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RESEARCH ARTICLE

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Summertime and the drivin' is easy? Daylight saving time and vehicle accidents

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Abstract

We investigate how exogenous variation in daylight caused by Daylight Saving Time affects road safety as measured by the count of vehicle crashes. We use administrative daily data from Greece covering the universe of all types of recorded vehicle accidents during the 2006–2016 period. Our regression discontinuity estimates support an ambient light mechanism that reduces the counts of serious vehicle accidents during the Spring transition and increases the count of minor ones during the Fall transition. The effects are driven from the hour intervals that are mostly affected from seasonal clock changes. We then discuss the potential cost implications of those seasonal transitions. In light of the talks about abolishing seasonal clock changes in the European Union (EU), our findings are policy relevant and can inform the public debate as empirical evidence for the block is scarce.

KEYWORDS

daylight saving time, regression discontinuity, vehicle accidents

JEL CLASSIFICATION

I12, I18, R41

1 | INTRODUCTION

Differences in ambient light conditions naturally affect driving capacity and road safety. For this reason, on June 2017 the European Parliament requested an ex-post evaluation of Directive 2000/84/EC regulating transition into and out of Summer time in EU countries (Anglmayer, 2017). Based on the report's findings, the European Parliament called on the European Commission (EC) to consider abolishing Daylight Saving Time (DST) for their member countries. In March 2019, the European Parliament approved the abolition of obligatory seasonal clock changes by 2021, with member states keeping their right to decide on their time zone afterward. Negotiations have not started and no law has been implemented yet, due to complications caused by Brexit and the COVID-19 pandemic. However, another important reason delaying any change in regulation is that the empirical evidence, in general and also with direct reference to the EU member states, is actually thin, as acknowledged by the European Parliament (Anglmayer, 2017); also because the EC report recommendations, raising concerns about the impact of DST on road safety, relied on studies for the UK and the US, which present mixed evidence about the impact of DST as well as its implications.[1]

We would like to thank participants in LSE seminars and in the 2019 International Association for Applied Econometrics Conference for their comments and suggestions. The usual disclaimer applies.

Redistribution of sunlight within the day is a first channel through which DST shifts affect driving behavior and vehicle accidents. During Spring transition, 1 hour of sunlight is reallocated from morning to evening. This creates a darker and riskier driving environment during the morning and one with better light conditions during the evening, while all other working and commuting schedules and patterns remain unchanged. During Fall transition, that extra hour of evening sunlight is returned back to mornings, hence creating a darker evening atmosphere. Light conditions have been shown to affect drivers' circadian rhythm and drowsiness (Chipman & Jin, 2009). A review of UK-based evidence suggests that collision risk reduces (increases) when entering (exiting) DST (Carey & Sarma, 2017). Bünnings and Schiele (2021) showed that darker environments increase year-round road safety costs in Great Britain, due to a positive, but weak, impact on fatal accidents when entering DST in Spring. For the US, Coate and Markowitz (2004) estimated that an additional hour of daylight reduces pedestrian fatalities by 33% between 05:00–10:00 and by 25% between 16:00–21:00, and that full-year DST could reduce pedestrian fatalities by 13% in these two time intervals. Thus, variation in ambient light conditions could be associated with the number of vehicle crashes—at least for the case of fatal and serious accidents.[2]

An alternative channel through which DST shifts affect driving behavior is sleep deprivation. DST has been shown to cause significant behavioral changes, especially during the Spring transition. Individuals sleep less, on average, and they tend to spend more time at home in the morning and less time at home during the evening (Sexton & Beatty, 2014).[3] Sleep deprivation affects drivers' alertness, and experimental evidence points toward a negative relationship with driving performance (Otmani et al., 2005; Philip et al., 2005). A US study used a regression discontinuity design to show that fatalities increase when entering DST through a sleep deprivation mechanism that affects both drivers and pedestrians (Smith, 2016).

Therefore, DST transitions could affect road safety via both the aforementioned channels. In the absence of robust and generalizable evidence, more empirical analyses are needed, because the climate and ambient light conditions, as well as peak traffic times, differ across mainland European countries. Our paper contributes to this debate, by providing detailed evidence on how exogenous variations in daylight ambience, due to DST shifts, affect vehicle accidents in Greece. The country provides an ideal setting for this study, as it is a European country with road quality and light conditions different from both the US and the UK. Moreover, Greece faces one of the highest fatality rates in the Eurozone: according to a 2017 Road Safety report of the European Commission, the country ranked sixth in the EU-28 (and first in the EU-15) with 69 fatalities per million inhabitants, 20 more than the EU-28 average.[4] Also, Greece ranks below the EU-28 average regarding its road network quality and second from the bottom regarding the efficiency of its train services, which are a safer transportation alternative compared to the road network.[5] Therefore, factors that affect driving behavior have important implications, especially when considering that vehicle accidents are a significant source of external mortality. According to official vital statistics provided by the Hellenic Statistical Authority for the period 2000–2016, more than 1500 people die every year from vehicle accidents, although this figure follows a declining trend since 2006. On average, this represents nearly 1.5% of the country's total annual mortality. However, apart from the extreme case of a fatal crash, the implications of vehicle accidents are numerous, for example, health status deterioration, heavier healthcare and other public services use, increased insurance premia, absence from work and foregone earnings, post-traumatic stress for those involved and their close ones etc. We discuss some of them in the last part of our Results section.

We contribute to the literature by providing additional evidence to the nexus between DST changes and road accidents, during the ongoing debate on the abolition of obligatory seasonal clock changes, using the same methods used by Smith (2016) and Bünnings and Schiele (2021), but applied to a country with quite different characteristics. To this end, we use a rich administrative dataset, with records on the universe of the reported vehicle accidents in Greece between January 01, 2006 and December 31, 2016. We consider the whole distribution of vehicle accidents (minor, non-fatal/serious, fatal), and we investigate how the impact of seasonal clock changes varies with weather conditions, drinking behavior, road type, and economic conditions. Finally, we attempt to quantify some of the costs associated with seasonal time changes.

As a member of the former European Economic Community, Greece adopted Daylight Saving Time in 1975. On the last Sunday of March each year, time in all member countries is set forward by 1 hour at 01:00 Greenwich Mean Time (GMT) until the last Sunday of October, when it is set backwards by 1 hour at 01:00 GMT. A limitation here is that, unlike the US, transition dates were not substantially changed. Throughout the period we cover, transitions occur between March 25–31 and between October 24–31. Another concern could be that two public holidays (March 25 and October 28) falling near the transition dates. Therefore, we excluded all public holidays from our estimations, and we performed several falsification tests to address this issue. Randomization needed to identify the causal impact relies on the natural experiment generated by entering and leaving DST (Imbens & Lemieux, 2008). Using a sharp regression discontinuity design, we examine whether entering into DST affects traffic accident counts. Results suggest that entering into DST does not affect daily counts of total and minor accidents. There is a significant reduction in daily count of serious accidents, and a weak increase for fatal accidents. Analyzing hour intervals within the day shows that the reduction in serious crashes occurs during evening hours that are affected by the reallocation of sunlight. Transitions back to Standard Time in Fall, increase total accidents, and this is due to greater minor accident counts during the evening hours, which are mostly affected by the reallocation of sunlight back into the morning. Our findings are in line with European evidence favoring an ambient light mechanism, rather than a sleep deprivation one, behind the observed effects right after obligatory seasonal clock changes. The ambient light mechanism is also supported by a separate examination of night accidents that take place in adequately lit locations versus locations with inadequate or no street lights. These results are supported by several robustness checks and falsification tests. Moreover, we quantify the implications of seasonal clock changes on road accidents in terms of insurance claims and material damages. The remainder of the paper is organized as follows: Section 2 presents the data and some descriptive evidence. Section 3 outlines the empirical strategy. Section 4 discusses the results, and Section 5 concludes.

2 | DATA

Our main data draw information from the universe of Road Accidents Reports between January 01, 2006 and December 31, 2016, provided by the Hellenic Statistical Authority (ELSTAT). Those reports are filled in after a crash by inspecting Road Police officers. They cover information on date, time, location, accident type and severity, that is, fatal, serious or minor accident. Fatal accidents involve the death of at least one involved individual within the following 30 days. Information on gender, age, nationality, driving license issue year, alcohol tests (and their results), is also collected. There is also information the vehicle type, their safety features (airbags, seatbelts etc.), and manufacture year. Weather conditions, and street light conditions for night accidents are also reported. Finally, there is information regarding the road network, for example, highway, within a residential area etc.

Because the first Sunday under DST is 1 hour shorter than the following days, crash counts were adjusted accordingly (Smith, 2016). First, we counted the 03:00–04:00 h twice, using it as a proxy for the missing 02:00–03:00 h on the DST entering day. At the same time, we divided the crashes occurred from 01:00–02:00 by two on the DST exit day as this hour occurs twice on every Fall transition. Second, we multiplied Spring transition date crashes by 24/23. Because that transition date has only 23 h, crash counts were inflated under the assumption that they evolve smoothly over the 24-h day. Fall transition date crashes were multiplied by 24/25. Third, we dropped the transition dates from the estimation sample. All results with adjusted counts were identical to those obtained using the original ones.

Our estimations mainly use accident counts aggregated by day or hour intervals at the national level. This is because of the scarcity of vehicle crashes, especially fatal and serious ones. Minor accidents represent 87.7% of the total, while serious and fatal accidents contribute 7.1% and 5.2% to the total count, respectively (Table A1). The average daily count of total vehicle accidents is 37, ranging between 8 and 73. Minor accidents largely shape the total crashes distribution. Fatal and serious accidents are rarer; their daily averages are 1.9 and 2.6, respectively. Figure 1 displays the distribution and the daily profile for each type of accident, and in particular the rarity of fatal and serious crashes.[6] Moreover, aggregation smooths out any confounders specific to weather conditions and other characteristics that might affect the daily crash count for specific locations but for not the total country.

Hourly profiles suggest that vehicle accidents are more frequent during evening and night hours, although fatal and serious counts are more evenly distributed throughout the day. Hence, substituting ambient light from low-traffic frequency hours (early morning) to high-traffic frequency ones (early evening), could be cost-effective in terms of road casualties (Broughton et al., 1999). More patterns on vehicle accidents are shown in Table 1. Mean daily counts from the first week of both transitions are compared to mean counts from 1 week before and 1 week after. To account for seasonal trends, counts from the first week after each transition are benchmarked against averages obtained using one and 2 weeks before and after. It seems that there is a small reduction when adopting DST in the Spring. Differences are less pronounced when returning back to Standard Time.

To examine whether changes during transitions vary within the day, we plotted the mean crash count by hour using a 7-day time window before and after each transition (Figure 2), in order to allow for the same days of the week to be used on each side of the transitions. This will indicate whether differences vary around the clock, especially for hours that are affected by advancing or moving clocks backwards. Changes in total accidents in Spring are small (panel A). However, serious accidents decrease in the evening, fatal accidents increase in the morning hours during the Spring transition. Panel B graphs the hour-specific means before and after the Fall transition. Fatal accidents rise during the evening hours on the first days after falling back to Standard Time, while serious crashes decrease in the morning.

