covid-19 and other patients.

Finally, we repeated the same type of analysis to see if other factors (other than the number of nursing and care homes) may be potentially responsible for the observed differences in mortality. We then added two additional triple interactions to our specification, one for the per-capita number of hospital ordinary beds and one for the per-capita number of beds in ICUs available at the municipality level. However, results showed the estimated coefficient of these interactions was not statistically different from zero, excluding the role of these structural characteristics of the RHS in explaining the observed mortality differences among the considered pairs of regions.[16]

7 Discussion and concluding remarks

The analysis in this paper demonstrates that Northern Italy's municipalities located in geographical areas that should be broadly subject to the same virus diffusion, environmental factors (e.g. humidity, wind speed and pollution levels), labour market, socio-economic conditions, demographic

[16] Results available upon request.

Table 5: Robustness check: DiD-GRDD with triple interactions—age class 81+

	First Wave				Second Wave			
Bandwidth	10km	15km	20km	25km	10km	15km	20km	25km
Piedmont								
Lomb#Post	1.465*	1.549**	1.058*	0.987*	0.0919	-0.106	0.214	0.534
	(0.827)	(0.703)	(0.631)	(0.569)	(0.795)	(0.669)	(0.598)	(0.549)
Lomb#Post#Care_homes	-0.136	0.257	0.298	0.155	-0.242	-0.160	-0.454	-0.636
	(0.929)	(0.763)	(0.674)	(0.605)	(0.893)	(0.726)	(0.639)	(0.584)
Trentino Alto Adige								
Lomb#Post	-0.434	0.617	0.768	-0.372	-1.570	-1.658	-1.811*	-1.410
	(1.467)	(1.264)	(1.122)	(1.034)	(1.314)	(1.192)	(1.062)	(0.956)
Lomb#Post#Care_homes	-2.711	-2.998**	-2.707**	-1.837*	-0.658	-1.235	-0.544	-0.486
	(1.839)	(1.490)	(1.254)	(1.113)	(1.647)	(1.405)	(1.187)	(1.029)
Veneto								
Lomb#Post	0.680	0.710	0.375	0.376	-1.963***	-1.702***	-1.541***	-1.422***
	(0.751)	(0.665)	(0.628)	(0.609)	(0.687)	(0.628)	(0.590)	(0.550)
Lomb#Post#Care_homes	0.882	1.349*	1.382**	1.462**	0.277	0.364	-0.168	-0.0214
	(0.940)	(0.778)	(0.699)	(0.660)	(0.860)	(0.735)	(0.656)	(0.596)
Emilia Romagna								
Lomb#Post	0.565	1.089	0.788	0.626	1.130	1.415	1.253	0.971
	(1.233)	(1.098)	(0.960)	(0.873)	(0.993)	(0.918)	(0.832)	(0.755)
Lomb#Post#Care_homes	2.504**	1.839*	2.185**	1.996**	-0.971	-1.045	-1.275	-1.130
	(1.264)	(1.095)	(0.980)	(0.886)	(1.017)	(0.915)	(0.850)	(0.766)

Note. The table reports the coefficients on the $Lombardy_i \times Post_t$ (Lomb#Post) indicator and its interaction with an indicator for hosting nursing and care homes (Lomb#Post#Care_homes), obtained using the DiD-GRDD models estimated on samples including Lombardy and each other region at the time. Estimates are presented for municipalities within different bandwidths around the Lombardy's border.

and epidemiological characteristics of the resident populations and similar mobility levels both before and during the lockdown (Figures A6, A7 and A8 in Appendix) but were ruled by different regional administrations, experienced different mortality rates during the 2020 Covid-19 pandemic. Our DiD-GRDD-based comparison accounts for baseline differences in mortality rates among the selected areas during the years preceding the pandemic (2017–2019), allowing us to estimate the deviations in mortality rates with respect to this baseline.

In the first semester of 2020, the impact of the regional pandemic management system adopted in Lombardy was shown to be responsible for a 1–2 pp excess in mortality rates at the border with respect to the previous years compared to neighbouring regions. Such an effect, which was only observed for the 81+ age group, is statistically significant and similar in magnitude across different bandwidths of the DiD-GRDD estimates for all comparisons with the other regions but Trentino Alto Adige (for which mortality among municipalities is not statistically different from the one experienced in Lombardy). Results were robust with respect to many placebo tests and a robustness analysis as well as to an event-study model, which confirms the validity of the parallel trend assumption (key for DiD-GRDD) for all regional pair comparisons but Trentino Alto Adige.

An interpretation of these results is that differences between the Lombardy region and the bordering regions derive from the former's poor management of the pandemic during the first emergency phase. If there were any relevant pre-existing systematic differences among the regional healthcare systems, in turn leading to differential mortality across regions, they remained constant during the years before 2020 as suggested by the event-study analysis. Results of a robustness analysis carried out including interaction terms between some structural differences among the different regional health systems (described in detail in Section 2) and our treatment effect showed they were not able to fully explain away the differences in mortality rates estimated in our baseline model. Significant, and sometimes even larger, differences remained across regions. In other words, past regional governments' decisions that were crystallised into the characteristics of the health systems could not fully explain the differential mortality, demonstrating how current decisions also made a difference.

Moreover, when the presence of nursing and care homes at the municipal level was included in the model via a triple interaction, the mortality gap in Lombardy during the first wave completely disappears. This proves how decisions regarding the management of nursing and care homes (both at the central level and *in loco*) had a crucial role in explaining the observed differences among regions. Indeed, the first reaction to an unprecedented pandemic outbreak required an immediate ability to act under scarce information and be able to implement and quickly scale successful and effective decision-making strategies. This proved to be difficult in Lombardy during the first Covid-19 wave. In this respect, a system traditionally organised to deliver patient-centred care might have been outperformed in the first wave by the ones of closer regions that were more community-focused and less hospital-centred, as explained in Section 2.

