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*Daylight Saving Time is causing Suicide*

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## **Abstract**

This paper seeks to verify whether an abrupt change in exposure time to solar luminosity affects suicide incidence. The article is based on the medical and psychiatric literature suggesting that this climate variable seems to affect reported cases of suicide worldwide. Methodologically, data relating to mortality in Southern Brazil were used over a period of 10 years, and a natural experiment was used to test the hypothesis that a longer exposure time to sunlight at the end of the day from the introduction date of Daylight Saving Time (DST) was reflected in an increase in suicide deaths. The regression discontinuity design results suggest a DST positive causal effect on suicide, i.e. the DST transition in average increase the treated state suicide rate in about 57% (p-value = 0.011), and this result is precisely zero in others untreated states. Another important results is that this effect is magnified with latitude i.e. considering the latitude effect the DST increase, on average, the suicide rate about 2% each 1,000 km variation.

**Keywords:** suicide, sunlight, daylight saving time, natural experiment, regression discontinuity design.

## **Highlights**

- A longer exposure time to sunlight at the end of the day from the introduction date of Daylight Saving Time was reflected in an increase in suicide deaths.
- The results suggest a positive causal effect in the southernmost state of the country, Rio Grande do Sul

## **1. Introduction**

Since the 1970s, specialized literature has systematically shown that sunlight is correlated with suicide<sup>1</sup>. This paper contributes to literature because it is the first one to apply natural experiments to demonstrate the causality between sunlight and suicide. Following Imbens and Lemieux; 2008<sup>2</sup> Angrist and Pischke; 2008<sup>3</sup> natural experiments is an alternative potentially as good as randomization to identify the effect of interest. Generally, the data on this worldwide mortality are not random throughout the year but tend to show seasonality, with a peak in the transition from darker to lighter seasons, suggesting that suicide has a clear sensitivity to periods of seasonal transition<sup>1</sup>.

The health literature to start trying to verify the causality of how the variation of sunlight might be affecting the incidence of suicide, first in regions of medium and high latitudes, as in the works of Meares et al. (1981)<sup>4</sup> and Partonen et al. (2004)<sup>5</sup>, and then more recently in regions of low latitudes, as seen the works of Yip and Yang (2004)<sup>6</sup>, Lee et al. (2006)<sup>7</sup> and Tsai (2010)<sup>8</sup>. Indeed, because a randomized experiment in this case comes up against ethical issues most studies that have failed at verifying that the positive variation of sunlight has a causal effect on suicide. Given this gap in the literature, we are using a natural experiment to verify the causal effect of sunlight on the incidence of suicide.

In addition, we are testing that the results found here fare due to the biological mechanism resulting from the use of longer sunstroke time at the end of the day (and its effect on mood) rather than issues related to the adjustment of circadian rhythm in the introduction of Daylight Saving Time (DST).

This question arises because study have associated the introduction of DST with changes in health, mainly due to the mechanism resulting from the change in sleep pattern, or even sleep deprivation originated from the adjustment related to the allocation of time that people face with the arrival of the intervention<sup>9</sup>. Thus, as the introduction to DST can affect the quality and

pattern of sleep<sup>10</sup>, the human body can react in different ways to this period of transition. As a result, there may be altered cognitive performance, such as attention or mood, as highlighted by Caldwell et al. (2004)<sup>11</sup> and Diekelmann and Born (2010)<sup>12</sup>.

Evidence has associated the phenomenon to several sunlight-dependent hormones (such as melatonin, serotonin and cortisol)<sup>13-16</sup> responsible for regulating mood<sup>15</sup>. Thus, it seems, changed regulation of these substances in the body can lead to changes in behavior in individuals, encouraging attempted self-inflicted death. Lambert et al. (2002)<sup>17</sup> found that the level of the hormone serotonin in the brain (an important neurotransmitter that is linked to feelings of well-being and happiness) is lower in the winter at a time of decreased sunlight incidence. They also found that variations in serotonin levels can occur quickly with increased sunlight, which can bring about bad feelings given its effect on neurotransmitters<sup>1</sup>.