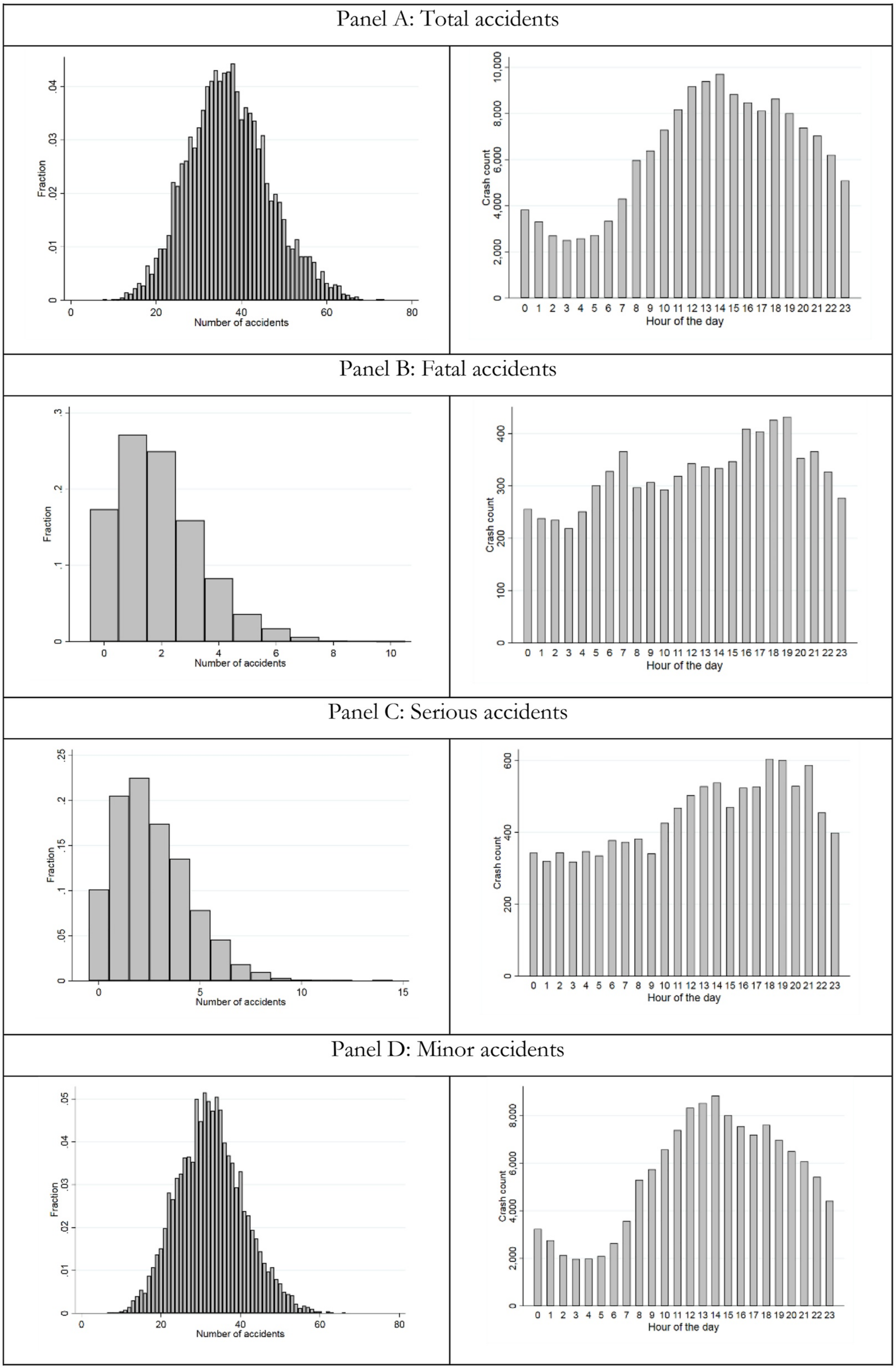

FIGURE 1 Distributions and hourly profiles by vehicle crash type. *Source*: Hellenic Statistical Authority (ELSTAT). Authors' calculations. Histograms use data for the total period (Jan 01, 2006 - Dec 31, 2016). [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Mean accidents counts before and after transition.

	First week (1)	1 week before (2)	1 week after (3)	1 week before and after (4)	2 weeks before and after (5)
Panel A: Spring transition					
Mean total crash count	33.74	34.77	37.42	36.09	36.05
t-Test relative to 1st week	-	0.505	0.009	0.061	0.044
Mean fatal crash count	1.68	1.87	2.12	1.99	1.91
t-Test relative to 1st week	-	0.399	0.053	0.114	0.212
Mean serious crash count	2.34	2.49	2.49	2.49	2.46
t-Test relative to 1st week	-	0.566	0.520	0.488	0.565
Mean minor crash count	29.73	30.40	32.81	31.60	31.68
t-Test relative to 1st week	-	0.626	0.017	0.099	0.056
Panel B: Fall transition					
Mean total crash count	37.25	38.08	35.00	36.54	37.31
t-Test relative to 1st week	-	0.573	0.118	0.578	0.953
Mean fatal crash count	1.83	2.04	1.90	1.97	1.90
t-Test relative to 1st week	-	0.402	0.782	0.502	0.708
Mean serious crash count	2.71	2.44	2.40	2.42	2.45
t-Test relative to 1st week	-	0.360	0.320	0.255	0.255
Mean minor crash count	32.70	33.60	30.70	32.15	32.97
t-Test relative to 1st week	-	0.497	0.123	0.629	0.796
Observations	77	77	77	154	308

Source: Hellenic Statistical Authority (ELSTAT). Authors' calculations.

3 | ESTIMATION STRATEGY

The causal effect of DST on vehicle accident counts is evaluated using a regression discontinuity (RD) design. Identification relies on a natural experiment based on the standard practice of advancing clocks by 1 hour each Spring, and moving them backwards by 1 hour each Fall. This generates an exogenous reallocation of sunlight from mornings to evenings. Figure A1 shows the sunrise and sunset times during the year. Advancing clocks forward when entering and adjusting them backwards when exiting DST generates an exogenous variation in the timing of daylight, especially around sunrise and sunset. In the Spring transition, sunrise is moved forward by an hour. Hence sunrise conditions are replaced by those occurring during the morning astronomical twilight, that is, when the geometrical center of the Sun is 12°–18° below the horizon. Similarly, light conditions occurring during civil and nautical twilight are replaced with a brighter environment in the evening.[7] Either through a sleep deprivation or an ambient light conditions mechanism, this variation could affect driving behavior and hence, the number of vehicle accidents. We measure the size of the discontinuity at the transition dates using a two-step augmented local linear approach (Hausman & Rapson, 2018; Smith, 2016). In the first step, persistent day-of-week, seasonal (monthly), and year influences are eliminated by demeaning the actual (logged) number of vehicle accident crashes (total, fatal, serious, minor) using the respective sets of fixed effects as controls.[8] The estimation sample covers the total period of our data (January 01, 2006 to December 31, 2016). Public holidays are excluded from the analysis. In the second step, the demeaned residuals are used as dependent variables in reduced form models as below:

$$Crashes_{iy} = b_0 + b_1 DST_{iy} + f\left(DaysToDST_{iy}\right) + f\left(DST_{iy} \times DaysToDST_{iy}\right) + u_{iy} \tag{1}$$

where DST indicates whether the i-th day falls under the DST period of the y-th year, $DaysToDST$ is the running variable centered on the transition dates, measuring the number of days before and after each transition, f is a function of the running variable, and u is the disturbance term. The coefficient of interest, b_1, measures the DST impact on vehicle accident counts at the transition dates. The effect of entering (or exiting) DST is identified under the assumption that other factors influencing driving behavior evolve smoothly at the transition dates. Hence, we test for discontinuities for fuel prices and vehicle miles traveled. We also perform falsification tests using placebo transition dates to support the validity of our baseline estimates. Moreover, we

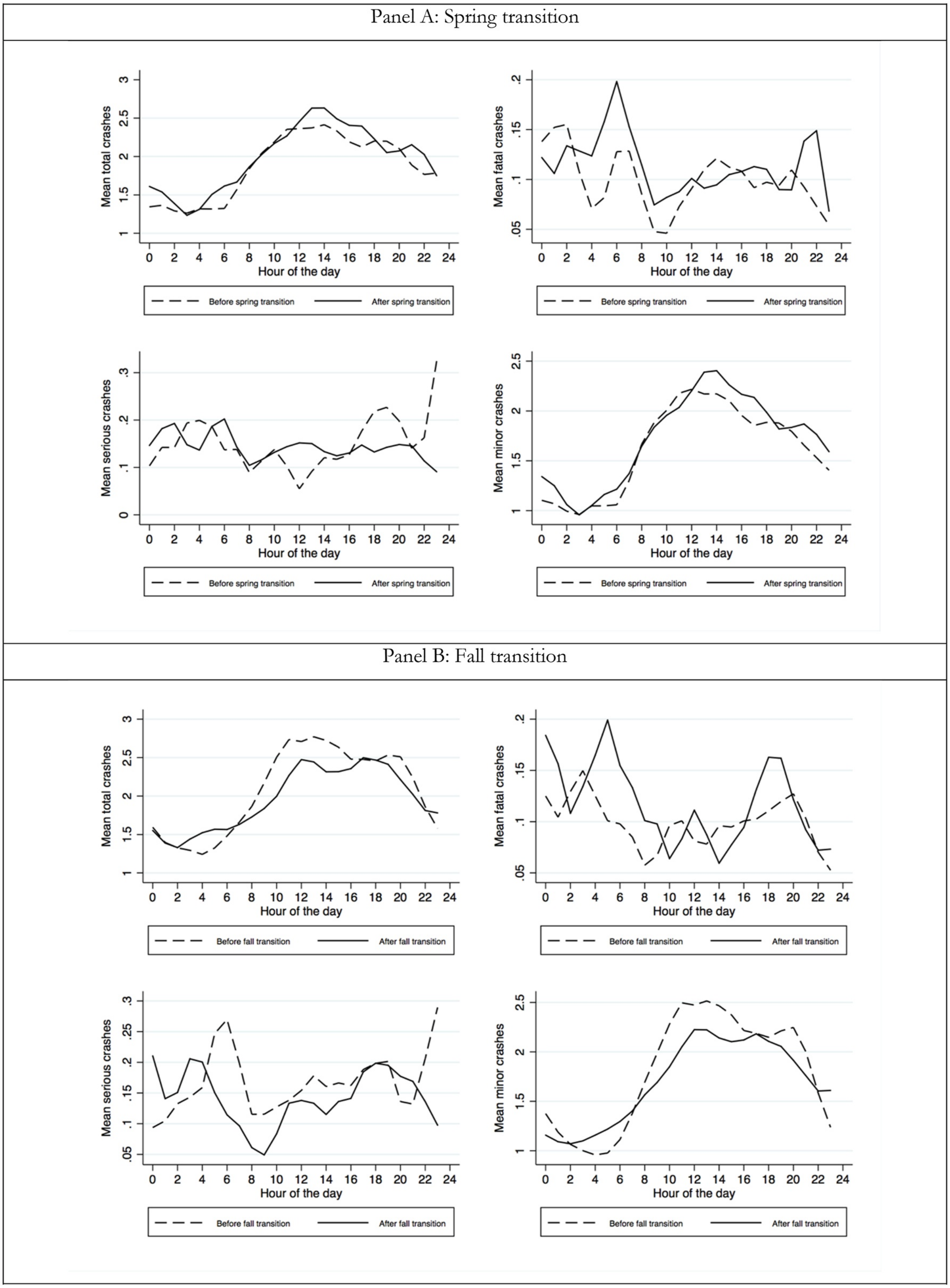

FIGURE 2 Mean crash count around the clock before and after each transition. *Source*: Hellenic Statistical Authority (ELSTAT). Authors' calculations. Means correspond to 7-day averages on both sides of spring and fall transitions. [Colour figure can be viewed at wileyonlinelibrary.com]

explore potential mechanisms behind the results, for example, the surrounding conditions, fuel market conditions, and driver heterogeneity.