However, the same healthcare system in Lombardy recovered after the first wave and exhibited similar performance to the other regions right after the emergency phase of the pandemic (i.e. in the second semester of 2020). On the one hand, the implementation of national-level policies based on risk zones may have partly contributed to the convergence observed during the second wave, which cannot be straightforwardly interpreted as Lombardy's government outperforming those of neighbouring regions during the second wave. On the other hand, evidence suggests that Lombardy gained ground on a region that was subjected to similar levels of national restrictions, namely Piedmont, which points to clear relative improvement of the pandemic management by

Lombardy during the second wave. This also may explain the non-significant role of care homes in the second wave.

Policy recommendations then point in the direction of strengthening emergency epidemic preparedness plans – which proved to be difficult in Lombardy – to be adopted in the very first phases of future epidemics in all regions/countries to ensure early warning and detection systems are always in place and ready to be implemented. These emergency plans may include scalable everyday systems, reserve corps of trained medical personnel and volunteers, a reserve of ICU beds and post-discharge beds in appropriate care centres as well as the prompt availability of emergency equipment, as already suggested after the Ebola epidemic (Gates, 2015).

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References

Alacevich, C., N. Cavalli, O. Giuntella, R. Lagravinese, F. Moscone, and C. Nicodemo (2021). The presence of care homes and excess deaths during the COVID-19 pandemic: Evidence from Italy. *Health Economics 30*(7), 1703–1710.

Arcà, E., F. Principe, and E. Van Doorslaer (2020). Death by austerity? The impact of cost containment on avoidable mortality in Italy. *Health economics 29*(12), 1500–1516.

Bailey, D., J. Clark, A. Colombelli, C. Corradini, L. D. Propris, B. Derudder, U. Fratesi, M. Fritsch, J. Harrison, M. Hatfield, T. Kemeny, D. F. Kogler, A. Lagendijk, P. Lawton, R. Ortega-Argilés, C. I. Otero, and S. Usai (2020). Regions in a time of pandemic. *Regional Studies 54*(9), 1163–1174.

Barbazza, E. and J. Tello (2014). A review of health governance: definitions, dimensions and tools to govern. *Health Policy 16*(1), 1–11.

Bartoszek, K., E. Guidotti, S. M. Iacus, and M. Okrój (2020). Are official confirmed cases and fatalities counts good enough to study the COVID-19 pandemic dynamics? A critical assessment through the case of Italy. *arXiv preprint arXiv:2005.07271*.

Becchetti, L., G. Conzo, P. Conzo, and F. Salustri (2020). Understanding the heterogeneity of adverse COVID-19 outcomes: the role of poor quality of air and lockdown decisions. *Available at SSRN 3572548*.

Berta, P., C. Seghieri, and G. Vittadini (2013). Comparing health outcomes among hospitals: The experience of the Lombardy Region. *Health Care Management Science 16*(3), 245–257.

Bertuzzo, E., L. Mari, D. Pasetto, S. Miccoli, R. Casagrandi, M. Gatto, and A. Rinaldo (2020). The geography of COVID-19 spread in Italy and implications for the relaxation of confinement measures. *Nature Communications 11*(1), 1–11.

Binkin, N., S. Salmaso, F. Michieletto, and F. Russo (2020). Protecting our health care workers while protecting our communities during the COVID-19 pandemic: A comparison of approaches and early outcomes in two Italian regions, Italy, 2020. *medRxiv*.

Bobini, M., G. Cinelli, M. del Vecchio, and F. Longo (2020). *Regioni e Aziende: modelli di coordinamento a confronto*, Chapter 8, pp. 347–378. Collana CERGAS.

Buonanno, P., S. Galletta, and M. Puca (2020). Estimating the severity of COVID-19: Evidence from the Italian epicenter. *Plos One 15*(10), e0239569.

Carrell, S. E., M. Hoekstra, and E. Kuka (2018, November). The long-run effects of disruptive peers. *American Economic Review 108*(11), 3377–3415.

Cartenì, A., L. Di Francesco, and M. Martino (2020). How mobility habits influenced the spread of the COVID-19 pandemic: Results from the Italian case study. *Science of the Total Environment 741*, 140489.

Castaldi, S., E. Luconi, B. A. Rivieccio, P. Boracchi, G. Marano, E. Pariani, L. Romano, F. Auxilia, F. Nicolussi, A. Micheletti, et al. (2021). Are epidemiological estimates able to describe the ability of health systems to cope with COVID-19 epidemic? *Risk Management and Healthcare Policy 14*, 2221.

Ceccarelli, G., G. d'Ettorre, G. P. Innocenti, C. M. Mastroianni, M. Ciccozzi, and G. d'Ettorre (2020). Is previous influenza-like illness a potential Trojan horse for COVID-19? *Critical care 24*(1), 1–2.

Chernozhukov, V., H. Kasahara, and P. Schrimpf (2021). Causal impact of masks, policies, behavior on early covid-19 pandemic in the US. *Journal of Econometrics 220*(1), 23–62.

Ciminelli, G. and S. Garcia-Mandicó (2020). Mitigation policies and emergency care management in Europe's Ground Zero for COVID-19. *Available at SSRN 3604688*.

Clark, E., K. Fredricks, L. Woc-Colburn, M. E. Bottazzi, and J. Weatherhead (2020). Disproportionate impact of the COVID-19 pandemic on immigrant communities in the United States. *PLoS Neglected Tropical Diseases 14*(7), e0008484.

Coker, E. S., L. Cavalli, E. Fabrizi, G. Guastella, E. Lippo, M. L. Parisi, N. Pontarollo, M. Rizzati, A. Varacca, and S. Vergalli (2020). The effects of air pollution on covid-19 related mortality in northern italy. *Environmental and Resource Economics 76*(4), 611–634.