Papadopoulos et al. (2005)<sup>18</sup> verifies that sunlight has different short- and long-term effects. Long term, as known in the literature, increased sunlight exposure can act as a natural antidepressant and improve mood. On the other hand, short-term increased sunlight exposure can change the state of motivation of individuals. Thus, sunlight could create a short-term increase in the courage to commit suicide. Thus, these works suggest that increased suicide incidence is sustained by a variation of sunlight that induces a variation in the level of the hormones responsible for mood.

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<sup>1</sup> These results reinforce that the biological mechanism by which sunlight changes mood, and consequently increases the chances of suicidal behavior, is a very short-term phenomenon, which reinforces the empirical strategy adopted in this work.

## **2. Data and Empirical Strategy**

The choice of Brazil to verify this phenomenon is related to two reasons: the first is the quality of information on suicide mortality, and the second concerns the population size of the country, which has more than 200 million inhabitants. Indeed, collecting information on this cause of death is somewhat complicated, since suicide is illegal or stigmatized in many places, or, when this problem does not occur, registration tends to be difficult, since it involves several responsible authorities. According to the institution, this makes suicide data difficult to obtain in much of the planet, especially in very populous countries that do not have a good system of vital records.

The regression analysis of the econometric models includes three Brazilian states: Paraná (PR), Santa Catarina (SC), and Rio Grande do Sul (RS). These states are only ones whose the most of the territories are below the Tropic of Capricorn (Figure 1). Thus, the states of the South region of Brazil have more hours of sunlight than the rest of the states of the country at this time of the year, regardless of DST. With the introduction of DST, the total use of the remaining natural daylight intensifies since these Brazilian states are the closest to the South Pole.

The RS is the southernmost state of the country, and its latitude marks the southern limit of the apparent declination of the sun on the planet, so that from this region, the effect of natural experiments induced by DST could be more noticeable by a greater use of the natural time of insolation and the duration of days when the summer solstice approaches. Indeed, it is the Brazilian state whose latitude have the most influence on the efficiency of using the longest time of natural light at the end of the day. Therefore, in this paper, we compare the incidence of suicide on the day before entering DST with the incidence of suicide on the first day after its initiation for RS using a Regression Discontinuity Design (RDD).



Figure 1: Brazilian's States of South Region highlighting, and the Tropic of Capricorn

Brazilian DST and RS latitude together will be used as exogenous source of longer exposure to sunlight, and death by suicide's reaction to the transition period associated with introduction of DST. The strategy of this natural experiment is to compare the average of reported suicide cases days after the date of introduction of DST (in RS latitude) and compare those with the days immediately prior to this date. In this case, the days marginally preceding the intervention will be the control group, while the days marginally following DST introduction (in RS latitude) will be the treated group. Thus, social behaviors that are correlated with sunlight can be circumvented, since the sudden shock of the longer time to use natural daylight is defined exogenously, thus circumventing this important factor. Below we present the model in reduced form:

$$SUICIDE_{i,k,y} = \alpha T(X_{i,k,y} \geq 0) + f(X_{i,k,y}) + \xi_{i,y} \quad (1)$$

where  $SUICIDE_{i,y}$  represents the total causes of death by suicide on day  $i$ , state  $k$  and year  $y$ ,  $X$  is the DST transition function, the transition date assumes the value zero, the following days assume values sequentially positive and the previous days assume values sequentially negative, so that in the estimation,  $X \in (0 - h; 0 + h)$ , where  $h$  represent an optimal bandwidth of days in relation to the date of intervention. Finally,  $f$  is a no parametric and function  $\varepsilon_{i,y} \sim N(0,1)$  represent the random error term. In addition, the model was also estimated by a robust estimator

by Calonico, Cattaneo and Titiunik (2014)<sup>19</sup>. In this model,  $\alpha$  allows evaluation of the effect of the introduction of DST in suicide cases, checking if there is any difference between the mean of the days immediately after and the mean of the days immediately before the date of DST implementation.

We are applying two robustness strategy. The first approach is following Kountouris and Remoundou (2014)<sup>20</sup>. In this case, the objective is to verify the effect of the first week after the introduction of DST, using a panel estimation with fixed effects also in the years 2005 to 2014. Fixed effects for day of the week and a time trend were included for two reasons: the first variable controls for a rapid daily variation in the suicide indicator between different days of the week, and the second controls for a slow seasonal variation in the indicator over the months. Thus, while the first variable captures a rapid change in social behaviors that may affect suicide deaths, the second variable captures a slow change in social behaviors correlated with the transition of the seasons.