Our preferred empirical specification uses local linear regressions (OLS) at both sides of the transition cutoffs, uniform kernels and optimal data-driven bandwidths (Calonico et al., 2014). Compared to high order polynomials of the running variable, local linear regressions perform better in RD settings (Gelman & Imbens, 2019; Smith, 2016). Results are robust when higher order polynomials, alternative kernels, and different bandwidths -close to the optimally chosen ones-are used. Consistent standard error estimates, clustered by days from transition, are retrieved through a bootstrapping procedure (1000 replications) so that first-step variance shows up in the second step. To address concerns regarding permanent differences across regions, for example, lighting conditions, road infrastructure, driving behavior, weather conditions etc., we also estimate Equation (1) using a balanced daily panel of 74 administrative regions. In this case, the logged crash counts are additionally demeaned by region in the first-step.

4 | RESULTS

4.1 | Baseline estimates

Figure 3 displays how vehicle crashes evolve around DST transitions. Using the total sample, we regress each (logged) daily crash count (aggregate national time series) on day-of-week, year, and month fixed effects.[9] The obtained residuals are then averaged by day-from-transition. There is a clear drop in serious crashes and a weak fatal crashes increase after the Spring transition (panel A). Regarding Fall transition, there is a visible increase for total accidents, driven by the jump in minor accidents, as well as a smaller drop for serious accidents (panel B). Overall, the graphs are indicative about the *immediate effects* that obligatory seasonal clock changes seem to have on road safety: as expected, the effects of interest seem to be short-termed in nature, that is, vehicle accidents tend to revert back to their pre-transition levels around 10 days after transitions. Our empirical approach will formally test for these breaks and indicate the mechanisms behind them.

For each accident type, Table 2 reports the estimated size of those breaks observed at both DST transitions. For robustness, we report RD estimates controlling for first and second order polynomials of the running variable around the cutoff date, using uniform kernels and optimally data-driven bandwidths (Calonico et al., 2014). However, models in column 1 (and 3) are our preferred specifications as local linear regressions are shown to perform better in RD settings relative to higher-order polynomials of the running variable (Gelman & Imbens, 2019). Consistent to the graphical evidence in Figure 3, there is a significant discontinuity in serious vehicle crashes around the DST start when using national time series. Weaker effects, significant at the 10% level, are found for total and minor accidents. The sizable discontinuity parameters suggest that the Spring transition causes a 15%–20% decrease in serious crashes.[10] No effect is uncovered for fatal crashes; the discontinuity parameter is positive (0.092) but noisy. Given a pre-transition average of 1.7 fatalities each year, and using a sample of 22 days before each Spring transition (equal to the bandwidth), if the estimated parameter was statistically significant it would imply about 1 more fatal crash, on average. When considering serious and minor crashes together as non-fatal ones, entering DST causes them to decrease by about 8%, as the overall impact is driven down by the larger number of minor crashes across the vehicle accidents distribution. The baseline estimates using a national time series are benchmarked against estimates using a balanced regional daily panel (columns 3–4), where counts are also demeaned by region in the first stage. The results are similar in the sense that the overall effect is driven by the decrease in non-fatal (serious and minor) accidents, which are both significant at the 5% level.[11]

Regarding the Fall transition, exiting DST causes a positive and significant impact on the total accidents, mainly due to the increased minor vehicle accidents (panel H). Column 1 suggests that minor accidents increase by 13% at the Fall transition. No significant effects on fatal and serious crashes are found. Again, regional-level panel estimates (columns 3–4) are in line with the national time series evidence. Moreover, for both transitions the results are identical when using the transformed variables to adjust for the missing hour during the first day of the DST period.[12]

Next, we performed some robustness checks. First, for the crash types for which a significant discontinuity parameter is reported in Table 2, we used alternative bandwidths around the cutoff dates. More specifically, we used different time windows that are +/−1 and +/−2 days wider than those under the optimally chosen bandwidth. As can be seen in Appendix Figure A2, the results are generally stable regardless the selected bandwidth. Considering serious crashes (Spring transition), the RD point estimates range between −0.1 and −0.2 irrespectively of the bandwidth used (recall that the baseline point estimate is 0.169 with a standard error equal to 0.085). The p-values of those parameters are between 0.02 and 0.10. Moreover, we also fail to reject a series of null hypotheses about the effect of interest computed with alternative bandwidths being equal to the baseline effect estimated with the optional bandwidth: the p-values from the associated Wald tests range between 0.12 and 0.77. The same is true for the case of the DST impact on minor crashes (Spring transition): for bandwidths of between +/−12 and +/−16 days, the results remain very similar to the baseline estimate of −0.079, which is significant at the 10% level. A series of Wald tests comparing the equality of coefficients obtained under slightly alternative bandwidths to the estimates with the optimal bandwidth fails to reject the null: the associated p-values range between 0.17 and 0.85.

Likewise, the effect of exiting DST on minor crashes (Panel C) remains statistically significant and similar to the baseline evidence when the bandwidth varies between +/−10 and +/−14 days. All estimates are significant at the 5% level (the p-values

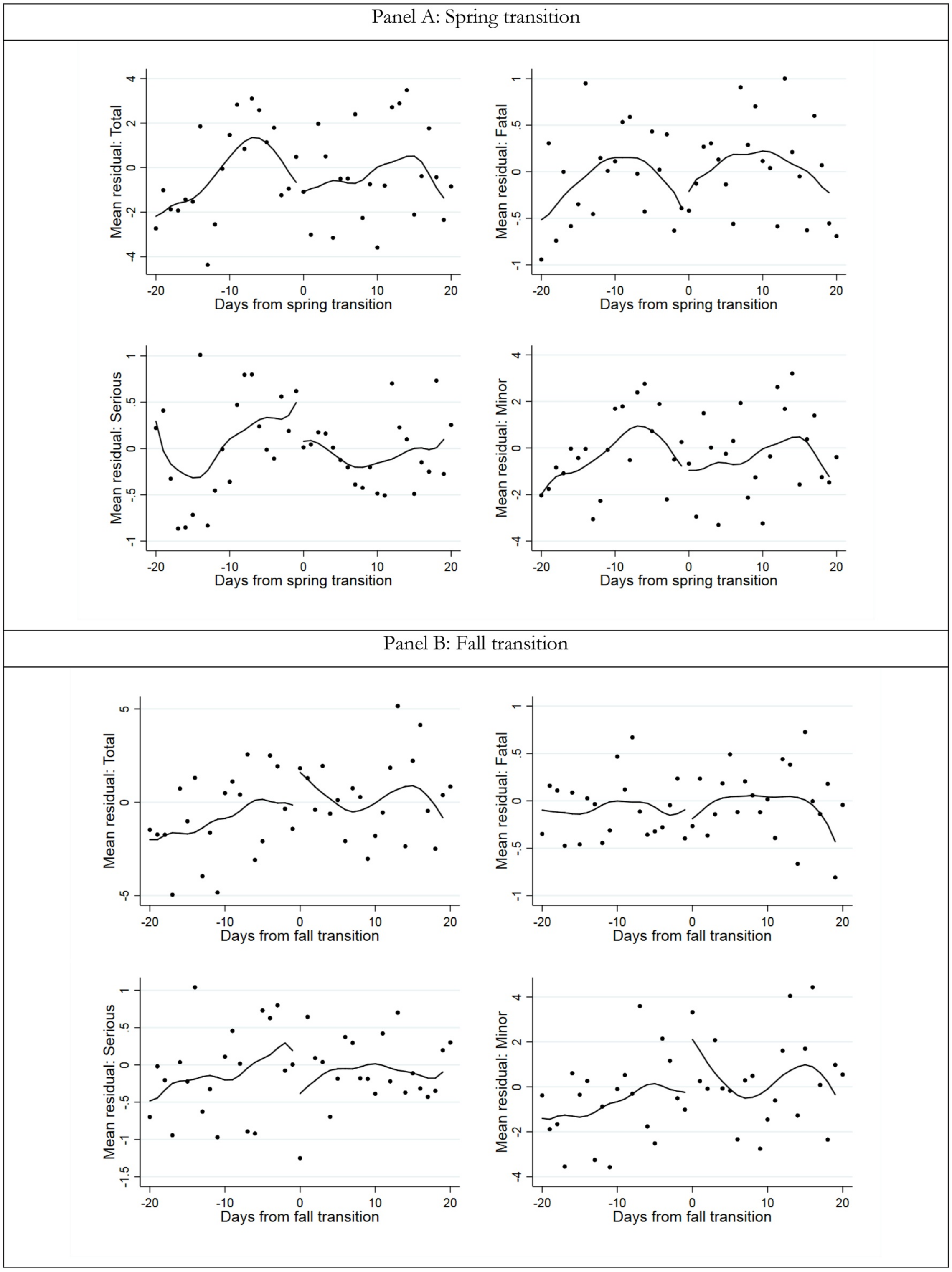

FIGURE 3 Locally weighted regression mean residual plots for the DST transition. *Source*: Hellenic Statistical Authority (ELSTAT). Dots represent mean (by days from transition) residuals, for the total period (Jan 01, 2006 - Dec 31, 2016) obtained after regressing the daily count of vehicle accidents on a set of day-of-week, month, and year fixed effects. Black lines are obtained from locally weighted regressions. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 2 RD estimates of the impact of the DST transition.

