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The long term impact of Daylight Saving Time regulations in daily life at several circles of latitude

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We analyze large scale (*N* ~ 10000) time use surveys in United States, Spain, Italy, France and Great Britain to ascertain seasonal variations in the sleep/wake cycle and the labor cycle after daylight saving time regulations have stood up for at least forty years. That is, not the usual search for the impact of the biannual transitions, but a search for how industrialized societies have answered to DST regulations at different circles of latitude. Results show that the labor cycle is equally distributed through seasons if measured in local time. It is an everyday experience which is a major outcome of DST. The sleep/wake cycle displays disturbances punctuated by solar events: sunrise, sunset and noon. In week-ends, under free preferences, sleep onset delays in summer, opposing to the regulation and following the delay in sunset time, while sleep offset advances, despite clock time already advanced in the spring transition. This advance still follows the advance in sunrise times. The best explanation for these findings is that human cycles are not misaligned by the size and direction of DST regulations, which explains the success of that practice. The sleep/wake cycle in Great Britain and France exhibit fewer statistically significant excursions than the sleep/wake cycle in Spain, Italy and United States, despite light and dark seasonal deviations are larger. That could be indicating that the preference for a seasonal regulation of time decreases with increasing latitude above 47°. The preferences for a seasonal regulation of clocks and for the choice of permanent summer time or permanent winter time are sketched from a previous report on human activity.

Legislative bodies in America and Europe are currently pondering the continuity of Daylight Saving Time regulations —DST—, also known as Summer Time Arrangements. They consist of a forward change of clocks in spring, which is reversed in autumn. They have become a part of everyday life in some industrial, urban societies since its inception one hundred years ago, amidst World War One, or since the 1970s, amidst the energy crisis.

DST regulations are conveniently described as a time zone shift —for instance from UTC + 1 to UTC + 2 in Central Europe at the spring transition— however, if nothing else change, they are simply a seasonal regulation in the phase of human cycles, all equal to a seasonal regulation of opening times. As an example in 1810, well before the standardization of time, the Spanish National Assembly started sessions at 10 am from October to April but at 9 am from May to September[1].

Either way, the seasonal regulation of human activity in industrialized, urban societies synced to clocks meets the biannual transitions that characterizes DST. Physiologists and medical doctors think of these transitions as a disruption to our circadian system[2,3]. A series of studies has tried to unveil their impact in the stocks markets[4], in suicide rates[5], in the rates of myocardial infarction[6], in accident rates[7], in accident and emergency visits and return visits[8] or in the rate of autopsies[9]. Generally speaking hazards happen to increase immediately after the spring transition. Physiologists then advocate for discontinuing DST[10–12] and setting winter time permanently or, in practical terms, delaying summer activity by one hour. However, and almost inadvertently, they also acknowledge the convenience of the practice, at least for some people[13].

The "benefits" of DST have been usually summarized in extended outdoor leisure activities and marginal savings in energy consumption. Some economists, decision-makers push to extend these benefits to winter, by discontinuing DST in the "permanent summer time" mode[14–16]. If nothing else changes this choice would advance human activity by one hour in winter pushing for start times ahead of sunrise in winter. The natural abhorrence for getting activated in the dark plays against this choice. When physiologists advocate for permanent winter time they are preventing against this kind of stress on the circadian system[11,12]. To be socially accepted an early start

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of human activity require tangible outcomes which usually come in the form of increasing scores of end times ahead of winter sunset.

The seasonal regulation of human activity —and also DST regulations— questions when human activity should start in view of the seasonal spread of sunrise times, sunset times, daytime and noon insolation. That is, upon which conditions individuals and societies synced to clock time would prefer seasonally varying opening times instead of year round opening times, even though annoying biannual transitions would be needed in the former. The answer to this question may depend on a number of issues that includes chronotype —preference for morningness versus eveningness— or economic sector —outdoor versus indoor activities—. From the point of view of the physical science the answer is dominated by latitude, a role that is virtually omitted in DST discussions[17]. For instance DST regulations have never been a choice in the Tropics, because there seasonal variations are small. Likewise, the preference for advancing human activity relative to winter sunrise is more frequent at high latitude just because there sunrise delays the most and sunset advances the most in winter. Generally speaking every circle of latitude exhibits a distinct pattern of seasonal light and dark cycle and human activity adapts to that accordingly[18–20].

The role of latitude is of the utmost importance in the European Union, where population and decision-makers spread from 35° latitude —Malta, Crete and Cyprus— to 70° latitude —Finnish Lapland— exhibiting vividly different natural conditions[21]. However, and based on internal market efficiency, the European Commission has been pushing for synchronous DST arrangements, preventing member states from opting-out. The Commission considered the impact of six possible scenarios in which a few members have asynchronous arrangements[22]. However no scenario simulated that the preference for DST regulations could stratify with latitude. In sharp contrast this preference does stratify with latitude in Australia, Brazil and Chile.

Time zone and time zone regulation only set arbitrary references of time. They have stood up unchanged for almost one hundred years in Great Britain, Ireland, Portugal, significant cities of United States; and for some fifty/forty years elsewhere in Europe and America. These settings allow people to make decisions based on clock time which are rationally linked to the cycle of light and dark[19].

This manuscript is aimed to inspect how these regulations impacted in human life through sensitive decisions. Time use surveys —large scale studies ($N \sim 10^4$) which try to ascertain how people share a standard day[23]— are the appropriate tool for that. This paper will analyze the case of five industrialized countries (United States, Spain, Italy, France and United Kingdom), where seasonal time arrangements have occurred in the forty years prior to the date of the survey. The two most basic daily cycles will be studied: the sleep/wake cycle —regulated by our physiology— and the labor cycle —strongly related to our social life—. The basic goal is to assess seasonal deviations in these cycles including their statistical significance and a sketch of the impact of latitude. It must be emphasized that this manuscript will focus on the long term —seasonal— effects of the regulation of time, not on effects around the transitions.

No counterfactual will be considered here. The obvious choice is a similar analysis of the time use surveys in independent countries where DST has not been applied regularly. The Republic of Korea and Japan are the best candidates.

Methods

The data sets. Microdata from time use surveys in Spain[24] and United States[25] are freely available at the internet. Microdata from surveys in Italy[26], France[27], Great Britain[28] could be obtained after petition to public authorities in 2014.

