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Compensation effect between deaths from Covid-19 and crashes: The Italian case

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ABSTRACT

Emergencies such as the Covid-19 pandemic pose several decision-making issues, while clear evidence of successful strategies are still unavailable, different policies may be identified. However, in such emergencies, the preservation of public health, by firstly reducing human loss of life may be prioritized and then restrictive measures are implemented. The trade-off between damage due to the threat and the decrease in damage due to the lockdown is largely unexplored. Here we show that there is a degree of compensation between damage from epidemic deaths and from traffic deaths, especially in the case of immediate restrictive measures imposed by governments. Based on the Italian case, we found that damage from loss of human Capital and health care costs could have been fully compensated if the lockdown had been imposed ten days earlier. Considering only one Italian region (Puglia), where the epidemic was delayed and then restrictions were timely, damage due to loss of human Capital was largely compensated in the real scenario. However, damage due to loss of welfare could not have been fully compensated for, since Covid-19 deaths largely outnumber traffic deaths in the simulated epidemic period and loss of welfare damage is scarcely dependent on the age-at-death. From a broader perspective, societies seem to react to external threats as a whole organism, thus tending to restore the original equilibrium. Governmental decisions could accelerate this process. However, in the case of similar threats, some wounds cannot be compensated for, such as the incalculable damage due to loss of welfare.

1. Introduction

Risk assessment is complex, because of the identification of the nature, characteristics and consequences of risks and, mostly, because of the different objectives which can be set and the methods to be used (Aven, 2012).

In fact, when the risks to be assessed directly involve health, up to potentially being fatal, different approaches are available for risk analysis. A "global" approach can equate human feelings to material factors and then, the "economic value" of all the involved factors is considered (including human factors). In this case, the objective function may be the overall cost minimization, including immaterial and material factors. From another perspective, the preservation of human life cannot be compared with other economic factors. Hence, the cost minimization will consider human loss-related risk factors, independently of other economic factors. This approach, which can be defined as a "vital" approach, tends to cancel costs from human losses (e.g., the "Vision Zero" policy, see Johansson, 2009).

Risk assessment choices related to the Covid-19 pandemic fall under the previous dichotomy. In this study, the "vital" approach is analyzed, thus considering the consequences from Covid-19 in terms of human losses using Italian data. All other positive or negative consequences unrelated to potential human losses, such as other economic and financial losses or environmental benefits, are thus not considered here.

In parallel to Covid-19 deaths, lockdown/shelter-in-place policies generally applied in several countries worldwide can also have other effects, such as decreasing traffic and, consequently, a reduction in traffic deaths (see e.g., Shilling and Waetjen, 2020). In this study, the possible compensation effects between the increase in deaths due to Covid-19 and the decrease in deaths due to governmental choices is investigated. Such compensation should not be regarded as a pure arithmetic comparison between deaths from Covid-19 and traffic deaths, since the age at death should be necessarily taken into account. In fact, the average age at death from Italian traffic crashes is notably lower than that from Covid-19. Hence, values of statistical life can be taken into account (Viscusi and Aldy, 2003; De Blaeij et al., 2003). Possible compensation mechanisms between damage due to deaths from Covid-19 and from traffic crashes are discussed from a multidisciplinary perspective after having considered a "vital approach" for Covid-19 risk assessments. A case study is presented from Italy, one of the countries most affected by Covid-19 in Europe in terms of deaths from the disease (*https://covid19.who.int/*).

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2. Methods

The methods used are described in detail below and summarized in Fig. 1.

2.1. Data collection

Data on Covid-19 deaths in Italy (up to May 2020) were retrieved from the *Istituto Superiore di Sanità* online sources. They are classified according to age at death and gender. The detailed evolution of the number of deaths over the days was retrieved from the *Dipartimento della Protezione Civile* online sources. The age ranges of Covid-19 and traffic deaths were homogenized.

Data about Italian deaths from traffic crashes were retrieved from the *Istituto Nazionale di Statistica (ISTAT)* (2018) online publications. The most recent data available refer to 2018, classified according to age at death and gender. They were used to estimate the expected number of deaths from traffic crashes between February and May 2020, in Italy. Lockdown policies also imply an increase in working from home, which may produce a decrease in work-related deaths. However, they may be counteracted by the deaths of healthcare professionals from Covid-19, as can emerge by interpreting recent data from the *Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro* online publications. Hence, work-related deaths were not considered in the compensation assessments, apart from work-related deaths which occurred in traffic (likely included in crash estimates).

A summary of data about deaths from Covid-19 and crashes in Italy during the pandemic spread is reported in Table 1.

2.2. Estimates of damage

To compare damage from the different considered causes, social damage was estimated, since ages at death from different causes may differ greatly. Hence, the simple comparison between raw numbers of deaths was not pursued.

Damage was computed as based on the *Ministero delle Infrastrutture e dei Trasporti* guidelines, to assess social costs from traffic crashes. They are