	National time series data		Regional panel data	
	(1)	(2)	(3)	(4)
(a) Spring DST transition				
Panel A: Total accidents				
RD estimate	−0.075* (0.044)	−0.103* (0.054)	−0.013** (0.006)	−0.018** (0.007)
Polynomial order	1	2	1	2
Days around transition	14	26	22	30
Observations	296	540	33,670	45,584
Panel B: Fatal accidents				
RD estimate	0.092 (0.096)	0.115 (0.138)	0.003 (0.002)	0.001 (0.003)
Polynomial order	1	2	1	2
Days around transition	22	24	24	28
Observations	455	499	36,926	42,550
Panel C: Serious accidents				
RD estimate	−0.169** (0.085)	−0.216** (0.106)	−0.005** (0.002)	−0.007** (0.003)
Polynomial order	1	2	1	2
Days around transition	19	27	24	32
Observations	401	556	36,926	48,618
Panel D: Minor accidents				
RD estimate	−0.079* (0.048)	−0.095* (0.055)	−0.013** (0.005)	−0.016** (0.007)
Polynomial order	1	2	1	2
Days around transition	14	26	20	29
Observations	296	540	30,858	43,956
(b) Fall DST transition				
Panel E: Total accidents				
RD estimate	0.110** (0.053)	0.176*** (0.052)	0.017** (0.008)	0.015* (0.008)
Polynomial order	1	2	1	2
Days around transition	11	24	13	26
Observations	242	528	21,164	42,328
Panel F: Fatal accidents				
RD estimate	−0.088 (0.128)	−0.098 (0.148)	−0.001 (0.003)	−0.001 (0.003)
Polynomial order	1	2	1	2
Days around transition	13	26	14	26
Observations	286	572	22,792	42,328
Panel G: Serious accidents				
RD estimate	−0.127 (0.121)	−0.144 (0.142)	−0.001 (0.004)	−0.001 (0.004)
Polynomial order	1	2	1	2
Days around transition	14	23	13	25
Observations	308	506	21,164	40,700
Panel H: Minor accidents				
RD estimate	0.146*** (0.052)	0.213*** (0.055)	0.019** (0.007)	0.019** (0.008)
Polynomial order	1	2	1	2

TABLE 2 (Continued)

	National time series data		Regional panel data	
	(1)	(2)	(3)	(4)
Days around transition	12	23	13	25
Observations	264	506	21,164	40,700

Note: Dependent variables are demeaned residuals obtained after demeaning the logged vehicle crash counts by day of week, year and month (and region in the case of regional panel). All specifications use a uniform kernel. Bootstrapped standard errors (1000 replications) in parentheses. Columns 1–2 use aggregated time series. Columns 3–4 use a regional panel. Days around transition are chosen using the bandwidth selector of Calonico et al. (2014).

Source: Hellenic Statistical Authority (ELSTAT). Authors' calculations.

Asterisks ***, ** and * denote statistical significance at the 1%, 5% and 10% level, respectively.

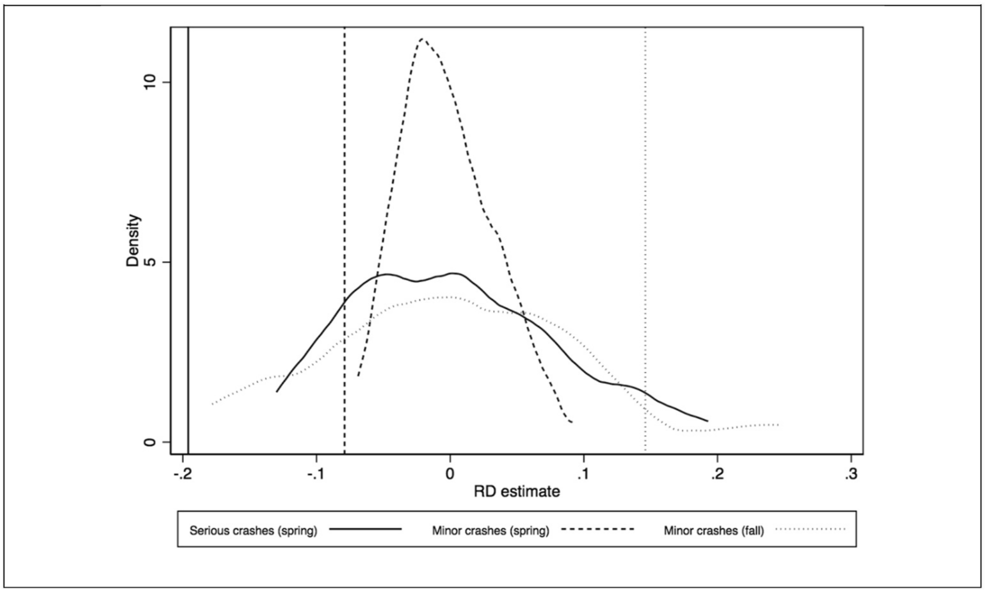

FIGURE 4 Distribution of discontinuity parameters using fake transition dates. *Source*: Hellenic Statistical Authority (ELSTAT). Authors' calculations. Density functions use an Epanechnikov kernel and represent the distribution of the estimated coefficients based on fake transition dates. Vertical lines represent the corresponding baseline estimates obtained when using the actual transition dates.

from point estimate t-tests are all lower than 0.03). Moreover, a series of Wald tests failed to reject the null hypothesis about the estimated coefficients based on alternative bandwidths being equal to the coefficients obtained under the optimally chosen bandwidths: the associated p-values range from 0.24 to 0.83.

To reassure about the validity of our estimates, we replaced actual transition dates with fake ones in placebo tests, starting from the first day outside the bandwidth used in Table 2, and covering a 90-day period after that. In this way, we avoided including days close to the actual DST transitions during which individuals might still be affected by the change. These tests are performed only for serious and minor accidents (Spring transition) and for minor accidents (Fall transition). The distributions of those estimates are plotted in Figure 4. For serious and minor crashes (Spring) the reported baseline estimates lie outside the obtained distributions, ensuring the validity of the results. For minor accidents (Fall) the vertical dotted line (baseline point estimate) falls within the plotted distribution, although the true effect lies on the upper 10% of the density plot and the larger coefficients in the density plot are related to dates occurring more than a month later than the actual Fall transition. The implied p-values are equal to 0 for serious and minor crashes during the Spring transition and to 0.11 for minor crashes during the Fall transition.

4.2 | The ambient light mechanism

Ambient light conditions and sleep deprivation are alternative mechanisms behind changes observed after entering and exiting DST. To disentangle any effects related to these alternative mechanisms, we used the aggregated national daily time series to apply our RD design on eight different intervals within the day, each one 3 h long. Therefore, we examined whether the baseline results using the total daily number of accidents are driven by specific hour intervals within the day, which in turn are affected by exogenous redistributions of sunlight after entering and exiting DST. To be comparable, intervals are common for both periods (Spring and Fall). They were constructed in order to correspond to the average sunset and sunrise times at both transition dates, so that there are some intervals that are clearly affected by the environment becoming darker or brighter after the mandatory seasonal clock changes.[13] Our rationale in this test is that, if the estimated effects are driven by a sleep deprivation mechanism, then they should be invariant across different hour-periods within the bandwidth of days relating to each transition. On the other hand, if the effect is specific to the hours which are directly affected by the transitions, then the ambiance mechanism would be the likely driver of the estimated effects.

Panel A of Figure 5 displays the results for Spring. For total accidents, all hour-specific estimates are not significant except the one corresponding to the 18:00–20:59 interval, which is only significant at the 10% level ($b = -0.190$; p-value = 0.056). This is when the sunlight reallocation toward evening hours occurs, creating a brighter environment. Consistent to the baseline evidence, this is mainly driven by the drop in serious crashes which is sizable and significant only during that specific hour interval ($b = -0.173$; p-value = 0.019), and not systematically different from zero during the rest of the day. Moreover, testing that the estimated parameter for the 18:00–20:59 interval is equal with each estimated parameter for the other intervals, was rejected by a series of Wald tests (p-values ranged from 0.091 to 0.001). Also, we failed to reject the null hypothesis that the parameters of all other hour intervals, except the 18:00–20:59 one, are jointly equal to zero (p-value = 0.493).

There is also a drop in fatal and minor accidents during the 18:00–20:59 interval (−0.089 and −0.162), however, their p-values are relatively high (0.091 and 0.098, respectively). On the other hand, there are no significant increases during the 06:00–08:59 interval, which becomes darker after the Spring transition. Taken together, the results show that the 18:00–20:59 interval effect is more statistically different than the effects of the other time-intervals in the case of serious accidents (followed by fatal accidents) and least different in the case of minor accidents. This is consistent with what we discussed earlier, that is, the way in which light ambience ought to affect different types of accidents. We thus conclude that the evidence we have is in favor of a positive ambient light reallocation mechanism driving the overall baseline (Spring) effect reported earlier.

Regarding the Fall transition, baseline estimates suggested that exiting DST increases minor vehicle accidents. The hour-specific estimates, shown in Panel B of Figure 5, are supportive of an ambient light conditions mechanism in this case as well. Parameter estimates are positive and significant for the evening interval that is affected by returning 1 hour of sunlight back in the morning, resulting in darker evenings. Regarding total accidents, all hour-specific estimates are not different from zero, except for the one based on data for the evening (15:00–17:59), which is positive and equal to 0.234 (p-value = 0.016). From a graphical inspection, this is due to the RD estimate for that hour interval when considering minor accidents alone ($b = 0.217$; p-value = 0.044), which is also significant at the 5% level. In this occasion, the results from Wald tests comparing the equality between the coefficient of that hour intervals with the other hour-specific coefficients were not very supportive, that is, the null could not be rejected as the associated p-values were slightly above 0.10.[14] However, the graphs do provide some evidence that the most notable changes (for total and minor crashes during the Fall transition) occur during the mostly affected hour intervals. For serious and fatal crashes, positive but non-significant point estimates are obtained when considering that evening interval.

The results above suggest that the DST impact on road safety is not due to sleep deprivation. This is because: (a) the overall effect is negative when springing forward; (b) it comes from changes in the evening hours both when entering and when exiting DST; and (c) the positive impact on minor accidents is observed during the Fall transition, which is not subject to any sleep deprivation. In fact, if anything, people actually gain some extra minutes of sleep (Barnes & Wagner, 2009; Sexton & Beatty, 2014). Hence, our results are in contrast to the findings of Smith (2016), who showed that a positive DST impact in the US was due to the lack of sleep and the drowsiness associated with it, and similar to the evidence from Bünnings and Schiele (2021) that ambient light conditions are more relevant. Although DST transitions have been shown to cause sleep disruption (Lahti et al., 2010), our results are in line with evidence from European countries suggesting that the marginal change in sleep does not deteriorate performance. For example, Herber et al. (2017) used individual-level data from six European countries (Denmark, Finland, Lithuania, Norway, Sweden, and Spain) to show that springing forward does not lower student performance. Evidence from Germany suggested only minor sleep deprivation effects, with most people going to sleep 1 hour earlier at Spring transition and people acting more carefully on the days right after springing forward (Jin & Ziebarth, 2015).