Every respondent of a time use survey filled a diary which consisted of $N_0 = 144$ time slots —each one representing ten minutes— or indexes. It is possible to discriminate the date of the diary at least to the level of a trimester and the day of the week. In this work the year will be partitioned into two semesters or seasons: summer (April to September, trimesters two and three) and winter (October to March, trimesters one and four). Notice that October is counted in the winter season although regulations at the time of the surveys extend summer time until end of October (Europe) or until start of November (United States). It is also assumed that seasonal partition does not introduce a bias in the distribution of chronotypes and economic sectors.

Diaries will be grouped in four items: (1) week day (Monday to Friday) diaries that report some working activity; (2) week day diaries that do not report any working activity; (3) week-end (Saturday and Sunday) diaries that report some working activity; and (4) week-end diaries that do not report any working activity.

Respondents in groups 1 and 3 will be labeled as "employees" hereafter. Groups 2 and 4 will only consider diaries filled by respondents aged at least twenty years; they will be labeled as "non-employees".

Group 1 encloses working respondents in a week day. They are least prone to free preferences and most prone to tight social timing, including the use of alarm clocks for getting activated. Group 4 is the most populated in every survey. It encloses non-working respondents in a week-end. It does not distinguish between those who worked during week days and those who not. Either case, respondents in this group are most prone to free preferences —for instance rising up at their will—. Contrastingly Group 3 is the least populated since the labor activity in week-ends is comparatively small. Table 1 lists sample sizes of every survey and group analyzed.

In the cases of Spain, France and United States only contiguous regions will be analyzed. Also Arizona respondents will not enter in the study since this state does not observe DST regulations.

Eventually the seasonal index will be permuted, re-sampled or re-shuffled and two partitions of the permuted samples will be compared to the unshuffled, seasonal, original partition to set the statistical significance of seasonal deviations.

The mathematical framework. The sleep/wake cycle —being awake or sleeping— and the labor cycle —being working or not working— will be studied. For either cycle two kind of magnitudes will be characterized: (1) the daily rhythm $R(i)$ —the shares of respondents doing a prescribed activity on a given index— and (2) the

Time Use Survey	Time offset	Latitude ϕ	Rise/set spread	Inso efficiency $\cos\theta_w/\cos\theta_s$	Sample size N_t	N_w	N_s	Ratio N_s/N_w	$\sqrt{N_h}$
Great Britain[25]	6 min	52.3°	04 h39 m	25/88					
1. Mon-Fri (employees)					4081	1745	2336	1.34	44.7
2. Mon-Fri (non-employees) age ≥20					3768	1481	2287	1.54	42.4
3. Sat-Sun (employees)					1378	599	779	1.30	26.0
4. Sat-Sun (non-employees), age ≥20					6473	2611	3862	1.48	55.8
France[24]	50 min	47.8°	03 h37 m	32/91					
1. Mon-Fri (employees)					6243	2872	3371	1.17	55.7
2. Mon-Fri (non-employees) age ≥20					6095	2622	3473	1.32	54.7
3. Sat-Sun (employees)					1890	877	1013	1.16	30.7
4. Sat-Sun (non-employees), age ≥20					8544	3729	4815	1.29	64.8
Italy[26]	11 min	43.6°	03 h11 m	39/94					
1. Mon-Fri (employees)					5576	2784	2792	1.00	52.8
2. Mon-Fri (non-employees) age ≥20					5390	2719	2671	0.98	51.9
3. Sat-Sun (employees)					3596	1805	1791	0.99	42.4
4. Sat-Sun (non-employees), age ≥20					15707	7698	8009	1.04	88.6
Spain[27]	72 min	40.4°	02 h49 m	44/96					
1. Mon-Fri (employees)					4271	2053	2218	1.08	46.2
2. Mon-Fri (non-employees) age ≥20					4889	2364	2525	1.07	49.4
3. Sat-Sun (employees)					971	505	466	0.92	22.0
4. Sat-Sun (non-employees), age ≥20					4965	2431	2534	1.04	49.8
United States[28]	8 min	38.5°	02 h36 m	47/97					
1. Mon-Fri (employees)					36498	18629	17869	0.96	135.1
2. Mon-Fri (non-employees) age ≥20					25589	13014	12575	0.97	113.1
3. Sat-Sun (employees)					14775	7631	7144	0.94	85.9
4. Sat-Sun (non-employees), age ≥20					47877	24408	23469	0.96	154.7

Table 1. List of participant countries with geophysical information: time offset, latitude ϕ, the spread of sunrise/sunset times and the efficiency of insolation at noon in winter $\cos\theta_w$ and summer $\cos\theta_s$. Notice that DST regulations apparently increase the spread of sunset times by one hour, decrease the spread of sunrise times by one hour. Also time offset increases by one hour after DST onset. The table also lists the sample size for every group of respondents. N_t is the whole number of respondents in group, N_s stands for the number of summer respondents, N_w is the number of winter respondents, N_s/N_w is the ratio and $\sqrt{N_h}$ is the square root of the harmonic mean of N_s and N_w.

experimental (sample) cumulative distribution function $P(i)$ and sample average value E of a set of five stochastic variables which characterizes each cycle for every individual. Figure S.1 in Supplementary Material sketches this set which is composed of:

- The daily duration of the activity d_1: the daily working time and the daily sleep or wake time.
- The center of gravity t_2: the moment when half the daily duration has been consumed and half remains.
- The first occurrence of the activity t_1 or onset time.
- The last occurrence of the activity t_3 or offset time.
- The distance from onset to offset d_2.

For these quantities the cycle begins at 4 am, around the point of daily minimum human activity. If the cycle is unimodal —just one period of activity, with no breaks— the center of gravity matches to the midpoint from onset to offset.

The domain of any of these stochastic variables consists of the N_0 indexes that fill one cycle (day). Therefore they all are discrete variables.

