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An empirical analysis of the effect of economic activity and COVID-19 restrictions on road traffic accidents in Italy

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Abstract

Road traffic accidents is one of the leading causes of death for the young segment of population. Prevention strategies can mitigate the occurrence of road accidents, and successful actions should take into account the most relevant causes of accidents. We use a comprehensive dataset which reports information from police records on all road traffic accidents with injures and/or deaths in Italy between 2014 and 2020 to explore the relationships among economic forces, driving behaviours and accident frequency and severity. More specifically, the natural experiment setting provided by the 2020 COVID-19-related movement restrictions allows to capture the effect of traffic intensity and other factors on the frequency of serious accidents and mortality. The empirical findings confirm a direct relationship between the level of economic activity and the frequency of accidents, whereas there is no clear link with their severity. Instead, lockdown periods are associated with a relatively higher occurrence of fatal road traffic accidents, due to both riskier driving behaviours at times of reduced traffic, and changes in transportation habits reflected by a higher probability of accidents involving bicycles and motorcycles.

JEL: R41, I12, I18

Keywords: Deaths, Mortality rates, Public Health, Accidents, Driving, COVID-19, Lockdown, Stay-at-home order.

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Abstract

Road traffic accidents is one of the leading causes of death for the young segment of population. Prevention strategies can mitigate the occurrence of road accidents, and successful actions should take into account the most relevant causes of accidents. We use a comprehensive dataset which reports information from police records on all road traffic accidents with injures and/or deaths in Italy between 2014 and 2020 to explore the relationships among economic forces, driving behaviours and accident frequency and severity. More specifically, the natural experiment setting provided by the 2020 COVID-19-related movement restrictions allows to capture the effect of traffic intensity and other factors on the frequency of serious accidents and mortality. The empirical findings confirm a direct relationship between the level of economic activity and the frequency of accidents, whereas there is no clear link with their severity. Instead, lockdown periods are associated with a relatively higher occurrence of fatal road traffic accidents, due to both riskier driving behaviours at times of reduced traffic, and changes in transportation habits reflected by a higher probability of accidents involving bicycles and motorcycles.

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1. Introduction

According to the latest available data by the Italian National Institute of Statistics (ISTAT), in Italy road traffic accidents (RTAs) accounted for 2,850 deaths in 2021. Although this figure is 30% lower compared to 2010, Italy remains one of the countries with most RTA-related deaths in Europe, second only to France in absolute terms, but with a higher mortality rate (49 per million population). Over the same period, deaths have decreased by 34% in the rest of the EU-27. RTAs remain the leading cause of death for Italians aged between 15 and 29, and account for 29% of deaths between 15 and 24 years of age. Considering deaths by accident only, RTAs account for 82% of these and represent the leading cause at all ages. A back-of-the-envelope and conservative estimate of the social costs of injuries and deaths caused by RTAs suggests a 2021 social cost around 14.5 billion euros, or 0.8% of the GDP[1]. After many years of declining figures, Italy has recorded 1,450 deaths in the first six months of 2022, a 15% increase relative to the same period in 2021, whereas the number of accidents rose by 25%, and injuries by 26%[2]. These numbers suggest that there is major room for improvement in road safety. In his 2022 New Year's eve speech, the Italian President of the Republic included an explicit appeal to younger drivers, calling for a reduction in the number of RTAs and casualties due to excess speed and driving under the influence.

The objective of this study is to investigate the relationship between RTAs in Italy and some economic determinants, namely the level of economic activity as proxied by the real household expenditure and labour force participation, and the cost of operation of personal transport equipment. These variables are known to influence traffic levels, hence RTAs. A unique opportunity to explore

[1]Official costs per RTA-related deaths and injuries were estimated in 2010 at 1.503 million euros per death and 42,219 euro per injury. These values were adjusted according to ISTAT inflation rates and applied to 2021 figures. See Ministero delle Infrastrutture e dei Trasporti (2012)

[2]ISTAT, Road accidents preliminary estimates, accessed 14 January 2023

causal patterns between economic activity and road safety is also provided by the introduction of major restrictions during the initial phase of the COVID-19 pandemic, including travel restrictions, closure of schools, bars, restaurants, and stay-at-home orders with closure of non-essential workplaces. These measures greatly reduced leisure-related travelling, and significantly decreased traffic levels over a prolonged period of time. Between 2019 and 2020 the number of RTAs with injuries and deaths fell by 31.3%, and the number of deaths by 24.5%. Since the application of restrictive measures varied by time and region, this variation can be exploited to estimate their impact on different road safety outcomes. More specifically, Italy was interested by an extended general lockdown period (albeit with measures of various types and intensity) between 11 March and 6 May, followed by a transition period until the beginning of June 2020. All restrictive measures were lifted during the summer of 2020. By mid-October, when COVID-19 cases rose again, the government introduced new restrictions, including a curfew between 10pm and 5am in all regions, and three levels of measures of varying intensity (from closure of bars and restaurants to stay-at-home orders) to be applied differentially in regions depending on their epidemic status.

For our purpose, we rely on a comprehensive dataset provided by ISTAT containing information on all RTAs with injuries and deaths recorded by Italian police forces between 2014 and 2020, for a total of 1,140,220 RTAs with injuries, of which 20,765 involved at least one death. Each record includes details on socio-demographic characteristics of those involved, vehicle characteristics, factors leading to the accident as reported by the police, weekday and time of the accident, route characteristics, and the exact location. We apply panel difference-in-differences (DiD) and triple difference (DDD) designs by aggregating individual RTA data by province and quarter, and we test for the robustness of our findings by estimating logistic regressions on individual RTA data.

More specifically, our analysis aims at answering the following research questions: (a) to what extent did the lockdown and post-lockdown periods affect the frequency of RTAs, and the number of deaths and injuries; (b) whether and how the level of economic activity and the costs associated with operating a motor vehicle influence these outcomes; (c) which factors and RTA characteristics changed during the lockdown and post-lockdown periods, and how they impacted on RTA numbers and mortality. The findings from this study provide relevant evidence not only by quantifying the effects of mobility restrictions on RTAs, but also by identifying risk factors that may be addressed by prevention policies.

2. Literature

The relationship between economic activity, traffic volumes and RTAs has been explored well before COVID-19 lockdowns, and there is consistent evidence of a pro-cyclical association, i.e. higher unemployment and lower incomes are linked to a lower number of RTAs and fewer deaths. The highly cited study on the links between economic recessions and health by Ruhm (2000) finds that mortality rates from motor vehicle accidents are by far the cause of death with the highest (negative) unemployment elasticity. Cotti and Tefft (2011) provide further empirical evidence by looking at the 2007-8 recession, and find that higher unemployment is associated with fewer accidents per mile. French and Gumus (2014) focus on fatalities from motorcycle accidents only, and they confirm a strong pro-cyclical link, as a 10% increase in real income is related to a 10.4% in fatalities. Similarly, Scuffham (2003) finds a negative relationship between fatal car accidents in New Zealand and both unemployment and real GDP. Joksch (1984) found a positive, significant and constant over time association between the industrial production index and deaths from car accidents in the United States between 1950 and 1982. Bishai et al. (2006) use macroeconomic data on GDP per-capita from 41 countries and associate a 10% increase in GDP with a 7.9% rise in the number of RTAs, and a 3.1% rise in the number of deaths in low income countries. Instead, in high income countries they find a lower number of deaths when GDP further grows. A time series analysis using Spanish monthly data by García-Ferrer et al. (2007) shows a correspondence between economic cycles and the number of RTAs. Furthermore, Cotti et al. (2015) find evidence that poor stock market performance is associated with an increase in fatal car accidents involving alcohol. Few studies provide counter evidence, one exception is the analysis on Ohio county-level data by Traynor (2009), which argued that income and unemployment levels reduce the probability of severe accidents as opposed to minor accidents; this however does not exclude a pro-cyclical absolute increase in the number of severe accidents. An original justification for the reduction in RTAs and fatalities is provided by Maheshri and Winston (2016), who look at data from Ohio between 2009 and 2013, hence including both recession and recovery periods, and argue that beyond the natural effect of economic activity on traffic levels, recession take off the road some particular categories of riskier drivers and cars, i.e. older ones.

Prices are another major economic determinant of road safety, and there is strong and consistent evidence on the impact of petrol prices on motor vehicle accidents. Burke and Nishitateno (2015) exploit data on prices and road fatalities for 144 countries between 1991 and 2010, and estimate that a 10% price increase is associated with a reduction between 3% and 6% in road fatalities. Many other studies bring similar evidence for specific countries (see e.g. Naqvi et al. 2020 for Great Britain or Grabowski and Morrisey 2004 for the US), also showing that fatalities involving younger drivers or drunk drivers are more price elastic (Chi et al., 2011). Interesting indirect evidence is found in Prakash et al. (2022), where an inverse relationship between prices and obesity is justified through a reduced use of cars, and increased walking and travel by bicycles, which would be consistent with a reduction in the number of RTAs which does not always translate into an equivalent decrease in injuries and deaths. Alcaraz Carrillo de Albornoz et al. (2022) have incorporated vehicle operating costs as a relevant dimension in their optimization model taking into account multiple social objectives beyond risk reduction.