Furthermore, Bünnings and Schiele (2021) show that darkness is an important crash factor throughout the year. Although here we focus more locally around DST transitions (and given the evidence in Figure 3), we examine the implications of darkness for vehicle accident counts throughout the year. As in Bünnings and Schiele (2021), we calculated the share of natural sunlight within each region-hour cell.[15] This darkness variable is equal to 1 before the sunrise and after the sunset in each region, that is, when the angle of the Sun is greater than 12° below the horizon (astronomical twilight) relative to that region,

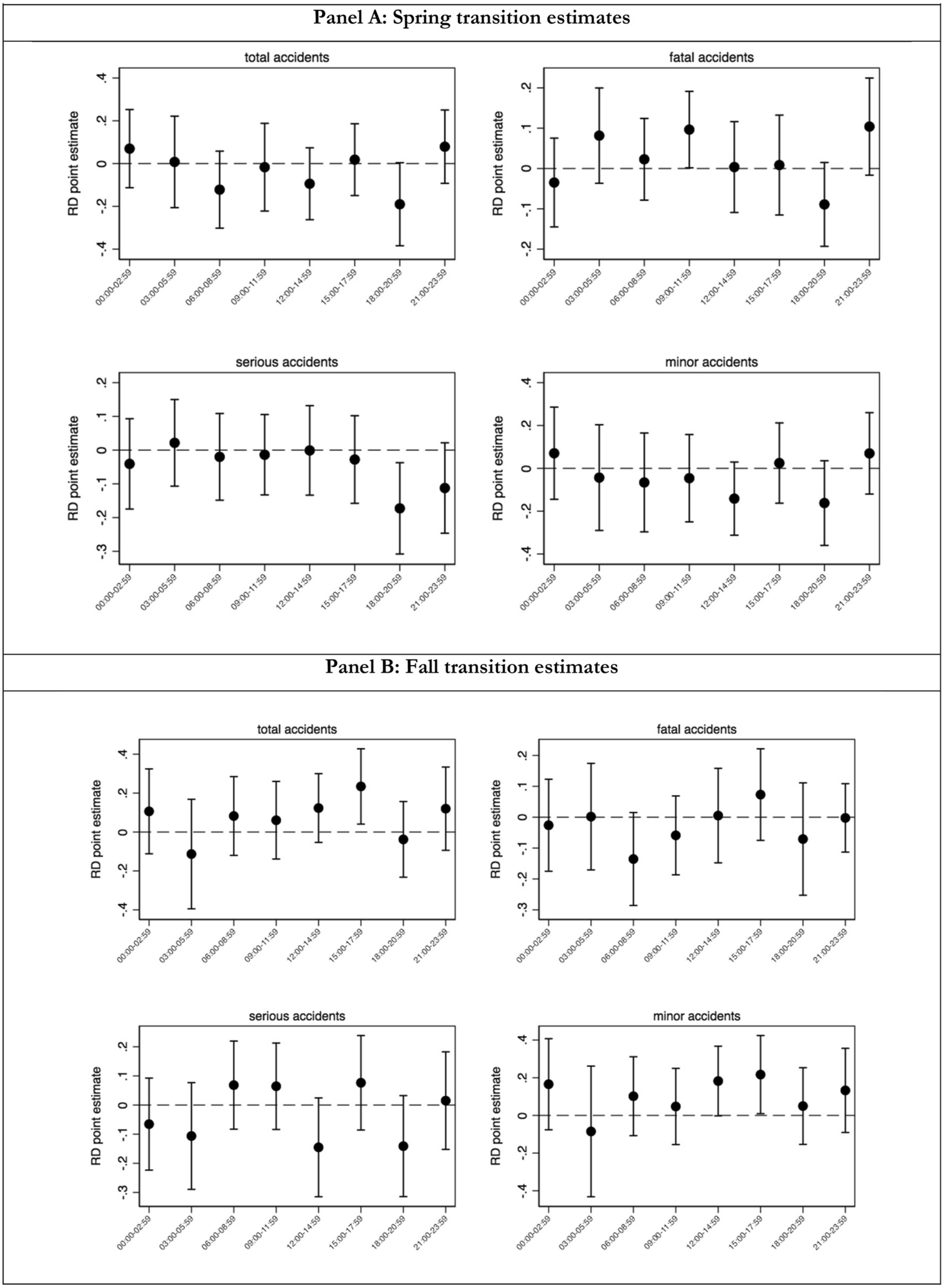

FIGURE 5 Around the clock RD estimates. *Source*: Hellenic Statistical Authority (ELSTAT). Authors' calculations. Dependent variables are demeaned residuals obtained after demeaning the logged vehicle crash counts by day of week, year, month and 3-h interval. All specifications use a uniform kernel. Bootstrapped standard errors (1000 replications) in parentheses.

and it is equal to 0 during day hours. During civil and astronomical twilights, the variable takes values close to 0 or close to 1. For accidents occurred during night hours, the ELSTAT data report whether lighting conditions at site were sufficient or not, as recorded by the inspecting police officers. Therefore, we constructed a categorical variable regarding the ambient and street lighting conditions, indicating whether street lights were off (during day hours), insufficient or off (during night hours), or sufficient (during night hours) when an accident took place in that location. To assess the effect of darkness, we regressed the accident count in each region-hour cell on region, year, month, day-of-week, day-of-year, and hour-of-day fixed effects. The estimated darkness coefficient will indicate how accident counts change when the environment becomes darker, given that darkness is exogenous conditional on the set of fixed effects.[16] Moreover, as the impact of darkness can be mitigated by sufficient light conditions, we interacted it with a variable indicating the availability of adequate street lighting conditions where an accident took place. Table A3 displays the negative binomial regressions results.[17] Total and minor accident counts are lower during night hours, when the darkness variable is greater than zero. This is in contrast to findings for the UK where darkness, as proxied by the Sun's relative position, was positively associated with all sorts of traffic accidents (Bünnings & Schiele, 2021). This could be due to several reasons. The within-day distribution of all road accidents is not the same between the two countries, and there are also different driving and commuting patterns, for example, the average commuting time in the UK and Greece is around 50 and 30 min, respectively (Giménez-Nadal et al., 2020a, 2020b). Also, the environment is generally darker in the UK; the mean number of sunshine hours is about double in Greece compared to the UK.[18] Moreover, as seen in Table A3, night accident counts are higher in locations with inadequate or no street lighting when the environment gets darker. On the other hand, darkness and insufficient light conditions are positively associated with fatal accidents throughout the year, and there is also a positive, but noisy, association with serious accidents.

4.3 | Crash factors

Next, we test whether the baseline discontinuous jump in road accident counts varies by weather conditions, drunk driving (measured at the accident scene or post-mortem for fatal crashes), area type (residential and non-residential), and period, as our data span over a normal and an economically turbulent period. If the economic turmoil affected driving behavior, this could be reflected on the estimated RD parameters. Vehicle accidents mortality decreased during the crisis (Laliotis et al., 2016; Laliotis & Stavropoulou, 2018). Reduced exposure in the amount of driving for work and leisure, and adoption of less risky behaviors like smoking, drinking and speeding during economic downturns have been shown to explain procyclical vehicle-related fatality (He, 2016; Ruhm, 2000). Figure A3 shows that crashes declined and became less volatile over time. We used the introduction of the austerity agenda (May 2010) in order to split the sample. Compared to normal times, there were 235 fewer total crashes every month, on average, and 28 fewer serious ones during the austerity period.

Table 3 reports RD estimates for various sub-samples. Bad weather conditions are associated with increased minor accidents at Fall transition. At Spring transition, there is a negative but insignificant effect on serious accidents, and a significant drop of minor accidents. The latter may seem unexpected as weather conditions are generally improving during that time of the year. However, this could simply imply that better ambient light conditions brought by DST mitigate the effects of adverse

TABLE 3 Impact of entering and exiting DST by crash factor, area type and period.

	Bad weather (1)	Drunk driving (2)	Residential areas (3)	Non-residential areas (4)	Before crisis (5)	During crisis (6)
Panel A: Spring transition						
Fatal accidents	0.405 (0.338)	0.168 (0.365)	0.244* (0.134)	0.218 (0.196)	−0.062 (0.064)	0.030 (0.050)
Serious accidents	−0.436 (0.318)	0.127 (0.448)	−0.347*** (0.108)	−0.063 (0.216)	−0.343* (0.188)	0.190 (0.213)
Minor accidents	−0.905*** (0.283)	−0.399*** (0.120)	0.048 (0.044)	−0.205*** (0.078)	−0.052 (0.066)	0.005 (0.049)
Panel B: Fall transition						
Fatal accidents	0.484 (0.464)	−1.340*** (0.430)	0.184 (0.158)	−0.265* (0.152)	−0.044 (0.171)	0.034 (0.141)
Serious accidents	−0.195 (0.404)	−0.702* (0.376)	−0.017 (0.146)	−0.315 (0.292)	0.091 (0.253)	−0.283 (0.185)
Minor accidents	0.454* (0.263)	0.418*** (0.106)	0.100** (0.043)	0.191** (0.092)	0.240*** (0.063)	0.037 (0.038)
Prevalence	8.27%	7.79%	79.69%	20.31%	44.35%	55.65%

Note: The dependent variable is the daily accident count by crash factor, area type and period. All models control for day-of-week, month, and year fixed effects and they are estimated over the bandwidth chosen for the baseline specifications. Standard errors in parentheses are corrected for clustering by day from transition. A uniform kernel is applied in all models.

Source: Hellenic Statistical Authority (ELSTAT). Authors' calculations.

Asterisks ***, ** and * denote statistical significance at the 1%, 5% and 10% level, respectively.

driving conditions due to bad weather, especially for minor accidents—where indeed we should expect the mitigation effect to be stronger. Drunk driving and road accidents are related in a conflicting way. Minor accidents drop at Spring transition and increase when adopting ST back. This could reflect people being more likely to (a) drink when light conditions deteriorate, and (b) devote more time to leisure and outdoor activities when gaining one extra hour of sunlight at Spring transition. At the same time, fatal and serious accidents where drunk driving is mentioned as a factor decrease at Fall transition.

The baseline Spring transition effects are primarily driven by accidents in residential areas. These results should be expected given the higher traffic volume in more densely populated locations. Minor accidents decrease at Spring transition in non-residential areas as well. This is also in line with the ambient light mechanism, as those less adequately lit areas are more affected by the sunlight reallocation within the day. The vast majority of accidents in non-residential areas (63.2%) take place in locations with inadequate or inexistent street lights. Finally, baseline effects are driven by changes occurring before the austerity period. This could indicate smaller exposure to the amount of driving during the crisis, and the adoption of less risky driving behaviors, for example, smoking, drinking and speeding. It could also indicate a substitution effect toward cheaper means of transportation, for example, cycling, walking, use of public transport and car-pooling, when economic conditions deteriorate.

4.4 | Omitted variables

To account for omitted variable biases, we tested whether factors that affect driving behavior are discontinuous around the cutoff. A first factor is fuel prices; being smooth around transition dates should reassure about the validity of our estimates. The two most popular fuel products in Greece were petrol and diesel. According to the European Automobile Manufacturers Association, 91.7% of the vehicle fleet was using petrol (unleaded 95 octane) and 4.9% was using diesel in 2015. Daily data on the national average prices for petrol and diesel were provided by the Fuel Price Observatory of the Ministry of Economy and Development. The available data series cover the period between January 01, 2012 and December 31, 2016. We used the demeaned (by the usual set of fixed effects) logged fuel prices as an outcome variable in a model like Equation (1), in order to test for any discontinuous jumps when entering or exiting DST. The RD parameters are practically zero, suggesting that fuel prices evolve smoothly at both transitions (Table A4, columns 1–4).

Another factor related to vehicle accident counts is the amount of driving. Exposure to driving adjusts to the supply of daylight, at least for certain time intervals within the day. For example, people might drive more for leisure when the extra hour of sunlight is allocated to the evening after the Spring transition, and drive less during the respective time interval when falling back to Standard Time. Smith (2016) tested for such behavioral changes at the Spring transition using vehicle miles traveled (VMT) data only for major highways in California, due to the absence of appropriate nation-wide time series. There was no evidence of a statistically significant discontinuity at the transition dates. We are also constrained by the lack of national daily time series on road usage. The only available data were provided by the Observatory Unit of Egnatia Road, a major highway network in northern Greece, and part of the European E90 highway system. For a large part of their network, Egnatia Road S.A. provided daily time series on road usage, in terms of number of vehicles passed through their toll stations between January 01, 2012 and December 31, 2016. However, no significant discontinuities for VMT were uncovered at the transition dates (Table A4, columns 5–6).