The second robustness methodological approach will test the hypothesis that there is a positive effect of the variation in latitude on these causes of death. If the argument that latitude is an important component in explaining the effect of the introduction of DST (and the consequent use of longer hours of sunshine in the late afternoon) is valid, the interaction ( $Week\_DST_{i,y} * Latitude$ ) is expected to generate a positive effect in cases of death by suicide.

The estimation of the panel model took place through a random effects model. The choice of this method was through tests that indicated this estimator, instead of the pooled model and the fixed effects model. Likewise, there is a theoretical argument: the random effects model assumes independence in relation to the regressors from the unobserved individual fixed effects of the cross-sectional units. In this case, it is unlikely that the unobserved fixed characteristics of the days of the year are correlated with the DST transition week, since this variable is exogenous.

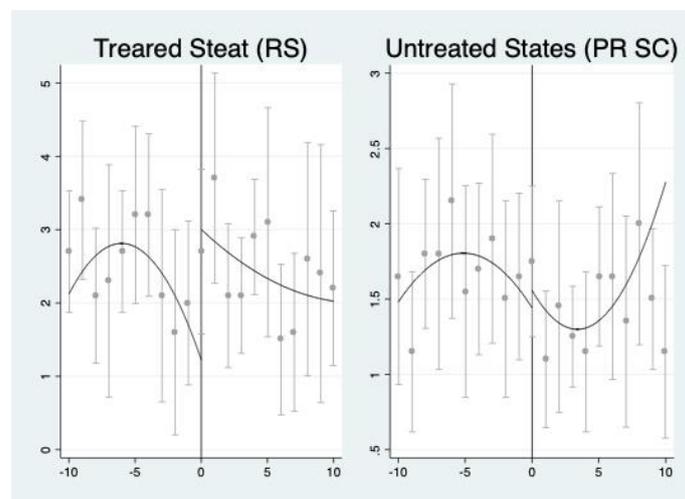
Finally, the mortality variable was obtained through data from the Mortality Information System of the Ministry of Health of Brazil (SIM/DataSus), for the period 2005-2014. Suicide is defined by the ICD-10 as death derived from intentional self-harm, so all causes of death belonging to the group between X60 and X84 were selected.

### 3. Results

According to data from the Brazilian Ministry of Health, between 2005 and 2014, 95,566 suicides were reported in the country. The North region had 6.47% of the notifications, the Northeast region 23%, the Southeast region 38.3%, the Midwest region 8.81% and, finally, the South region had 23.42%.

Our main results is report in Figure 2. It reports the discontinuity of the mean number of deaths around the transition cutoff in this state. A clear jump in the average suicide pattern is seen in the days immediately following the introduction of summertime with the days immediately preceding DST implementation.

**Figure 2. Average reported suicide cases in RS during the DST transition period (2005-2014).**



Note: the vertical axis contains the daily average of suicide cases, while the horizontal axis contains the days of transition to DST (the entry date assumes zero value). We used the Calonico, Cattaneo and Titiunik (2014)<sup>19</sup> estimator, which automatically calculates the optimal bandwidth in a discontinuous regression with the sample mean within the bins.

Analyzing the effect of DST on suicide (table 1), the RDD regression shows that after DST, suicide rate increased around 1,3 point in treated state, i.e. the DST transition in average increase the RS suicide rate in about 57%, and this result is precisely zero the others untreated

states. No difference is found for the entire region, just for state of Rio Grande do Sul (RS). In Table 1, columns (1), (2) and (3), it is verified that the results remain qualitatively the same when changing the specification and the selection procedure of the optimal band (MSTWO and MSECOMB2).