Seasonal differences will be obtained by subtracting results from winter respondents to results form summer respondents. The statistical significance of the seasonal deviations $R_s(i) - R_w(i)$ will be determined by the Welch's t-test for unequal variances[29]. The statistical significance of $P_s - P_w$ and $E_s - E_w$ will be determined by analyzing random permutations of the seasonal index. The size of the permutation test will be $M = 10^7$, much smaller than

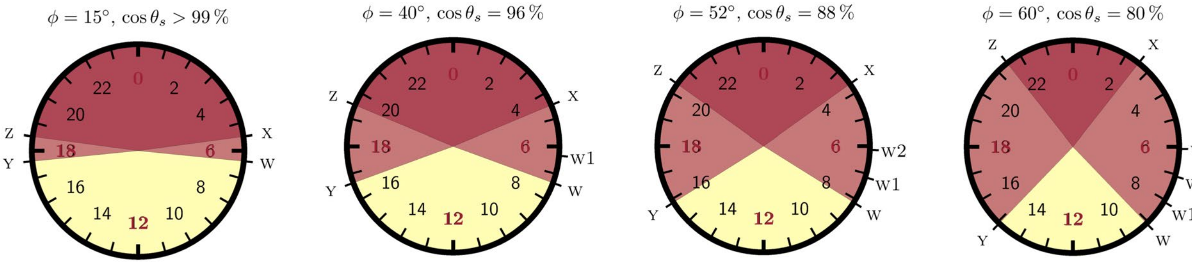

Figure 1. The seasonal cycle of light and dark depicted in four clocks with 24-H analog dial. Clocks are located at circles of latitude $\phi = 15°, 40°, 52°, 60°$. Every clock locates morning hours on the right half, from 0 (midnight) to 12 (noon); afternoon hours (12–24), on the left half. The equinoctial night is located on the top half, from 18 (sunset) to 6 (sunrise) and the equinoctial daytime, on the bottom half. The red ink displays permanent night, the yellow ink displays permanent daytime, and the pink ink displays the region where light and dark alternate seasonally. Point z denotes summer sunset; x, summer sunrise; Y, winter sunset; w, winter sunrise; and the number in w*n* annotates hours before winter sunrise. Notice that w and z are separated by some 12h irrespective of latitude. Clock faces display mean solar time and local time at time meridians. Time offset —see Table 1— must be added to find local time values or, alternatively, clock faces must be turned counterclockwise one degree per every four minutes of time offset.

the whole number of permutations ($\approx 10^N$) and large enough for the purpose. The *p*-value will be the fraction of random permutations which yields larger deviations than the tested seasonal value, thus questioning whether the observed difference is seasonal or random. Significance will be set at the standard level $\alpha = 5\%$. This test will be one-tailed to assess first-order stochastic ordering.

It should be noticed that for R, t_1, t_2 and t_3 the seasonal deviation will compare t to $t - 1$h if t is given as a universal time and DST regulations apply.

For the purpose of comparing samples with different sizes $R_s - R_w$ will be scaled by variance and sample size to get the Welch's statistics of the deviations and $P_s - P_w$ will be scaled by sample size to get the Kolmogorov-Smirnov statistics of the deviations. In Supplementary material the mathematical framework is thoroughly described (see Section S.1).

The geophysical framework. Summer time arrangements are related to seasons, which arises from the obliquity $\varepsilon = 23.5°$ of Earth's rotation axis relative to the revolution axis. Without obliquity there would be no seasons. The Sun would climb up to the same zenith angle day after day. Sunrises and sunsets will happen with a recurrence of $T = 24$h (Earth's rotation period) due East (dawn) and due West (dusk) year round.

With non-zero obliquity every of these magnitudes change from date to date in a quantity prescribed solely by latitude. Table 1 lists time offset, latitude ϕ, the spread of sunrise/sunset times from summer to winter, and the cosine of the solar zenith angle at noon in winter θ_w and summer θ_s. Instead of the bare angle θ, its cosine is a more sensitive magnitude for understanding human behavior since insolation is proportional to it. Figure 1 summarizes the spread of sunrise and sunset times at four representative circles of latitude helped by clocks with 24-H analog dial.

In Supplementary material (Section S.2) the seasonal variations are thoroughly described.

Notice that as per DST regulations, time offset increases by one whole hour in spring, and sets back to the value listed in Table 1 in autumn; the spread of sunrise apparently decreases by one whole hour as measured local time, while the spread of sunset apparently increases by one whole hour.

Results

Normalized seasonal differences of daily rhythms are shown in Fig. 2. As Supplementary Material seasonal daily rhythms from which seasonal differences were computed are shown in Fig. S.3. There, seasonal differences are usually hard to visualize. Sleep/wake daily rhythm looks like a window function showing the overwhelming preference for monophasic sleep —one continued period of sleep, followed by one continued period of wake per day— and a great deal of coordination in the transitions, with the wake tied to sunrise and sleep determined by homeostasis[20]. The only deviation from this behavior occurs in Italy and Spain; it is due to *siesta*, an afternoon, short take of sleep. Labor daily rhythms are notably more complex.

Seasonal deviations in thirty daily rhythms are shown in Fig. 2. They are arranged in 5×4 panels. On every row a time use survey is presented; on every column a daily rhythm: sleep/wake in a week-day (groups 1 and 2), labor in a week-day (group 1) and then the same for a week-end. Darker lines refer to employees, lighter lines to non-employees. Solar ephemerides —sunrise, noon and sunset— are noted by dotted vertical lines and range from summer to winter values.

Darker horizontal gray bands highlight the region where Welch's *t*-test would sustain the null hypothesis H_0: $R_s(i) - R_w(i) = 0$ at the standard level of significance. Lighter bands highlight the region where $10^{-7} < p < \alpha$. As Supplementary Material Fig. S.4 shows the corresponding values $p(i)$ of these seasonal deviations, and Table 2 reports the occurrence of significant deviations $p(i) < \alpha$ in morning and afternoon hours.

Likewise, Fig. 3 (sleep/wake) and Fig. 4 (labor) show the normalized seasonal deviations of the stochastic variables obtained from each cycle. As Supplementary material Fig. S.5 (sleep/wake cycle) and Fig. S.6 (labor cycle)