4.5 | Implications and cost-benefit analysis

The estimated DST impacts on vehicle accident counts may have serious implications on health, healthcare and other services utilisation, productivity, and foregone hours of work and personal time. Although a precise evaluation of the overall impact is challenging, we attempt some back-of-the-envelope calculations that could partly quantify some of the associated welfare costs. We begin with the baseline DST transition impacts on vehicle insurance claims, in order to calculate the total insurance claims costs that could be spared in the absence of the DST policy. We use information from the Statistical Yearbooks for Motor Insurance, published by the Hellenic Association of Insurance Companies (HAIC), which is available online for the period 2010–2016.

We first consider minor accidents when leaving DST in the Fall, for which we got a significant baseline discontinuity parameter (minor accidents were not affected by the Spring transition). We used total vehicle insurance claims net of those related to fire and theft, assuming a maximum settlement amount of €2000. Because the HAIC Yearbooks report the annual number of claims, we multiplied those figures with 12/365, that is, using the number of days suggested by the bandwidth choice. Appendix Table A5 displays the results. The number of claims (column 4), is multiplied by $1-\left(e^{b}-1\right)$, where b was the baseline effect in Fall transition for minor crashes (0.146). The results suggest 2281 fewer claims worth up to €2000 for motor accidents each year, on average. Multiplying the annual claims differences (column 6) by the total amount of settlements for insurance claims worth up to €2000 implies an average extra annual cost of nearly €1.59 million.[19]

Similar back-of-the-envelope calculations using the baseline for serious accidents during the Spring transition (using the baseline estimate in Table 2, i.e., −0.169) can be performed, although it is difficult to choose a settlement amount for serious, non-fatal crashes. Assuming settlements between €2001 and €50,000 (and a 19-day bandwidth), suggests that entering DST is associated with nearly 3.6 thousand fewer claims each year, hence generating annual cost savings of about €7.5 million, on average.[20] Combining the insurance claims implications for serious accidents when entering DST and minor accidents when leaving DST implies an average annual cost reduction of about €9.13 million from abolishing the DST policy.

Alternatively, we can quantify the cost implications of DST using monetary values for the prevention of traffic injuries, recommended by the Developing Harmonized European Approaches for Transport Costing and Project Assessment (HEATCO) report (Bickel et al., 2006). Each accident (fatal, severe, slight) was valuated in terms of: (a) direct and indirect economic costs (medical and rehabilitation cost, legal administrative cost, production losses), (b) a value of safety per se (willingness to pay for safeguarding human life), and (c) material damages. The reports suggest material damage monetary values by accident type, as reliable valuations for (a) and (b) were not available. Regarding Greece, the estimated avoided costs for fatalities, severe injuries, and slight injuries were €836,000, €109,500 and €8,400, respectively (in 2002 prices). To quantify the impact of DST transitions using these monetary values, we applied the same method to produce our baseline estimates (i.e., column 2, Table 2), but now using the daily counts of persons who died, got seriously injured, and slightly injured as outcomes. The results in Table A6 are in line with the baseline evidence for the number of accidents. There is a negative effect on the number of those seriously injured in the spring transition, and a positive effect on those slightly injured in the Fall transition. Using a data-driven 15-day bandwidth for serious injuries before the Spring transition, the total number of accidents for the 2006–2016 period was 638. The estimate reported in Table A6 implies 132 fewer seriously injured people in the post-Spring transition period. According to the HEATCO valuation for serious accidents, this translates into an avoidable €14.5 million cost. Similarly, the positive and significant RD estimates for the count of the slightly injured implies their post-Fall transition number, during the total period of our study, increased by 889 injuries. Using the slight injury HEATCO valuation, the implied extra casualty cost was about €7.5 million.[21]

However, these are conservative, lower bound estimates that should be seen as the ‘tip of the iceberg’ of the total road safety costs associated to time changes that could be spared. Even a minor traffic accident, can induce hospitals visits, forgone hours of work and leisure, engagement in administrative procedures to cope with insurance reimbursements, and post-traumatic stress. Such events imply healthcare costs to be sustained by the individual and/or the state, absence from work and forgone earnings, increased vehicle insurance premia, payment of charges for driver misconduct, and monetary and non-monetary expenses related to mental health distress, for example, decrease in productivity, greater anxiety etc. Lack of reliable data on these events restricts us from a proper quantification of the overall costs faced by individuals involved into vehicle accidents. Moreover, to the extent that our results are driven by an ambient light conditions mechanism, they indicate the importance of developing and maintaining appropriate road infrastructure networks that facilitate a higher level of road safety. As shown in Table A3, adequate street light conditions tend to mitigate the adverse effect of darkness on road crashes throughout the year.

5 | CONCLUSIONS

Driving conditions, including ambient light and sleep deprivation, are critical to driving behavior and road safety, but there is scarce evidence to establish such a causal link, especially in the European context. This paper investigates this relationship by relying on the exogenous variations generated by obligatory seasonal clock changes in Greece, and its results point toward an ambient light conditions mechanism at the root of the increase in vehicle crashes.

According to our findings, entering DST does not affect the number of total and minor accidents. However, there is a significant reduction in the daily count of serious accidents. An analysis by hour of the day reveals that this reduction occurs during the day interval that is mostly affected by reallocating an hour of sunlight into the evening. More specifically, serious crashes are reduced between 06:00 p.m. and 09:00 p.m., when morning light is allocated into the evening. Similarly, fatal accidents are slightly reduced during the morning hours that are mostly impacted when falling backwards to Standard Time at Fall transition. There is also a positive and significant impact on minor crashes when leaving DST, again associated with the evening hours that are mostly affected by reallocating an hour of sunlight back in the morning, that is, between 3:00 p.m. and 6:00 p.m. This reduction is also reflected in the results for total accidents, although there are (less precise) increases for fatal and serious accidents during that interval of the day. Moreover, we show that these changes do not correlate to other factors related to vehicle accidents, by testing for discontinuities in fuel prices and road usage around transitions. Finally, we show that the results are driven from the period before the economic crisis and the implementation of the austerity agenda. We argue that this can be attributed to smaller exposure to the amount of driving and shifts toward less risky behaviors, for example, smoking, drinking and speeding, during more turbulent times; taking these risk factors into considerations is also quite relevant to the implementation of any policy encompassing at the same time road safety, public transportation and the healthcare provision related to road accidents.

Overall, our analysis suggests that adopting DST has rather small effects on the realisation of car crashes, and that these effects are different with respect to different categories of road accidents by severity. A concern is that transition dates over the period do not vary as much as in other settings, for example, the US, and that there are two public holidays occurring near the transition dates. Although the former remains as a limitation of our paper, the latter is addressed by excluding all public holidays from our estimation sample. Moreover, falsification tests, where actual transition dates are replaced by other dates around transitions, provide further reassurance regarding the validity of our baseline results. Further research is needed to assess the full cost implications in terms of temporary or long-lasting effects on physical and mental health as well as changes in productivity and labor-related outcomes due to injuries and legal implications. But, on the basis of our results for Greece, it emerges that changes in road accidents are not a strongly compelling reason either for the abolition or the adoption of DST. However, these findings offer some empirical evidence that a consistent mechanism driven by ambient light conditions may be at play, differently from the sleep deprivation hypothesis supported by US data crashes (Smith, 2016) and more in line to UK-based findings (Bünnings & Schiele, 2021), thus highlighting the benefits that better ambient light conditions could have on overall road safety.

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CONFLICT OF INTEREST STATEMENT

The authors have no competing interests to declare that are relevant to the content of this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the Hellenic Statistical Authority (ELSTAT). Restrictions apply to the availability of these data, which were used under license for this study.

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ENDNOTES

[1] The report discussed several effects of DST, for example, health inconveniences causing disruptions of individuals' circadian rhythm (Kantermann et al., 2007). However, it concluded that Summer Time is overall beneficial, as it benefits the transportation and the outdoor leisure activities sectors, and it marginally reduces energy consumption. Regarding health implications, transition to DST has also been shown to increase heart attacks (Janszky & Ljung, 2008; Toro et al., 2015) and to negatively influence mood and life satisfaction (Kountouris & Remoundou, 2014; Sexton & Beatty, 2014).

[2] As fatal accidents are much less frequent, our a priory expectation would be that the strongest effect should be observed for the case of serious accidents. Minor accidents instead should be less strongly associated to the ambience mechanism.

[3] The amount of sleep loss is 15–20 min according to Sexton and Beatty (2014). In a previous study, Barnes and Wagner (2009) also used the American Time Use Survey and found that individuals sleep 40 min less, on average, on the night of spring transition. Both studies showed that sleep gains during the fall transition are not statistically significant.

[4] https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/pdf/scoreboard_2017_en.pdf.

[5] https://ec.europa.eu/transport/facts-fundings/scoreboard/countries/greece/investments-infrastructure_en.

[6] There are 74 administrative regions in our data. However, all vehicle crash types had a region-specific mode equal to zero.

[7] The geometrical center of the Sun is less than 6° below the horizon during the civil twilight and 6°–12° below the horizon during the nautical twilight.

[8] The inclusion of month fixed effects in the first-stage regression might create discontinuities at the end of each month, given that in Greece, similarly to all countries that adopt this regime, transitions into and out of DST are near the end of specific months. However, that would be problematic in the case where daily crash counts were severely serially correlated, for example, being steadily increasing or decreasing each day throughout the year. In various checks we performed, and that are available upon request, daily crash counts were not serially correlated within the year. Moreover, no discontinuities were uncovered in residuals obtained from regressions with and without month fixed effects, and the correlation coefficient

between the two respective residual series is quite high. In the discussion of our results, we also compare our baseline parameters to those obtained when excluding month fixed effects from the first stage regressions.

[9] We obtain similar results when ran Poisson regressions using the raw accident counts as outcomes.

[10] This is calculated as: $100 \times \left(e^{b} - 1\right)$, where b is the estimated coefficient.

[11] The Spring DST effects using national time-series are similar when estimating the first-stage regressions without controlling for month fixed effects, and reported in Appendix Table A2. Specifically, for total accidents the RD estimate is equal to −0.080 (standard error = 0.048) and −0.123 (standard error = 0.055) when using first and second order polynomials, respectively. The respective parameters are 0.114 (standard error = 0.088) and 0.071 (0.131) for fatal accidents, −0.178 (standard error = 0.085) and −0.197 (standard error = 0.106) for serious accidents, and −0.081 (standard error = 0.049) and −0.104 (0.059) for minor accidents. Using regional panel data, the results are also robust to the exclusion of month fixed effects from the first-stage regressions.

[12] Results for Fall transition are also robust to the omission of month fixed effects from the first-stage regressions, using both national time series and regional panel data (see Table A2). Regarding the former, the RD estimate is equal to 0.128 (standard error = 0.054) and 0.187 (standard error = 0.049) when using first and second order polynomials, respectively. The respective parameters are −0.068 (standard error = 0.130) and −0.091 (0.147) for fatal accidents, −0.106 (standard error = 0.105) and −0.073 (standard error = 0.133) for serious accidents, and 0.172 (standard error = 0.052) and 0.218 (0.052) for minor accidents.

