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The welfare effects of time reallocation: evidence from Daylight Saving Time

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Abstract

Daylight Saving Time (DST) is a widely adopted practice implemented by over 70 countries to align sunlight with day-to-day activities and reduce energy demands. However, we do not have a clear knowledge of how it affects individuals' welfare. Using a regression discontinuity combined with a difference-in-differences design, we find that the Spring DST transition causes a significant decline in life satisfaction. By inducing a reallocation of time, the transition into DST deteriorates sleep quality and increases time stress, which in turn affects physical and emotional health. Using an event study approach, we find that such effects persist for about six days after the DST transition. Conversely, we provide evidence that the Autumn DST transition gives rise to a significant increase in life satisfaction. Finally, using a simple cost-benefit analysis, we discuss the potential benefits of ending DST.

1 | INTRODUCTION

Daylight Saving Time (DST) is currently implemented by more than 70 countries around the world with the aim of aligning sunlight with day-to-day activities and reducing demand for energy. However, recent studies have shown that DST does not save energy and could actually increase the use of electricity (Kotchen and Grant 2011). Moreover, opponents of DST argue that a time change, even if it is by only one hour, can have lasting effects on the health and some dimensions of wellbeing of individuals. Studies have linked the DST transition to greater risks of car accidents (Smith 2016; Fritz *et al.* 2020; Bünnings and Schiele 2021), workplace injuries (Barnes and Wagner 2009), heart attacks (Manfredini *et al.* 2018) and depressive symptoms (Hansen *et al.* 2017).[1] In this paper, we show that the Spring DST transition generates welfare costs, specifically we document a reduction in life satisfaction. Investigating a broad range of outcomes, we show that such decline in life satisfaction can be explained by a decrease in sleep satisfaction following the DST transition, and an increase in time pressure, which significantly affects individuals' physical and emotional health in the subsequent days after the DST transition. In contrast, we provide evidence that the Autumn DST transition is associated with a significant increase in life satisfaction.

Over recent years, the DST policy has become increasingly controversial, with the European Parliament voting in March 2019 in favour of putting an end to DST. Yet, so far, the process has been halted. First, because of the worldwide pandemic, but also because some countries, such as the UK and Ireland, argue that ending DST will create a patchwork of time zones, destabilizing further the European Union. At the time of writing this paper, no negotiations have started yet, and it could be some time before we see the end of DST in the European Union. Similarly, in the United States (US), DST has been implemented since 1966 in most states, and has been extended as part of the Energy Policy Act of 2005. However, in 2022, the US Senate approved a permanent version of DST. While the rationale for implementing DST has been to align social and economic activities more closely with sunlight and reduce energy consumption 2011, an important, and often neglected argumentation is that it can also have many other impacts on people's lives. To shed light on this debate, it is crucial that policymakers have at their disposal overall estimates of the welfare costs and benefits associated with DST.

This paper examines the first-order effects of DST, namely, its impact on individuals' wellbeing. So far, most of the DST literature has explored the effects of DST on specific outcomes in isolation (e.g. energy consumption, car accidents, heart attacks, workplace injuries). But in order to assess the welfare costs and benefits of DST, it is crucial that we also consider how people *experience* this transition. DST could exert an impact on population's wellbeing through two primary mechanisms. First, it induces a reallocation of time, which can largely affect individuals' sleep schedules. According to Barnes and Wagner (2009), sleep duration reduces by 40 minutes on average on Mondays following the Spring transition. Lack of sleep may result in a tendency to err from both fatigue and poor attention, and impair cognitive abilities and work performance (Nuckols *et al.* 2009; Carrell *et al.* 2011; Giuntella *et al.* 2017; Avery *et al.* 2019; Gibson and Shrader 2018). Second, by moving clocks forward one hour, the transition into DST reduces the total time available to individuals, and hence, strengthens the time constraint in the days following the transition. Even though tighter time constraints exert mainly short-term effects, they are likely to increase people's feelings of being 'rushed' by time (Hamermesh and Lee 2007) and impact negatively on their emotional health (Scholtz *et al.* 2004; Frankenhaeuser *et al.* 1989; Garling *et al.* 2015). Moreover, by increasing time pressure, individuals are more likely to devote less time to carry out restorative activities, such as eating, socializing or exercising, which are essential to their health and emotional wellbeing. By contrast, the Autumn DST transition has been shown to increase people's sleep duration, which can result in significant health benefits, reducing hospital admissions in the days following the Autumn transition (Jin and Ziebarth 2020).

To date, existing evidence of the impact of DST on individuals' wellbeing is still scarce. Only two studies have focused on the effects on life satisfaction, drawing on German and UK data, and have documented that the Spring DST transition is associated with lower levels of life satisfaction (Kountouris and Remoundou 2014; Kuehnle and Wunder 2015). The contribution of our paper is threefold.

First, we implement a regression discontinuity (RD) design combined with a difference-in-differences (DiD) strategy to assess the effects of DST on individuals' wellbeing.[2] We compare the average wellbeing of individuals on the days just before and after the DST transition, as it's standard practice in the application of RD models. However, we also compare this wellbeing change with the average wellbeing of individuals on the days just before and after the last Sunday of the month in the previous and subsequent months (January, February, April and May) as a counterfactual. The use of these two identification strategies in tandem, using both the discontinuity in wellbeing around the DST threshold, and the change in wellbeing that occurs typically around the last Sunday of the month as a counterfactual, allows us not only to capture local effects of DST over subsequent days following the transition, but also to deal with the concern that DST effects could be partially downward biased by endogenous sorting of respondents around the last Sunday of the month. To the best of our knowledge, no study so far has investigated the effects of DST using this empirical approach.

Second, we investigate the effects of DST on a broad range of outcomes to decompose the overall wellbeing impact into sleep and other time allocations. This includes investigating the consequences of the Spring DST transition on sleep, the feeling of being rushed for time, and an individual's satisfaction with day-to-day activities, as well as physical and emotional health of respondents. Previous research so far has focused only on life satisfaction to proxy for individuals' wellbeing, or some outcomes in isolation, without being able to deepen into the mechanisms through which the DST transition can affect individuals' wellbeing.

Finally, we estimate the effects of the Autumn DST transition, and we use our estimates to perform a simple cost–benefit analysis. Such estimates are then used to discuss to what extent putting an end to DST could be welfare-enhancing, providing policymakers with guidance on the welfare costs and advantages of this practice.

To identify the impact of DST on individuals' wellbeing, we use individual panel data from the German Socio-Economic Panel, from 1984 to 2018. This allows us to follow the same individuals, as they are interviewed repeatedly every year. We first implement an RD design, exploiting the changes between Standard Time and DST on the last Sunday of March. Then, using the previous and subsequent months as counterfactual, we use an RD design combined with a DiD strategy that relies on the comparison of the average wellbeing of individuals around the Spring DST transition with the average wellbeing of individuals on the counterfactual day around the last Sunday of the month in other months. In both specifications, we find a reduction in life satisfaction following the DST transition. RD estimates indicate a decrease of 0.058 standard deviations (SD)—equivalent to a 1.39% decrease—while the RD-DiD estimates suggest negative effects of around 0.060 SD—equivalent to a 1.44% decrease. To address the possibility that some unobserved factors are driving the results, we also consider a specification with individual fixed effects, alongside year, region, time window and day of the week fixed effects. The estimates are robust to the use of different (i) bandwidths, (ii) polynomial functions of the distance in days from the last Sunday of the month, (iii) time windows, (iv) kernel distribution and (v) alternative counterfactual months. In contrast, we find no discontinuity in life satisfaction around the last Sunday of the month in previous and subsequent months (January, February, April and May).

To investigate the persistence of these effects, we implement an event study analysis. The results indicate that the negative effects of the Spring DST transition on individuals' life satisfaction persist for about six days after the nighttime shift and then dissipate. Interestingly, on the first weekend following the Spring transition, there is a positive effect on life satisfaction, which could suggest that, at least temporarily, people enjoy having one extra hour of daylight in the evening once they have adjusted to the new time schedule.[3] We then examine a number of potential mechanisms.