Dell, M. (2010). The persistent effects of Peru's mining mita. *Econometrica 78*(6), 1863–1903.

Drefahl, S., M. Wallace, E. Mussino, S. Aradhya, M. Kolk, M. Brandén, B. Malmberg, and G. Andersson (2020). A population-based cohort study of socio-demographic risk factors for COVID-19 deaths in Sweden. *Nature communications 11*(1), 1–7.

Flaxman, S., S. Mishra, A. Gandy, H. J. T. Unwin, T. A. Mellan, H. Coupland, C. Whittaker, H. Zhu, T. Berah, J. W. Eaton, et al. (2020). Estimating the effects of non-pharmaceutical interventions on COVID-19 in Europe. *Nature 584*(7820), 257–261.

France, G., F. Taroni, and A. Donatini (2005). The Italian health-care system. *Health Economics 14*(S1), S187–S202.

Gates, B. (2015). The next epidemic—lessons from Ebola. *New England Journal of Medicine 372*(15), 1381–1384.

Gibertoni, D., K. Y. C. Adja, D. Golinelli, C. Reno, L. Regazzi, J. Lenzi, F. Sanmarchi, and M. P. Fantini (2021). Patterns of COVID-19 related excess mortality in the municipalities of northern italy during the first wave of the pandemic. *Health & Place 67*, 102508.

Godøy, A. and I. Huitfeldt (2020). Regional variation in health care utilization and mortality. *Journal of Health Economics 71*, 102254.

Green, I., S. Ashkenazi, E. Merzon, S. Vinker, and A. Golan-Cohen (2021). The association of previous influenza vaccination and coronavirus disease-2019. *Human Vaccines & Immunotherapeutics*, 1–7.

Grembi, V., T. Nannicini, and U. Troiano (2016). Do fiscal rules matter? *American Economic Journal: Applied Economics 8*(3), 1–30.

Hadjidemetriou, G. M., M. Sasidharan, G. Kouyialis, and A. K. Parlikad (2020). The impact of government measures and human mobility trend on COVID-19 related deaths in the UK. *Transportation Research Interdisciplinary Perspectives 6*, 100167.

Hersbach, H., B. Bell, P. Berrisford, S. Hirahara, A. Horányi, J. Muñoz-Sabater, J. Nicolas, C. Peubey, R. Radu, D. Schepers, A. Simmons, C. Soci, S. Abdalla, X. Abellan, G. Balsamo, P. Bechtold, G. Biavati, J. Bidlot, M. Bonavita, G. De Chiara, P. Dahlgren, D. Dee, M. Diamantakis, R. Dragani, J. Flemming, R. Forbes, M. Fuentes, A. Geer, L. Haimberger, S. Healy, R. J. Hogan, E. Hólm, M. Janisková, S. Keeley, P. Laloyaux, P. Lopez, C. Lupu, G. Radnoti, P. de Rosnay, I. Rozum, F. Vamborg, S. Villaume, and J.-N. Thépaut (2020). The ERA5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society 146*(730), 1999–2049.

Hsiang, S., D. Allen, S. Annan-Phan, K. Bell, I. Bolliger, T. Chong, H. Druckenmiller, L. Y. Huang, A. Hultgren, E. Krasovich, et al. (2020). The effect of large-scale anti-contagion policies on the COVID-19 pandemic. *Nature 584*(7820), 262–267.

Iacus, S. M., F. Sermi, S. Spyratos, D. Tarchi, and M. Vespe (2021). Anomaly detection of mobile positioning data with applications to covid-19 situational awareness. *Japanese Journal of Statistics and Data Science*, 1–19.

Inness, A., M. Ades, A. Agustí-Panareda, J. Barré, A. Benedictow, A.-M. Blechschmidt, J. J. Dominguez, R. Engelen, H. Eskes, J. Flemming, V. Huijnen, L. Jones, Z. Kipling, S. Massart, M. Parrington, V.-H. Peuch, M. Razinger, S. Remy, M. Schulz, and M. Suttie (2019). The CAMS reanalysis of atmospheric composition. *Atmospheric Chemistry and Physics 19*(6), 3515–3556.

Jordan, R. E., P. Adab, and K. Cheng (2020). Covid-19: risk factors for severe disease and death.

Karaivanov, A., S. E. Lu, H. Shigeoka, C. Chen, and S. Pamplona (2021). Face masks, public policies and slowing the spread of COVID-19: Evidence from Canada. *Journal of Health Economics*, 102475.

Lau, H., V. Khosrawipour, P. Kocbach, A. Mikolajczyk, J. Schubert, J. Bania, and T. Khosrawipour (2020). The positive impact of lockdown in Wuhan on containing the COVID-19 outbreak in China. *Journal of Travel Medicine 27*(3), taaa037.

Lin, Z. (2021). Analysis of hospital resource availability and COVID-19 mortality across the United States. *Journal of Hospital Medicine 16*(4), 211–214.

Ma, Y., Y. Zhao, J. Liu, X. He, B. Wang, S. Fu, J. Yan, J. Niu, J. Zhou, and B. Luo (2020). Effects of temperature variation and humidity on the death of COVID-19 in Wuhan, China. *Science of The Total Environment*, 138226.

Manica, M., G. Guzzetta, F. Riccardo, A. Valenti, P. Poletti, V. Marziano, F. Trentini, X. Andrianou, A. M. Urdiales, M. Del Manso, et al. (2021). Effectiveness of regional restrictions in reducing SARS-CoV- transmission during the second wave of covid-19, italy. *medRxiv*.

Mays, G. P. and S. A. Smith (2011). Evidence links increases in public health spending to declines in preventable deaths. *Health Affairs 30*(8), 1585–1593.