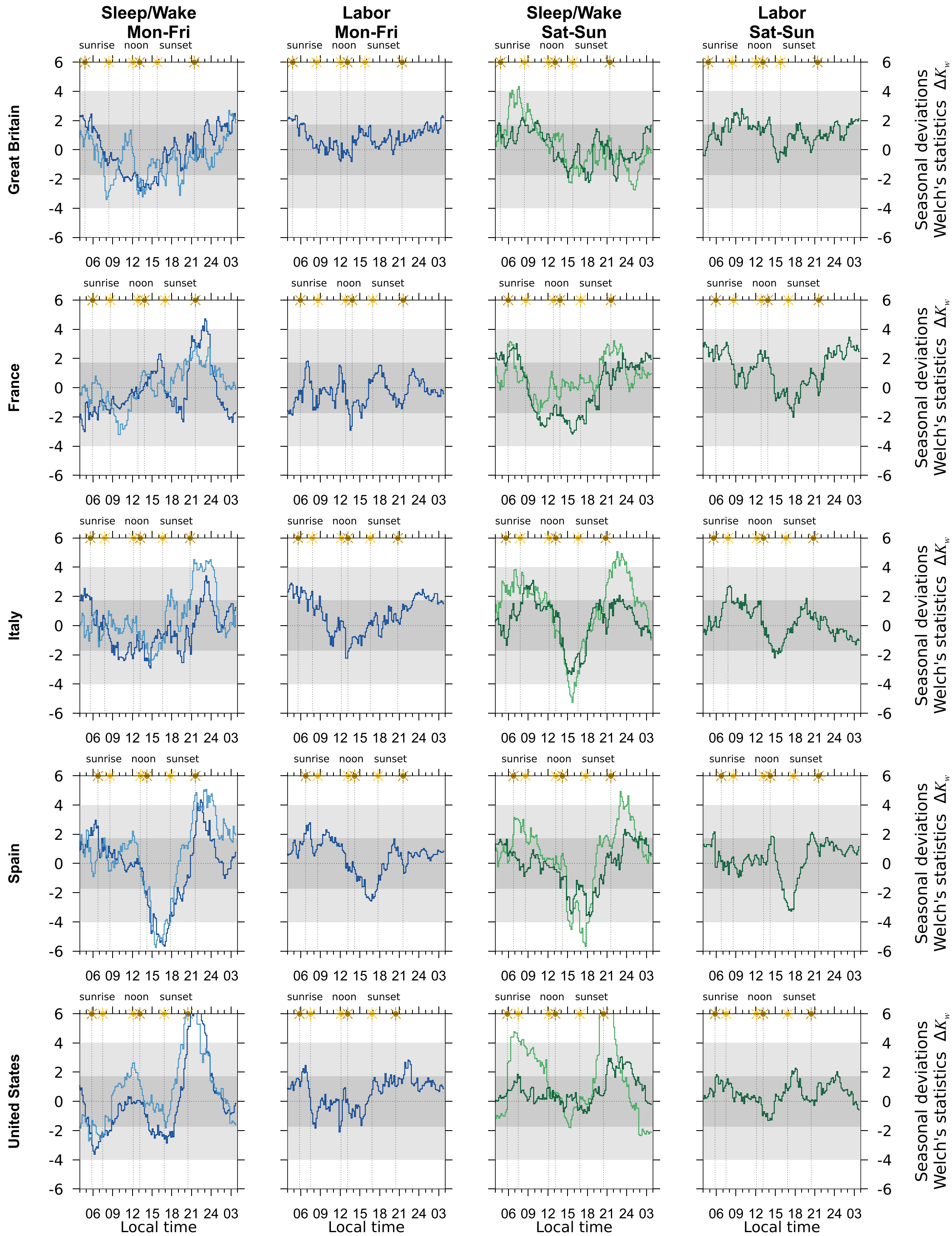

Figure 2. Normalized seasonal deviations $\Delta K_w = \sqrt{N} \cdot (R_s - R_w)/s_{\mathrm{rms}}\sqrt{2}$. Blueish inks display week-day statistics (groups 1 and 2). Greenish inks display week-end statistics (groups 3 and 4). Darker lines apply to employees (groups 1 and 3); lighter lines to non-employees (groups 2 and 4). The darker horizontal gray band highlight the region where the Welch's t-test sustains the null hypothesis H_0: $R_s - R_w = 0$ at the standard level of significance $\alpha = 5\%$. The lighter horizontal gray bands highlight the region $10^{-7} \le p < \alpha$. For $\Delta K_w = 6$ the p-value equals to $10^{-8.69}$. Vertical lines show solar ephemerides (sunrise, noon and sunset) in winter and summer as measured in local time. Darker sun applies to summer.

show the seasonal sample cumulative distribution functions from which seasonal differences were computed; in most of the circumstances seasonal differences are hard to visualize.

Figure 3 displays one-hundred seasonal deviations and Fig. 4, fifty. They are arranged in 5×5 panels each showing results from four groups (sleep/wake) and two groups (labor). Vertically, panels display the results of one

ΔK_w breakdown	Group 1	Group 2	Group 3	Group 4	
	Mon-Fri	Mon-Fri	Sat-Sun	Sat-Sun	
	employees	non-employees	employees	non-employees	All groups
$p < \alpha$	am/pm	am/pm	am/pm	am/pm	total
Sleep/wake					
Great Britain	17/20	16/16	4/4	31/3	111
France	14/21	13/11	31/24	7/21	142
Italy	16/17	7/26	11/19	43/32	171
Spain	6/44	13/48	0/26	18/39	194
United States	21/44	12/34	7/15	45/24	202
Labor					
Great Britain	13/0		22/2		37
France	0/3		48/16		67
Italy	31/4		6/1		42
Spain	10/9		2/13		34
United States	4/7		1/4		16

Table 2. Breakdown of statistically significant deviations in ΔK_w after a Welch's *t*-test of unequal variance was performed. Significance is taken at the standard level $\alpha = 5\%$. Every group of respondents splits occurrences in morning/afternoon (am/pm) indexes. The remaining indexes up to a total of 72/72 sustained the null hypothesis H_0: $R_s(i) - R_w(i) = 0$. The right-most column list the whole number of excursions $p < \alpha$, from a total of $4N_0 = 576$ (sleep/wake) and $2N_0 = 288$ (labor) analysis. In Spain am/pm divide was set at 1 pm local time, see time offset in Table 1.

stochastic variable: first three columns display time marks, last two columns durations; along a row panels display the results of one time use survey. On every panel the horizontal axis displays the variable —either a local time or an elapsed time— and the vertical axis displays the Kolmogorov-Smirnov distance, see Eq. (S8).

As in Fig. 2 blueish lines refer to week-day groups; greenish lines to week-end groups; darker lines refer to employees; lighter lines to non-employees. Finally, boxes locate the first, median and third quartile of the distributions; and for time-marks —three right most columns— the panel also displays solar ephemerides: sunrise, sunset and noon in winter and summer (vertical dotted lines).

Unlike in Fig. 2, the direction of deviations in Figs. 3 and 4 is easy to address: positive excursions ($P_s > P_w$) indicate that the summer distribution advances relative to the winter distribution: earlier times for time-marks, shorter durations for elapsed times. Negative excursions ($P_s < P_w$) indicate the opposite. One single peak usually indicates a shift in the mean of the distributions.