A number of studies have investigated the effects COVID-19-related restrictions on road safety. Although most of the quantitative studies have limited geographical and time focus, the evidence that stay-at-home orders have reduced the number of RTAs and casualties is compelling. While this finding is hardly unexpected, there is less consensus on the effects of restrictions on the relative accident severity, as some studies suggest that reduction in traffic and other behavioural changes observed during the pandemic may have led to riskier behaviours, especially speeding and drinking, and more deaths per accident (see e.g. Dong et al., 2022; Doucette et al., 2021; Adanu et al., 2021). Li and Zhao (2022) consider traffic accident data from the city of Los Angeles and New York City, and explain the increase in severity with a rise in accidents involving bicycles. A short-term analysis on Missouri data by Qureshi et al. (2020) associates the lockdown with a major reduction in accidents with minor injuries, whereas no significant change is found for serious or fatal injuries.

A review article by Yasin et al. (2021) explores evidence from 36 countries. Considering April 2020 only, related to April 2019, they find a decrease in total road deaths in 32 countries, with reductions above 50% in 12 countries and below 25% in 6 countries. When expanding the analysis to the full 2020 year relative to 2019, the impact becomes weaker and more heterogeneous, including an increase in road deaths in 9 countries out of 42, which was mainly ascribed to reduced crowding and increased speeding. The latter interpretation is supported by the findings in Katrakazas et al. (2020) who exploit data for Greece and Saudi Arabia from a mobile phone app to explore the relationship between reduced traffic volume due to lockdowns and increased driving speeds. They find lockdowns to be associated with average speed increases between 6 and 11%, but they also observe an increase in harsh acceleration and harsh braking (up to 12% increase), as well as mobile phone use while driving (between 21 and 42%). Similar evidence is provided by Shirani-bidabadi et al. (2021), they analyse high frequency data to compare within-day speed variations before and after the stay-at-

home order in Alabama. Speed changes were especially relevant when considering commuting hours, with lockdowns significantly reducing the time window and the extent of speed reductions associated with congested roads, especially in the morning. Sekadakis et al. (2021) consider traffic volumes from a comprehensive Greek dataset and show that the reduction in the number of RTAs is less than proportionate, again with an increase in fatalities. Das and Sarkar (2022) take an alternative approach and apply content analysis to media reports of RTAs: their findings are again consistent with a relative increase in speed-related RTAs, mostly associated with the traffic reduction, albeit they also report doubling of RTAs caused by racing, which is a signal of riskier driving behaviours during lockdowns. A descriptive exploration of the underlying psychological mechanism of extreme speeding behaviours during stay-at-home periods can be found in Tucker and Marsh (2021). Their theoretical explanation is associated with impaired ability to accurately perceive and control speed under traffic conditions different than usual, but also a lower importance of social norms about appropriate speeds, lower risk perception and increased boredom leading to riskier behaviours. Self-reports from an annual North-american public opinion survey analysed in Vanlaar et al. (2021) show a non negligible proportion of respondents (especially younger ones) admitting to take riskier behaviours during the pandemic, including speeding and drinking and driving. A study unrelated to COVID-19, but potentially relevant to this research, has shown that stress and anxiety due to economic uncertainty were associated with the number of motor vehicle collisions in Great Britain between 2005 and 2015 (Vandoros et al., 2018).
Few studies have looked specifically at Italian motor vehicle accident data in relation to economic activity and lockdowns. The study by Colonna and Intini (2020) draws from pre-COVID-19 data from a single Italian region (Apulia) to predict the reduction in mortality due to RTAs, based on traffic flows data. Valent (2022) compares regional March and April data between 2020 and 2019 and finds major reductions, but also inter-regional variability. Moreover, in the last quarter of 2020 the Italian government introduced a curfew. While this restriction has certainly reduced night traffic, this does not necessarily hold for RTAs. Indeed, existing evidence on the effect of closing hours for bars and restaurants is conflicting, with some studies finding no effect or even a reduction of alcohol-related RTAs when closing times are liberalised (Green et al., 2014; Green and Krehic, 2022).

3. Data

3.1. Road traffic accident variables

Detailed information on all road traffic accidents with injuries and/or fatalities which have occurred in Italy between 2014 and 2020 is taken from the Survey on Road Accidents resulting in death (within 30 days) or injury, carried out by ISTAT together with the Italian Automobile Club and a selection of regional and local authorities. The survey collects information on all RTAs that (a) resulted in death or injury; (b) were recorded by one of the police authorities; and (c) had at least one of the vehicles circulating on the road network, which excludes private areas and accidents not involving any vehicle. Each record in the dataset corresponds to an individual accident. Prior to 2014 data collection was based on probabilistic sampling, hence we restricted our analysis to the currently available seven years with exhaustive information. The survey collects information on date, time and location of the accident, although the exact date is not available to researchers due to privacy restrictions. Thus, the timing information refers to the weekday and quarter the RTA occurred. Other variables relate to the type of road, road surface, signals, weather conditions, the type of accident (e.g. collision, pedestrian traffic accidents, etc.), the types of vehicles involved, the accident outcomes for those involved, the causes of the accident as reported by the police force.

Table 1 reports aggregate statistics on RTAs in Italy over the period 2014-2020 covered by our

Table 1. Accidents with injures and/or deaths in Italy, 2014-2020, descriptive statistics on selected variables.

	All accidents		Fatal accidents	
	N	%	N	%
Total number of accidents	1,164,907		21,000	1.80
Total number of deaths	22,334		22,334	
Total number of injuries	1,637,102		14,822	
	Weekdays vs. weekends			
Weekdays	881,149	75.66	14,286	68.07
Weekends	283,438	24.34	6,701	31.92
	Time of the day			
Between 12am and 5.59am	77,474	6.67	2,899	13.84
Between 6am and 11.59am	357,713	30.79	5,718	27.31
Between 12pm and 5.59pm	448,864	38.63	6,890	32.90
Between 6pm and 11.59pm	277,794	23.91	5,433	25.95
	Quarter			
January-March	258,414	22.18	4,494	21.40
April-June	300,848	25.83	5,148	24.51
July-September	314,896	27.03	6,188	29.47
October-December	290,749	24.96	5,170	24.62
	Road type			
Intersections	420,854	36.12	4,228	20.13
Straight roads	548,921	47.12	11,705	55.74
Curves	123,706	10.62	4,047	19.27
Other	71,426	6.14	1,020	4.86
	Location			
Urban residential area	748,084	64.22	6,896	32.84
Other residential areas	117,547	10.10	2,542	12.11
Motorway	61,046	5.24	1,724	8.21
Other roads	238,230	20.44	9,838	46.85
	Type of accident			
Head-on collision	66,136	5.68	3,095	14.74
Side-impact collision	380,893	32.70	4,359	20.76
Side collision	134,623	11.56	1,034	4.92
Rear-end collision	216,101	18.55	2,103	10.01
Collision involving pedestrians	129,248	11.10	3,632	17.30
Swerve or run-off-road collision	104,229	8.95	3,703	17.63
Other collisions	133,677	11.48	3,074	14.64
	Number of vehicles involved			
1	330,667	28.39	9,874	47.02
2	722,435	62.02	9,192	43.77
3 or more	111,805	9.6	1,934	9.21
	Type of vehicles involved			
One car only	121,209	10.41	3,887	18.51
Two or more cars	361,200	31.01	3,160	15.05
Pedestrians and vehicle(s)	125,646	10.79	3,396	16.17
Car(s) and bicycle	98,386	8.45	1,339	6.38
One motorcycle only	57,462	4.93	1,641	7.81
Motorcycle(s) and other vehicles	256,259	22.00	3,316	15.79
Lorry (and other vehicles)	113,255	9.72	3,381	16.10
Other vehicles	31,490	2.70	880	4.19
Hit-and-Run accidents	11,299	0.97	81	0.39
	Cause (from police reports)			
Distracted or erratic driving	209,812	18.01	3,783	18.02
No safe distance	134,501	11.55	1,360	6.48
Not giving way or running through a stop/TL	254,571	21.85	2,513	11.97
Driving against traffic	28,476	2.44	1,358	6.47
Excess speed	137,264	11.78	4,322	20.59
Other causes (or not defined)	373,466	32.07	6,935	33.04
Pedestrian misbehaviour	26,755	2.3	724	3.45
	Age of drivers			
Average per accident - mean (sd)	43.51	13.16	46.10	14.67
At least one driver over 65	252,211	21.65	5,856	27.89
At least one driver aged 18-20	92,571	7.95	1,278	6.09