Mesas, A. E., I. Cavero-Redondo, C. Álvarez-Bueno, M. A. Sarriá Cabrera, S. Maffei de Andrade, I. Sequí-Dominguez, and V. Martínez-Vizcaíno (2020). Predictors of in-hospital COVID-19 mortality: A comprehensive systematic review and meta-analysis exploring differences by age, sex and health conditions. *PloS One 15*(11), e0241742.

Neri, S. (2011). *Health Studies: Economic, Management and Policy*, Chapter The Evolution of Regional Health Services and the New Governance of the NHS in Italy, pp. 269 – 282. Athens: Atiner.

Nuti, S., F. Vola, A. Bonini, and M. Vainieri (2016). Making governance work in the health care sector: evidence from a 'natural experiment' in Italy. *Health Economics, Policy and Law 11*(1), 17–38.

OECD (2020). Beyond containment: Health systems responses to covid-19 in the oecd. Technical report, OECD Policy Responses to Coronavirus (COVID-19).

OECD (2021). Strengthening the frontline: How primary health care helps health systems adapt during the covid 19 pandemic. Technical report, OECD Policy Responses to Coronavirus (COVID-19).

Onder, G., G. Rezza, and S. Brusaferro (2020). Case-fatality rate and characteristics of patients dying in relation to COVID-19 in Italy. *Jama 323*(18), 1775–1776.

Pisano, G. P., R. Sadun, and M. Zanini (2020). Lessons from Italy's response to coronavirus. *Harvard Business Review 27*, https://hbr.org/2020/03/lessons--from--italys--response--to--coronavirus.

Qiu, Y., X. Chen, and W. Shi (2020). Impacts of social and economic factors on the transmission of coronavirus disease 2019 (COVID-19) in China. *Journal of Population Economics 33*(4), 1127–1172.

Rhodes, R. A. W. (1997). *Understanding governance : policy networks, governance, reflexivity, and accountability / R.A.W. Rhodes.* Open University Press Buckingham ; Philadephia.

Robilotti, E. V., N. E. Babady, P. A. Mead, T. Rolling, R. Perez-Johnston, M. Bernardes, Y. Bogler, M. Caldararo, C. J. F. Ortiz, M. S. Glickman, et al. (2020). Determinants of severity in cancer patients with COVID-19 illness. *Nature Medicine 26*(8), 1218.

Rosenbaum, L. (2020). The untold toll — the pandemic's effects on patients without Covid-19. *New England Journal of Medicine 382*(24), 2368–2371.

Santamaria, C., F. Sermi, S. Spyratos, S. M. Iacus, A. Annunziato, D. Tarchi, and M. Vespe (2020). Measuring the impact of COVID-19 confinement measures on human mobility using mobile positioning data. a European regional analysis. *Safety Science 132*, 104925.

Tediosi, F., S. Gabriele, and F. Longo (2009). Governing decentralization in health care under tough budget constraint: What can we learn from the Italian experience? *Health Policy 90*(2), 303–312.

Tobías, A. (2020). Evaluation of the lockdowns for the SARS-CoV-2 epidemic in Italy and Spain after one month follow up. *Science of the Total Environment*, 138539.

Usuelli, M. (2020). The Lombardy region of Italy launches the first investigative COVID-19 commission. *The Lancet 396*(10262), e86–e87.

van Lerberghe, W., Z. Matthews, E. Achadi, C. Ancona, J. Campbell, A. Channon, L. De Bernis, V. De Brouwere, V. Fauveau, H. Fogstad, et al. (2014). Country experience with strengthening of health systems and deployment of midwives in countries with high maternal mortality. *The Lancet 384*(9949), 1215–1225.

Vespe, M., U. Minora, S. M. Iacus, S. Spyratos, F. Sermi, M. Fontana, B. Ciuffo, and P. Christidis (2021). Mobility and economic impact of COVID-19 restrictions in Italy using mobile network operator data. *arXiv preprint arXiv:2106.00460*.

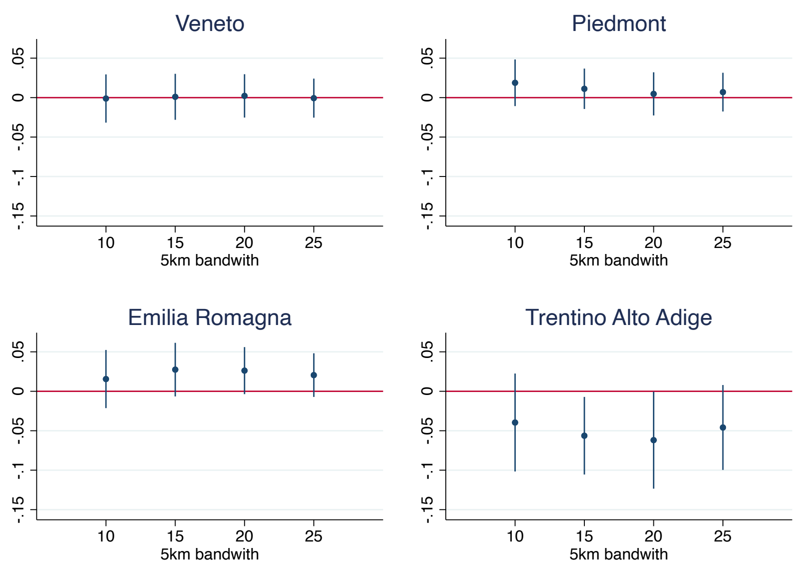
Wood, R. M., C. J. McWilliams, M. J. Thomas, C. P. Bourdeaux, and C. Vasilakis (2020). COVID-19 scenario modelling for the mitigation of capacity-dependent deaths in intensive care. *Health Care Management Science 23*(3), 315–324.

Wu, X., R. C. Nethery, B. M. Sabath, D. Braun, and F. Dominici (2020). Exposure to air pollution and COVID-19 mortality in the United States. *MedRxiv*.