To better understand the channels through which the Spring DST transition affects individuals' wellbeing, we implement our RD-DiD strategy using a number of outcomes. First, we isolate the DST effect on sleep by examining changes in sleep satisfaction. Then we look at the effects on a range of health variables, including overall health assessment, hospital admissions and mental health. Second, we explore further the time pressure explanation, by examining the effect of DST on people's feeling of being rushed for time, and their satisfaction with day-to-day activities, including work, leisure, childcare and family life. The results suggest that the Spring DST transition decreases sleep satisfaction by 0.21 SD, and increases their reported time pressure by 0.19 SD. Moreover, individuals tend to report lower physical and emotional health following the Spring DST transition, as well as lower satisfaction with day-to-day activities. Once we control for sleep and time pressure, the impact of DST on life satisfaction falls by about 52% and is no longer significant.

Conversely, we find that the Autumn DST transition, by moving clocks backwards by one hour, increases the total amount of available time. Therefore sleep patterns may adjust more quickly to the Autumn transition. We replicate our empirical strategy on the Autumn DST transition, and report evidence of a significant increase in life satisfaction after the nighttime shift occurring at the end of October. These results are consistent with the idea that people may sleep longer or have more time to carry out their activities on the Sunday following the Autumn transition. These estimates also cast some doubt on the idea that respondents report lower levels of wellbeing after the Spring transition simply because they do not like schedule changes.

These findings are timely, given the recent debate on DST policy. They reveal evidence of an immediate decrease of 0.060 SD in life satisfaction, persisting for six days following the Spring transition. This suggests that the nighttime shift occurring at the end of March decreases individual wellbeing by approximately 0.001 SD annually. Such estimate is equivalent to an income loss of 354 euros per year.[5] We can compare these effects to the wellbeing effects associated with the Autumn transition, equivalent to an income gain of 564 euros. Overall, our estimates suggest that ending DST would be associated with a small income loss of 210 euros. Naturally, other impacts could be included to the analysis. (e.g. workplace injuries or value of life estimates and health spending effects associated with car accidents). The inclusion of the latter would be relevant if we believe that such effects are not fully taken into account in the life satisfaction estimates. For instance, when adding health and productivity effects to the analysis, we find that ending DST could be associated with a welfare gain, equivalent to 754 additional euros per capita per year.

Finally, we can also consider the potential costs that result from energy savings—for the sake of the exercise, we consider a decrease in energy consumption by 0.5% over the year, according to Aries and Newsham (2008). We find that putting an end to DST would cost approximately 4.85 euros per capita.[6] But note that this estimation is a lower bound as the existing evidence that DST delivers energy savings is increasingly challenged.

The remainder of this paper is organized as follows. The next section summarises briefly the literature and the mechanisms though which DST affects individuals' wellbeing. Section III describes the data, Section IV discusses the empirical strategy, and Section V reports the results. After a brief cost–benefit analysis in Section VI, we conclude in Section VII.

2 | DAYLIGHT SAVING TIME POLICY

Each year, Germany and most other European countries set clocks forwards one hour on the last Sunday of March (summertime). This time change always occurs at 2 am, where the clocks are set forward to 3 am. Clocks are then moved back one hour at the end of DST, that is, on the last Sunday of October. This process moves one extra hour of daylight from the morning to the end of the day after the end of March, hence potentially allowing us to reduce electricity usage for lighting. However, by inducing a reallocation of time, the DST policy has many other impacts on people's day-to-day lives.

We identify two ways in which the Spring DST transition affects individuals' wellbeing: disrupting sleep and increasing time constraints. Previous research has shown the influence of DST on sleep patterns (Barnes and Wagner 2009; Lahti *et al.* 2006); although, none of these studies has linked the decrease in sleep due to the Spring DST transition to decreases in individuals' wellbeing in the first days following the transition. Using the American Time Use Survey, Barnes and Wagner (2009) find that DST reduces sleep by 40 minutes on average on the Mondays following the Spring transition. However, its worth noting that there are individual differences in their adaptation to DST, with some people requiring more than two weeks to adjust their sleep patterns (Valdez *et al.* 1996). On average it takes about one week for people to adjust (Harrison 2013). Sleep deprivation has been shown to increase attention problems, reducing work performance and increasing workplace injuries (Barnes and Wagner 2009; Wagner *et al.* 2012). It also reduces driving safety and increases traffic accidents (Smith 2016). Sleep disruptions may lead to greater risk of heart attacks and strokes, as well as a higher likelihood of episodes of depression and mental distress (Chandola *et al.* 2010; Giuntella and Mazzona 2019). From a societal point of view, sleep disruptions may induce substantial costs, particularly in societies where sleep deprivation has become a public health issue (CDC 2022).

The other mechanism through which the Spring DST transition is likely to affect individuals' wellbeing is through the reduction in the total time available following the nighttime shift. Clocks are set forward from 2 a.m to 3 a.m on the date of transition. This reduces the transition day by one hour, compared to the standard 24-hour day. This "missing" hour could be cut from sleep time, but it could also reduce time devoted to other day-to-day activities such as work and leisure. By tightening time constraints, the Spring DST transition may ultimately increase the price of time, and people's feeling of being rushed for time (Hamermesh and Lee 2007). Increasing time pressure is likely to result in time stress, affecting people's productivity (Roskes *et al.* 2013) and decision-making (Sutter *et al.* 2003; Kocher and Sutter 2006; Kirchler *et al.* 2017), and significantly decreasing people's health and emotional wellbeing (Scholtz *et al.* 2004; Frankenhaeuser *et al.* 1989; Garling *et al.* 2015).

In contrast, the Autumn DST transition by moving clocks backwards one hour increases the total amount of available time. Fewer studies have investigated the effects of the Autumn DST transition. However, while Barnes and Wagner (2009) find no significant effect of the Autumn transition on sleep, Jin and Ziebarth (2020) provide evidence that setting clocks back by one hour significantly extends people's sleep duration. Consistent with studies examining the effect of jet lag (Klein *et al.* 1972; Monk *et al.* 2001; Flower *et al.* 2003), sleep patterns may adjust more quickly to the Autumn transition.

It is also useful to think about the long-term effects. Indeed, although the sleep effects are likely to be felt for a relatively short period following the Spring or Autumn DST transition, if individuals' time constraints are tightened, then it could well be the case that once individuals have adjusted to the new time schedules, the Spring DST transition actually relaxes individuals' time constraints by increasing the quantity of daylight in the evening. This light effect could be felt for the entire duration of DST, and causes positive effects on individuals' wellbeing. We will use an event study analyses to investigate these longer-term effects.

3 | DATA

To investigate the effects of Spring DST on individuals' wellbeing, we use data from the German Socio-Economic Panel (SOEP), which is a large panel survey of adults aged 15 and above living in Germany. Around 11,000 households and 30,000 respondents are interviewed repeatedly every year from 1984 to 2018. Almost 70% of them are interviewed between January and May. Importantly, the SOEP contains data on the day, week, month and year of interview. This information allows us to identify the individuals who were interviewed before, during and after the day of change in clocks. We focus on the four weeks around the time shift, and compare survey responses of respondents during these four weeks with those of respondents interviewed two weeks before and two weeks after the last Sunday of the month in the previous and subsequent months (i.e. January, February, April and May). Most importantly, respondents were interviewed continuously in the days before and after the last Sunday of each month, which allows us to have enough observations around the cut-off dates.