Source: Our processing on data from the Survey on Road Accidents, ISTAT, years 2014-2020.

dataset. During these seven years there were 1,164,906 accidents with injuries and/or deaths in Italy, causing 22,334 deaths and 1,637,101 injuries. In total, the number of fatal accidents was 21,000, corresponding to about 1.83 per 100 accidents with injuries only. Interestingly, the comparison between all accidents and fatal accidents in term of covariates shows relevant differences: fatal accidents are more likely to happen in weekends and during the night relative to other accidents; they are also more likely during the summer, less likely at intersections, and much less likely to occur in urban residential area. Head-on collisions, collisions involving pedestrians, swerving or run-off-road collisions are more likely to result in deadly accidents. Moreover, nearly half of fatal accidents involve a single vehicle (47%), a much larger proportion relative to the overall set of accidents (28.4%). Fatal accidents are also more likely to involve drivers aged above 65 (27.8% versus 21.6% overall), and to involve a lorry. Considering the variety of reported causes, fatal accidents are more likely to be associated with excess speed (20.7% of accidents vs. 11.9% overall).

3.2. Economic variables, COVID-19 restrictions and panel aggregation

Based on the evidence provided in similar studies, we consider three key economic variables associated with RTAs: (real) total household consumption expenditure ($REALEXP$), labour force participation (LFP) and a (real) consumer price index associated with the costs of operating a car ($PRICE$). These economic variables act as a proxy for traffic intensity, since no traffic data are available. Furthermore, they contribute to the evidence on the relationship between RTAs and the business cycle.

Household expenditure information comes from the ISTAT Household Budget Survey[3], which covers about 30,000 households every year and is representative at the regional level. We average total monthly household expenditure by region and quarter, deflated by the overall Consumer Price Index, also provided at the regional level. Real consumption expenditure is an adequate proxy for traffic levels, as it responds to income shocks and – unlike income – is further affected by movement restrictions, which also resulted in shop closures.

Data about labour force participation come from the ISTAT Labour Force Survey[4]. The LFP rate is provided at regional level on a quarterly basis, and reflects the proportion of employed persons and unemployed job-seekers on the total population aged between 15 and 64. Like consumption expenditure, the LFP rate follows the business cycle, while being less responsive and more heterogeneous across socio-demographic groups (De Philippis, 2017). During the pandemic there were norms preventing firings, which limits the explanatory power of the LFP rate to the case of reduction in the number of unemployed job seekers, due to expectations of lower labour demand in the near future.

Quarterly petrol prices are not provided at the sub-national level, but ISTAT publishes a monthly province-level consumer price index at the 3-digit COICOP level, which aggregates a variety of prices related to operating personal transport equipment. These includes the prices of parts and accessories (e.g. tyres), fuels and lubricants, the costs to maintain and repair vehicles, parking prices and toll prices. For our purposes, this comprehensive index seems more appropriate than merely consider petrol and diesel prices as in other studies. Summary statistics at national level and by year for these economic variables are reported along those of RTAs in Table 2 and Figure 1.

Figures for the year 2020 are clearly and expectedly outliers relative to previous trends. The COVID-19 pandemic has brought a sharp decrease in all economic variables, the largest is observed on real household expenditure which was driven by both the movement restrictions which directly affected consumption, and the economic downturn which followed the onset of the pandemic. The drop in labour force participation and prices is less pronounced, as expected, since those looking for

[3] `https://www.istat.it/en/archivio/180353`, last accessed 3 February 2023.
[4] `https://www.istat.it/en/archivio/127804`, last accessed 3 February 2023.

Table 2. Labour force participation, real price of operating vehicles, and road traffic accidents in Italy, 2014-2020.

	Economic variables			Road traffic accidents	
	REALEXP	LFP	PRICE	No. RTAs	Deaths
2014	2,551.04	66.09	104.75	177,031	3,381
	(387.68)	(7.57)	(1.18)		
2015	2,564.82	66.22	100.00	174,539	3,428
	(408.70)	(7.56)	(1.22)		
2016	2,594.47	66.99	97.95	175,791	3,283
	(416.52)	(7.45)	(1.15)		
2017	2,592.67	67.32	100.24	174,933	3,378
	(410.72)	(7.32)	(1.08)		
2018	2,571.89	67.53	102.77	172,545	3,334
	(358.95)	(7.55)	(1.21)		
2019	2,545.41	67.20	102.21	172,183	3,173
	(353.98)	(7.98)	(1.20)		
2020	2,319.36	65.81	98.55	117,885	2,357
	(328.88)	(7.86)	(2.31)		

Notes: Standard deviations in brackets. REALEXP: Real total household expenditure in Euros at 2015 prices. LFP: Labour force participation rate, age 15-64. RPC: Real price index for operating private transport equipment, 2015=100.
Sources: Our processing on ISTAT data (Household Expenditure Survey, Labour Force Survey, Consumer Prices, and the Survey on Road Accidents), years 2014-2020.

a job are the only component affected by the pandemic, whereas the employment and unemployment components were kept relatively stable by laws preventing firings for most of 2020. For our objectives, the 2020 events and policy decisions create an interesting natural experiment. Movement restrictions heavily influenced road traffic between March and May 2020 (Bosa et al., 2022). In the months between June and September 2020 most restrictions were lifted, but this period was still affected by concerns about lower but continuing risks of COVID-19 infections – especially for more fragile individuals – and by the international financial crisis generated by the pandemic. In November 2020 the government reintroduced a varying level of restrictive measures at a regional base, implemented depending on a set of indicators related to infection levels and stress on the regional health system (Manica et al., 2021). Within this traffic light system of restrictions, leisure activities were strongly limited in regions with orange and red levels. For example, bars and restaurant were closed (takeaway services were only allowed before 10pm in orange regions), and a curfew was introduced to restrict non-essential travelling after 10pm.

The sequence of the key measures adopted by the Italian government is shown in Table 3. We adopt two slightly different classifications of the periods covered by the varying movement restrictions to check for the robustness of our estimates. The first classification distinguishes two sub-periods, first a time window of major movement restrictions between 11 March and 17 May 2020 (*LOCKDOWN*), then a post-lockdown period from 18 May until 31 December 2020 (*POSTLOCK*). Within this post-lockdown period and after 6 November, the regional variation in the intensity of restrictive measures reflected by the traffic-light system is captured by the variable *ORANGERED*, separating those regions with an orange or red classification (slightly softer restrictions relative to the lockdown period) from those with a wider freedom of movement. The second classification distinguishes four separate sub-periods: (1) the initial period interested by the stay-at-home order until 4 May 2020 (*STAYHOME*); (2) a transition period with gradually softer measures until 15 June (*TRANSITION*); (3) summer without movement restrictions between 15 June and 24 October (*UNRESTRICTED*), followed by another transition period until 6 November; (4) a fourth sub-period from 6 November until the end-of-the year interested by the traffic light system, this time without considering the colour heterogeneity across regions (*ZONES*).