Zheng, Z., F. Peng, B. Xu, J. Zhao, H. Liu, J. Peng, Q. Li, C. Jiang, Y. Zhou, S. Liu, et al. (2020). Risk factors of critical & mortal covid-19 cases: A systematic literature review and meta-analysis. *Journal of Infection 81*(2), e16–e25.

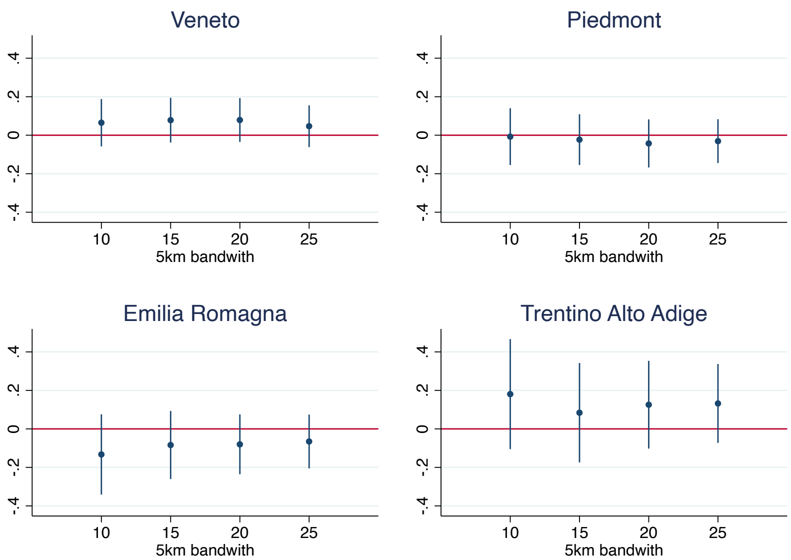
A Appendix: Additional figures

Figure A1: DiD-GRDD impact on mortality rates of age 0-50 population — first semester



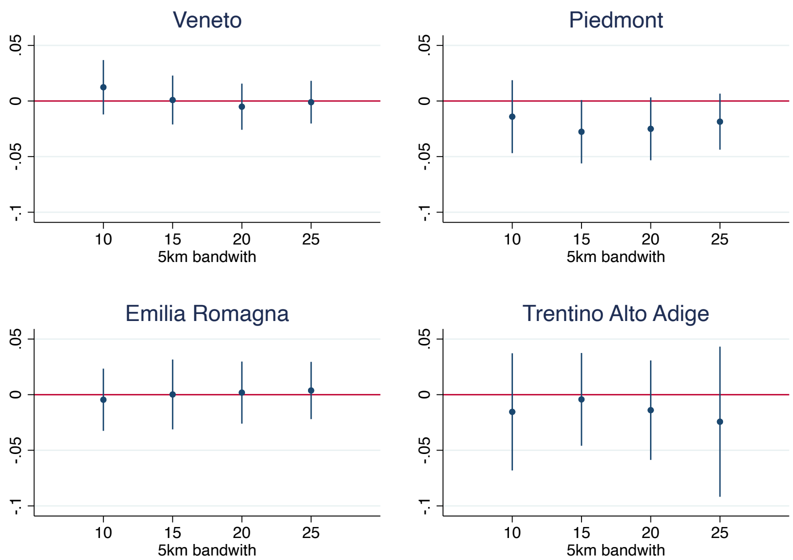
Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated in the horizontal axis.

Figure A2: DiD-GRDD impact on mortality rates of age 51-70 population — first semester



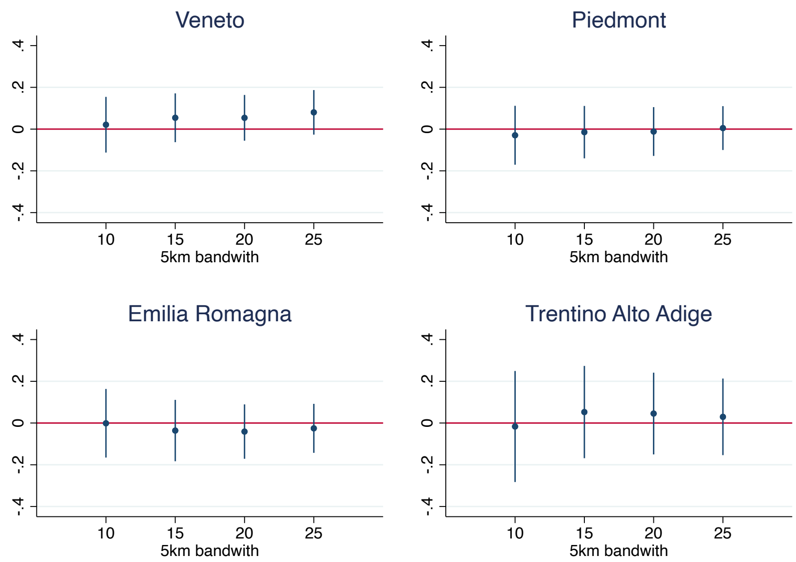
Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated in the horizontal axis.

Figure A3: DiD-GRDD impact on mortality rates of age 0-50 population — second semester



Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated in the horizontal axis.

Figure A4: DiD-GRDD impact on mortality rates of age 51-70 population — second semester



Note. Plots of the coefficients (points) and confidence intervals (bars) of the DiD-GRDD estimates obtained with different distance bandwidths (in km.) from the administrative border indicated in the horizontal axis.