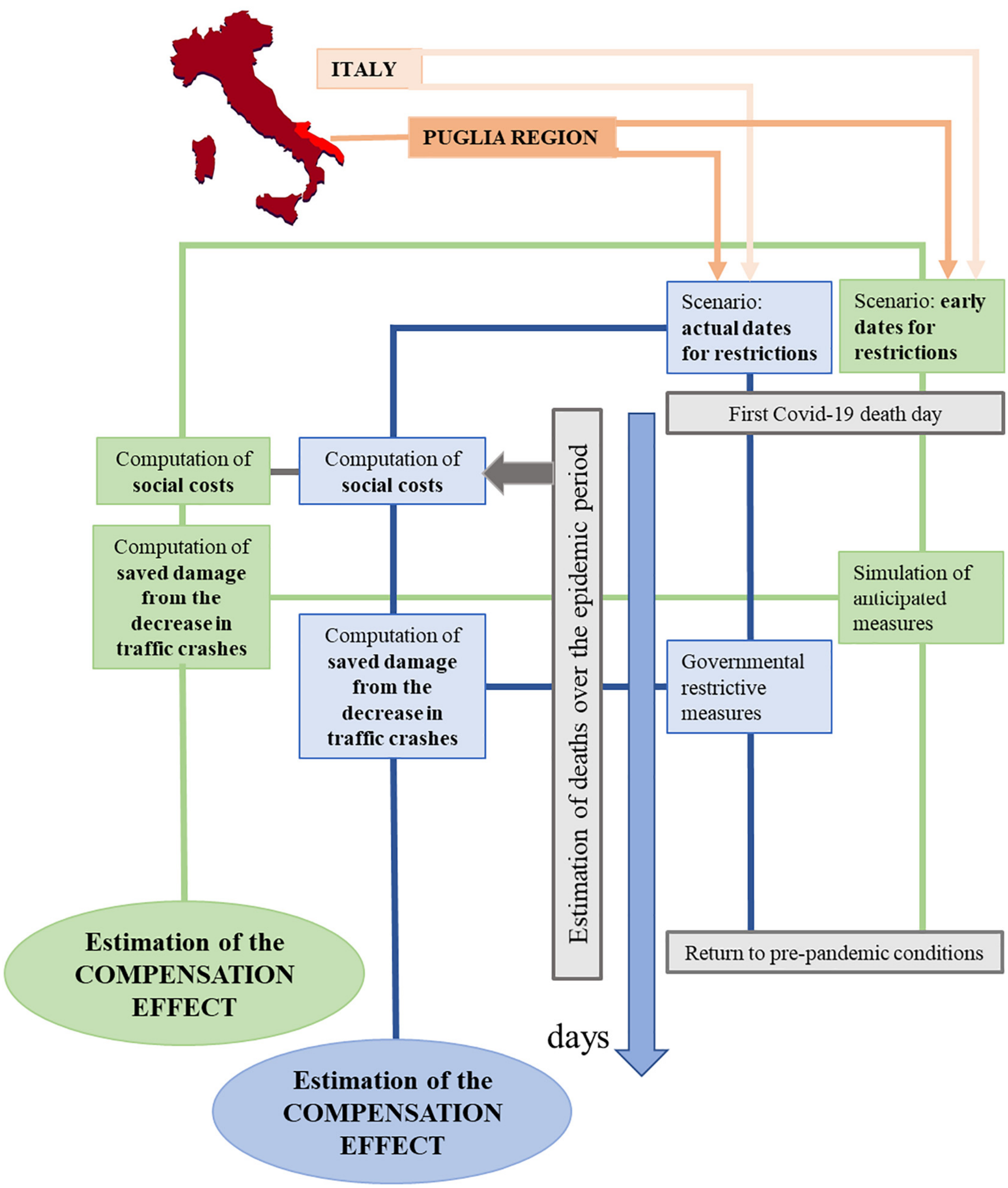

Fig. 1. Flow chart of the research process.

Table 1
Data on Italian deaths from Covid-19 and expected deaths from traffic crashes (between February 22nd, first Covid-19 death day and May 3rd, 2020, the day on which mobility restrictions were generally loosened).

Cause of death	Gender	Age class									
		0–14	15–24	25–34	35–44	45–54	55–64	65 +	No data	Total	Total/day
Covid-19	Male	1	4	23	110	482	1524	14,912	0	17,056	236.9
	Female	3	1	11	44	149	465	11,155	0	11,828	164.3
	Total	4	5	34	154	631	1989	26,067	0	28,884	401.2
Traffic crashes	Male	5	54	63	63	63	67	138	7	460	6.4
	Female	2	12	9	8	13	18	50	2	114	1.6
	Total	7	66	72	71	76	85	188	9	574	8.0

divided in this document into: a) material damage associated to the "loss of human Capital" from death, b) damage from "loss of welfare": "moral" damage due to the loss of a beloved person (caused by other people), c) health care costs.

Material damage was estimated as follows, based on the cited guidelines, for each age and gender combination (Table 1):

$$\mathrm{DLHC}_{j,k} = \left(\mathrm{EWLL}_{j,k}\right) * (\mathrm{Ij}, \mathrm{k}) * (1 + \mathrm{r})^{(-y)} \tag{1}$$

where:

DLHC = Damage from Loss of Human Capital per death, for the j-th age class and the k-th gender (€);

EWLL = average Expected Working Life Lost (years), for the j-th age class and the k-th gender, considering the average Italian employment trends and retirement ages;

I = average Income, computed by weighting the Gross Domestic Product (GDP) per capita (2018) with the employment rate (€), for the j-th age class and the k-th gender;

r = discount rate (%), estimated according to the GDP trend (2010–2018);

y = years considered for the estimate, coherently with the computed EWLL.

Estimates for the loss of welfare damages -DLW- per death were also taken from the cited guidelines. They vary between 0.71 million euros for an age at death <15 and 0.44 million euros for an age at death ≥ 65. They are independent of gender.

In the case of traffic deaths, using the same reference source, health care costs are negligible with respect to the other two types of damage (0.1% of total costs). In the case of Covid-19 deaths, health care costs can be hard to estimate during the pandemic spread. Hence, preliminary and incomplete estimates are used (ALTEMS, 2020), assuming that all Covid-19 deaths occurred in hospitals (independently of age and gender). Considering other health care costs (e.g., building new hospitals, re-organizing hospital spaces, etc.) will drive the assessment towards a comprehensive country-wide economic assessment, involving several other factors, which is outside the scope of this study. In fact, a "vital approach" is used here, which only includes damage due to individual deaths.