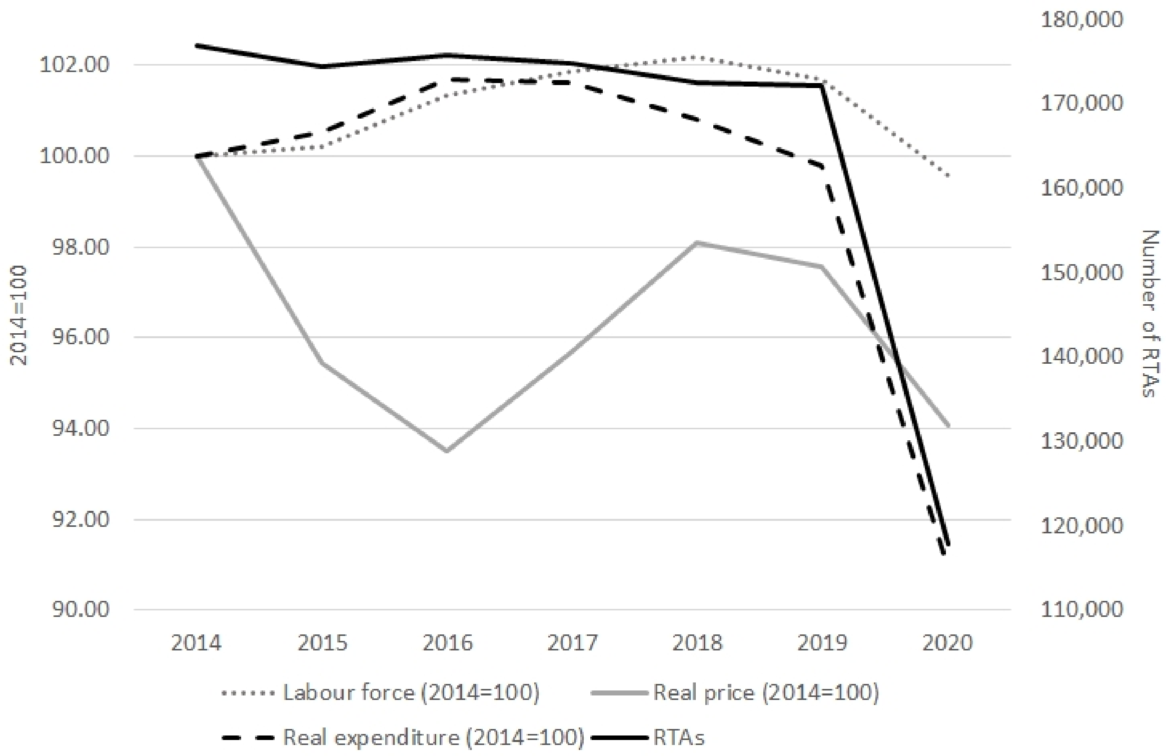

Figure 1: **Trends in economic variables and road traffic accidents in Italy, 2014-2020.**

We aggregate the raw data referring to individual RTAs by province (107 provinces) and quarter (28 quarters between 2014 and 2020) to account for pre-existing trend and explore the causal impact of the restrictive measures. The quarterly aggregation is necessary due to lack of more detailed information on the date of individual RTAs. Hence, aggregate restriction variables reflect the proportion of days in each quarter which are subject to the different types of restrictive measures. All restriction variables are constant across provinces within the same quarter, except the classification into orange and red zones since 6 November, which varies by region. Table 4 shows the value of the restriction variables over the four 2020 quarters. During the first quarter, the proportion of lockdown (or stay-at-home) days was 23.1%. The second quarter was almost equally divided between the lockdown period (51.6%) and the post-lockdown window (48.4%). When considering the second classification, the second quarter includes the residual stay-at-home period, representing 36.3% of the quarter, a long transition period (47.3% of the quarter), and a short window without restrictions, (16.5% of the quarter). The third quarter refers to summer and is entirely free from restrictions, i.e. post-lockdown according to the first classification or unrestricted according to the second. Finally, the last quarter is 100% post-lockdown, but regional heterogeneity is accounted for into the *ORANGERED* period, which covers 36.1% of the last quarter. According to the second classification, 25% of the fourth quarter is unrestricted, 14.1% reflects a new transition period before the introduction of the colored zones which represent 60.9% of the last quarter.
These varying levels of restrictions have had a clear impact on RTA outcomes. On average, RTAs and injuries fell by about 27% during the first quarter; by half during the second quarter; around 10% during the third quarter; and by more than one third in the last quarter, when compared to the same quarter in 2019. The impact on deaths, however, was minimal in the first and fourth quarter, and an average relative increase was observed during the unrestricted summer quarter. During the

Table 3. COVID-19 restrictive measures in Italy and related binary variables.

		Restriction variables	
Date	Measures	Classification 1	Classification 2
11-Mar	Closure of bars and restaurants	*LOCKDOWN*	*STAYHOME*
22-Mar	Closure of all non-essential productive activities	*LOCKDOWN*	*STAYHOME*
25-Mar	Further restrictions on movement	*LOCKDOWN*	*STAYHOME*
04-May	Reopening of most factories and various wholesale businesses, increase in mobility	*LOCKDOWN*	*TRANSITION*
18-May	Reopening of bar, restaurants, shops and some social activities (e.g. public worship)	*POSTLOCK*	*TRANSITION*
04-Jun	Resuming of unrestricted inter-regional movement	*POSTLOCK*	*TRANSITION*
15-Jun	Resuming of recreational activities	*POSTLOCK*	*UNRESTRICTED*
24-Oct	(second wawe) New movement restrictions. curfew at 11 in selected regions	*POSTLOCK*	*TRANSITION*
06-Nov	Traffic-light system for restrictions: partial closure of schools, curfew at 10pm (no unnecessary travel), most shops closed during weekends, bar and restaurants closed at 6pm	*POSTLOCK*	*ZONES*
	Orange: no extra-regional travel, bars and restaurant closed (except takeaway)	*ORANGERED*	*ZONES*
	Red: no travel outside town, all shops closed except food and health, all bars and restaurants closed, only necessary public workers in presence	*ORANGERED*	*ZONES*

Based on Bosa et al. (2022) and Manica et al. (2021)

second quarter, heavily interested by the most restrictive movement measures, deaths fell on average by 32%.

Table 4. Restriction variables and percentage change in outcomes, average by province and quarter, 2020.

Variable	Q1	Q2	Q3	Q4
		Restriction variables		
LOCKDOWN	0.231	0.516	0.000	0.000
POSTLOCK	0.000	0.484	1.000	1.000
ORANGERED	0.000	0.000	0.000	0.361
				(0.157)
STAYHOME	0.231	0.363	0.000	0.000
TRANSITION	0.000	0.473	0.000	0.141
UNRESTRICTED	0.000	0.165	1.000	0.250
ZONES	0.000	0.000	0.000	0.609
		% change in outcomes		
RTAs	-27.11	-49.54	-9.40	-33.38
Injuries	-27.89	-54.02	-12.14	-37.78
Deaths	-2.15	-32.35	7.02	-4.63

Notes: Standard deviation for regionally-varying red and orange zones (*ORANGERED*) in brackets. The other restriction variables do not vary by province.
Percent changes in outcomes are computed relative to the same quarter of 2019.

4. Empirical approach

Table 5 below summarizes all variables used in our empirical approach, together with their original level of detail.

Our identification strategy is based on different model specifications, and a different level of data processing and aggregation. More specifically, we estimate:

1. A panel difference-in-difference model using quarterly aggregate data at the province level. We consider all accident characteristics and outcomes, and we explore the relative effect of economic variables and movement restrictions on these outcomes;

2. A logistic regression model on the probability of accidents resulting in death(s) using raw RTA data, while controlling for fixed province and seasonal effects. This model controls for observed RTA characteristics and economic variables in order to identify the marginal effects of movement restrictions;

3. A logistic regression model on the probability of accidents with a given characteristic or cause (e.g. night accidents, excess speed, etc.) where the marginal effects of movement restrictions are identified after controlling for changes in traffic intensity as captured by economic variables.

4.1. Panel difference-in-differences models

The identification of the effects of the restrictive measures on the outcomes of interest is based on the following panel model based on data aggregated at the province ($p = 1, ..., 107$) and quarter level over the 7 years time span ($t = 1, ...28$):

$$y_{pt} = \alpha + \mathbf{x}'_{pt}\beta + \mathbf{q}'_{t}\gamma + \mathbf{r}'_{rt,p\in r}\delta + \omega trend + \upsilon_p + \varepsilon_{pt} \quad (1)$$

Table 5. Summary list of variables, description and level of details.

	Variable	Description	Original level of detail
		Accident characteristics (absolute values)	
1	RTA	Total number of accidents with injuries and/or deaths	Province and quarter
2	INJ	Number of injured individuals	Single accident
3	DEATHS	Number of deaths	Single accident
		Accident characteristics (binary variable / rates)	
4	FATAL	Whether the accident resulted in death(s)	Single accident
5	WEEKEND	Occurred during a weekend	Single accident
6	NIGHT	Occurred at night (12am to 6am)	Single accident
7	WORK	Occurred during working days and hours (Mon-Fri 6am-8pm)	Single accident
8	RESID	Occurred in a residential area	Single accident
9	MWAY	Occurred in a motorway	Single accident
10	STRAIGHT	Occurred in a straight stretch of road	Single accident
11	ELDERLY	Involved at least one driver over 65	Single accident
12	YOUNG	Involved at least one driver aged 18-20	Single accident
13	SINGLE	Only one car involved	Single accident
14	PEDS	Pedestrian(s) involved	Single accident
15	BIKE	Bicycle(s) involved	Single accident
16	MCYCLE	Motorcycle(s) involved	Single accident
		Cause of accidents	
17	SPEED	At least one vehicle had excess speed	Single accident
18	ERRATIC	Distracted or erratic driving	Single accident
19	DISTANCE	Not keeping safe distance	Single accident
20	AGAINST	Vehicle driving against traffic	Single accident
21	GIVEWAY	Vehicle(s) not giving way or driving through a red traffic light	Single accident
22	TURNING	Illegal or dangerous turning	Single accident
23	OVERTK	Illegal or dangerous overtaking	Single accident
24	TECHNIC	Vehicle technical issues	Single accident
25	PEDMISB	Pedestrian misbehaviour	Single accident
		Economic variables	
26	REALEXP	Average real household consumption expenditure (€2015)	Region and month
27	LFP	Labour force participation (% of individuals aged 15-64)	Region and quarter
28	PRICE	Real cost of operating a car (index, 2015=100)	Province and month
		Restriction variables	
29	LOCKDOWN	Proportion of days under lockdown	Quarter
30	POSTLOCK	Proportion of days following the lockdown	Quarter
31	ORANGERED	Proportion of days with orange/red restrictions	Quarter
32	STAYHOME	Proportion of days with stay home order	Quarter
33	TRANSITION	Proportion of days during transition periods (softer rules)	Quarter
34	UNREST	Proportion of days free from restrictions	Quarter
35	ZONES	Proportion of days interested by the traffic light system	Quarter