Figure A5: Mobility patterns over time in 2020

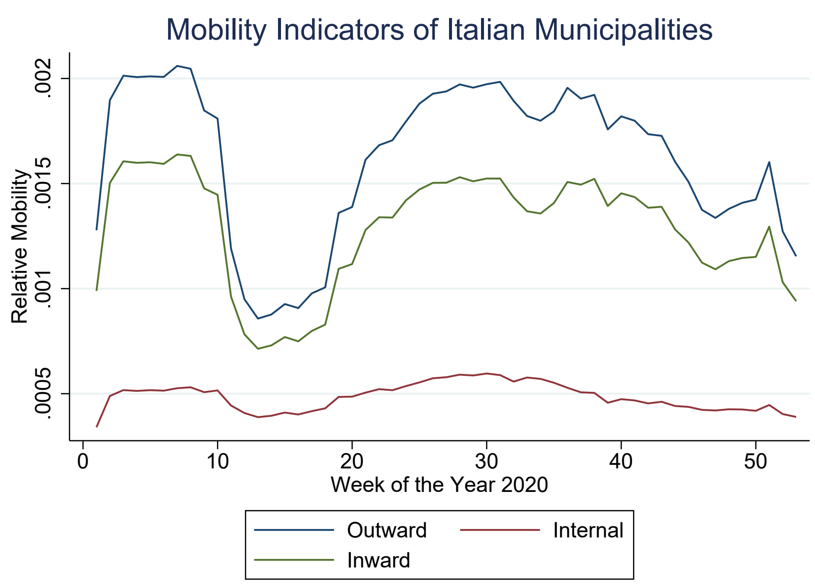


Figure A6: Mobility patterns—pre Lockdown

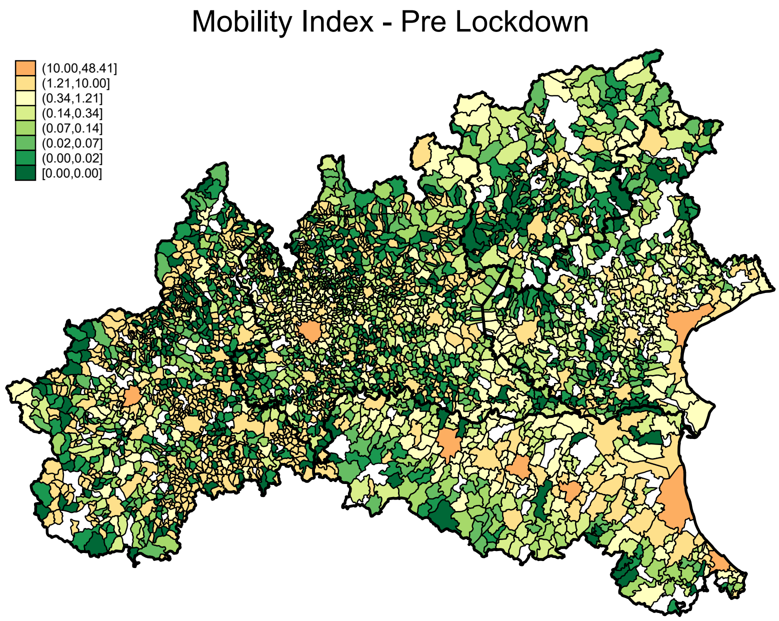


Figure A7: Mobility patterns during lockdown

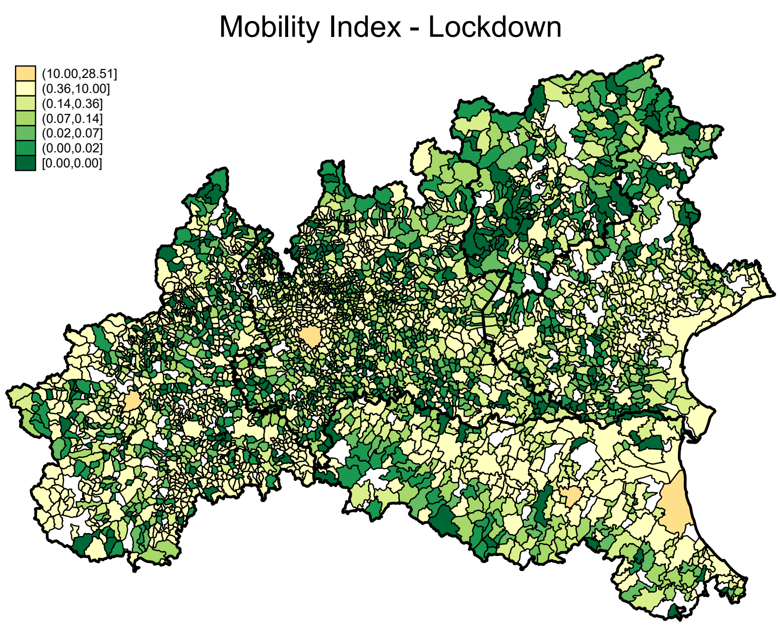


Figure A8: Mobility patterns—lockdown reduction

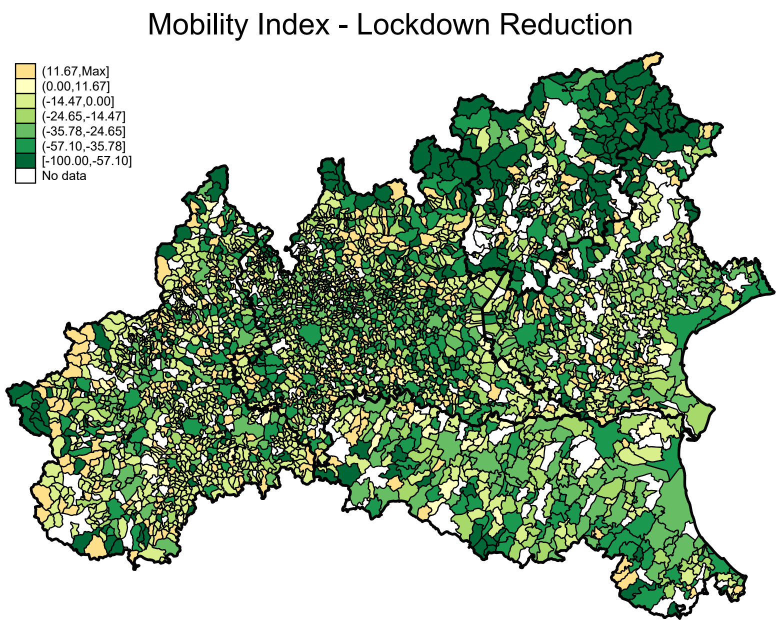


Table A1: Descriptive Statistics

	Lombardy				Piedmont				Trentino Alto Adige				Emilia Romagna				Veneto			
	2017-2019		2020		2017-2019		2020		2017-2019		2020		2017-2019		2020		2017-2019		2020	
	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
Mortality overall*100,000 inab	0.555	0.309	0.659	0.333	0.725	0.422	0.897	0.513	0.473	0.244	0.577	0.273	0.621	0.318	0.682	0.289	0.517	0.197	0.657	0.221
Mortality 0-50ys*100,000 inab	0.023	0.079	0.026	0.064	0.027	0.092	0.035	0.111	0.026	0.078	0.022	0.059	0.027	0.044	0.023	0.034	0.022	0.039	0.022	0.048
Mortality 51-70ys*100,000 inab	0.264	0.275	0.297	0.310	0.292	0.398	0.345	0.441	0.259	0.276	0.222	0.221	0.263	0.275	0.277	0.249	0.262	0.182	0.255	0.188
Mortality 71-80ys*100,000 inab	1.139	0.947	1.289	1.012	1.183	1.329	1.368	1.364	1.055	1.040	1.149	1.065	1.086	0.658	1.164	0.493	1.018	0.607	1.265	0.729
Mortality 81+ys*100,000 inab	5.415	2.750	6.255	3.095	5.937	3.464	7.132	3.944	4.869	2.582	6.288	3.254	5.385	1.363	5.969	1.507	5.247	1.823	6.817	1.991
% of population in age class 51-60	0.154	0.016	0.161	0.016	0.160	0.020	0.167	0.020	0.153	0.015	0.158	0.018	0.150	0.011	0.156	0.011	0.154	0.015	0.159	0.014
% of population in age class 61-70	0.126	0.019	0.127	0.019	0.137	0.019	0.138	0.019	0.122	0.021	0.126	0.021	0.123	0.019	0.124	0.019	0.126	0.018	0.129	0.020
% of population in age class 71-80	0.096	0.019	0.100	0.019	0.111	0.022	0.115	0.022	0.087	0.014	0.091	0.016	0.100	0.025	0.104	0.025	0.092	0.014	0.096	0.014
% of population in age class 81+	0.065	0.023	0.069	0.024	0.082	0.024	0.086	0.023	0.059	0.015	0.062	0.014	0.078	0.037	0.081	0.036	0.063	0.015	0.066	0.016
% of migrant citizens	0.088	0.044	0.087	0.043	0.068	0.038	0.067	0.037	0.065	0.033	0.065	0.031	0.113	0.036	0.114	0.037	0.096	0.032	0.096	0.031
Population density	408.750	663.584	403.993	659.136	127.223	156.034	124.640	153.524	97.235	142.569	98.015	145.293	207.165	178.008	204.956	178.944	230.693	237.002	229.724	237.790
Hospitalization rate for COPD	1.800	0.282	1.677	0.284	1.311	0.239	1.441	0.254	1.403	0.154	1.427	0.116	2.530	0.367	2.362	0.203	1.590	0.179	1.547	0.139
Hospitalization rate for influenza	0.136	0.070	0.128	0.062	0.082	0.061	0.093	0.060	0.204	0.233	0.319	0.245	0.166	0.084	0.162	0.079	0.072	0.085	0.090	0.103