Once average DLHC and DLW per death had been estimated for each combination of gender and age class, they were multiplied by the number of deaths from different causes in Table 1. Hence, the obtained damage can be summed up to compute total DLHC and DLW damage due to the two causes: Covid-19 and traffic crashes, during the pandemic period up to May 2020, in Italy. This total damage is then divided by the number of deaths for each death cause:

$$Dpd, i = \frac{\Sigma_{j=1}^{8}\Sigma_{k=1}^{2}\left(\left(DLHC_{j,k} + LWD_j\right) * N_{j,k}\right)}{N_{tot}} \tag{2}$$

where:

Dpd = Average damage per death for each i-th cause: Covid-19, traffic crash (€);

$N_{j,k}$ = Deaths for the j-th age class and the k-th gender;

N_{tot} = Total number of deaths for each i-th cause;

DLHC and LWD as previously defined.

2.3. Simulation of the Covid-19 pandemic evolution

To estimate damage compensation effects, the evolution of the Covid-19 pandemic should be simulated, starting from data in Table 1. The cumulative number of deaths were simulated according to a model found in the literature (Tappe, 2020). This model was developed for the Chinese epidemic and initially tested in Italy with data updated to March, 19th. Among available models for pandemic spread and related containment measures (see e.g. Colizza et al., 2007; Ferguson et al., 2006) it was chosen because of its flexibility, simplicity and case-specificity.

The selected model was used to fit the available data until May, 3rd, by using the following equations:

$$t \leq T_X : D(t), L = \exp(\ln(t_1) + (\ln(t_n) - \ln(t_1))*((\ln(t) - \ln(t_1))*(\ln(t_n) - \ln(t_1)))^{\beta} \tag{3}$$

$$t > T_X : D(t), R = \exp(\ln(D(TX), L) + \lambda*(1 - \exp(-\upsilon*(t - T_X)))) \tag{4}$$

where:

t = number of days starting from the first Covid-19 death;

T_X = day in which the effects from restrictive measures start being observed (i.e., the shape of the cumulative curve changed). T_X is identified to be typically 17 days after the restrictive measures (Tappe, 2020), while here it is estimated to be 8 days according to the available data;

D(t) = cumulative deaths (D(t),L in Eq. (3), D(t),R in Eq. (4));

t_1 = day on which the first epidemic death was recorded: February, 22nd;

t_n = generic day between t_1 and T_X;

β = parameter here set to 0.53 based on the curve fitting (Italian country-wide data);

λ = parameter here set to 2.25 based on Italian country-wide curve fitting (it can be interpreted as follows: the smaller the parameter is, the more rigorous are the measures);

υ = parameter obtained as a combination of the other parameters.

The model parameters do not allow consideration of different levels of restrictions during and immediately after the lockdown (i.e., to consider the loosening of restrictions after May, 4th). Hence, data fitting was limited to May 3rd, in order to represent homogeneous conditions of restrictive measures. However, as further discussed, May 3rd is at the end of the cumulative curve of Covid-19 deaths. Hence, the error from using modelled rather than actual data after May 4th was considered as still acceptable (less than 10%, for data up to June, 25th), and a new rapid increase in the cumulative curve as not evident at the time of writing.

2.4. Simulation of effects from restrictions on traffic deaths

In this study, it is assumed that most traffic-related deaths may have decreased due to governmental restrictions and so some of the damage computed for Covid-19 deaths can be counterbalanced by the decrease in damage due to traffic deaths. However, as previously indicated, other economic damage has not been considered, since the study is focused on damage due to mortality. Hence, in this case, the computation of risks (i.e., probability multiplied by its consequences) and the further risk compensation estimates are based on: a) estimates of the likelihood of death from different causes, b) estimates of consequences from these deaths, in terms of damage to society.

Since the traffic volume is the main factor for predicting crashes due to risk exposure, the reduction in traffic volumes after the restrictive measures were implemented. The traffic volume reduction from March to May 2020, is evident if compared with the previous year, according to recent online data from the *Ente Nazionale per le Strade*. In particular, by manually combining data from both light and heavy vehicle trends, the traffic volumes abruptly decreased during March (restrictive measures were issued in the second week of March and were nearly stable (with a slight increase) during April).

Whereas, a rapid increase in traffic volumes was noted in May, due to the gradual loosening of mobility restrictions from May 4th up to a progressive return to normal conditions, even if the pandemic was still ongoing. Hence, traffic volumes gradually tended to the average pre-pandemic volume (similar to the previous year's traffic volume).

Using raw weekly values from the available sources would result in considering a discontinuous function with differences only between weeks. Hence, a more realistic trend was simulated, by fitting the above reported tendencies for all the days in the considered period. Traffic trends were projected towards the day on which the traffic volume reached the average traffic volume in the same period (based on 2019 data), that is when the pandemic should have stopped affecting traffic volumes.

Since traffic deaths can be assumed to be proportional to traffic volumes (e.g., Elvik et al., 2009), the same decreasing trend was also adopted for the number of traffic deaths. Note that traffic reductions have indeed been found to be comparable with a fall in traffic deaths by Shilling and Waetjen (2020) under restrictions from Covid-19 in California.

The output measure from this stage is the number of deaths which did not occur from traffic crashes due to the restrictive measures. It can be plotted as a cumulative curve, similarly to the evolution of Covid-19 deaths. For each day *t* of the epidemic period from the first-death day, the deaths which did not occur ΔD(t) from crashes are computed as the difference between crashes expected in the case of no restrictions and crashes modelled in the case of restrictions, as follows:

$$\Delta D(t), \text{crashes} = D(t), \text{crashes (no restrictions)} – D(t), \text{crashes (restrictions)} \quad (5)$$

2.5. Estimation of compensation effects

Once the cumulative deaths curves have been obtained for Covid-19 and traffic crashes, compensation effects can be computed.