Data on life satisfaction have been collected from 1984, while data on sleep and time pressure were collected for the first time in 2008. The exact question asked about life satisfaction is: 'How satisfied are you with your life, all things considered?' The possible responses range from 0 (completely dissatisfied) to 10 (completely satisfied). The average life satisfaction in our sample is 7.1, with a standard deviation of 1.71. Figure 1 plots the life satisfaction reported in the four weeks surrounding the Spring DST transition. There is a clear drop in life satisfaction, happening right after the transition into DST. This provides graphical evidence that the Spring DST transition is associated with a short-term decrease in life satisfaction. Our

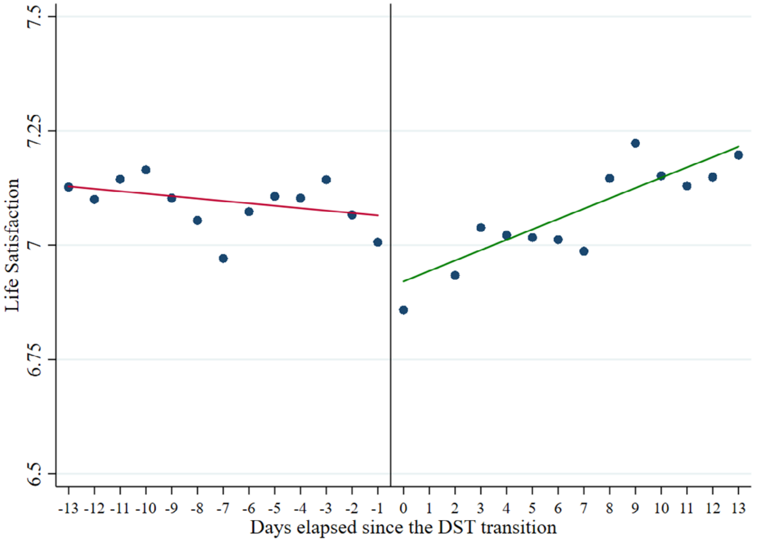

FIGURE 1 Life satisfaction around the Spring DST transition. *Notes*: Each point represents the average life satisfaction during that day, from 1984 to 2018.

initial empirical strategy, using RD and RD-DiD designs, allows us to test formally for this discontinuity.

We measure a respondent's sleep satisfaction using the question: 'How satisfied are you today with your sleep?' The possible reponses range from 0 (completely satisfied) to 10 (completely satisfied). Data on sleep satisfaction are available only from 2008 to 2018. Summary statistics of all our variables are provided in Online Appendix Table A1.

The SOEP questionnaire also includes a section labelled 'Health and illness', which provides detailed information on the current health status of individuals. More specifically, we are interested in the individuals' answers to the following questions.

(1) 'During the last four weeks, how often did you feel: (i) rushed or pressed for time; (ii) down and melancholic; (iii) well-balanced; or (iv) full of energy?' Possible responses: always, often, sometimes, almost never, never.
(2) 'How satisfied are you today with your health?' Possible answers range from 0 (completely satisfied) to 10 (completely satisfied).
(3) 'How would you describe your current health?' Possible responses: bad, poor, satisfactory, good, very good.
(4) 'What about hospital stays in the last year—were you admitted to a hospital for at least one night?'
(5) 'During the last four weeks, how often did you feel that due to mental health or emotional problems: (i) you achieved less than you wanted to at work or in everyday activities; (ii) you carried out your work or everyday tasks less thoroughly than usual?' Possible responses: always, often, sometimes, almost never, never.

Combining information from questions (1) and (5), and following the methodology used to compute summary indices from the SF-12 questionnaire, we retreive an average measure of a respondent's mental health (see Online Appendix Table A2). Again, these variables are available only for the years 2008, 2010, 2012, 2014, 2016, 2017 and 2018.

Finally, the SOEP questionnaire includes information on a respondent's satisfaction with day-to-day activities, including work, leisure, childcare and family life. For each of these dimensions, respondents were asked: 'How satisfied are you today with your job? Your leisure time? Childcare? Your family life?' Possible answers range from 0 (completely satisfied) to 10 (completely satisfied). It also includes a measure of whether a respondent feels that 'he/she is barely able to cope with things', on a 1–4 scale. We analyse the effects of DST on each of these dimensions.

4 | EMPIRICAL STRATEGY

4.1 | Regression discontinuity method

We aim to estimate the effects of DST on individuals' wellbeing. To run this analysis, we first adopt an RD design, which consists in comparing individuals' life satisfaction responses just before and after the Spring DST transition.[7] This RD design estimates the immediate effect of the DST transition.

More specifically, we first residualize the life satisfaction controlling for observed individual characteristics (age, age-squared, years of education, full-time or part-time employed, net household income, married, widowed, separated or divorced, number of children in the household, and disability status) and a set of fixed effects, which includes region, year, the four-week time window around the last Sunday of the month, day of the week (Monday to Sunday), as well as individual fixed effects. We estimate the equation

$$WB_{it} = X_{it}\mu + \eta_r + \tau_{ywd} + \rho_i + u_{it}, \qquad (1)$$

where WB_{it} is the life satisfaction of individual i interviewed on date $t = (y, w, d)$, with y the year of interview, w the window of interview, and d the day of the week (Monday to Sunday). Here, X is a vector of individual characteristics (see above). We also control for region fixed effects η_r, year, window and day of the week effects in the matrix τ_{ywd}, and individual fixed effects ρ_i. The estimated results are reported in the online Appendix Table A3. To have more precisely estimated coefficients, we perform this first step using the full SOEP sample, without restriction to the four-week time windows around the DST transition. This allows us to purge the life satisfaction estimates from differences across respondents that are due to observed characteristics, unobserved time-invariant characteristics, and persistent day of the week effects or more long-term time trends. Then we implement the standard RD specification, following Calonico *et al.* (2014), with the residualized life satisfaction as our outcome variable. The estimated equation is

$$WB^*_{it} = \alpha + \beta\ POST_{t(i)} + f(D_{t(i)}) + f(D_{t(i)} * POST_{t(i)}) + \varepsilon_{it}, \qquad (2)$$

where WB^*_{it} is the residualized life satisfaction of individual i interviewed on date t. Here, $POST_{t(i)}$ is a dummy variable that takes value 1 if a respondent is interviewed in the two weeks after the nighttime shift, and 0 otherwise. Also, $f(D_{t(i)})$ is a linear function of the distance in days from the transition date (i.e. $-13, \dots, 0, \dots, 13$, where 0 indicates the day of transition), interacted with treatment variable $POST_{t(i)}$, which allows for different trends on either side of the cut-off. Coefficient β is our coefficient of interest and reflects the effect of DST on life satisfaction at the transition date. The standard errors are clustered over time (at the day of the week level).

In this setting, one important assumption that must be made is that, conditional on the control variables included in the regression, individuals are randomly interviewed just before and after the day of change in clocks. Hence comparing mean life satisfaction of individuals interviewed just before and after the Spring DST transition would provide estimates of the immediate effect of DST on life satisfaction. However, individuals may have preferences over the day of the interview (Taylor 2006), or may systematically favour being interviewed before or after the DST transition. Online Appendix Table A4 examines the comparability of the 'before' and 'after' groups for the four-week time window around the DST transition. The 'before' group tends to be different from the 'after group'. Respondents in the 'before' group are significantly older, more likely to be married, poorer, less likely to work full-time, and have fewer children at home.

Moreover, our RD design assumes that there is no other major change on the day of change in clocks that may also affect individuals' life satisfaction. However, DST transition always occurs at the end of the month. If wellbeing is not continuous at the end of the month—for instance, there is a hike in life satisfaction when most people receive a paycheck—then the RD design will produce biased estimates of the DST effects. The use of an RD model combined with a DiD strategy allows us to deal with these empirical issues.

4.2 | RD combined with DiD

To implement the RD model combined with a DiD strategy, we take advantage of respondents' answers to the life satisfaction question on counterfactual days in the previous and subsequent months, which allows to construct a plausible control group. If wellbeing varies discontinuously, or if respondents sort endogenously around the last Sunday of the month, then using counterfactual days in the previous and subsequent months could allow us to control for these effects. Online Appendix Table A4 examines the comparability of the 'before' and 'after' groups for the four-week time window around the last Sunday of the month in previous and subsequent months to DST transition. We find that the 'before' and 'after' groups differ systematically. They differ in terms of age, income, employment, education and number of children. However, these differences are qualitatively the same to those observed between the 'before' and 'after' groups for the four-week time window around the last Sunday of March. It suggests that if individuals are not interviewed randomly just before and after the last Sunday of the month, then it is unlikely that this endogenous sorting differs across months.[8] Moreover, we will control for these variables in our estimations.

Figure 2 shows the life satisfaction in the four weeks surrounding the Spring DST transition as well as in the four weeks surrounding the last Sunday of the month in previous and subsequent months (January, February, April and May). It allows us to offer support for the 'common trends' assumption that life satisfaction behaves similarly in the days before the day of change in clocks (treatment group) and in the days before the last Sunday of the month (control group). Figure 2 shows parallel trends in life satisfaction between the treatment and control groups, consistent with the common trend assumption. We also detect a decrease in life satisfaction in the treatment group, while there is no discontinuity in life satisfaction at the cut-off date in the control group.