[13] During the period we cover (2006–2016), the Sun rises between 07:11–07:21 (spring transition), and between 06:43–06:49 (fall transition). This corresponds to the 06:00–08:59 interval in our estimations, which becomes darker (brighter) in spring (fall). On the other hand, the Sun sets between 19:40–19:47 in spring, therefore the 18:00–20:59 interval becomes brighter, and it sets between 17:27–17:35 in fall, which causes the 15:00–17:59 interval to become darker during that period. However, the exact hour and minute each accident happened are not available in order to allow a more fine-grained analysis.

[14] Given the two levels of stratification of the sample (i.e., by accidents severity and hour intervals) required for the analysis reported in Figure 5, the RDD estimates of interest are mildly imprecise due to lower overall statistical power implied by using the stratified sub-samples, and so the 95% confidence intervals around the same estimates are partially overlapping.

[15] More specifically, using the longitude and latitude for each region, we obtained the sunrise and sunset times for each date in our data. Then we divided the total number of minutes in each cell with the number of minutes before (after) the astronomical twilight during the morning (evening), to obtain the fraction of the hour in each region that is dark.

[16] By including hour fixed effects we control for accidents and darkness being unevenly distributed across 24 h of each day (Figures 1 and 3). Day-of-year and day-of-week fixed effects should capture variation in ambient light, road network conditions, and driving patterns throughout the year and the week. Year fixed effects control for common variation over time, and region fixed effects control for permanent differences in road network, light conditions and driving behavior across regions. A limitation is that weather controls at the region-date-hour cell were not available to us; however, their inclusion did not affected the results in the UK study relative to models controlling only for fixed effects (Bünnings & Schiele, 2021).

[17] We use negative binomial regressions because outcome variables are overdispersed due to a large number of zeros. As the models include a full set of fixed effects, we expect that any incidental parameter biases should be small, especially given the large number of time periods in our context (Bünnings & Schiele, 2021; Cameron & Trivedi, 2015; Greene, 2004). All results are robust to the use of OLS where the outcome variables are transformed as $\log(y+1)$.

[18] According to data from the World Meteorological Organization (WMO), the annual number of sunshine hours is approximately 2700 h (based on an average of eight WMO stations), and 1424 h in the UK (based on an average of 20 WMO stations). The difference is more pronounced during the winter period where the monthly hours of sunshine in the UK are about to 40% or less, compared to Greece.

[19] These results are determined by the use of the total period DST impact, incorporating both periods before and during the crisis. Using the post-2010 estimate, that is, b = 0.037 but not statistically significant (column 6 in Table 3; panel B), in order to match exactly with the period covered by the HAIC Statistical Yearbooks suggests that there would be nearly 638 extra claims for minor vehicle damages due to leaving DST, inducing extra annual costs of about €445,000 on average.

[20] Full results for insurance claims implications of serious accidents are available upon request.

[21] Valuations can be downward biased as they are based on 2002 prices.

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APPENDIX A

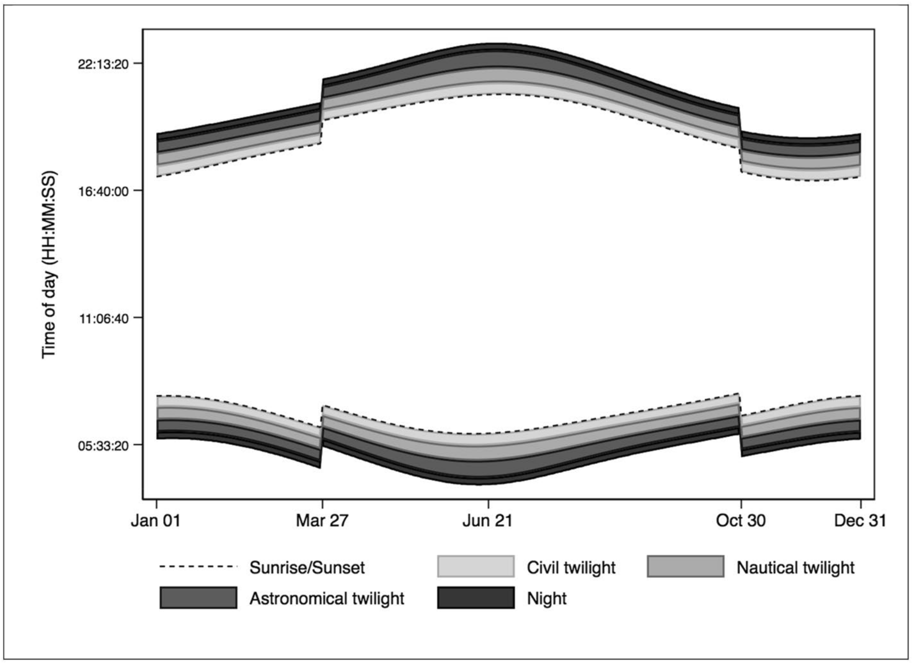

FIGURE A1 Sunrise and sunset times. 2016 data for central Athens. Civil twilight occurs when the (geometrical center of the) Sun is less than 6° below the horizon. Nautical twilight occurs when the Sun is 6°–12° below the horizon. Astronomical twilight occurs when the Sun is 12°–18° below the horizon.

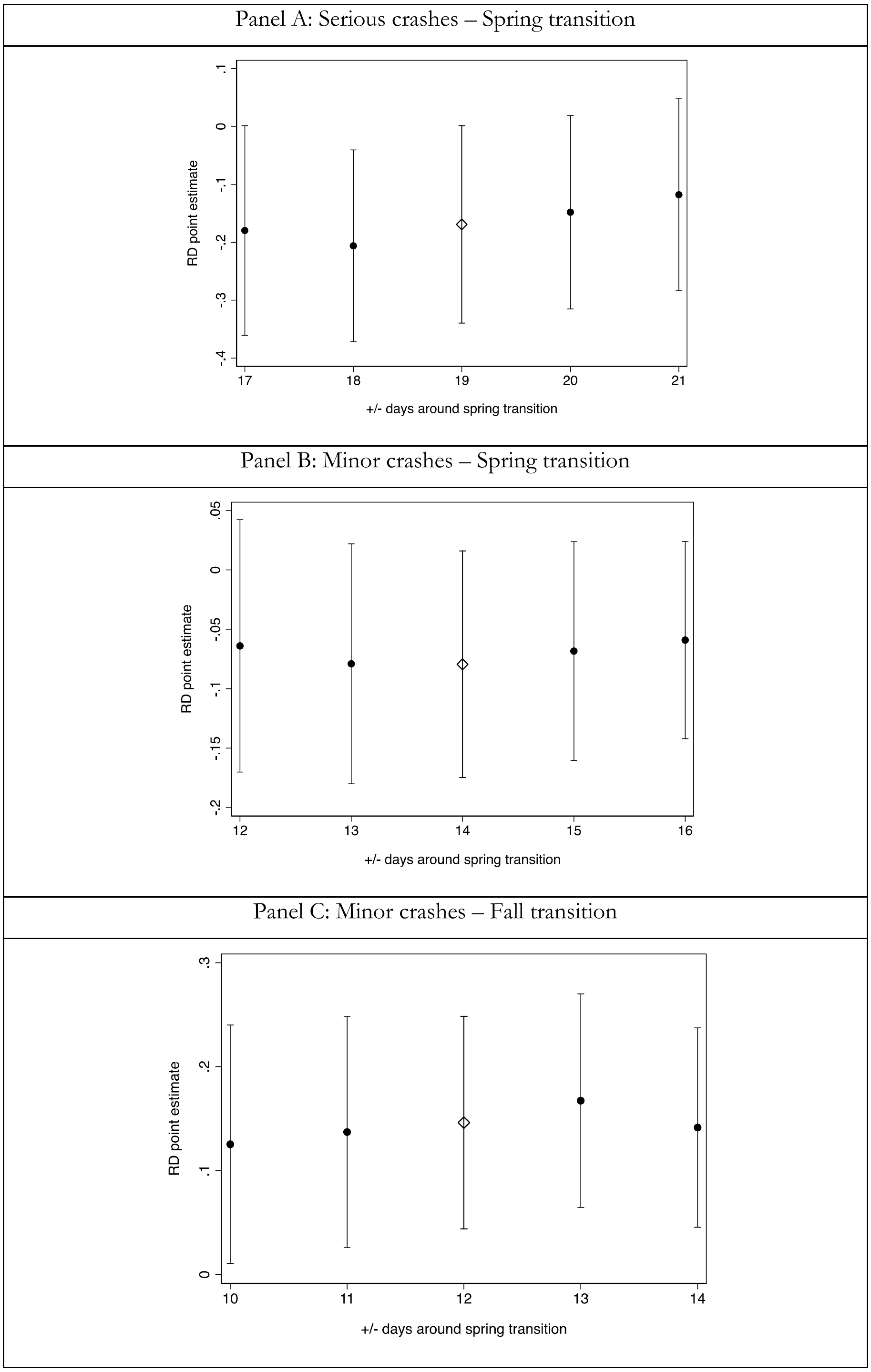

FIGURE A2 RD estimates using alternative, close to the optimally chosen ones, bandwidths. Source: Hellenic Statistical Authority (ELSTAT). Authors' calculations. Hollow rectangular marker symbols indicate the baseline effects reported in column 1 of Table 2 (using the optimally chose bandwidths). Solid round marker symbols represent the discontinuity parameters obtained when using alternative bandwidths. Vertical lines represent the 95% confidence intervals.