where y_{pt} is the observed outcome in province p at time t, $\mathbf{x}_{pt}$ is the vector of economic variables (*REALEXP*, *LFP* and *PRICE*)[5], $\mathbf{q}_t$ is a vector of quarterly seasonal dummies, $\mathbf{r}_{rt,p\in r}$ is the vector of variables capturing the level of movement restrictions (*LOCKDOWN*, *POSTLOCK* and *ORANGERED*) within region r to which the province p belongs. The model accounts for a linear yearly time trend (*trend*) and allows for province-level fixed- or random-effects (υ_p), depending on the results from the Hausman specification test. Model (1) can be interpreted as a panel a difference-in-differences model: the impact of the 2020 restrictions is captured by the δ vector of coefficients, which measures the impact of moving from 0 days per quarter in a specific restriction status to a full quarter within such restriction status. The elasticity of the outcomes to changes in economic determinants is estimated through the β vector of coefficients. The model is estimated on the 25

[5] *REALEXP* and *LFP* only vary across regions, whereas *PRICE* is at province level

different outcome variables listed in Table 5.
Model 1 assumes that the yearly trend in outcomes is the same across provinces. The common trend assumption can be relaxed by allowing province-specific trends ($trend_a$). This implies an estimation trade-off, as province-specific trends may be collinear with other province-level trends in economic variables, hence reducing the identification power for the latter effects. Estimates of model 1 allowing for differential linear trends is provided as a robustness check.

4.2. Logistic regressions on individual RTA data

The application of logistic regression on raw data, i.e. considering each RTA as an individual observation, allows to validate and extend our analysis on the factors associated with the rate of fatal RTAs and how they changed in response to restrictions. A first model considers the probability of an accident to result in deaths and is specified as follows:

$$F_a = \alpha + \mathbf{x}'_{pt,a\in p,t}\beta + \mathbf{r}'_{rt,a\in r,t}\delta + \mathbf{z}'_a\omega + \mathbf{q}'_t\gamma + \upsilon_{p,a\in p} + \phi trend + \epsilon_a \tag{2}$$

Here F_a is a binary variable equal to 1 when the accident a resulted in at least one death, and 0 otherwise (injuries only). The model estimates the effect of economic variables ($\mathbf{x}'_{pt}$), restriction variables ($\mathbf{r}'_{rt}$), and a set of accident characteristics ($\mathbf{z}'_{at}$) on the probability that an accident causes at least one death. The vector $\mathbf{z}'_{at}$ includes the variables in Table 5 which record the RTA characteristics (variables 5 to 16), and those on the cause of the accident as reported by the police force (variables 17 to 25)[6]. The model in (2) allows for a linear yearly trend, as well as fixed province effects ($\upsilon_p, a \in p$) and seasonal quarterly effects ($\mathbf{q}'_t$).
A further set of logistic regressions are used to test whether the characteristics of RTAs have changed significantly during lockdown periods. The generic model specification is the following:

$$D_a = \alpha + \mathbf{x}'_{pt,a\in p,t}\beta + \mathbf{r}'_{rt,a\in r,t}\delta + \mathbf{q}'_t\gamma + \upsilon_{p,a\in p} + \phi trend + \epsilon_a \tag{3}$$

Where D_a is a binary variable equal to 1 when the accident a has a specific characteristic (e.g. excess speed), and 0 otherwise. A separate model is estimated for each characteristic as listed in Table 5 (variables 4 to 25) and the right hand side covariates include economic factors $\mathbf{x}'_{jt}$, province and seasonal effects, and a linear time trend. The coefficients δ estimate whether the implementation of restrictions is associated with a change in observing such characteristic.

4.3. Robustness checks

In order to test how our findings on the movement restriction effects depend on the chosen data aggregation and model specification, we perform four robustness checks:

1. We allow for province-level differential linear time trends in the DID panel model (1), hence relaxing the common trend assumption;
2. We consider the alternative classification of restriction variables as described in Table 4;
3. Using an alternative data source providing monthly national-level aggregate information on RTAs, we estimate the effect of restrictive measures using a time series regression under the same specification as the panel model;

[6] The variable WORK is omitted, so that the baseline refers to accidents occurring during working days and work hours. An interaction term to estimate the odds of fatal accidents on weekend nights is also included.

4. We estimate a triple difference model on quarterly and province-level aggregate data. Here the dependent variable is built as the difference – within the same province and time period – between the rate of accident resulting in death(s) with a given characteristics (e.g. night accidents, excess speed, etc.) and the rate of fatal accidents without that characteristic. The triple difference model helps controlling for unobserved factors that vary by time period and province, but not by type of accident. In other words, it allows to see whether the movement restrictions have had a differential impact on different types of accident.

The last two robustness checks are described in more detail below.

4.3.3. Aggregate time series model

Our dataset does not contain precise information on the date of the accident, but only the quarter. We exploit an alternative dataset with monthly frequency provided by the Italian traffic police[7]. The data includes any RTA recorded by the traffic police, which cover all motorways and national roads. Thus, it is a subset of the total number of RTAs. The three economic variables used in our former specifications (*REALEXP*, *LFP* and *PRICE*) are also available on a monthly frequency at the national level. We adjust the restriction variables (*LOCKDOWN*, *POSTLOCK*, and *ORANGERED*) to reflect the number of days covered by each restriction in each month. A quarterly seasonal term is included in the model, as well as a yearly linear trend, like in equation (1). Thus, the model specification is the following:

$$y_t = \alpha + \mathbf{x'}_t\beta + \mathbf{q'}_t\gamma + \mathbf{r'}_t\delta + \omega trend + \epsilon_t \tag{4}$$

Where y_t is the observed outcome at time t, $\mathbf{x}_t$ is the vector of economic variables, $\mathbf{q}_t$ are quarterly seasonal dummies, $\mathbf{r}_t$ is the vector of variables capturing the level of movement restrictions in Italy at time t. The model accounts for a linear yearly time trend (*trend*). For consistency with the previous specifications, we estimate the model using the monthly number of RTAs resulting in injuries and/or deaths and the rate of fatal accidents as dependent variables.

4.3.3. Triple difference model

As a further robustness check, we investigate how the combination of COVID-19 restrictions and RTA characteristics impact on the rate of fatal accidents (*FATAL*) by considering as the dependent variable the difference in the outcome within a province according to a third classification variable referring to a given accident characteristics. For example, we test whether the difference between the rate of fatal accidents caused by excess speed and those associated with other causes varies depending on the intensity of the restrictions. This implies replacing the outcome variable y_{pt} with a differenced variable $\Delta y_{pt} = y^T_{pt} - y^C_{pt}$ where y^T_{pt} is the rate of fatal accidents measured for accidents belonging to the target group T within each province p at time t (e.g. group T includes accidents caused by excess speed) and y^C_{pt} is the outcome measured for accidents belonging to the complementary group C, i.e. those not caused by excess speed. This difference-in-difference-in-difference model (DDD) includes the same explanatory variable as Equation (1), and the δ coefficients capture the effects of the restrictions on the distance between the two groups. The interpretation of the other coefficients needs to be adjusted accordingly, as the β vector of coefficients reflects the elasticity of the difference between the two groups to changes in economic variables, and the fixed/random effects control for idiosyncratic between-group gaps at the province level. We explore the potential factors leading

[7] See https://www.poliziadistato.it/pds/stradale/archivio/

to a change in mortality rates by splitting the dataset into two separate groups depending on the presence/absence of each of the characteristics listed in the previous section, and using the difference between mortality rates in the two groups as the dependent variable. The advantage of the DDD specification is that the differenced outcome variables purges out any unobservable factor which is common to different types of accident within the same province and time period, so that the common trend assumption applies to the remaining unobservable factors only. In other words, it relaxes the parallel trend assumptions to the point that the triple difference estimator will be unbiased even if the original difference-in-differences estimators are biased, if the bias is the same in both estimators (Olden and Møen, 2022).