In fact, the damages per death obtained through Eq. (2) for each cause of death were multiplied by:

- the number of Covid-19 deaths taken from the modelled cumulative curve (Eqs. (3), (4));
- the number of expected avoided traffic deaths due to the restrictions (Eq. (5)).

In this way, the following curves can be estimated:

- the curves of cumulative damage from Covid-19 deaths for each type of damage: loss of human Capital (summed with health care costs) and loss of welfare;
- the curve of cumulative saved damage due to the decrease in traffic crashes.

The compensation effects can be discussed based on those curves.

2.6. Different considered scenarios

Italian country-wide data were collected. However, country-wide restrictions (March, 11th) were imposed in Italy when some regions (especially in Southern Italy) had experienced very few Covid-19 deaths.

Hence, the entire process (including curve fitting) was repeated for Puglia: a region in Southern Italy. In Puglia, the first Covid-19 death occurred 11 days after the first Italian death, while country-wide limitations were applied only one week after the first Puglia death. Hence, the Puglia case is useful to test whether the compensation effect can exist in a case of very timely restrictive measures.

The type of data used is the same described for the country-wide case. The cumulative curve of Covid-19 deaths and expected traffic deaths were also available for the Puglia region. When the exact classification into different gender and age classes was not available, data were cross-combined. In Puglia, 424 Covid-19 deaths had occurred up to May, 3rd, while 42 traffic deaths were normally to be expected in the same period considered in the country-wide simulation.

Moreover, an additional scenario considering hypothetical country-wide earlier implementation of restrictions was modelled. In this case, the hypothetical earlier date for restrictions was set in order to achieve the full compensation of damage from loss of human Capital and health care costs. This hypothesis was used to estimate the cumulative curve from Eqs. (3) and (4), by fitting the curve to the available data between the first death day and the day on which the restrictive measures reveal their effects (estimated at eight days after application of restrictive measures), and extending the curve up to the predicted day on which the pandemic stopped affecting traffic (and thus, crashes). This hypothesis is useful to test whether timely restrictive measures could have been associated to damage compensation.

Hence, in summary, the overall presented framework was repeated for the following four scenarios:

- Italian country-wide data (actual restrictive measures dates);
- Puglia regional data (actual restrictive measures dates);
- Italian country-wide data (hypothetical earlier dates for restrictive measures);
- Puglia regional data (hypothetical earlier dates for restrictive measures).

In the case of hypothetical earlier restrictive measures, the simulated decreasing traffic trend was also brought forward, accordingly.

3. Results

3.1. Simulated trends of cumulative deaths and related damage

The estimated average damage per death (Eq. (2)) in Italy are shown in Table 2.

The unitary damage from loss of human Capital is evidently much higher for traffic than from Covid-19 deaths, mainly due to the great difference between the average ages at death from the different causes. Damage from loss of welfare is very similar, because it scarcely depends on age. Health care costs are much higher for Covid-19 than for traffic crashes, but still lower than other damage.

The results from the epidemic model fitting (Tappe, 2020, Eqs. (3) and (4)) to data from Covid-19 deaths in Italy are presented in Fig. 2.

The estimated decreasing traffic volume trend during the epidemic period on Italian roads is shown in Fig. 3. The average "pre-pandemic" volume (based on the previous year's estimates) would be reached on June 25th. Hence, this date was assumed as the day on which the pandemic should stop affecting traffic volumes (and crashes) and thus, it was assumed as the end of the simulation.

Table 2
Estimated average damage per death in Italy from Covid-19 and traffic crashes (February, 22nd–May, 3rd, 2020).

Cause of death	Damage per death (€)			
	Loss of human capital	Health care costs	Loss of welfare	Total damage
Covid-19	72,223	9,796	449,231	531,250
Traffic crashes	939,184	1,965	542,213	1,483,362

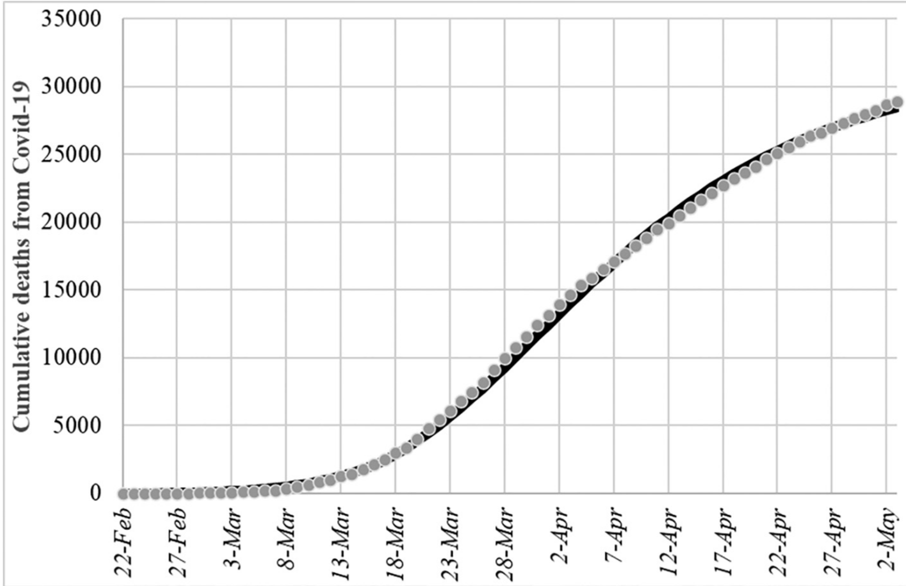

Fig. 2. Predicted evolution of the cumulative number of Covid-19 deaths in Italy, black curve fitted to real data points in grey (up to May 3rd).