Relative Humidity Jan-Mar	-0.356	0.678	-0.410	0.640	-0.495	0.633	-0.483	0.827	-1.664	0.957	-1.713	0.542	-0.074	0.525	0.267	0.141	-0.244	0.301	0.013	0.363
Temperature at 2mt Jan-Mar	-0.136	0.785	-0.180	0.795	-0.242	0.496	-0.267	0.481	-2.068	1.208	-2.112	1.259	0.141	0.263	0.162	0.227	0.200	0.236	0.183	0.214
Total precipitations Jan-Mar	-0.776	0.517	-0.601	0.625	-0.186	1.074	-0.186	0.832	-0.566	0.505	0.467	0.472	-0.919	0.525	-0.980	0.666	-1.026	0.226	-1.031	0.394
Wind Speed Jan-Mar	-0.415	0.521	-0.487	0.712	-0.409	0.473	-0.337	0.499	-0.670	0.647	-0.587	0.684	-0.535	0.513	-0.873	0.306	-0.037	0.869	-0.568	0.392
Relative Humidity Apr-Jun	-0.491	0.912	-0.829	0.936	-0.240	0.659	0.009	0.447	0.885	0.589	0.632	0.369	-1.098	0.722	-1.641	0.740	-0.672	0.455	-1.529	0.696
Temperature at 2mt Apr-Jun	0.288	0.962	0.361	0.986	0.028	0.727	0.066	0.691	-2.074	1.164	-2.040	1.211	0.678	0.518	0.696	0.512	0.766	0.427	0.805	0.447
Total precipitations Apr-Jun	0.465	0.729	0.345	0.796	0.824	1.181	0.889	1.168	1.199	0.633	1.159	0.500	-0.299	0.350	-0.676	0.377	0.068	0.380	-0.388	0.395
Wind Speed Apr-Jun	-0.209	0.600	-0.236	0.489	0.055	0.709	-0.064	0.866	-1.026	0.288	-0.532	0.178	-0.101	0.599	0.223	0.357	0.861	0.984	0.678	0.801
Relative Humidity Jul-Sep	0.092	0.764	0.211	0.695	0.129	0.689	0.233	0.534	1.457	0.372	1.479	0.267	-0.387	0.629	-0.274	0.638	-0.161	0.326	-0.137	0.367
Temperature at 2mt Jul-Sep	0.129	0.910	0.091	0.900	-0.084	0.716	-0.129	0.696	-2.176	1.028	-2.186	0.982	0.503	0.500	0.456	0.503	0.576	0.395	0.537	0.409
Total precipitations Jul-Sep	0.411	0.604	0.643	0.666	0.436	1.228	0.504	1.114	1.783	0.773	2.027	0.691	0.096	0.295	-0.080	0.292	0.411	0.306	0.533	0.318
Wind Speed Jul-Sep	-0.243	0.472	-0.268	0.413	-0.112	0.618	-0.232	0.508	-0.852	0.216	-0.865	0.166	-0.372	0.478	-0.333	0.487	0.442	0.941	0.527	0.864
Relative Humidity Oct-Dec	0.246	0.749	0.601	0.676	0.037	0.652	0.229	0.795	-0.881	0.977	-1.066	1.131	0.828	0.528	0.802	0.570	0.296	0.816	0.388	0.242
Temperature at 2mt Oct-Dec	-0.222	0.692	-0.288	0.655	-0.395	0.480	-0.466	0.421	-1.959	1.060	-1.967	0.969	0.049	0.256	-0.007	0.287	0.167	0.217	0.130	0.233
Total precipitations Oct-Dec	-0.129	0.876	0.009	0.645	0.671	1.450	0.174	1.128	0.221	0.329	1.117	0.457	-0.646	0.651	-0.236	0.589	-0.755	0.493	0.051	0.456
Wind Speed Oct-Dec	-0.222	0.703	-0.742	0.697	0.003	0.704	-0.253	0.417	-0.833	0.554	-0.780	0.463	-0.634	0.505	-1.021	0.417	0.233	0.816	-0.021	0.493
Beds (per capita) in public hospitals	0.634	3.760	0.657	3.873	0.203	1.135	0.202	1.144	0.714	2.836	0.708	2.829	1.002	3.018	0.984	3.021	1.177	5.720	1.180	5.813