The darker gray band highlights the region where the null hypothesis H_0: $P_s - P_w = 0$ would sustain at the standard level of significance if the distribution were continuous, which was never the case here. The lighter gray strip highlight the region where $10^{-7} < p < \alpha$ still in the continuous case.

Table 3 lists the occurrences of the four possible outcomes of the one-tailed permutation test: $P_s = P_w$, $P_s \neq P_w$, $P_s > P_w$ and $P_s < P_w$. A score is obtained after assigning $+1$ to $P_s > P_w$, -1 to $P_s < P_w$ and 0 otherwise. As Supplementary material Table S.1 (sleep/wake) and Table S.2 (labor) list the results of the permutation test for every of the 100 (sleep/wake) and 50 (labor) analyses.

The occurrence of outcomes for the test on the average values $E_s - E_w$ is not different from results in Table 3 save for the fact that inequalities are shifted: $P_s > P_w$ leads to $E_s < E_w$ and conversely. As Supplementary material Table S.3 (sleep/wake cycle) and Table S.4 (labor cycle) lists the results for every of the analyses. Probability differences $P_s(i) - P_w(i)$ —vertical differences in Fig. S.5— can be transposed into quantile or "horizontal" differences. As Supplementary material and for the sake of completeness Table S.5 (sleep/wake) and Table S.6 (labor) list quartile differences.

Discussion

Figure 2 highlights the stability of the labor cycle in week-days —column 2— and week-ends —column 4—. Seasonal deviations seldom climb up to 2 and the null hypothesis H_0: $R_s(i) - R_w(i) = 0$ is seldom rejected at the standard level of significance, see Table 2. Labor cycle in a week-end (group 3) is slightly more prone to seasonal alterations, although it must be taken into account that week-end labor cycle differs significantly from week-day labor cycle, see Fig. S.3 and that sample sizes are smaller in group 3 by a factor ranging from 2 to 8, see Table 1.

In the same way Fig. 4 displays modest seasonal deviations in variables related to the labor cycle, which do not break the null hypothesis H_0: $P_s - P_w = 0$ (see Table 3) at the standard level of significance as deduced from a permutation test of size $M = 10^7$. Also it is seldom the case that the null hypothesis H_0: $E_s - E_w = 0$ (see Table S.4) is rejected. Therefore labor cycle is equally distributed through seasons in environments under DST regulations.

The stability of the labor cycle is probably the main silent goal and the main outcome of summer time regulations. Indeed time regulations have always been aimed towards social life, of which working hours is one of its most significant examples.

It is a question to understand the seasonal deviations in the labor cycle of countries with the same degree of social development, latitude and not exposed to seasonal clock changing. The obvious choices would be