Using respondents' life satisfaction before and after the last Sunday of the month as a plausible control group, we thus combine our RD design with a DiD strategy. We first residualize the life satisfaction using the same controls as before, that is, observed individual characteristics and a set of fixed effects, which includes region, year, window and day of the week (Monday to Sunday), as well as individual fixed effects, across the full SOEP sample. We then run the following specification using the residualized life satisfaction as our outcome variable:

$$\begin{aligned} WB^*_{it} = {} & \alpha' + \beta'\ POST_{t(i)} * TREATED_{t(i)} + \gamma'\ POST_{t(i)} + \delta'\ TREATED_{t(i)} \\ & + f(D_{t(i)} * TREATED_{t(i)}) + f(D_{t(i)} * POST_{t(i)} * TREATED_{t(i)}) \\ & + f(D_{t(i)}) + f(D_{t(i)} * POST_{t(i)}) + \varepsilon_{it}, \end{aligned} \tag{3}$$

where WB^*_{it} is the residualized life satisfaction of individual i interviewed on date t. Here, $POST_{t(i)}$ is a dummy variable that takes value 1 in the 14 days after the last Sunday of the month, and is 0 in the 14 days beforehand, and $TREATED_{t(i)}$ is dummy variable that takes value 1 if a respondent is interviewed in the four-week window around the last Sunday of March, and 0 otherwise. The coefficient of interest, β' here, is the difference between the change in life satisfaction that we observe just before and after the day of change in clocks, and the change in life satisfaction that

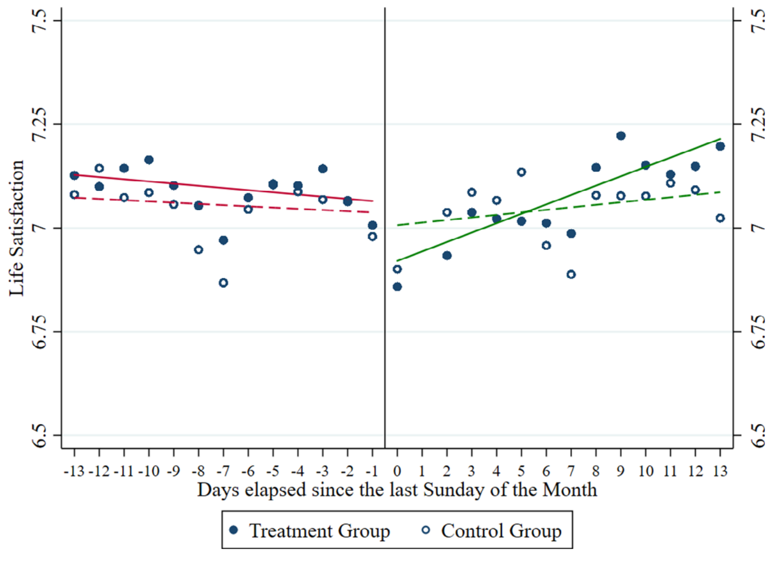

FIGURE 2 Life satisfaction around the Spring DST transition and the last Sunday of the month. *Notes*: Each point represents the average life satisfaction during that day in the treatment group (around the last Sunday of March) and in the control group (around the last Sunday of the month in January, February, April and May), from 1984 to 2018.

occurs typically just before and after the last Sunday of the month in previous and subsequent months (January, February, April and May). The standard errors are clustered over time (at the day of the week and window levels).

Our baseline specifications use an optimal bandwidth selector, a first-order polynomial function of the distance in days from the last Sunday of the month, $f(D_{t(i)})$, and a triangular kernel. For robustness checks, we provide evidence that our results are robust using (i) alternative bandwidth selectors, (ii) higher-order polynomial functions, (iii) different time windows, (iv) a uniform kernel, and (v) alternative control groups (i.e. only February and April, or only February, as counterfactuals). As our dependent variable is estimated from a previous regression, we also provide evidence that our results are robust to using alternative standard error calculations.

The RD or RD-DiD designs allow us to capture the effect of DST right at the transition date. However, they do not allow us to estimate longer-term impacts. To test whether the effects persist over time, we also conduct event study analyses, up to two weeks after the DST transition.

5 | RESULTS

5.1 | RD and RD-DiD results

Table 1 reports estimates using RD and RD-DiD models. The RD estimate in column (1) indicates that the Spring DST transition is associated with a reduction in life satisfaction of 0.058 SD.[9] The results persist using a common coverage error (CER) optimal bandwidth selector instead of a common mean square error (MSE) optimal bandwidth selector as shown in column (2).[10] We then run the RD-DiD strategy and present the results in columns (3) and (4). Using counterfactual days in previous and subsequent months as a plausible control group, the point estimates for both bandwidth selectors remain negative and significant. They reveal a reduction in life satisfaction that is larger than the estimated reduction in columns (1) and (2), of 0.060 SD and 0.093 SD, respectively.

To address the concerns that our results could be driven by the width of the time window that we have chosen, we perform the analysis for a stricter definition, considering only the two-week time window around the DST transition/last Sunday of the month. Results are very similar to the main specifications. The online Appendix Table A6 shows that the results are robust to

TABLE 1 The impact of the Spring DST transition on life satisfaction (standardized).

	RD 1984–2018 (1)	RD 1984–2018 (2)	RD-DiD 1984–2018 (3)	RD-DiD 1984–2018 (4)	RD-DiD 1984–2008 (5)	RD-DiD 2008–2018 (6)
POST	−0.058*	−0.085**				
	(0.032)	(0.038)				
POST ∗ TREATED			−0.060*	−0.093**	−0.011	−0.078**
			(0.035)	(0.046)	(0.035)	(0.034)
Bandwidth selector	MSE	CER	MSE	CER	MSE	MSE
Observations	94,408	94,408	370,737	370,737	221,644	149,093

Notes: The dependent variable is the life satisfaction residual, net of differences in observed characteristics, and year, region, window, day of the week and individual fixed effects. All specifications use a triangular kernel. *POST* (or *POST ∗ TREATED*) is the estimate of the discontinuity in life satisfaction that occurs immediately after the DST transition. In columns (1) and (2), RD models are estimated using the four weeks around the DST transition. In columns (3)–(6), RD-DiD models are estimated using the four weeks around the last Sunday of the month at the end of January, February, April and May as a reference period. There are respectively 62,572 observations in the window around the last Sunday of January, 127,263 for the February window, 94,408 for the March window, 53,923 for the April window, and 32,571 for the May window. MSE refers to one common mean square error optimal bandwidth selector, and CER to one common coverage error optimal bandwidth selector. Robust bias-corrected standard errors (in parentheses) are clustered at the time level. *, **, *** indicate significant at the 10%, 5%, 1% level, respectively.

higher-order polynomial functions, alternative control groups (i.e. restricting to February and April, or using February only, as a counterfactual), the use of the Kolesár and Rothe (2018) confidence intervals, and a uniform kernel instead of a triangular one. Overall, these results demonstrate that both RD models and RD-DiD strategies retreive a negative effect of the Spring DST transition on life satisfaction.

The effects are larger than prior empirical findings examining the effects of DST on life satisfaction. The average estimates of Kountouris and Remoundou (2014) indicate that DST is associated with a decrease in life satisfaction of approximately 0.015 SD. Using the SOEP data, from years 1986 to 2010, they estimate a fixed effects panel regression, with a dummy variable equal to 1 if the individual was interviewed within a week of the Spring DST transition, and 0 otherwise. Using the same data for the years 1984–2004 and an RD design, Kuehnle and Wunder (2015) find a coefficient 0.041 SD over the first week of transition. To assess the possibility that the effect of DST varies over time, we reproduce our results for the periods 1984–2008 and 2008–2018, respectively (see columns (5) and (6) of Table 1). Splitting the sample into two periods reveals that the effects are smaller for the former, with coefficient 0.011 SD, consistent with prior findings, while the Spring DST transition is associated with a larger decrease in life satisfaction of around 0.078 SD in the later period. This suggests that people are increasingly affected by the DST transition.

5.2 | Event study analysis

To investigate longer-term effects, we then use event study analyses. Figure 3 shows the deviation from average life satisfaction in previous and subsequent months (January, February, April and May), before and after the last Sunday of March. Arguably, the sleep and time pressure mechanisms should be felt strongly over the first days of the transition, and dissipate once people get used to the new time schedule.