According to Table 1, in normal conditions, an average of 8 deaths daily could have occurred between the end of February and the beginning of May. Hence, since there is no reason to assume an increase in the cumulative number of deaths different from a linear increase, the cumulative traffic deaths were assumed as linearly increasing from the epidemic "first-death" day (Fig. 2) to the first week of March. In the case of no restrictions, a continuous linear increase could have been assumed; while in case of restrictive measures, after the first week of March, crashes are assumed to follow the trend in Fig. 3. The difference curve in Fig. 4 (Eq. (5)) estimates the cumulative number of saved traffic deaths in the case of restrictions.

3.2. Estimates of compensation effects

Based on the modelled cumulative deaths curves (Fig. 2) with simulations extended up to June, 25th and of deaths from crashes potentially not occurred (Fig. 4), the cumulative damage curves were plotted. They were obtained by multiplying the estimated average damage per death (Table 2) by the cumulative deaths from the different causes for each day from the day of the first death.

The results from the calculations of cumulative damage are reported in the following Figs. 5 and 6, in the four considered scenarios.

These results show that damage from loss of human Capital and health care costs due to Covid-19 deaths in the actual restriction scenarios are partially compensated for in the Italian case and almost fully compensated in the Puglia case, while damage from loss of welfare are almost entirely not compensated for. Italian damage from loss of human Capital and health care costs could have been compensated for by bringing forward restrictions by ten days. Moreover, even Puglia damage from loss of welfare could have been partially compensated in the case of earlier implementation of measures.

The plotted differences in loss of welfare damage must be interpreted either as "suffering" or "well-being" depending on whether the difference is above or below zero. Therefore, the diagrams could show a tendency towards an almost zero-level of change in suffering in the actual restriction scenario. However, under hypothetical scenarios of timely restrictive measures, there could even be surprising results. For example, in the hypothetical anticipated scenario, in the case of Puglia, there could be a tendency towards a reduction in suffering (43% in Figure 6), besides environmental benefits. These effects could be even more evident in case of immediate measures. Some populations, attentive to the "vision zero" approach even if not directly affected by the disease, could not acquire full awareness of the pain caused by Covid-19 deaths, while still accepting to live under lockdown for a long time.

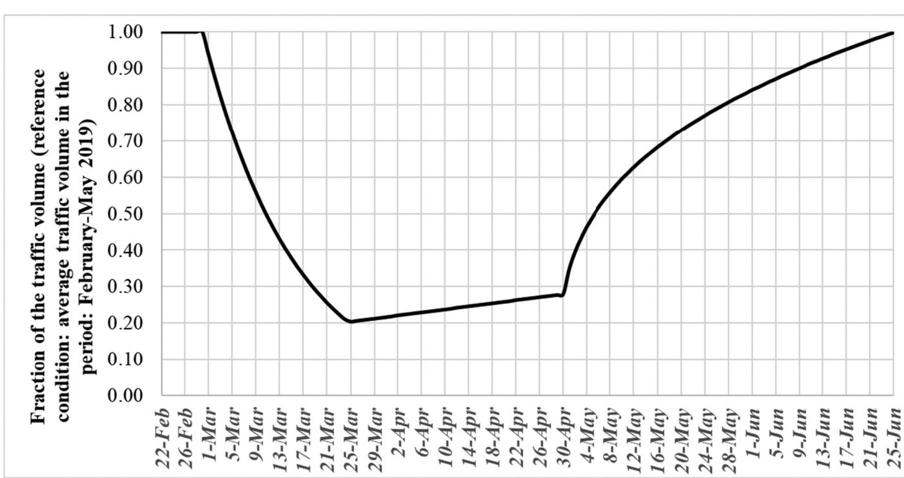

Fig. 3. Decreasing traffic trend on Italian main roads in the considered epidemic period.

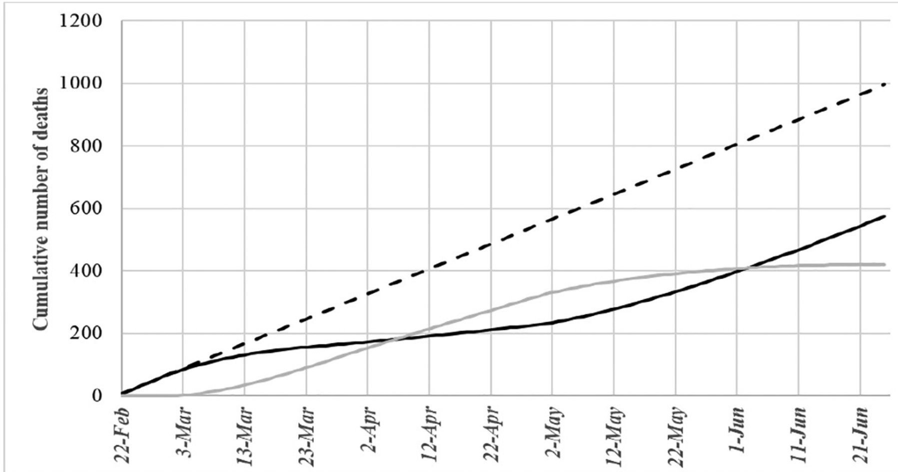

Fig. 4. Curve of the expected cumulative number of deaths from traffic crashes in the case of restrictive measures (black solid line) or without restrictions (black dashed line). The difference curve (grey solid line) indicates the cumulative number of deaths which are expected to have been avoided due to the restrictions.

4. Discussion

In this section, the previously described results are discussed in light of their possible implications, from a multidisciplinary perspective.