5. Results and Discussion

5.1. Impact of economic factors and mobility restrictions

We first assess the impact of economic factors and COVID-19 measures on different RTA-related outcomes through model (1). Results are shown in Table 6 and confirm the direct relation between the number of RTAs and the level of economic activity, as captured by real household expenditure. Labour force participation is also associated with more RTAs, although the relationship is weaker. An inverse relationship is observed between the number of RTAs and the prices related to operating personal transport equipment. These findings are consistent with the expected responsiveness of traffic volumes to economic activity and the cost of driving and maintaining a vehicle, and similar associations are found for the number of injuries. An additional €1,000 in real household expenditure is associated with an average increase of around 25 RTAs per province and quarter, and about 38 extra injuries per province and quarter. Instead, there is no apparent relationship between economic factors and the number of deaths. These results confirm cross-country previous evidence that during economic expansions a rise in traffic levels is associated with a higher number of accidents, but less severe on average.

Table 6. Impact of economic determinants and COVID-19 restrictions on road traffic accidents in Italy, 2014-2020.

DEP. VAR.	MODEL	REALEXP	LFP	PRICE	LOCKDOWN	POSTLOCK	ORANGERED
		Outcomes in absolute values (total change by province/quarter)					
RTA	RE	25.140**	3.100	−1.495**	−352.785***	−50.498***	−197.069***
		(12.482)	(1.936)	(0.738)	(25.167)	(10.799)	(32.819)
INJ	RE	38.033**	4.785*	−2.181**	−511.192***	−86.861***	−280.191***
		(17.563)	(2.711)	(1.039)	(35.363)	(15.190)	(46.190)
DEATHS	FE	0.326	0.070	−0.031	−4.516***	−1.458***	−0.735
		(0.415)	(0.068)	(0.024)	(0.849)	(0.360)	(1.088)
		Outcomes in rates (change relative to 100 RTAs)					
FATAL	FE	−0.104	0.031	−0.003	0.826**	0.136	0.345
		(0.159)	(0.026)	(0.009)	(0.326)	(0.138)	(0.417)
WEEKEND	RE	0.084	0.133*	0.005	0.660	0.577	−4.253***
		(0.457)	(0.075)	(0.027)	(0.935)	(0.397)	(1.198)
NIGHT	RE	−0.274	0.047	−0.011	−0.818	−0.753***	−4.766***
		(0.250)	(0.041)	(0.015)	(0.511)	(0.217)	(0.655)
WORK	RE	0.271	−0.233***	−0.010	−0.092	−0.104	6.441***
		(0.499)	(0.081)	(0.029)	(1.021)	(0.433)	(1.308)
RESID	RE	0.581	−0.106	0.040	0.672	0.248	−0.247
		(0.540)	(0.074)	(0.032)	(1.056)	(0.465)	(1.430)
MWAY	RE	0.311	−0.063**	−0.010	−0.984**	−0.881***	1.191**
		(0.224)	(0.029)	(0.013)	(0.430)	(0.192)	(0.594)
STRAIGHT	RE	0.944*	0.047	0.046	−1.993**	0.014	−1.544
		(0.527)	(0.047)	(0.032)	(0.971)	(0.454)	(1.434)
ELDERLY	FE	0.095	0.116*	−0.023	3.535***	−0.799**	−4.374***
		(0.431)	(0.070)	(0.025)	(0.882)	(0.374)	(1.130)
YOUNG	RE	0.357	0.017	−0.001	−2.925***	0.196	−2.399***
		(0.262)	(0.043)	(0.015)	(0.537)	(0.228)	(0.687)
SINGLE	RE	−0.463	−0.180**	0.010	5.470***	1.088**	−2.906**
		(0.509)	(0.083)	(0.030)	(1.042)	(0.442)	(1.335)
PEDS	RE	0.434	0.120**	0.025	0.058	0.086	−1.555*
		(0.345)	(0.056)	(0.020)	(0.706)	(0.299)	(0.904)
BIKE	FE	−0.170	−0.068	−0.008	4.381***	1.235***	−0.728
		(0.282)	(0.046)	(0.017)	(0.577)	(0.245)	(0.739)
MCYCLE	RE	0.661	−0.096	−0.037	0.484	1.112***	−0.220
		(0.472)	(0.065)	(0.028)	(0.923)	(0.406)	(1.251)
SPEED	RE	−0.075	−0.284***	−0.004	0.248	−0.075	0.619
		(0.432)	(0.043)	(0.026)	(0.802)	(0.370)	(1.163)
ERRATIC	RE	−0.126	−0.079	0.014	2.547***	0.616	1.590
		(0.475)	(0.078)	(0.028)	(0.972)	(0.412)	(1.246)
DISTANCE	RE	−0.399	0.049*	−0.047**	−3.218***	−0.837***	0.055
		(0.335)	(0.025)	(0.021)	(0.617)	(0.293)	(0.930)
AGAINST	FE	−0.099	0.029***	−0.019*	0.366	−0.063	−0.332
		(0.162)	(0.011)	(0.010)	(0.303)	(0.145)	(0.462)
GIVEWAY	RE	0.185	0.032	0.046	0.165	0.418	2.070
		(0.476)	(0.052)	(0.029)	(0.893)	(0.408)	(1.276)
TURNING	FE	0.447*	−0.002	−0.024	1.063**	0.448*	0.386
		(0.272)	(0.019)	(0.017)	(0.502)	(0.239)	(0.762)
OVERTK	FE	0.053	0.002	−0.009	−0.071	0.009	0.092
		(0.124)	(0.007)	(0.008)	(0.241)	(0.116)	(0.372)
TECHNIC	FE	−0.179*	0.014	−0.007	0.262	−0.024	0.029
		(0.108)	(0.018)	(0.006)	(0.222)	(0.094)	(0.284)
PEDMISB	RE	0.049	0.009	−0.012	−0.419*	0.122	−0.061
		(0.132)	(0.008)	(0.009)	(0.248)	(0.119)	(0.380)

Notes: Coefficient estimates from panel model in (1). RTAs only include accidents with injuries and/or deaths. Rate variables refer to the number of RTAs with the selected characteristics relative to 100 RTAs. Asterisks refer to estimates' significance at 0.01 (***), 0.05 (**) and 0.1 (*) level.

The effect of restrictive measures remains large and significant despite conditioning on the economic variables. Obtained estimates indicate an average reduction of about 353 RTAs per province per quarter of full lockdown, which translates into 511 less injuries per province/quarter and about 4.5 fewer deaths per province per quarter. During the post-lockdown period – when the movement restrictions were lifted – outcomes did not return to the pre-COVID-19 level, although their value is much smaller if compared to estimates during lockdown (50 fewer RTAs, 87 fewer injuries and 1.5 fewer deaths). When considering orange and red zones during the post lockdown period, there is a further additional reduction relative to the post-lockdown average (about 197 fewer incidents and 280 fewer injuries), without a significant change in deaths.

When looking at specific RTA characteristics, as captured by the impact on rates reported in the bottom part of Table 6, results are mixed and informative[8]. For example, the lockdown period is associated with a significantly higher rate of accidents with at least one death, relative to the overall number of RTAs with injuries or deaths. The rate has increased by about 0.83 fatal accidents per 100 RTAs with injuries or deaths, which means that the rate of fatal accidents increased by almost half its average level (1.80 over the period 2014-2020). Nonetheless, the magnitude of the reduction in number of traffic accidents during the lockdown period is substantial enough to result in fewer number of deaths overall.

During the lockdown period there is also a major rise in the rate of accidents caused by distracted or erratic driving (+2.5 per 100 RTA relative to an average of 18 over the period 2014-2020). At times of hard movement restrictions, there was also an increase in the rate of accidents with at least one elderly driver (aged more than 65), of those involving a single vehicle (+5.5 relative to an average of 28.4 per province/quarter) as well as a large rise in the proportion of accidents with bicycles (+4.4 per 100 RTA relative to an average of 9.8 per province/quarter), and an increase in the rate of accidents caused by illegal or dangerous turning (+1.06 per 100 RTAs). Instead, the lockdown is associated with relatively less RTAs in motorways or in straight stretches of road, less RTAs with at least one young driver (aged 18-20), and less RTAs caused by not keeping a safe distance or by pedestrian misbehaviour.

During the post-lockdown period (hence Summer 2020), relative to the baseline and pre-existing trends and conditional on economic factors, there were relatively less accidents at night or involving elderly drivers, but again slightly more accidents involving bicycles, although the increase was not as large as in the lockdown period, and motorcycles. When considering "orange" and "red" regions where new movement restrictions were introduced to tackle rising levels of infections, the marginal effect is a rise in motorway accidents (which compensates the post-lockdown reduction), a major increase in RTAs during work days and hours, and a large decrease in the rate of accidents happening on weekends or at night, involving single cars, elderly or young drivers.