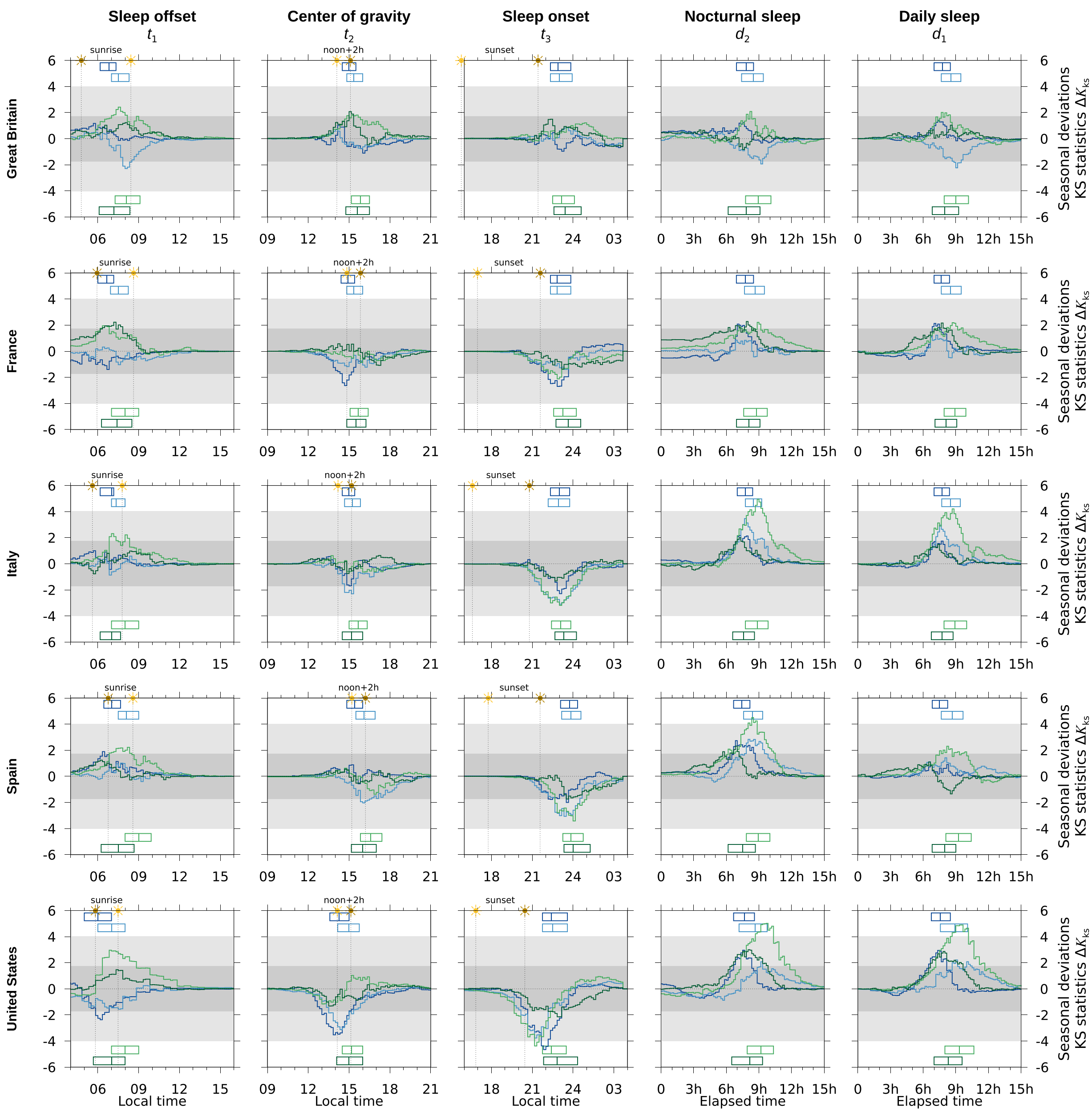

Figure 3. Normalized seasonal deviations $\Delta K_{ks} = \sqrt{N_h} \cdot (P_s - P_w)$ for the stochastic variables related to the sleep/wake cycle. Along a row a time use survey is shown, along a column one variable is shown. Blueish lines show week-day respondents. Greenish lines show week-end respondents. Darker lines show employees; lighter lines, non-employees. Boxes locate first, second and third quartiles of the distributions. For sided tests on continuous samples, which is never the case here, the darker horizontal gray band highlights the region where $p < \alpha$; the lighter band, the region $10^{-7} < p < \alpha$; and for $\Delta K_{ks} = 6$ the p-value equals $10^{-15.7}$. In the left most three columns vertical dotted lines locate solar ephemerides —sunrise, noon, sunset— in winter and summer. Darkest sun applies to summer.

the Republic of Korea and Japan. Irrespective of that the softest conclusion of the preceding results is that the labor cycle tolerates a seasonal shift of its phase equal to one hour in the direction prescribed by the regulations (advance in spring, delay in autumn). It is out of the scope of this manuscript to correlate this practice with economic outcomes like the Gross Domestic Product.

On its way the sleep/wake cycle is more significantly altered and it does so in different ways. Figure 2 —columns 1 and 3— suffices to understand this idea: ΔK_w climbs up to 4 or 6, sometime towards the positive side, sometime towards the negative side, and excursions $p(i) < \alpha$ are more frequent, see Table 2. It is also worthy to mention that excursions weigh on the afternoon, which makes sense taking into account the direction of DST regulations, which pushes for stabilizing morning times only. Finally Table 3 lists occurrences of stochastic dominance in the sleep/wake cycle and in the labor cycle, and provides a score: differences among both cycles are self evident, with the sleep/wake cycle heavily exhibiting stochastic dominance and labor cycle reluctant to that.

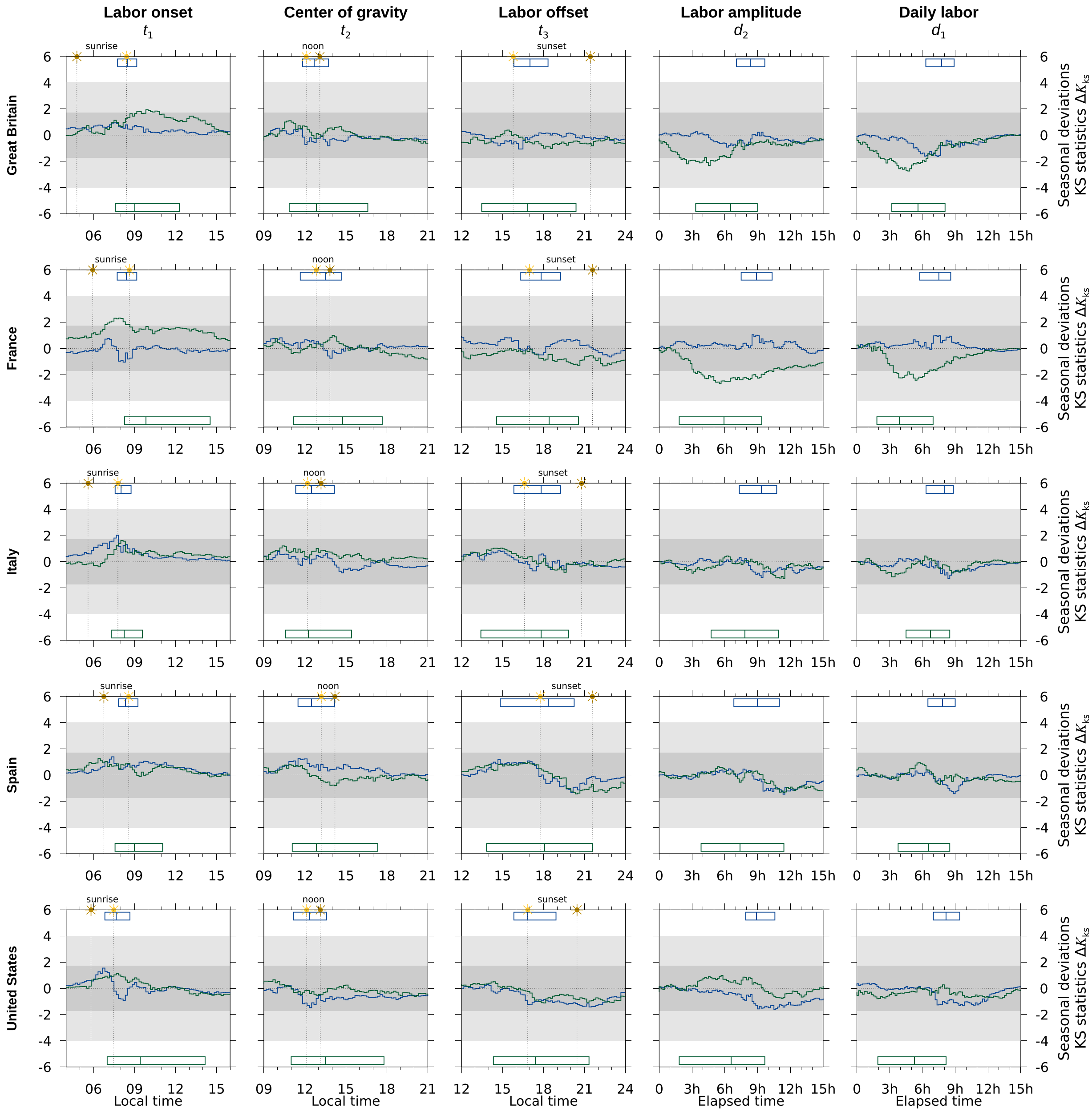

Figure 4. Same as Fig. 3 but for the stochastic variables related to the labor cycle.

Virtually every sleep/wake cycle in Fig. 2 is signaling a large excursion by the time of summer sunset, when the permanent night begins. Since, by then, the daily rhythm is decreasing as more people is coming to bed, and the excursion goes towards the positive side, a delay in R_s is observed or R_s fades out later as a result of later sunsets.