4.1. Populations as individuals

Worldwide problems such as Covid-19 affect entire populations simultaneously, especially in a complex globalized system, where risks are shared (Helbing, 2013). Governments may use prevention measures to protect the unaffected parts of the population. This can be obtained by imposing restrictions to individual rights, to limit the spread of infection. The natural need of human beings for mobility (Colonna, 2009) was greatly limited during the Covid-19 pandemic.

However, it is suggested here that governmental measures may generate "homeostatic" compensation effects in the population, between Covid-19 and traffic deaths (considering the age at death).

Homeostasis is a physiological characteristic of human beings (at the bottom level of the hierarchy of needs according to Maslow, 1954), who react to events which are external to individuals and able to undermine their equilibrium. Homeostasis can be associated to both systems (Germain, 2012) or specific measures and factors (Benzinger, 1969; Pittendrigh and Caldarola, 1973). The reaction to those destabilizing events occurs inside the organism, while leading to a new internal equilibrium, by acting on controllable functions.

The entire population could be considered in this case as a whole homeostatic individual. In fact, the population/individual was affected by an external problem (i.e., Covid-19), which disrupted the equilibrium. However, the pandemic would have been hard to precisely forecast and be properly managed by the population through standard "homeostatic" mechanisms, such as available medicines or vaccines, to restore the equilibrium in the short-term period. Hence, Institutions at different levels coped with damage produced by the disrupting event. Intervention strategies generally consisted of both prevention for unaffected people and restrictive measures. However, the restrictive measures could also have some beneficial effects, such as the reduction in traffic crashes as described here.

Hence, the damage produced by Covid-19 to the population can be partly compensated for by the saved damage from traffic deaths, as shown at different levels in Figs. 5 and 6. This means that the organism (i.e., the whole population), once attacked (i.e., by the pandemic), may react through "physiological" behavior, which globally tends to reduce damage to the whole organism, through a long-term homeostatic process.

4.2. Risk internalization

Based on the previous discussion, it can be stated that the external ("outer") risk posed by Covid-19 was transferred into the personal "internal" sphere (i.e., "internalization") and humans rely on their own capabilities to compensate for these risks, through homeostatic mechanisms.

At this point some examples from the Homeostatic Risk Theory (Wilde, 1982) in the field of road safety are described to better define what is intended here by "risk internalization". Based on this theory, drivers continuously compare the perceived risk with an internal value, constant in the long-term period (unless boundary conditions are significantly modified): the "target risk", which they are willing to spend. If the perceived risk is close to or greater than the target risk, they will adapt their behavior accordingly. Although the complete risk compensation mechanism described by this theory has often been criticized, some forms of risk compensation are frequently observed (Noland, 2013).

For example, drivers who are struck by sudden illness may not address road environmental risks as well as in ordinary conditions. Hence, they will try to compensate for their decreased capabilities by e.g., reducing the vehicle speed in order to keep their target risk constant. This means that they are trying to "internalize" a potential outer risk, thus achieving risk compensation.

On the other hand, road sections with sharp curves placed after very long road tangents may be dangerous because they are unexpected, especially for drivers unfamiliar with the routes (Intini et al., 2019a, 2019b). In this case, the risk comes from outside the drivers (i.e., external risks), thus they cannot compensate for an unexpected risk. The implementation of engineering countermeasures (e.g., road signs, traffic control systems) will lead drivers to react by reducing their speeds, because dangerous curves are expected or due to the control systems. Hence, countermeasures may elicit the timely internalization of the risk by drivers and high-level policies can be implemented to keep the target risks of all drivers below a given threshold, so that they can internalize the generic risk. In other words, the internalization of risk by drivers can foster driver reactions and risk compensation (Colonna and Berloco, 2011).

The same risk internalization process is proposed in this study to explain the compensation for fatal risks caused by Covid-19 (Figs. 5 and 6). In fact, ordinary seasonal flu epidemics are already risks internalized by society, thanks to medical science, vaccines (similarly to road signs in the case of road dangers) and prevention campaigns. On the other hand, the Covid-19 pandemic was a typical external risk, not transferrable into the internal area (which cannot be "internalized" yet) either by individuals or by society.

Similarly to the previously discussed road risks, the only possible method of risk compensation is internalization, in order to elicit more