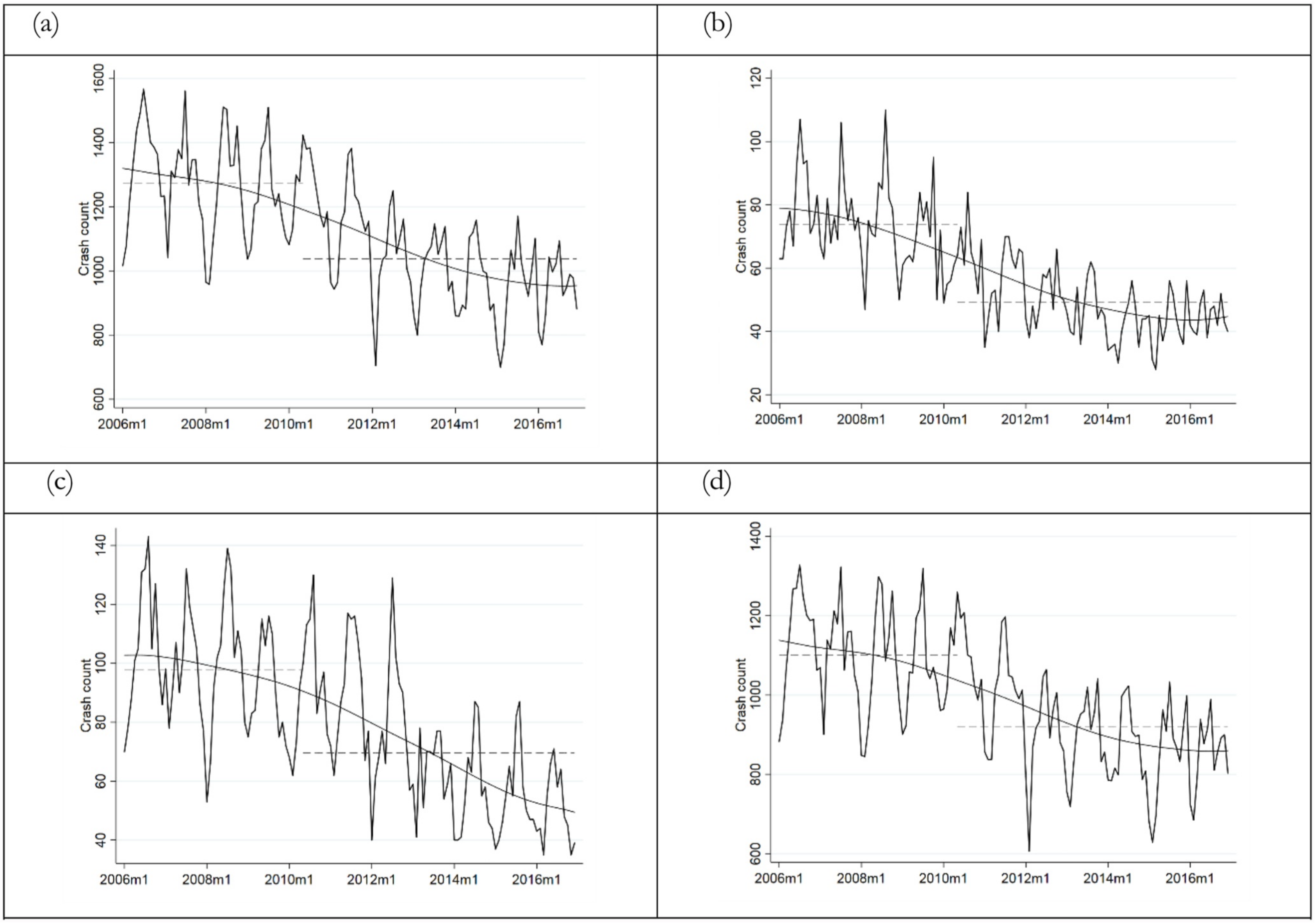

FIGURE A3 Vehicle accidents over time. (a) Total vehicle accidents. (b) Fatal vehicle accidents. (c) Serious vehicle accidents. (d) Minor vehicle accidents. *Source*: Hellenic Statistical Authority (ELSTAT). Authors' calculations. Black lines are monthly totals. Smoothed lines are obtained from locally weighted regressions. Dashed lines are period-specific means, that is, before and during the austerity period specified from May 2010 onwards. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE A1 Descriptive statistics for accident variables.

	Mean	Std. Dev.	Min.	Max.	Observations
	(1)	(2)	(3)	(4)	(5)
Total accidents	37.14	9.59	8	73	4018
Fatal accidents	1.93	1.52	0	10	4018
Serious accidents	2.65	1.87	0	14	4018
Minor accidents	32.56	8.45	7	66	4018

Note: Daily averages for the period between Jan 01, 2006 and Dec 31, 2016.
Source: Hellenic Statistical Authority (ELSTAT).

TABLE A2 RD estimates of the impact of the DST transition: Robustness checks.

	National time series data		Regional panel data	
	(1)	(2)	(3)	(4)
Panel A: Total accidents (spring transition)				
RD estimate	−0.080* (0.048)	−0.123** (0.055)	−0.008 (0.006)	−0.017** (0.008)

TABLE A2 (Continued)

	National time series data		Regional panel data	
	(1)	**(2)**	**(3)**	**(4)**
Polynomial order	1	2	1	2
Days around transition	14	27	18	30
Observations	296	556	28,268	45,584
Panel B: Fatal accidents (spring transition)				
RD estimate	0.114 (0.088)	0.071 (0.131)	0.003 (0.002)	0.001 (0.003)
Polynomial order	1	2	1	2
Days around transition	25	24	24	28
Observations	521	499	36,926	42,550
Panel C: Serious accidents (spring transition)				
RD estimate	−0.178** (0.085)	−0.197* (0.106)	−0.004* (0.003)	−0.007** (0.003)
Polynomial order	1	2	1	2
Days around transition	18	28	23	34
Observations	382	556	35,298	51,208
Panel D: Minor accidents (spring transition)				
RD estimate	−0.081* (0.049)	−0.104* (0.059)	−0.008* (0.005)	−0.014* (0.007)
Polynomial order	1	2	1	2
Days around transition	14	25	19	27
Observations	296	521	29,674	41,144
Panel E: Total accidents (fall transition)				
RD estimate	0.128** (0.054)	0.187*** (0.049)	0.011* (0.006)	0.020** (0.009)
Polynomial order	1	2	1	2
Days around transition	11	26	16	23
Observations	242	572	26,048	37,444
Panel F: Fatal accidents (fall transition)				
RD estimate	−0.068 (0.130)	−0.091 (0.147)	−0.001 (0.003)	−0.001 (0.003)
Polynomial order	1	2	1	2
Days around transition	13	27	16	26
Observations	286	594	26,048	42,328
Panel G: Serious accidents (fall transition)				
RD estimate	−0.106 (0.105)	−0.073 (0.133)	−0.002 (0.003)	−0.001 (0.004)
Polynomial order	1	2	1	2
Days around transition	17	24	19	25
Observations	374	528	30,932	40,700
Panel H: Minor accidents (fall transition)				
RD estimate	0.172*** (0.052)	0.218*** (0.052)	0.013** (0.007)	0.013* (0.008)
Polynomial order	1	2	1	2
Days around transition	12	26	15	29
Observations	264	572	24,420	47,212

Note: Dependent variables are demeaned residuals obtained after demeaning the logged vehicle crash counts by day of week and year (and region in the case of regional panel). All specifications use a uniform kernel. Bootstrapped standard errors (1000 replications) in parentheses. Columns 1–2 use aggregated time series. Columns 3–4 use a regional panel. Days around transition are chosen using the bandwidth selector of Calonico et al. (2014).

Source: Hellenic Statistical Authority (ELSTAT). Authors' calculations.

Asterisks ***, ** and * denote statistical significance at the 1%, 5% and 10% level, respectively.

TABLE A3 Darkness, street lights conditions, and vehicle accidents.

	Type of accident				
	All	Non-fatal	Minor	Serious	Fatal
Darkness	−0.069*** (0.14)	−0.118*** (0.024)	−0.132*** (0.34)	0.147 (0.231)	0.032** (0.016)
Insufficient lighting conditions	−0.079* (0.036)	−0.117*** (0.035)	−0.116*** (0.036)	−0.110 (0.135)	0.021** (0.009)
Sufficient lighting conditions	−0.039*** (0.007)	−0.044*** (0.013)	−0.048*** (0.016)	0.048 (0.095)	0.003 (0.006)
Darkness × insufficient lighting conditions	0.061*** (0.017)	0.056** (0.022)	0.040* (0.023)	−0.009 (0.157)	0.004 (0.010)
Darkness × sufficient lighting conditions	0.025** (0.010)	0.041*** (0.014)	0.065*** (0.020)	−0.217 (0.152)	−0.010 (0.008)
Observations	129,534	129,534	129,534	129,534	129,534

Note: Negative binomial regressions with counts as outcomes. Each cell comes for a separate regression. All regressions include hour, day-of-week, day-of-year, year, and region fixed effects. Standard errors clustered at the region level in parentheses. For insufficient and sufficient lighting conditions (during the night), day is the reference group (darkness is equal to zero).

Source: Hellenic Statistical Authority (ELSTAT). Authors' calculations.

Asterisks ***, ** and * denote statistical significance at the 1%, 5% and 10% level, respectively.

TABLE A4 RD estimates on the impact of DST transitions on fuel prices and miles traveled.

	Petrol price		Diesel price		Vehicle miles traveled	
	Spring transition	Fall transition	Spring transition	Fall transition	Spring transition	Fall transition
	(1)	(2)	(3)	(4)	(5)	(6)
RD estimate	0.002 (0.002)	0.001 (0.001)	0.001 (0.002)	−0.001 (0.001)	−0.013 (0.045)	0.025 (0.025)
Kernel	Uniform	Uniform	Uniform	Uniform	Uniform	Uniform
Days around transition	16	12	21	13	14	15

Note: Data cover the period between January 01, 2012 and December 31, 2016 (older series were not available). The dependent variable is the demeaned daily price for each fuel product and vehicle miles traveled, demeaned by day-of-week, month, and year fixed effects. Standard errors in parentheses are clustered by day from transition.

Source: Ministry of Economy and Development; General Secretariat of Commerce and Consumer Protection; Fuel Prices Observatory; Egnatia Road Observatory Unit. Authors' calculations.

Asterisks ***, ** and * denote statistical significance at the 1%, 5% and 10% level, respectively.

TABLE A5 Estimates of insurance claims costs for minor accidents due to DST.

	Total number of declared claims	Theft claims	Fire claims	Actual net total claims = (1) − [(2) + (3)]	Net total claims without DST	Difference due to DST = (4) − (5)	Estimated total cost (€) due to DST
Year	(1)	(2)	(3)	(4)	(5)	(6)	(7)
2010	18,672	402	33	18,237	15,370	2867	1,886,940
2011	17,312	450	31	16,831	14,185	2646	1,742,278
2012	14,312	413	26	13,873	11,692	2181	1,552,683
2013	13,489	333	20	13,135	11,070	2065	1,524,205
2014	13,349	296	14	13,129	11,065	2064	1,507,937
2015	13,269	308	15	12,946	10,911	2035	1,489,263
2016	13,782	337	18	13,437	11,325	2112	1,435,231

Note: Column (5) is the counterfactual number of total claims in the absence of DST, computed as: Actual Net Total Claims × [1 − (exp(0.146) − 1)], where 0.146 is the baseline estimate for minor crashes during the fall transition date. Column (7) is column (6) multiplied by the total amount of settlements for insurance claims worth up to €2000.

Source: Statistical Yearbook for Motor Insurance, 2010–2013 (Hellenic Association of Insurance Companies).

TABLE A6 RD estimates on the number of victims.

	Fatalities (1)	Serious injuries (2)	Light injuries (3)
HEATCO value for each avoided casualty in Greece (2002 prices)	836,000 euros	109,500 euros	8400 euros
Panel A: Spring transition			
RD estimate	0.091 (0.102)	−0.231* (0.131)	0.001 (0.035)
Days around transition	22	15	16
Observations	495	341	363
Panel B: Fall transition			
RD estimate	−0.070 (0.089)	−0.218 (0.150)	0.126*** (0.037)
Days around transition	17	14	13
Observations	385	319	297

Note: The dependent variable is the logged daily victim count by accident type demeaned by day-of-week, month, and year fixed effects. Standard errors in parentheses are clustered by day from transition. First order polynomials of the running variable on both sides of the transition dates are used.

Source: Hellenic Statistical Authority (ELSTAT). Authors' calculations.

Asterisks ***, ** and * denote statistical significance at the 1%, 5% and 10% level, respectively.