5.2. Robustness checks

Table 7 shows, for selected outcomes (number of RTAs and rate of fatal accidents), that the estimates are robust to change in the specification of the model in (1). When allowing for differential province-level linear trend – despite the loss of efficiency due to the larger number of coefficients being estimated – the effects of the restrictive measures and their lifting remain large, significant and similar in size to those estimated under the assumption of a common trend. Altering the classification of the measures and considering four periods instead of three (stay-at-home, transition, unrestricted movement, and coloured zones as explained in Table 3) also leads to very consistent results, and confirm both the magnitude of the reductions in RTAs, and the evidence of an increase in the rate of fatal accidents

[8] Estimates considering absolute numbers rather than rates are provided in the on-line appendix, and are consistent with estimates on aggregate outcomes.

Table 7. Robustness checks, alternative specifications.

	Baseline (1)	Differential trends (2)	Classification 2 (3)	Monthly regression (4)
		Number of RTAs		
REALEXP	25.140**	14.233	25.920**	0.504**
	(12.482)	(11.189)	(12.455)	(0.238)
LFP	−1.495**	−0.780	−1.500**	−4.717
	(0.738)	(0.632)	(0.746)	(23.791)
PRICE	3.100	0.249	2.801	−1.451
	(1.936)	(1.811)	(1.937)	(3.462)
LOCKDOWN	−352.785***	−377.720***		−1326.601***
	(25.167)	(21.786)		(169.852)
POSTLOCK	−50.498***	−51.540***		−194.003**
	(10.799)	(9.184)		(88.447)
ORANGERED	−197.069***	−214.813***		−622.278***
	(32.819)	(27.509)		
STAYHOME			−365.461***	
			(48.851)	
TRANSITION			−143.353***	
			(41.863)	
UNREST			−39.129***	
			(11.588)	
ZONES			−172.281***	
			(20.654)	
		Rate of fatal accidents		
REALEXP	−0.104	−0.109	−0.091	−0.001
	(0.159)	(0.171)	(0.159)	(0.001)
LFP	−0.003	−0.007	−0.004	0.040
	(0.009)	(0.010)	(0.009)	(0.069)
PRICE	0.031	0.022	0.035	0.006
	(0.026)	(0.028)	(0.026)	(0.010)
LOCKDOWN	0.826**	0.755**		1.303**
	(0.326)	(0.333)		(0.489)
POSTLOCK	0.136	0.101		−0.206
	(0.138)	(0.140)		(0.255)
ORANGERED	0.345	0.363		0.434
	(0.417)	(0.420)		(0.357)
STAYHOME			1.214*	
			(0.624)	
TRANSITION			0.092	
			(0.534)	
UNREST			0.006	
			(0.148)	
ZONES			0.690***	
			(0.264)	

(1) Estimates from panel model (1); (2) Estimates allowing for different province-level linear trends; (3) Estimates using the alternative classification shown in table 3; (4) Estimates using the monthly time series regression model (??). Standard errors in brackets. Asterisks refer to estimates' significance at 0.01 (***), 0.05 (**) and 0.1 (*) level.

in times of restrictions. Finally, working with a different dataset on national level monthly data on RTAs occurring on motorways and national roads, we find extremely consistent relative effects, with lockdown restrictions estimated to have about 7 times the post-lockdown effects on RTAs, and the impact of traffic light restrictions having less than half the impact of lockdown restrictions. The scale is obviously different as the dependent variable here captures national monthly RTAs with injuries and/or deaths on a subset of the national road network. In terms of the rate of fatal accident, the regression estimates also show evidence of a significant increase (about +1.3%), a slightly larger effect which can be justified by the fact that the monthly statistics do not include urban and rural roads, hence refer to roads with a higher average speed.

5.3. Factors driving accident fatality and the effects of COVID-19 restrictions

While the reduction in the absolute number of RTAs, injuries and deaths during restrictions could be expected in response to the major reduction in road traffic, the increase in the rate of fatal accidents could relate to riskier driving behaviours associated with emptier roads, and deserves some further investigation. We first explore the association between the probability for an accident with injuries to be fatal and a variety of accident characteristics through the logistic regression model in (2).

Table 8. Probability of fatal accidents, economic factors and RTA characteristics (odds ratios).

	2020	2019	2014-20
REALEXP	1.456	1.043	0.942
LFP	1.019	0.984	0.997
PRICE	1.038	1.042	0.995
WEEKEND	1.221***	1.264***	1.238***
NIGHT	2.115**	2.321***	2.407***
WEEKEND & NIGHT	0.819***	0.927	0.809***
RESID	0.287***	0.241***	0.249***
MWAY	0.998	0.983	0.812***
STRAIGHT	1.065	1.154***	1.172***
ELDERLY	1.715***	1.662***	1.760***
YOUNG	0.767**	0.849**	0.828***
SINGLE	1.608***	1.563***	1.569***
PEDS	2.977***	3.027***	3.192***
BIKE	1.226**	1.722***	1.567***
MCYCLE	1.763***	1.865***	1.763***
SPEED	1.576***	1.699***	1.619***
ERRATIC	0.907	1.087	1.016
DISTANCE	0.735***	0.731***	0.690***
AGAINST	2.269***	3.084***	2.804***
GIVEWAY	0.576***	0.711***	0.692***
TURNING	0.905	0.981	0.898***
OVERTK	1.099	1.444***	1.225***
TECHNIC	1.138	0.773	1.279***
PEDMISB	0.688***	1.012	0.798***

Notes: Odds ratios from logistic regression in (2), including fixed province and seasonal effects. Estimates on the full time window 2014-2020 includes a linear yearly trend. Asterisks refer to estimates' significance at 0.01 (***), 0.05 (**) and 0.1 (*) level.

Table 8 shows the odds ratio estimated separately on 2020 and 2019 data, and those on the full 2014-2020 time window. The direction and size of the estimates is mostly consistent across the

three samples. Considering daytime and working days as the benchmark, estimates show that the odds that a RTA becomes fatal more than double at night during working days and are more than 20% higher on weekend daytimes, whereas it is slightly lower on weekend nights. Accidents more likely to result in deaths are those involving pedestrians (three times the odds of RTAs not involving any pedestrian). Accidents involving bicycles and motorcycles also have significantly higher odds of fatality. Driving against traffic is another cause with a strong association with fatality, with almost three times the odds compared to other accidents, considering the period 2014-2020. Other RTAs with a higher odds of having at least one death are those involving elderly drivers (about 1.7 relative to the odds of RTAs without elderly drivers), and those involving a single vehicle (60% higher odds relative to multiple vehicles RTAs).
Speed is a known factor in determining the severity of RTA outcomes, and our estimates confirm that when at least one vehicle has excess speed the odds of a fatal accident increases by more than 60% (70% in 2019); interestingly, the increase in fatality odds related to speed is lower in 2020 (+57.6%). Other factors which are closely related to traffic intensity also become less prominent in 2020, i.e. RTAs involving driving against traffic, occurring in straight traits of road, and occurring at night. The types of accidents with lower odds of fatality are those in residential urban areas, those caused by not keeping safe distance or by not giving way or running through a red light. All three characteristics are typical of RTAs at lower speed. Accidents involving at least one driver aged 18-20 and those caused by pedestrian misbehaviour are also relatively less likely to be fatal. Economic factors do not emerge as relevant in explaining the probability of an accident to result in death.
Given the list of factors associated with RTAs fatality, estimates from the DDD model reported in Table 9 allow to identify the ones associated with the increase in rates of fatal accidents observed at times of COVID-19 restrictions. Very few associations emerge as significant. The gap between rates of fatal accidents during weekends relative to work days/times has increased by 1.34 fatal accidents per 100 RTAs with injuries. The fatality rate was already higher during weekends before 2020 (2.36 vs. 1.61), the model suggests that – conditional on economic factors – the gap becomes larger at times of mobility restrictions. The other relevant association emerging from the DDD model is the increase in fatality explained by accidents with bicycles and motorcycles during the late 2020 regional colour-based restrictions.

This triple difference in differences estimate is, however, relative to the chosen benchmark. Thus, larger gaps might also signal a reduction in fatality in the benchmark situation, i.e. a reduction in the rate of fatal accidents during work hours. A more complete picture is obtained by looking at which factors significantly change during lockdowns. Thus, we estimate the logit model in (3) to identify which RTA characteristics have been affected by lockdowns, also in relation to their association with fatality rates[9]. We make a distinction between weekends and weekdays, as this factor emerged as relevant in explaining changes in fatality rates.