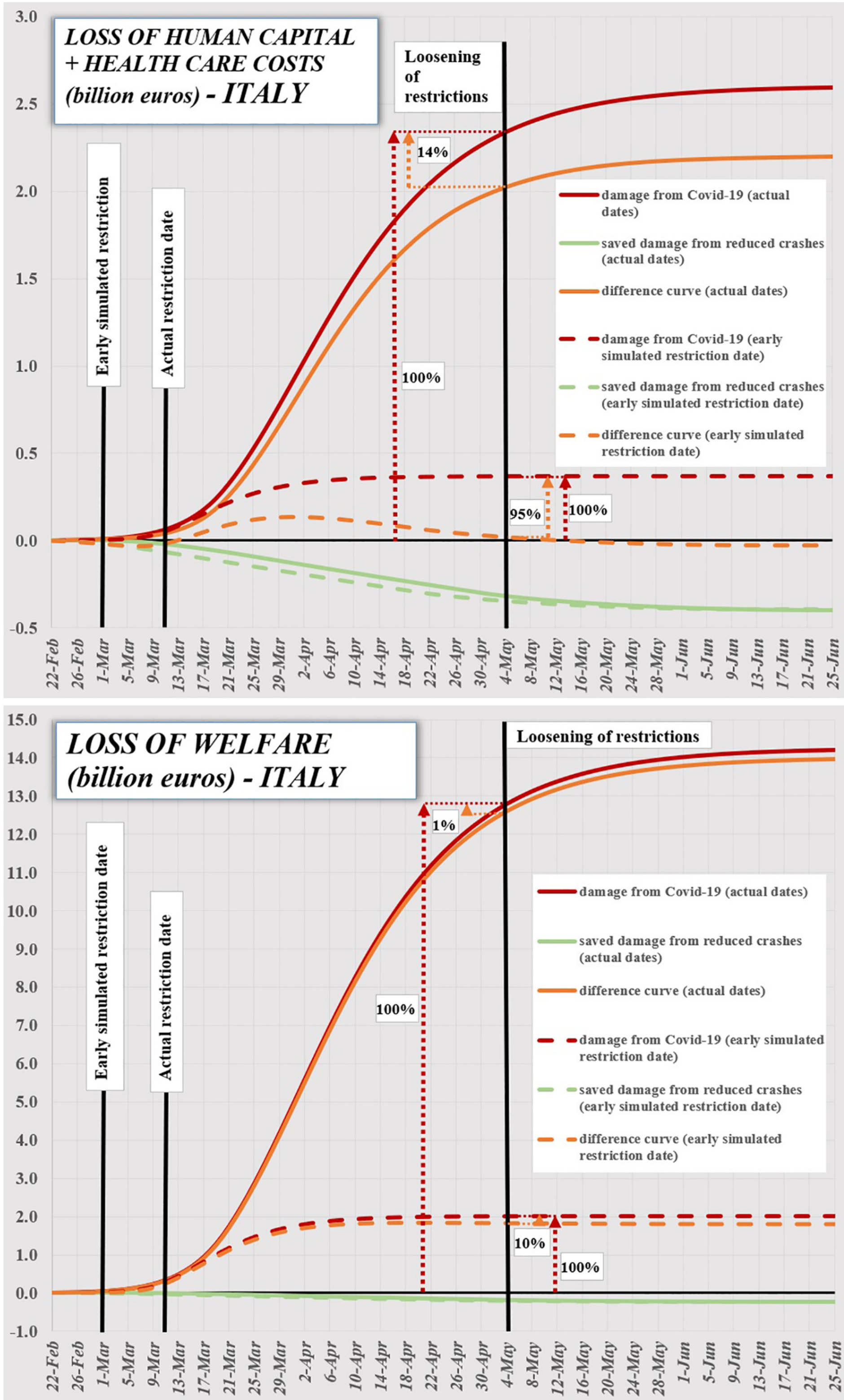

Fig. 5. Cumulative damage computed in the country-wide Italian scenario with indication of the compensation effect (percentages computed for May, 4th).

prudent behavior. In fact, the governments of affected countries, even in completely uncertain scenarios (Chater, 2020), have fostered risk internalization by the population through restrictive measures. However, it was shown that restrictive measures may also produce damage compensation effects, which can be considered as a symptom of risk internalization within society, to restore the initial equilibrium.

4.3. Effectiveness of restrictive measures

Another interesting aspect concerns the effectiveness and timeliness of prevention measures. Our results have shown that the more rapid is the implementation of restrictions (simulated scenario of anticipated restrictions or the Puglia case) the more evident the compensation effect will be,