In the morning, smaller but still positive excursions are observed in some groups, notably in the week-end. They occur in the range when light and dark seasonally alternate. Since, by then, the daily rhythm is uprising, as more people is getting up, the positive excursion is now signaling an advance in R_s, which soars earlier.

Figure 3 shows these results in the form of probability distributions. Here sleep onset has generally a negative excursion, which leads to stochastic dominance $P_s < P_w$ or P_s delays, while sleep offset display the opposite dominance $P_s > P_w$, or P_s advances. Table 3 provides a summary for this observation: sleep offset gets a positive (advanced) score; sleep onset, a negative negative (delayed) score.

As for durations are concerned, sleep time and nocturnal sleep (onset to offset time) more than often decreases as a result of relatively delayed sleep onset and slightly advanced sleep offset. Both elapsed times get positive (decrease) scores in Table 3. Likewise the center of gravity tends to delay only in a few cases.

No matter how statistically significant any of these deviations can be, they have little significance in average values as seen in Table S.3: $E_s - E_w$ lie in the range of few minutes, much smaller than the size of clock changing and the spread of sunrise time and sunset time. In the same way, quartile differences are most frequently equal or less than one time slot or ten minutes, see Table S.5.

	Group 1					Group 2					Group 3					Group 4									
	Mon-Fri employees					Mon-Fri non-employees					Sat-Sun non-employees					Sat-Sun employees					All Groups				
	$P_s \leftrightarrow P_w$				Score	$P_s \leftrightarrow P_w$				Score	$P_s \leftrightarrow P_w$				Score	$P_s \leftrightarrow P_w$				Score	$P_s \leftrightarrow P_w$				Score
Counts	$<$	$=$	$\neq$	$>$		$<$	$=$	$\neq$	$>$		$<$	$=$	$\neq$	$>$		$<$	$=$	$\neq$	$>$		$<$	$=$	$\neq$	$>$	
Sleep offset	2	2	0	1	−0.2	1	2	1	1	0.0	0	3	0	2	+0.4	0	0	0	5	+1.0	3	7	1	9	+0.3
Center of gravity	3	2	0	0	−0.6	3	2	0	0	−0.6	0	4	0	1	+0.2	0	4	0	1	+0.2	6	12	0	2	−0.2
Sleep onset	4	1	0	0	−0.8	4	1	0	0	−0.8	2	3	0	0	−0.4	4	1	0	0	−0.5	14	6	0	0	−0.7
Onset to offset	0	1	0	4	+0.8	1	0	1	3	+0.4	0	1	0	4	+0.8	0	0	0	5	+1.0	1	2	1	16	+0.8
Sleep time	0	2	0	3	+0.6	1	2	0	2	+0.2	0	3	0	2	+0.4	0	0	0	5	+1.0	1	7	0	12	+0.6
All combined	9	8	0	8	0.0	10	7	2	6	−0.2	2	14	0	9	+0.3	4	5	0	16	+0.5	25	34	2	39	+0.1
Labor onset	0	4	0	1	+0.2						0	3	0	2	+0.4						0	7	0	3	+0.3
Center of gravity	0	5	0	0	0.0						0	5	0	0	0.0						0	10	0	0	0.0
Labor offset	0	5	0	0	0.0						0	5	0	0	0.0						0	10	0	0	0.0
Onset to offset	0	5	0	0	0.0						2	3	0	0	−0.4						2	8	0	0	−0.2
Labor time	0	5	0	0	0.0						2	3	0	0	−0.4						2	8	0	0	−0.2
All combined	0	24	0	1	0.0						4	19	0	2	−0.1						4	43	0	3	0.0
Survey	**Sleep/Wake**										**Labor**														
	$<$	$=$	$\neq$	$>$	**Score**						$<$	$=$	$\neq$	$>$	**Score**										
Great Britain	3	12	0	5	+0.1						2	7	0	1	−0.1										
France	5	5	2	8	+0.1						2	7	0	1	−0.1										
Italy	5	7	0	8	+0.1						0	9	0	1	+0.1										
Spain	5	6	0	9	+0.2						0	10	0	0	0.0										
United States	7	4	0	9	+0.1						0	10	0	0	0.0										
All combined	25	34	2	39	+0.1						4	43	0	3	0.0										

Table 3. Occurrences of hypotheses $P_s > P_w$, $P_s \neq P_w$, $P_s = P_w$ and $P_s < P_w$ after a permutation test of size $M = 10^7$ in the seasonal indexes was performed. Detailed results are shown as Supplementary material in Tables S.1 and S.2. The score is obtained after assigning +1, 0, 0, −1 to each outcome and scaling by the whole number of tests.

Notwithstanding all this the fact that sleep offset and sleep onset seasonal deviations are opposite must be further discussed in relation to the impact of DST. If sleep onset and sleep offset had got the same type of stochastic dominance —be that an advance or a delay— then it could be argued that the size of the seasonal change is too small —if both tended to advanced, amplifying the advance of clock time— or too large —if both tended to delay, fighting against the advance of clock time. Either way societies would be expressing a global preference for pushing or pulling the sleep/wake cycle. With stochastic dominance leaning in opposite directions such a preference can not be identified and DST can not be easily challenged. Indeed they are showing that sunrise and sunset still impact human behaviour, even after having altered clocks, and that the sleep/wake cycle is not misaligned by the regulations.

Since DST advances clocks only in spring, delays them only in autumn, thus pushing for stabilizing sunrise times as measured local time, morning results must be further discussed. As for the labor cycle is concerned the point to note is that DST does not prevent employers and employees from delaying their timing after the spring transition or from advancing their timing after the autumn transition. However results show that this is seldom the case. Also it is seldom the case that they need a further advance in spring, or a further delay in winter. In view of that all, data show seasonal regulations of time operate timely, easing the preference for earlier times in summer and the preference for later times in winter. It also does so with a high degree of coordination.

As for the sleep/wake cycle is concerned the group most prone to free preferences —non-employees in a week-end, group 4— exhibits the largest shift of sleep offset in summer with $P_s > P_w$ in the five surveys (see Tables 3 and S.1 in Supplementary Material). Historically winter time and winter activity is taken as the normal, since transitions were first set on spring. Upon this view, results suggest that virtually no respondent in the surveys wants to delay summer morning duties, whereas a number of people pushes for an advance in summer, even though local time was already advanced by time regulations. This is compatible with the spontaneous preference for permanent summer time in polls[30], since the primary outcome of winter permanent time would be a delay in summer human activity if nothing else changes.