**Table 1: RDD: estimate of the impact of DST entry on suicide cases**

	Treated State (RS)			Untreated State (PR e SC)		
	(1)	(2)	(3)	(4)	(5)	(6)
<b>DST entry</b>	1.3307**	1.2942**	1.3089**	-0.334	-0.33835	-0.34723
	(0.526)	(0.526)	(0.523)	(0.310)	(0.293)	(0.285)
<b>Specification</b>		Quadratic	Quadratic		Quadratic	Quadratic
<b>Bandwidth</b>		mstwo	msecomb2		mstwo	msecomb2
<b>Fixed effects<sup>§</sup></b>	yes	yes	yes	yes	yes	yes
<b>Obs. to the right</b>	140	160	160	896	896	896
<b>Obs. to the left</b>	130	130	130	844	844	844
<b>Total</b>	270	290	290	1740	1740	1740

\*significant at 10%, \*\* at 5%, \*\*\* at 1%, p-values were calculate on robust confidence interval. Standard-errors in parentheses. <sup>§</sup> The results remain similar in the absence of fixed effects. MSTWO and MSECOMB2 refer to Calonico, Cattaneo and Farrel<sup>21</sup> optimal bandwidth selectors, RS - DST - Regression Discontinuity Design.

Below we will present a set of robustness tests to support our main results i.e. the discontinuity found in DST entrance transition cause suicide in reason of the biological mechanism.

As shown in Table 2, no statistically significant parameters were found for these two analyses, which corroborates the robustness found in the previous results.

**Table 2. Panel robustness test: estimates of week effect prior to transition and the week after DST in suicide cases (RS).**

	(1)	(2)
<b>Effect in the week prior to DST</b>	0.1627	0.1598
	(0.2219)	(0.1872)
<b>Effect in the week after DST</b>	-0.1433	0.0068
	-0.2039	-0.1779
<b>Trend and fixed effects</b>	no	yes
<b>Prob&gt;F</b>	0	0
<b>Obs.</b>	910	910

\*significant at 10%, \*\* at 5%, \*\*\* at 1%. Robust standard errors in parentheses. RS - Rio Grande do Sul. DST - Daylight Saving Time

Table 3 reports the effect of the week of introduction of DST in the entire Southern region of Brazil. No statistical significance was found, which corroborates the argument that the phenomenon under analysis is not due to the hypothesis of change in circadian rhythm previously presented.

Table 3. Panel: estimation of transition week effect in suicide cases (South region).

	(1)	(2)
<b>Transition week effect</b>	0.0603 (0.1107)	0.0816 (0.1080)
<b>Trend and fixed effects</b>	no	yes
<b>Prob&gt;F</b>	0.00	0.00
<b>Obs.</b>	2,730	2,730

\*significant at 10%, \*\* at 5%, \*\*\* at 1%. Robust standard errors in parentheses.

If, in fact, the greater use of end-of-day light is important and latitude is a relevant component, it is expected that the interaction of the transition week dummy with some measure that captures the variation in latitude has a positive and significant effect on the results. Thus, this new variable would capture the effect of the intervention week, as the time of use of natural light at the end of the day with the change of latitude is increased. To test this, the latitude of the centroid of each state in the southern region was taken, and the distance (in km) from the Tropic of Capricorn was calculated<sup>2</sup>. Thus, by interacting this measure of latitude with the transition dummy, how the transition week reacts to the change of latitude in cases of suicide in the entire southern region is seen. Methodologically, as the latitude measurement is an exogenous variable (not correlated with the transition week), there is no risk of falling into an endogeneity bias in the estimation of this parameter. Table 4 shows the positive and significant results for the latter model.

<sup>2</sup> Such distances were obtained at the National Institute for Space Research of Brazil (INPE). Available from: [inpe.br](http://inpe.br)

Table 4. Panel: estimation of the effect of the interaction of the transition week with the variation of latitude in cases of suicide (South region: PR, SC and RS).

	(1)	(2)
<b>Transition week</b>	0.2666 (0.8596)	
<b>Transition week * latitude</b>		0.0004** (0.0002)
<b>Trend and fixed effects</b>	yes	yes
<b>Prob&gt;F</b>	0.00	0.00
<b>Obs.</b>	2,730	2,730

\*significant at 10%, \*\* at 5%, \*\*\* at 1%. Robust standard errors in parentheses.

Thus, although the transition week has not been significant for suicide cases in the South (table 4, column (1)), when taking into account the effect of the change in latitude (table 4, column(2)), and thus the geographical effect of the variation in the longest time of sunstroke at the end of the day, there is a positive and statistically significant sign of suicide cases in the week of introduction of summertime in the entire region. Indeed, 1 km increase in distance from the Tropic of Capricorn generates, on average, an increase of 0.0004 cases of suicide in the transition week, i.e. considering the latitude effect the DST increase, on average, the suicide rate in South about 2% each 1,000 km variation.