According to Figure 3, we find no statistical differences between the treatment and control groups before the DST transition. This is consistent with our common trend assumption and the

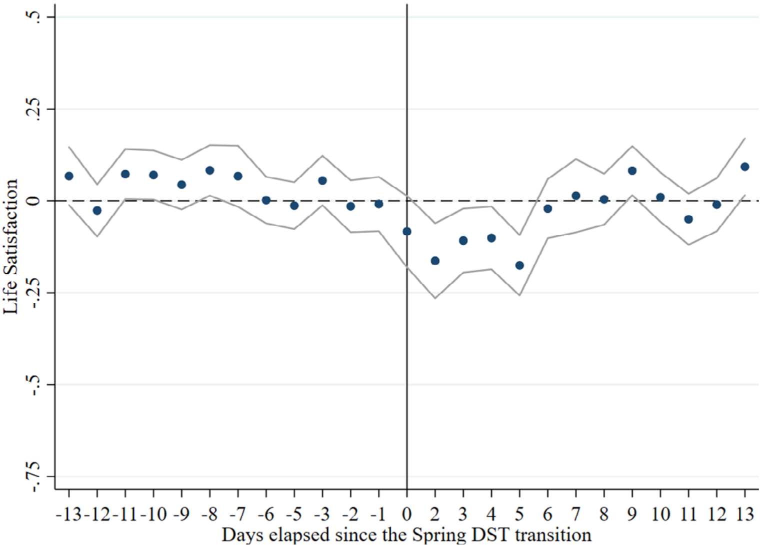

FIGURE 3 Dynamic impacts of the Spring DST on life satisfaction. *Notes*: Based on a model where life satisfaction is predicted with window fixed effects as well as dummy variables that correspond to days elapsed from the Spring DST transition. The effects of these dummies are plotted on the figure. Information from both the treatment and control groups (four-week time window around the last Sundays of January, February, April and May) are used. Grey lines represents the 90% confidence interval.

graph depicted in Figure 2. In addition, we see that the average life satisfaction decreases after the Spring DST transition with an effect that last for about six days before it dissipates.

Table 2 reports the results from the event study analysis. While columns (1) and (2) examine the average effects of the Spring DST over the first and second weeks of transition, column (3) breaks the DST into four components: the first three days of DST, the next three days of DST, the first weekend following the nighttime shift, and the remainder of DST (the next seven days).

Beginning with the average effect over the first and second weeks of transition, columns (1) and (2) of Table 2 show that Spring DST is not associated with a significant decrease in life satisfaction over the period. Column (1) compares the first and second weeks after the last Sunday of March with the two previous weeks, while column (2) implements a DiD strategy, where changes in life satisfaction around the DST transition are compared with changes in life satisfaction around the last Sunday of the month in previous and subsequent months. The two strategies provide similar results. In addition to dummies for the week of interview, note that columns (1) and (2) use the same controls as in the RD and RD-DiD designs. This confirms that averaging out the effects of Spring DST over the entire first week would lead us to underestimate its effects on life satisfaction.

Turning to column (3) of Table 2, the results are consistent with the idea that the Spring DST impact persists for about six days after the transition, but does not have detrimental effects on life satisfaction over the long term. The first three days of DST show a significant decline in life satisfaction of 0.038 SD, which compare to the 0.058 SD and 0.060 SD decreases found in the RD and RD-DiD designs. The point estimate then decreases to 0.021 SD during the next three days, which suggests that the effect fades over time.

Conversely, on the first weekend following the Spring DST transition, we find a significant and positive effect on life satisfaction. Disrupting sleep and increasing time pressures are likely to be the primary mechanisms through which DST affects individuals' life satisfaction over the first six days. But these effects are likely to be felt for a relatively short period following the Spring DST transition.[11] If the individuals' time constraints are tightened at the beginning, then it could well be the case that once individuals have adjusted to the new time schedules, DST actually relaxes individuals' time constraints by increasing the quantity of daylight in the evening. Such extra light effect could explain the positive effect on individuals' wellbeing estimated over the first weekend following the Spring DST transition.[12]

TABLE 2 Dynamic impacts of the Spring DST on life satisfaction (standardized), 2008–2018.

	OLS	DiD	DiD
	(1)	(2)	(3)
First seven days of DST	0.012	0.009	
	(0.022)	(0.036)	
Next seven days of DST	0.013	0.008	0.003
	(0.014)	(0.012)	(0.011)
First three days of DST			−0.038***
			(0.003)
Next three days of DST			−0.021
			(0.023)
First weekend of DST			0.131***
			(0.021)
Observations	36,957	149,093	149,093

Notes: The dependent variable is the standardized life satisfaction, net of differences in individual characteristics, year, region, window and day of the week fixed effects, as well as individual fixed effects. First seven days of DST is an indicator variable equal to 1 if the day of interview occurs in the first week of DST. Next seven days of DST is an indicator variable equal to 1 if the day of interview occurs in the second week of DST. First three days of DST is an indicator variable equal to1 if the day of interview occurs in the first three days of DST. Next three days of DST is an indicator variable equal to 1 if the day of interview occurs in the next three days of DST. First weekend of DST is an indicator variable equal to 1 if the day of interview occurs in the first weekend of DST. In column (1), only observations from the four-week time window around the DST transition are used. In columns (2) and (3), information from both the treatment and control groups (four-week time window around the last Sundays of January, February, April and May) are used. In column (2), additional controls include indicators for the first seven days after the last Sunday, and the next seven days after the last Sunday (not shown). In column (3), additional controls include indicators for first two days after the last Sunday, the next three days after the last Sunday, the first weekend after the last Sunday, and the next seven days after the last Sunday (not shown). Standard errors (in parentheses) are clustered at the time level.
*, **, *** indicate significant at the 10%, 5%, 1% level, respectively.

Overall, the evidence from the event study analysis aligns with previous evidence from RD and RD-DiD models. There is a significant short-term decrease in life satisfaction following the Spring transition, consistent with a detrimental impact on sleep and the feeling of being rushed for time. However, we also find evidence of a positive effect on the first weekend after the DST transition, consistent with an extra light mechanism. Finally, the effect dissipates in the remainder of DST.

5.3 | Potential mechanisms

The Spring DST transition is likely to affect individuals' wellbeing through disrupted sleep and increasing time constraints.[13] Hence, the decrease in life satisfaction should go along with a subsequent reduction in sleep satisfaction and an increase in time stress. In order to analyse these hypothesis, we investigate the effects of DST on a range of outcomes, ranging from sleep to health and satisfaction with day-to-day activities. To perform this analysis, we focus on the years 2008–2018, for which we observe respondent's sleep and time stress.

5.3.1 | Sleep and health

Upon entering DST in the Spring, clocks are set forward from 2 am to 3 am. This reduces the transition day by one hour, compared to the standard 24-hour day. It is an empirical question whether such a 'missing' hour gives rise to a reduction of sleep time and sleep satisfaction. To test

TABLE 3 The impact of the Spring DST on sleep and health outcomes (standardized), 2008–2018.

	Satisfied with sleep in t (1)	Full of energy in t (2)	Feel run-down in t (3)	Satisfied with health in $t+1$ (4)	Current health in $t+1$ (5)	Hospital night in $t+1$ (6)
POST ∗ TREATED	−0.213***	−0.121***	0.065**	−0.149***	−0.112***	0.110***
	(0.044)	(0.046)	(0.028)	(0.039)	(0.017)	(0.028)
Bandwidth selector	MSE	MSE	MSE	MSE	MSE	MSE
Observations	144,447	69,773	69,971	146,022	146,274	143,933

Notes: All dependent variables are net of differences in observed characteristics, year, region, window and day of the week effects, as well as individual fixed effects. All specifications use a first-order polynomial and a triangular kernel, and are estimated for the years 2008–2018. *POST ∗ TREATED* are RD estimates combined with DiD using the four weeks around the DST transition and the last Sunday of the month in January, February, April and May. In columns (3)–(6), a one-day lag is introduced in equation (2). Robust bias-corrected standard errors (in parentheses) are clustered at the time level.
*, **, *** indicate significant at the 10%, 5%, 1% level, respectively.

this hypothesis, we run our RD-DiD strategy described in equation (3) using sleep satisfaction as our outcome variable. The results, reported in Table 3, indicate that entering DST is associated with a significant reduction in sleep satisfaction. The effect is about 0.21 SD, which suggests that sleep plays an important role in the decline in life satisfaction observed after the night time shift. According to columns (2) and (3), we also detect a significant effect of the Spring DST on the respondent's feeling full of energy and feeling run-down after the transition.