Estimates in Table 10 confirm that lockdowns and regional mobility restrictions towards the end of the year were associated with large increases in fatality of accidents during weekends (88% and 87% increase in odds, respectively), but not during weekdays. Looking at the RTA characteristics, and considering only weekends, the first lockdown had a significant effect on the probability of accidents due to distracted or erratic driving (+19.8% in odds with respect to other periods), on accidents with one vehicle only (+29.2% in odds), and especially on accidents involving bicycles and motorcycles (+91.3% and +29% in odds, respectively). When comparing these estimates with those from weekdays, the only relevant differences emerge for accidents involving bicycles, that are also

[9] We also tested the extent of changes in economic factors due to COVID-19 restrictions by estimating three panel difference-in-difference models specified similarly to (1), but with REALEXP, LFP and PRICE (in natural logs) as dependent variables, respectively. Since we now focus on RTAs fatality – and economic variables were previously found not to affect fatality – estimation results are not shown in the main text, but they are available as supplemental material.

Table 9. DDD model: association between RTA characteristics, COVID-19 restrictions and rate of fatal accidents.

	LOCKDOWN	POSTLOCK	ORANGERED
WEEKEND	1.342**	−0.450	1.226
	(0.647)	(0.318)	(1.017)
NIGHT	−0.861	−1.026	−0.103
	(1.567)	(0.765)	(2.462)
WORK	−0.703	0.555*	−1.040
	(0.613)	(0.301)	(0.963)
RESID	0.864	0.051	−0.236
	(0.663)	(0.321)	(1.025)
MWAY	−0.019	−1.352	0.611
	(2.286)	(0.969)	(2.903)
STRAIGHT	0.681	−0.553*	1.656*
	(0.570)	(0.279)	(0.893)
ELDERLY	0.944	0.067	0.046
	(0.750)	(0.367)	(1.177)
YOUNG	−0.253	0.149	−0.769
	(0.862)	(0.422)	(1.357)
SPEED	−0.854	0.254	1.178
	(0.925)	(0.451)	(1.444)
ERRATIC	1.136	−0.339	−0.219
	(0.725)	(0.356)	(1.142)
DISTANCE	1.376*	0.460	−1.447
	(0.674)	(0.329)	(1.054)
SINGLE	0.902	−0.260	1.875*
	(0.821)	(0.348)	(1.052)
PEDS	0.072	−0.131	0.668
	(1.575)	(0.670)	(2.020)
BIKE	0.655	−0.068	4.685*
	(1.485)	(0.733)	(2.337)
MCYCLE	0.823	−0.060	3.153**
	(1.176)	(0.498)	(1.504)

Notes: Selected coefficient estimates from panel DDD model (Section **??**), conditional on economic variables and including linear yearly trend, seasonal effects and fixed or random province effects depending on Hausman text. The dependent variable is the difference in fatal accident rates between the two groups defined by each of the variables listed in Table. The differenced WEEKEND rate is relative to work days/times. Work days/times are Mon-Fri 6am-8pm, WORK is relative to any time/day outside this window. NIGHT are 12am-5.59am. Standard errors in brackets. Asterisks refer to estimates' significance at 0.01 (***), 0.05 (**) and 0.1 (*) level.

more likely during lockdown but to a lesser extent (+63.5% in odds with respect to other periods), and for accidents involving motorcycles, which become less likely during lockdown (-15.5% in odds). These results remain valid, albeit with a smaller magnitude, during the post-lockdown period and especially in orange and red regional zones. Another relevant result is that the probability of accidents caused by excess speed, compared to other causes, does not significantly increase in lockdown during weekends, but is significantly higher during weekdays of lockdown, compared to weekdays in other periods.

Insights from the above results can be combined with those on the impact of RTAs characteristics on accidents fatality as reported in Table 8, together with results on the DDD model shown in Table 9, in an attempt to explain the observed increase in the probability of fatal accidents during the first Italian lockdown. We find this probability to be associated with the presence of elderly drivers,

Table 10. Impact of COVID-19 restrictions on probability of different types of RTAs, on weekends and weekdays (odds ratios).

	LOCKDOWN		POSTLOCK		ORANGERED	
	Weekends	Weekdays	Weekends	Weekdays	Weekends	Weekdays
FATAL	1.881***	1.240	0.936	0.982	1.868**	1.370*
NIGHT	0.632***	0.863	0.884***	0.890***	0.148***	0.374***
RESID	1.063	1.001	0.992	1.029*	1.217**	0.900*
MWAY	0.525***	0.705***	0.746***	0.837***	0.824	1.255**
STRAIGHT	0.873**	0.877***	0.968	0.995	0.886	0.928
OLD	1.124	1.193***	0.913***	0.969*	0.818*	0.756***
YOUNG	0.673***	0.716***	1.018	1.032	0.817	0.739***
SINGLE	1.292***	1.316***	1.107***	1.072***	0.864*	0.917*
PEDS	1.021	0.893*	1.062	0.991	0.907	0.845**
BIKE	1.913***	1.635***	1.197***	1.146***	1.344**	0.965
MCYCLE	1.290***	0.845***	1.085***	0.969**	1.232**	1.091
SPEED	1.055	1.163***	0.969	1.055**	1.208	1.224***
ERRATIC	1.198**	1.168***	1.016	1.036**	0.938	1.010
DISTANCE	0.925	0.793***	0.957	0.957**	1.021	1.082
AGAINST	1.119	1.104	1.058	1.000	1.379	0.832
GIVEWAY	1.113	1.119**	1.051	1.049***	1.274**	1.072
TURNING	0.915	1.079	1.056	1.076***	1.187	1.019
OVERTK	0.836	0.918	1.116	1.012	0.832	1.179
TECHNIC	1.198	1.284	0.887	1.107	0.487	1.107
PEDMISB	0.724	1.069	1.075	1.019	1.013	1.075

Notes: Odds ratios from logistic regressions (3), conditional on economic variables and including linear yearly trend and fixed province and seasonal effects. Asterisks refer to estimates' significance at 0.01 (***), 0.05 (**) and 0.1 (*) level.

weekends and night time crashes, and excessive speed. Weekend crashes in particular seem to be linked with an increase in the rate of fatal accidents during lockdown. More specifically, evidence points towards an increase in probability of accidents happening in lockdown involving motorcycles during weekends, and also occurring at daytime. Nonetheless, RTAs involving a single vehicle, due to excessive speed and distracted/erratic driving, or involving bikes are also more likely to happen during lockdown, without a clear distinction between weekends and weekdays.

6. Conclusions

A comprehensive database including all road traffic accidents with injuries and deaths reported by police forces in Italy between 2014 and 2020 and sub-national level data on economic factors were combined in this study. The natural experiment provided by the COVID-19-related movement restrictions allows to investigate their impact on the frequency and severity of RTAs. Our quantification effort confirms the recent body of evidence from other countries, showing that (1) economic activity is directly related to the number of RTAs, whereas rising driving-related prices reduce accidentality; (2) movement restrictions had a large effect in reducing the number of RTAs and injuries, but also led to a relatively higher rate of fatal accidents.

Our findings suggest that behind the increase in fatality rates observed at times of lockdown there is a mixture of lifestyle changes and riskier driving behaviours: the former are reflected in higher probability of accidents involving bikes and weekend accidents involving motorcycles; the latter in a generalized increase in accidents caused by distraction and erratic driving, as well as a higher probability of accidents caused by excess speed during weekdays. The effect of the second period of restrictions on the probability of RTAs caused by excessive speed is even strengthened. In terms of implications for policy-makers, the most relevant result of this study relates precisely to the increase in the fatal rate of accidents. Looking at the estimated absolute reduction in RTAs and related deaths, one might feel quite comfortable in stating that the lockdown had a positive effect on RTAs and deaths reduction. However, this hides a huge increase in fatal rate of traffic accidents, which more than doubled. The decrease in traffic is so pronounced that it offsets the increase in deaths. Still, our results reveal that drivers were in general less prudent and more distracted during lockdown. This evidence calls for a thorough reflection on the safety of streets in times of country-wide instability such as during a pandemic, further enhanced by the finding of a relative increase of accidents involving bicycles. While it is true that during a pandemic police forces are called to act on multiple fronts, safety on the roads must not be forgotten. Furthermore, information campaigns could be implemented on the importance of paying attention while driving. A relative increase in RTAs severity also add further stress on hospitals, already put to the test during pandemic times.

Our results also emphasize the need to reassess road safety performance (Chen et al., 2022) during mobility restrictions or after major economic shocks altering traffic levels, to allow for immediate policy response. Moreover, as the economy recovers from the pandemic period, and with all restrictions now lifted, there is a real risk of a new increase in RTA-related mortality after several years of improvement in one of the European countries with most deaths from RTAs. Successful control of risky driving behaviours, especially excess speed, will be key to avoid a trend reversal.

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