#### 4. Discussion

Brazilian DST was used as an exogenous source of longer exposure to sunlight, and death by suicide reaction to the transition period associated with introduction of DST is assessed. The strategy of this experiment is to compare the average of reported suicide cases days after the date of introduction of DST and compare those with the days immediately prior to this date. In this case, the days marginally preceding the intervention will be the control group, while the days marginally following DST introduction will be the treated group. Thus, social behaviors

that are correlated with sunlight can be circumvented, since the sudden shock of the longer time to use natural daylight is defined exogenously, thus circumventing this important factor.

The positive and significant coefficient suggests that there is a positive causal effect of the introduction of DST in cases of suicide in RS during the analysis period. In the latter case, we followed the Calonico, Cattaneo and Farrel selectors (2018)<sup>21</sup>, which have been widely used in sensitivity analyses of discontinuous regressions in recent years. Therefore, the peak in the transition from darker to lighter seasons, suggesting that suicide has a clear sensitivity to periods of seasonal transition<sup>1</sup>.

A study in Austria showed that seasonal changes in sunlight are responsible for variations in both the number of suicides and the more violent form of their perpetration. The influence of sunlight interacts with serotonin neurotransmission and may trigger impulsivity and suicide<sup>22</sup>. In addition, sunlight has a bimodal effect on suicidal behavior, as an increase in suicide was found on shorter time scales, while after longer periods, more sunlight was associated with decreased suicide<sup>23</sup>.

As in the RDD model, robustness tests were performed, and following Kountouris and Remoundou (2014)<sup>20</sup>, the validity of these results was tested by checking the effect of the week after the week of transition on the incidence of death. In this case, the effect of the week prior to the transition week is not expected to demonstrate statistical significance, as it is a pretreatment effect. According to the empirical strategy adopted in this study, DST is only a mechanism that introduces a positive shock in the use of the insolation time at the end of the day, and this shock seems to positively affect the indicator of death of interest in this state.

It is argued here that this possibility, in this case, can be ruled out. First, because if the mechanism of adjustment of time allocation and sleep deprivation were valid, statistical significance would be found in the results of discontinuous regression for the entire Southern

region and each of its states, and not only for the state of RS. This argument is validated in Table 4.

Studies such as that of Bjorksten et al. (2009)<sup>24</sup> and Hiltunen et al. (2011)<sup>25</sup>, for example, have suggested that suicide cases react positively to increased latitude, possibly due to the biological mechanism already presented.

This suggests that the effect of the increase in suicide deaths after the introduction of DST is possibly due to the effect of greater use of natural daylight in the late afternoon. It is worth remembering that the measure of latitude is the distance from the centroid of each state to the Tropic of Capricorn, and this measure is in kilometers. Given this, each 1 km increase in distance from the Tropic of Capricorn generates, on average, an increase of 0.0004 cases of suicide in the transition week (or 0.4 cases for each 1,000 km variation, on average).

Despite this study being the first one to use natural experiments to evaluate the causal effect to sunlight on suicide, some limitations can be observed. First, RS is the only Brazilian state whose latitude is compatible with the hours of sunshine needed to act as a trigger for suicide. Another limitation is the robustness test, which would be more accurate with the exact time of suicide. If our hypothesis is correct, suicide should occur at the end of the day, however we do not have this information in our data set.

## **5. Final Considerations**

Through two statistical approaches, empirical evidence was provided that a positive variation in sunlight exposure time can positively influence suicide deaths. In the first case, from a discontinuous regression, it was found that the introduction of DST resulted in an increase in reported cases of this type of death in the southernmost state of the country (RS), where latitude seems to influence the efficiency of the mechanism used to verify the causal effect of interest.

In the second case, the effect of the change of latitude in the 03 states of the southern region of the country was tested to verify the hypothesis that the week of transition of DST reacts to changes of latitude with respect to these cases of death.

All of the results suggest that the introduction of DST has generated an increase in suicide cases, and it seems that, in fact, this effect is due to the reaction mechanism of the organism to changes in exposure to sunlight (as suggested in the medical and psychiatric literature) and not due to other mechanisms such as sleep deprivation and adjustment of the body's circadian rhythm to the change in allocation of hours in the days immediately following the event.

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