Sleep disruption, even if only for a short period of time, can result in poor physical and mental health. (Chandola *et al.* 2010; Giuntella and Mazzona 2019; Jin and Ziebarth 2020). In columns (4)–(6) of Table 3, we test whether DST significantly decreases a respondent's health outcomes. We incorporate a one-day lag into our equation (2) to account for the possibility that the health consequences do not occur right away following the transition day. The results reveal significant effects of DST on respondents' satisfaction with health ($\beta' = -0.149$) and reported health ($\beta' = -0.112$) one day after the DST transition. Consistently, we find that the respondent's likelihood of a hospital admission increases significantly by 0.11 SD on the Monday following the DST transition.[14] This provides suggestive evidence that the DST transition, even though it only affects people's sleep for a short period of time, it can lead to detrimental health events consistent with previous work that has demonstrated DST effects on heart attacks and vehicle fatalities.[15]

To further investigate the effect of the DST transition on health outcomes, the online Appendix Table A7 provides evidence that the Spring DST reduces people's self-reported physical health ($\beta' = 0.144$ SD) and mental health ($\beta' = 0.09$ SD) using the SF-12 questionnaire (see Online Appendix Table A2 for a brief description). Consistently with Table 3, we also find that the Spring DST increases the number of doctor visits ($\beta' = 0.28$ SD) and the likelihood of having a heart attack ($\beta' = 0.16$ SD) on Mondays following the transition. These results are consistent with previous work suggesting detrimental effects of DST on people's health, and help to raise confidence in the validity of our empirical strategy.[16]

5.3.2 | Time stress and day-to-day activities

A second potential mechanism through which DST can affect individuals' life satisfaction is through the reduction in the total time available. The 'missing' hour in the day(s) following the DST transition could be cut from sleep time, but it could also reduce time devoted to other day-to-day activities, such as work and leisure. By tightening time constraints, the DST transition ultimately may increase the price of time and people's feeling of being rushed for time. In

TABLE 4 The impact of the Spring DST on time stress and satisfaction with day-to-day activities (standardized), 2008–2018.

	Feel rushed for time in $t+1$ (1)	Barely cope with things in $t+1$ (2)	Satisfied with work in $t+1$ (3)	Satisfied with leisure in $t+1$ (4)	Satisfied with childcare in $t+1$ (5)	Satisfied with family in $t+1$ (6)
POST ∗ TREATED	0.194**	0.276	−0.183***	−0.193***	−0.770***	−0.018
	(0.076)	(0.556)	(0.024)	(0.049)	(0.282)	(0.052)
Bandwidth selector	MSE	MSE	MSE	MSE	MSE	MSE
Observations	69,942	7814	85,615	134,043	23,827	142,914

Notes: All dependent variables are net of differences in observed characteristics, year, region, window and day of the week effects, as well as individual fixed effects. All specifications use a first-order polynomial and a triangular kernel, and are estimated for the years 2008–2018. *POST ∗ TREATED* are RD estimates combined with DiD using the four weeks around the DST transition and the last Sunday of the month in January, February, April and May. In all columns, a one-day lag is introduced in equation (2). Robust bias-corrected standard errors (in parentheses) are clustered at the time level.
*, **, *** indicate significant at the 10%, 5%, 1% level, respectively.

the SOEP, respondents are asked whether they feel that they are rushed for time. We use this variable to test for this additional channel. Column (1) in Table 4 shows that the DST transition increases people's feeling of being rushed for time by 0.19 SD, one day after the DST transition.[17] Similarly, respondents are asked whether they are able to cope with things. According to column (2), respondents are more likely to say that they barely cope with things one day after the DST transition (although the coefficient is not significant at conventional levels).

If individuals have less time to carry out day-to-day activities, then we might expect satisfaction with those activities to be altered. Columns (3)–(6) of Table 4 investigate the effect of DST on satisfaction with work, leisure, childcare and family life. The estimates suggest that satisfaction with work and leisure are affected significantly by the DST transition. The DST transition decreases satisfaction with work by 0.18 SD on Mondays following the transition, and satisfaction with leisure by 0.19 SD. Similarly, column (5) shows that satisfaction with childcare is affected significantly by the Spring DST transition. The evidence is consistent with the hypothesis that people have less time to accomplish their desired tasks after the Spring DST transition, and therefore derive less utility from these activities. This is also consistent with previous work showing that DST may induce lower productivity among workers following the nighttime shift at the end of March (see Wagner *et al.* 2012).

To provide further evidence on these mechanisms, the online Appendix Table A8 uses information on a respondent's time spent at work and doing leisure activities. Interestingly, we find that the number of hours worked increases by 0.14 SD (roughly 40 minutes) on Mondays following the transition, while the time when a respondent starts working remains the same. This would be consistent with the idea that people become less productive in the days following the night-time shift and so need more time to complete tasks (Costa-Font & Flèche 2020; Costa-Font *et al.* 2024). We also provide evidence that the number of hours spent on leisure decreases by 0.06 SD (roughly 10 minutes) following the transition, consistent with a decrease in leisure satisfaction.

5.3.3 | Sleep versus time stress

To better understand the relative impacts of the sleep and time pressure/time use mechanisms, we introduce sleep, health, time stress and satisfaction with day-to-day activities variables in the life satisfaction specification. More specifically, we estimate equation (3) controlling successively for: (i) sleep satisfaction, feeling full of energy and run-down; (ii) satisfaction with health, health status, and hospital night admission; (iii) feeling rushed for time and barely coping with things; and (iv) satisfaction with work and satisfaction with leisure. Online Appendix Table A9 details the results. Column (1) reproduces the baseline estimates. According to column (2), controlling for sleep in the life satisfaction specification decreases the effect of DST by 24%, with an effect on life satisfaction that decreases from −0.078 SD to −0.059 SD. This result suggests that sleep plays an important role in the decline in life satisfaction observed after the nighttime shift. Similarly, including health, time stress or satisfaction with day-to-day activities as controls decreases the coefficient on DST by another 25%, which suggest that those mechanisms also play an equal role in the decrease in life satisfaction observed after the Spring DST transition. Controlling for all these variables all together, we find that the coefficient associated with DST decreases by 52% and is no longer significant.

5.3.4 | A disruption effect?

Given that most of our variables are self-reported, one may also argue that respondents report lower satisfaction after the DST transition not because they are less satisfied with life *per se*, but simply because they do not like schedule changes. To address this hypothesis, we turn to the Autumn transition. The Autumn transition is likely to increase the total time available, with an additional hour on the Sunday of the transition. Therefore we expect the sleep and time pressure mechanisms to be muted or even to exert positive effects on life satisfaction after the Autumn transition.[18] Alternatively, if we find any negative effect of the Autumn DST on life satisfaction, then this could suggest that individuals dislike time changes.[19] The online Appendix Table A9 reports the estimates using our RD-DiD strategy implemented on the Autumn DST. The results provide evidence of a significant increase in life satisfaction after the Autumn transition, which suggests that individuals adapt easily to the Autumn transition.

Furthermore, this raises some questions about the notion that respondents' negative feelings about schedule changes are the only reason they report being less satisfied following the DST switch.

Note, however, that these Autumn DST estimations have to be taken with caution as most individuals are being interviewed during the first part of the year in SOEP, therefore the sample size for this analysis is quite reduced (around 3500 observations) and may not be representative.

To provide further evidence on this, we replicate our results using the British Household Panel Survey (BHPS, 1996–2008). Indeed, in the BHPS, most individuals are being interviewed during the second part of the year. This allows us to implement our RD-DiD strategy using a larger sample of 98,000 observations around the Autumn DST. The results are reported in columns (5) and (6) of Online Appendix Table A10. We find again evidence of a short-term positive effect of the Autumn DST on people's life satisfaction. According to these estimates, the Autumn DST transition increases life satisfaction by approximately 0.114 SD. This is also consistent with the idea that the Autumn transition increases the total time available, with an additional hour on the Sunday of the transition, therefore people may sleep longer or have more time to carry out their activities after the transition.