Beds (per capita) in ICU in public hospitals	0.009	0.073	0.010	0.077	0.005	0.032	0.005	0.032	0.005	0.031	0.005	0.030	0.018	0.074	0.018	0.073	0.032	0.177	0.032	0.178
Beds (per capita) in private hospitals	1.025	18.114	1.075	18.778	1.901	23.814	1.870	23.351	0.304	2.291	0.300	2.271	0.499	2.784	0.487	2.760	0.507	3.357	0.510	3.399
Per capita taxable income	20.633	3.065	20.957	3.070	20.135	2.741	20.469	2.844	19.121	2.063	19.557	2.099	20.951	2.138	21.318	2.123	18.723	2.126	19.066	2.104
Num of care homes	0.001	0.002	0.001	0.002	0.001	0.001	0.001	0.001	0.000	0.001	0.000	0.001	0.001	0.000	0.001	0.000	0.001	0.002	0.001	0.002
Particulate matter 2.5	18.355	4.150	18.355	4.152	14.689	3.377	14.689	3.380	9.454	2.942	9.454	2.953	16.867	2.467	16.867	2.474	19.462	1.985	19.462	1.990
Distance from airport	33.150	15.557	33.150	15.564	41.119	14.209	41.119	14.223	55.830	10.865	55.830	10.908	37.142	14.364	37.142	14.405	37.195	18.468	37.195	18.520
Distance from care homes	2.611	2.422	2.611	2.423	2.676	2.673	2.676	2.676	6.634	7.718	6.634	7.749	1.367	2.576	1.367	2.583	4.558	3.691	4.558	3.702
Distance from red zone	60.273	30.924	60.273	30.937	97.873	20.056	97.873	20.075	110.904	28.783	110.904	28.897	53.743	24.056	53.743	24.124	45.641	17.783	45.641	17.833
Size ICU in private hospitals	0.680	0.787	0.680	0.788	0.385	0.435	0.385	0.436	1.047	1.012	1.047	1.016	0.245	0.342	0.245	0.343	0.253	0.220	0.253	0.220
Size ICU in public hospitals	0.363	0.363	0.363	0.363	0.214	0.215	0.214	0.215	0.535	0.540	0.535	0.542	0.247	0.242	0.247	0.242	0.553	0.486	0.553	0.488
Size public hospitals	12.474	13.531	12.474	13.537	7.991	10.670	7.991	10.680	11.739	8.137	11.739	8.170	7.770	6.809	7.770	6.828	15.097	17.859	15.097	17.909
Size private hospitals	46.215	122.134	46.215	122.186	40.906	79.789	40.906	79.875	13.306	9.292	13.306	9.329	31.771	106.231	31.771	106.531	9.300	9.421	9.300	9.447
Distance from ICU in private hospital	28.893	15.317	28.893	15.323	46.285	11.855	46.285	11.867	67.632	27.327	67.632	27.436	35.445	18.589	35.445	18.641	26.278	10.913	26.278	10.944
Distance from ICU in public hospital	10.697	5.569	10.697	5.571	11.866	5.135	11.866	5.140	23.068	11.038	23.068	11.082	13.103	8.457	13.103	8.481	11.447	5.273	11.447	5.288
Distance from private hospital	13.797	11.254	13.797	11.258	11.405	5.788	11.405	5.794	21.726	13.242	21.726	13.294	14.184	7.686	14.184	7.708	16.354	8.653	16.354	8.678
Distance from public hospital	7.673	4.050	7.673	4.052	10.261	4.619	10.261	4.623	11.170	6.090	11.170	6.114	10.055	6.243	10.055	6.260	8.481	4.120	8.481	4.132

Note: For data sources and available years, please refer to table 3. For those variables not available in 2020, we proxied 2020 values using 2019.