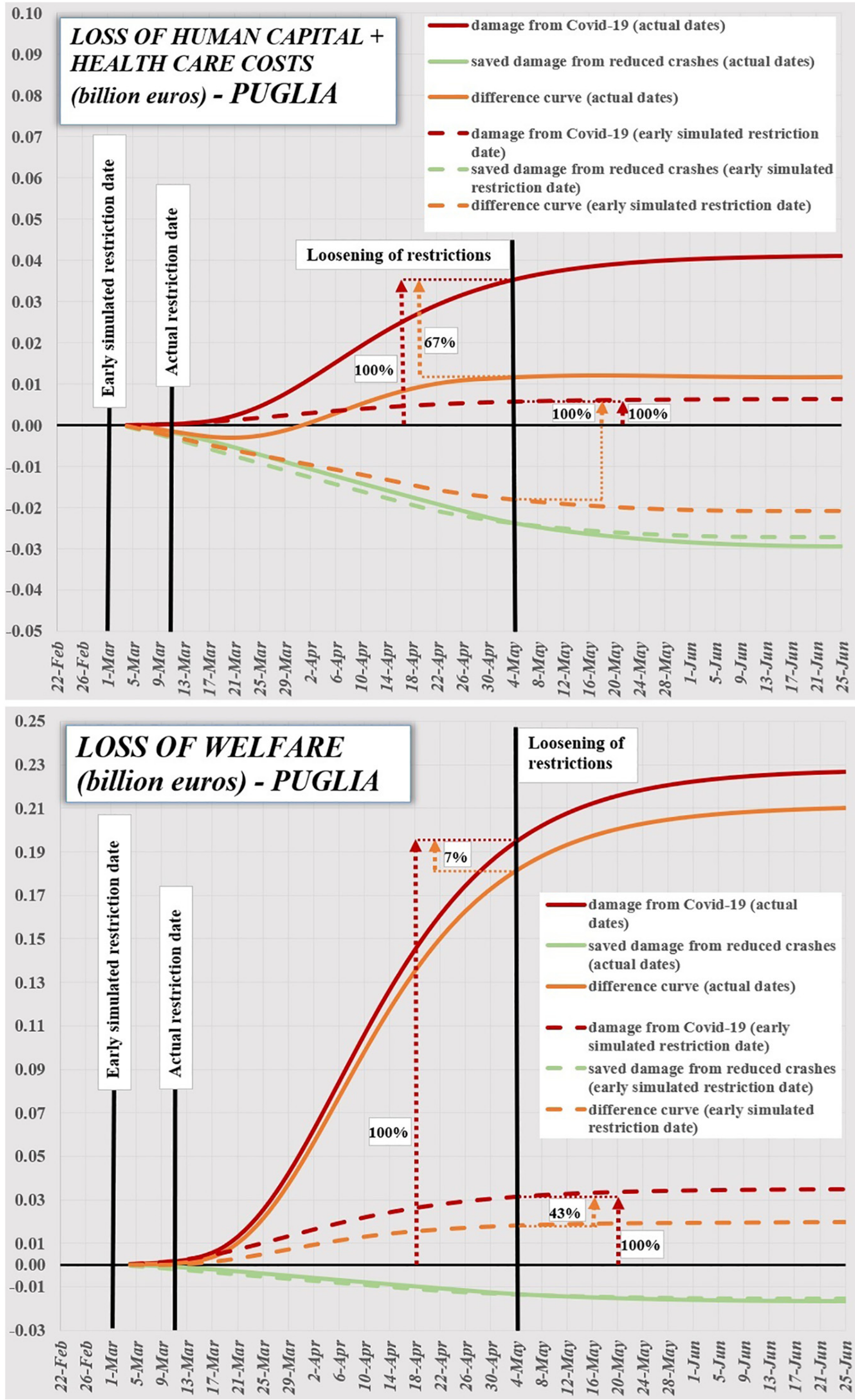

Fig. 6. Cumulative damage computed in the Puglia region scenario with indication of the compensation effect (percentages computed for May, 4th).

particularly considering losses of human Capital and health care costs, up to total compensation.

In particular, we show here (Figs. 5 and 6) that earlier implementation of measures (ten days before the actual date) could have significantly decreased the damage in terms of loss of human Capital and health care costs, as based on the country-wide simulations. This earlier implementation could have resulted in full damage compensation (loss of human Capital and health care costs) with saved traffic deaths. The same compensation effect was noted in the Puglia region, where saved damage from traffic deaths was estimated to be about comparable with that from Covid-19 deaths, even in the actual scenario. In fact, in this region, the restrictions were actually timely, compared to the regional epidemic curve. Moreover, if restrictive measures had been implemented earlier for the Puglia region (ten days before), even damage from loss of welfare could have been partially compensated for (the only scenario in which this was noted).

Clearly, all the analyses of these results are dependent on the intrinsic uncertainty of estimates. In this regard:

- Our estimates are based on an epidemic model which is necessarily simple, according to the study aims, while more sophisticated models should be used for accurate forecasting of the evolution of the pandemic or the effectiveness and timeliness of restrictive measures (even if the modeling errors could be acceptable given the resolution of this study, see Table 3);
- Our estimates of damages are based on costs estimated from Italian local

Table 3
Root mean square percentage errors (RMSEP) of the used epidemic model in the four considered scenarios.

Scenario	Days between the first death day and the restrictive measures	Days considered for curve fitting (actual data of deaths/day)	RMSEP (%) - overall	RMSEP (%) – after the day of application of restrictive measures[a]
Italy – actual restrictions	18	72	67[b]	4
Italy – early restrictions	8	17	20	8
Puglia- actual restrictions	7	61	14	12
Puglia – early restrictions	−3[c]	6	–	29[c]

[a] The most significant error for the predictive aim of this study is related to the evolution of the pandemic and then, after the application of restrictive measures.
[b] Most of this error is due to the unsatisfactory model fit in the first few days after the first death day. In fact, excluding the first 18 days, the RMSEP is 4% on average.
[c] The first death day was on March, 4th, while the early restrictive measures were hypothetically implemented (according to the country-wide case) on March, 1st. For this reason, the RMSEP can only be computed for the days following the restrictive measures. The high RMSEP in the early restrictions scenario is then strictly connected to the few available days.

sources, given the case study (other countries may have significantly different costs);

- The Covid-19 pandemic is still ongoing at the time of writing and so all estimates are intrinsically uncertain, because they are based on incomplete or historic data in similar conditions;
- Comprehensive benefit-cost analyses were outside the scope of this study, in which a "vital" approach was considered, and so only individual death-related damage was taken into account;
- Our crash data are estimated rather than measured, but crash reductions coherent with traffic volume reductions have also been recently suggested by Shilling and Waetjen (2020) in the United States.

5. Conclusions

In this study, possible risk compensation mechanisms have been explored, between deaths from Covid-19 and traffic crashes, which were expected to decrease due to the lockdown. Results from the Italian case study are discussed in light of a multidisciplinary perspective.

Based on the results, the following conclusions are drawn:

- some trade-offs between social costs produced by Covid-19 deaths and saved costs from the reduction in traffic crashes under lockdown conditions are suggested and this compensation effect may increase with the timeliness of measures.
- The compensation in terms of social costs mostly involve damage from loss of human Capital and health care costs, while the incalculable damage due to loss of welfare can be very hard to compensate for.
- We suggest considering populations as living organisms which may react to external threats through homeostatic mechanisms, to restore the original equilibrium.
- Governments can be vectors of the internalization of external risks within the population, by possibly fostering homeostatic reactions through restrictive measures.

In line with the aims of this study, we focused only on damage related to deaths, while all the other important effects caused by both the disease and the restrictions have not been treated. However, under these hypotheses, referred to as the "vital" approach, possible homeostatic compensation patterns of a whole population have been shown, considering damage due to human losses (in particular, loss of human Capital).

The results from this study, at times surprising, could be in line with the choices of governments which are particularly attentive to the "vision zero" approach. However, given the discussed intrinsic limitations, the results from this study should be applied with care, especially in contexts different from Italy, whereas the proposed interpretation of the inquired compensation effect could potentially be transferred everywhere.

CRediT authorship contribution statement

Pasquale Colonna: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Paolo Intini:** Data curation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no competing interests.

The data that support the findings of this study are all available online at the sources cited in the References section.

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