5.4 | Heterogeneous effects

While all people living under DST experience the nighttime shift around the last Sunday of March, the effects are likely to differ across individuals. For example, if the Spring DST transition decreases sleep, then it is possible that individuals who are sleep-deprived or face more severe time constraints experience a larger drop in wellbeing. To investigate heterogeneous effects of the

TABLE 5 RD-DiD estimates of the impact of the Spring DST on life satisfaction (standardized)—heterogeneous effects.

	Not full-time (1)	Full-time employed (2)	Hours worked: bottom 25% (3)	Hours worked: top 25% (4)	Low levels of time stress (5)	High levels of time stress (6)
POST ∗ TREATED	−0.050	−0.084***	−0.208***	−0.865***	0.068	−0.083***
	(0.038)	(0.024)	(0.051)	(0.085)	(0.082)	(0.010)
Bandwidth selector	MSE	MSE	MSE	MSE	MSE	MSE
Observations	96,074	53,019	22,348	91,602	43,481	71,154
	Blue-collar (7)	White-collar (8)	Female (9)	Male (10)	Without children (11)	With children (12)
POST ∗ TREATED	−0.358***	0.009	0.041	−0.213**	−0.058	−0.054***
	(0.036)	(0.003)	(0.047)	(0.086)	(0.040)	(0.018)
Bandwidth selector	MSE	MSE	MSE	MSE	MSE	MSE
Observations	32,195	112, 730	80,120	68,973	100,319	48,577

Notes: The dependent variable is the life satisfaction residual, net of differences in observed characteristics, and year, region, window, day of the week and individual fixed effects. All specifications use a triangular kernel. *POST ∗ TREATED* is the estimate of the discontinuity in life satisfaction that occurs immediately after the DST transition. RD-DiD models are estimated using the four weeks around the last Sunday of the month at the end of January, February, April and May as a reference period. MSE refers to one common MSE-optimal bandwidth selector. Robust bias-corrected standard errors (in parentheses) are clustered at the time level.
*, **, *** indicate significant at the 10%, 5%, 1% level, respectively.

DST transition, we estimate separate regressions by subgroups. Table 5 reports the results. For robustness checks, we also estimate regressions with interaction effects in the online Appendix Table A11.

Columns (1)–(8) of Table 5 present the estimates for respondents (i) who work part-time, (ii) who work full-time, (iii) whose working hours are in the bottom 25% of the distribution, (iv) whose working hours are in the top 25% of the distribution, (v) with low levels of time stress, (vi) with high levels of time stress, (vii) who are blue-collar, and (viii) who are white-collar. The results suggest large and statistically significant effects for full-time employed people, working long hours, with high levels of time stress and in blue-collar jobs.[20] These patterns may be consistent with the idea that individuals with those characteristics face less flexible time schedules, and therefore may adapt less quickly to the new schedule. This echoes the work by Biddle and Hamermesh (1990) and Hamermesh and Lee (2007), who demonstrate that sleep deprivation and time stress are more prevalent in a household that spends more time on the labour market. To corroborate this idea, the online Appendix Table A12 provides evidence that respondents who work full-time, longer hours, and in blue-collar jobs do indeed report higher time stress than people working part-time, fewer hours and in white-collar jobs.

Columns (9) and (10) of Table 5 show the effects for men and women separately. The effect of the DST transition on wellbeing is negative and statistically significant for men, but not for women. Again, this may be consistent with the idea that men work on average longer hours than women, and may face less flexible time schedules. It is consistent with the idea that men adapt less swiftly to changes in their time schedules due to higher sleep volatility (Hamermesh and Pfann 2022).

Finally, columns (11) and (12) of Table 5 test for any significant differences between parents and non-parents. One could expect individuals with children to face tighter time schedules, and therefore to be more affected by the Spring DST transition than individuals without children. However, looking at the coefficients in columns (11) and (12), we find that individuals with children experience a similar reduction in their life satisfaction, compared to individuals without children. The difference is not statistically significant when including an interaction term (see the online Appendix Table A11).

6 | BACK-OF-AN-ENVELOPE CALCULATION

As a way of evaluating DST as a policy, we quantify its welfare costs and benefits by measuring the effects on wellbeing. In this section, we present a basic framework for evaluating the effects of ending DST. We begin with the effects of the Spring transition, and then we incorporate those of the Autumn transition. Naturally, conducting such a cost–benefit analysis entails several assumptions, and one must be very cautious when interpreting these findings. Additionally, other factors beyond wellbeing could also be taken into account. Nonetheless, we believe that such an exercise offers valuable insights into whether the DST policy should be retained or abolished.

Table 6 shows the estimates under different scenarios. We first monetize the wellbeing benefits of ending DST using our life satisfaction estimates. Our RD-DiD estimate for the Spring DST implies a total loss in life satisfaction of 0.060 SD over six days. This suggests that ending the Spring DST would generate an increase of 0.0009 SD in life satisfaction annually. If we multiply this effect by 1.71 (the standard deviation of life satisfaction), then we get an effect of 0.0016 points per year. Next, we compare this figure with the gain in wellbeing associated with a 1% gain in income, following the extensive literature evaluating the relationship between income and life satisfaction that suggests that a 1% gain in income increases life satisfaction by around 0.002 points (see Layard *et al.* 2020). Hence, for an average annual income in Germany of 42,000 euros, we estimate that ending the Spring DST would give rise to an increase in life satisfaction equivalent to an income gain of 354 euros per capita per year.

TABLE 6 The welfare costs and benefits of implementing DST.

	Life satisfaction (1)	Doctor visits (2)	Hospital nights (3)	Heart attacks (4)	Productivity (5)	Total (6)
Spring DST						
Estimated effect	−0.06 SD	+1.12	+0.03 pp	+10%	−40 min	
Cost per capita (euros)	−354	−46	−34	−1400	−25	−1859
Autumn DST						
Estimated effect	+0.114 SD		−8.3% JZ (2020)	−3.75% JZ (2020)	+1.1% JZ (2020)	
Benefit per capita (euros)	+564		+12.45	+525	+3.25	1104.7
Total per capita						
	Scenario 1: Only life satisfaction (euros)					210
	Scenario 2: Life satisfaction + health + productivity (euros)					−754.3

Notes: JZ (2020) refers to Jin and Ziebarth (2020).

Next, we can add to our analysis the additional estimates resulting from ending the Autumn DST. Our RD-DiD estimates are suggestive of an increase in life satisfaction of 0.114 SD following the Autumn transition (see Online Appendix Table A10). According to Jin and Ziebarth (2020) and our own estimations, these effects are expected to last for about four days. The wellbeing effects associated with the Autumn transition are thus equivalent to an income gain of 564 euros.[21] Assuming that we can add these gains to the negative effects experienced during the Spring transition, ending the entire Spring and Autumn DST would be equivalent to a income loss of 210 euros per capita.

Naturally, additional costs and benefits of ending DST could be considered, including health or productivity effects, if we assume that they are not fully captured by the DST effects on life satisfaction. According to our estimates, the Spring DST is associated with an increase in doctor visits by 0.28 SD (i.e. 1.12 additional visits). Given the average cost of a doctor visit in Germany (278 euros for 6 months, according to Grupp *et al.* 2016), this translates into an income loss of roughly 46 euros per capita per year.[22] Similarly, the Spring DST leads to an increase in hospital admissions by 3 percentage points. The average cost of a hospital admission in Germany is about 612 euros for 6 months (Grupp *et al.* 2016), that is, roughly 150 euros per day. The economic cost of an increase in the likelihood of being admitted to a hospital for one night over the last year is thus about 34 euros per capita per year. Finally, we can assess the value of an increase in heart attacks by 10%. According to Schmid (2015), the average direct costs associated with heart attacks are about 14,000 euros per person in Germany. Therefore ending the Spring DST would be associated with an income gain of 1400 euros per capita per year due to lower risk of heart attacks.

According to our estimates, the Spring DST is also associated with an increase in working hours by 40 minutes. We can compute the opportunity cost of working 40 minutes more on Mondays following the nighttime shift. The average hourly wage in Germany is about 37 euros. An increase in working hours by 40 minutes thus costs roughly 25 euros per capita.

By contrast, according to Jin and Ziebarth (2020) (JZ (2020) in Table 6), the Autumn DST is associated with a reduction in hospital admissions of 8.3%, which is equivalent to a decrease in hospital admissions by 1 percentage point. According to our estimates, ending the Autumn DST would thus cost 12.45 euros per capita per year. They also find that the Autumn DST is associated with a decrease in heart attacks by 0.06 points, which is a 3.75% reduction, equivalent to 525 euros per capita. Finally, Jin and Ziebarth (2020) monetize the productivity benefits of the Autumn DST, which amount, according to them, to 3.43 dollars, equivalent to 3.25 euros per capita per year.

Overall, as shown by the last row of Table 6, taking into account all these potential effects of DST transitions, ending DST would give rise to both large positive and negative effects. If we add them all, we find that its effect would be equivalent to an income gain of roughly 754 euros per capita.

We can also compare these costs and benefits of ending DST with the costs associated with an increase in electricity consumption. According to a literature review by Aries and Newsham (2008), simple estimates suggest a reduction in national electricity use of around 0.5% on average due to DST. Hence ending DST in Germany could increase electricity consumption $0.005 \times 6453\,\text{kWh} = 32.2\,\text{kWh}$ per capita. Given that the average cost of 1 kWh is about 0.1505 euros in Germany, the energy costs that accrue from ending DST are estimated at roughly 4.85 euros per capita per year.

7 | CONCLUSION

The Daylight Saving Time (DST) policy affects over 1.5 billion people every year. However, we still do not have clear evidence of how it affects people's wellbeing. This paper exploits evidence from a regression discontinuity design combined with a difference-in-differences strategy to estimate the impact of DST transitions on individual wellbeing. Our main finding suggests that the Spring transition into DST decreases life satisfaction by about 0.060 SD—equivalent to a 1.4% decrease.

We perform several tests to assess whether this effect is due to sleep deprivation or increasing time pressure caused by the one hour reduction in the transition day. These tests indicate that people experience a large and significant reduction in sleep satisfaction following the Spring DST transition. They are also more likely to report time stress after the nighttime shift, and lower satisfaction with day-to-day activities. We show that the effect persists for the first six days of DST. It then dissipates once people get used to the new schedule.

These negative effects on sleep and wellbeing, even though they are felt only for a short amount of time, affect people's health significantly. We find evidence of poorer health and a higher likelihood of hospitalisations on Mondays following the Spring transition. However, we document large differences across individuals in how they experience the transition: the effects are larger among individuals with less flexible time schedules, including among men, blue-collar workers, and people who spend more time on the labour market in general. In contrast, we find that the Autumn transition is associated with an increase in life satisfaction of around 0.11 SD.

Given that the DST policy has become increasingly controversial, these results are important to inform the wider policy debate. Evaluating how people experience the DST transition is a crucial step in assessing the costs and benefits of the DST transition. Our cost–benefit analysis reveals that ending DST would be associated with a small welfare loss, equivalent to an income loss of 210 euros per capita. However, when adding additional effects to the cost–benefit analysis (including health and productivity effects), we find that ending DST would instead be associated with some welfare gains, equivalent to an income gain of roughly 754 euros per capita per year.

More broadly, our results call for the need to take wellbeing effects into account when considering policy evaluations. New insights into policies may be gained by including how people experience such policy changes. Although our results consider only the effects of the DST transitions alone, the same logic may be applied to any time changes that potentially affect people's wellbeing (e.g. new work schedules or jet lag effects).

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ENDNOTES

[1] Other studies have found some positive effects of DST. See, for instance, Doleac and Sanders (2015), Cook (2022) or Tealde (2022) for the effects of DST on crime.

[2] Some previous studies have used either an RD strategy or a DiD strategy (see, for example, Doleac and Sanders (2015), using administrative data on criminal activity in the USA), but did not implement both strategies in tandem.

[3] Investigating the dynamics of DST effects is important as negative shocks on sleep and wellbeing have potential long-term impacts on individuals' health, which would go undetected if focusing only on average long-term effects.

[4] $0.001 = (0.060/365) \times 6$.

[5] Monetary equivalent is based on the common finding in the happiness literature that a 1% gain in income increases life satisfaction by around 0.002 points (see Layard *et al.* 2020). Comparing these 0.002 points with 0.001×1.71 (the standard deviation of life satisfaction) implies that the DST wellbeing effect is equivalent to an income loss of 0.84% per year. Using the German average income of 42,000 euros, it amounts to a decrease of approximately 354 euros per year.

[6] Using the German average electricity cost of 0.15 euros per kWh, and an energy consumption per capita of 6453 kWh.

[7] These are, of course, different individuals (for a given wave) who are interviewed before and after the DST transition.

[8] To test this possibility formally, we compute the DiD estimates for each of these sociodemographic variables. Some of these DiD estimates are statistically significant, but overall the differences are relatively small and confirm that the endogenous sorting of respondents does not differ strongly between the two groups.

[9] We provide alternative standard error calculations in Online Appendix Table A5, including the conventional and bias corrected standard errors of Calonico *et al.* (2014). All coefficients remain negative and significant at conventional levels.

[10] According to Calonico *et al.* (2014), using an MSE optimal bandwidth selector yields RD treatment effects that are invalid for inference. Therefore they recommend using the CER optimal bandwidth selector, which is designed to construct robust bias-corrected confidence intervals with the smaller coverage error.

[11] Event study analyses suggest no significant effects of DST on sleep satisfaction and time pressure one week after the Spring DST transition.

[12] To explore this possibility further, we replicate the analysis introducing controls for daily temperature: the positive effect on life satisfaction over the first weekend decreases slightly. Another possibility would be a comparison effect in that individuals enjoy not feeling so bad as they did at the beginning of the week.

[13] But note that a decrease in wellbeing could also affect people's sleep. For example, prior work has shown that having people focus on negative thoughts leads to a delay in sleep onset Vandekerckhove and Wang (2018).

[14] This variable measures whether the respondent was admitted to hospital for at least one night in the last year (Yes/No). There are 48 weeks in common between treatment and control groups. This means that the probability of being admitted to hospital for at least one night increases by 0.11 SD in four weeks. According to Online Appendix Table A1, SD(hospital nights) = 0.33, so this is equivalent to an increase of $0.11 \times 0.33 = 0.03$, i.e. 3 percentage points.

[15] For comparison, Giuntella and Mazzona (2019) provide evidence that a one-hour difference in sunset time is related to a 0.3 SD decline in self-reported health. In addition, Jin and Ziebarth (2020) find that during the week of Autumn transition, hospital daily admissions decrease by 8.3%. These results are consistent with our estimates.

[16] Giuntella and Mazzona (2019) show that a one-hour variation in sunset time is related with a 0.27 SD increase in stroke likelihood. Manfredini *et al.* (2018) review the relationship between DST and cardiovascular health, and find an increase in the risk of acute myocardial infarction from 4% to 29% following the Spring DST transition. Our results point to an increase of roughly 10%. Columns (5) and (6) of Online Appendix Table A10 also provide evidence that the Spring DST is associated with fewer positive emotions (being happy) by 0.11 SD and more negative emotions (such as being sad, worried or angry) by 0.06 SD.

[17] Alternatively, we can replicate this finding considering respondents who have been interviewed more than four weeks after the Spring DST transition (instead of during the four-week time window right after the DST transition) to make sure that the increase in people's feeling of being rushed for time (during the last four weeks) can indeed be attributed to the DST transition.

[18] Barnes and Wagner (2009) and Jin and Ziebarth (2020) do find a positive effect of DST on sleep.

[19] Or reductions in daylight exposure and disruption in circadian rhythms outweigh the positive effects from an additional hour on life satisfaction.

[20] Note that levels of time stress could be influenced by the Spring DST transition. Therefore differentiating the results by levels of time stress could be endogenous. To tackle this issue, we use the level of time stress reported in the previous year. We do believe that this provides a first piece of evidence that the Spring DST transition has stronger negative effects on individuals with high levels of time stress.

[21] This is $(((((0.114/365) \times 4) \times 2.15)/0.002)/100) \times 42\,000 = 564$, where SD(life satisfaction) = 2.15 in the BHPS when life satisfaction has been rescaled from 1–7 to 0–10.

[22] People have seen their doctor 3.4 times on average over the last three months according to SOEP data.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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