With only five surveys, the impact of latitude in seasonal behavior can only be sketched with some caution. The most apparent result is reported in Table 2: the occurrence of significant deviations ($p(i) < \alpha$) in the sleep/wake cycle increases with decreasing latitude. In Figs. 2 and 3 this is noted by the stability of sleep/wake cycles in Great Britain or France compared to those elsewhere, even though the spread of sunrise and sunset times is larger the higher the latitude. These results are in accordance with the impact of latitude in periods of low calling activity in mobile phone data of a large number ($N \sim 10^6$) of individuals for short range of latitudes[18] ($\phi = \{37°, 40°, 42.5°\}$, see Fig. 2 in the Reference). There the lowest latitude showed the strongest seasonal variations in the periods.

The rationale is that human activity is less able to track large spreads of sunrise and sunset times. Therefore, even if the clock is regulated seasonally, societies at lower latitudes societies are willing to finely tune the sleep/wake cycle and solar activity, whereas at higher latitude they could be finding cues of synchronization by clock time only. As an example, a great deal of excursions $p(i) < \alpha$ in Spain and Italy come in the afternoon (see Fig. 2) as a result of the seasonal changes in *siesta*, a short take of sleep in the afternoon. *Siesta* is a transfer of sleep time from morning to afternoon, much preferred in summer due to the high noon insolation, see Table 1. It could be argued *siesta* is favored by DST since it brings sleep offset closer to summer sunrise. But with the word "siesta" meaning "six" —the ancient hour for noon— a more sensitive description is that DST plus year round timing is the modern way in which this ancient seasonal behavior is achieved. A dip in human activity around noon is also found in the Tropics[31–33], where insolation is similar.

In the same sense, an without overemphasizing the importance of historical records, a few of them put forward differences in latitude. For instance Willet's pamphlet[34] (1907) advocating for DST shows British human activity delayed in summer by 1907 perhaps after it got synced to clock time. On the contrary Cádiz Cortes, Spanish first National Assembly, opening and closing times shows in 1810 a seasonal regulation[1] —10 am to 2 pm from October to April, but 9 am to 1 pm from May to September—, in every leg equivalent to modern DST, from which it is one hundred years ahead. Even Benjamin Franklin observations[35,36] after moving (1784) from Pennsylvania ($\phi = 40°$) to Paris ($\phi = 49°$) may be showing the shocking changes of human behavior due to latitude.

Much more recently in 2015 Chile, which spread from $\phi \sim 20°$ to $\phi \sim 55°$, tried to discontinue DST, switching to permanent summer time. The new layout was socially abhorred and only lasted for one winter. However, since 2017, the Magallanes Province ($\phi \sim 53°$) sustains permanent summer time.

We are now in a position to address the relevant issue to which DST regulation is related: when should human activity start in view of the seasonal spread of sunrise and sunset times? To answer this question the clocks with 24-H analog dial shown in Fig. 1 come handy. As for human activity is concerned data extracted from time use surveys and reported in ref. [19]. —see Fig. 2 in this reference— will help to sketch real scenarios.

Sunrise has always been a lodestar for the start of human activity, even after the advent of efficient artificial light. Our physiology makes us prone to be activated by natural light and abhor getting activated too early in the morning darkness[37]. In the Tropics sunrise and sunset times are pretty stable and insolation is high —see the left most panel in Fig. 1, which displays the case for $\phi = 15°$—. Human activity in pre-industrial societies starts by the sunrise —around 6 am— despite photoperiod is twelve hours, as a way of preventing noon insolation.

As latitude increases winter sunrise w, which marks the starting point of permanent daytime, increasingly lags. At $\phi = 40°$ it delays more than one hour with respect to the normal 6 am. Winter sunset Y —the end of permanent daytime— comes 9.5 h later so that a great deal of human activity can be developed in daytime, irrespective of season. Not surprisingly w is the choice for human start of activity in United States and Spain. A paradigm runs as follows: school children can come to school after sunrise and can go before sunset year round.

In summer, the starting point w would delay some 3 from sunrise —now occurring at x—. Human activity finds relief in advancing activity, pushing towards the normal 6 am and keeping sunrise as a lodestar. This is met in modern times by DST regulations, which bring the start point to w1 in summer if nothing else changes. A clear, ancient outcome for this shift is linked to latitude: it prevents exposition to noon insolation and overheating. The paradigm would be: there is no need to subject school children to arrive to school some three hours after sunrise if insolation efficiency is going to climb up to 96%. A modern outcome is the trade of morning daytime leisure for afternoon daytime leisure. However this outcome is only related to the direction of the regulation and it is found elsewhere, irrespective of latitude.

In this scenario permanent summer time policy pushes to make w1 the starting point of activity year round. This is not always welcome at $\phi = 40°$ since there is no need to transfer human activity into dawn in winter —or there is no need to subject school children to morning darkness if daytime lasts for more than 9.5 h—. Indeed permanent summer time failed in United States and Portugal (1970s), and recently in Chile. To some extend it also failed in Spain, where permanent summer time in 1945 was met with a delay in social timing which brought the normal starting point back to w.

The seasonal arrangement w↔w1 is also found at $\phi = 52°$ in Great Britain and Ireland, despite w delays and y advances so that human activity increasingly occurs in the darkness —now, school children start being subjected to darkness, either at dawn or at dusk—. Some individuals may find relief in trading activity at dusk for activity at dawn. One way of so doing is a permanent summer time setting which advocates making w1 the normal. That was the case in Saskatchewan (Canada, 1960) and Magallanes Province(Chile, 2017). It is a bet for non-seasonal behavior, without biannual transitions. It must be noted though that this choice failed in Great Britain and Ireland in the 1970s, due to morning darkness.

Nevertheless w1 can become the normal starting point of activity just by advancing social timing, finding relief in earlier end times. That is the case in Germany and Poland. Still then, it is possible that DST regulations apply in summer. That would bring the start point in summer to w2. Long after the seasonal regulation of clocks occurred people may push for discontinuing DST. A permanent summer time would now make w2 the normal starting point. This is two hours before winter sunrise and it may come too early so that the choice may not sustain for a long time. As an example Russia switched to permanent summer time in 2011 and to permanent winter time in 2014.

At $\phi = 60°$ latitude the spread of sunrise time is even larger. Winter sunrise (w) delays so much that it can hardly be the normal for the start of activity. Indeed Finland, Norway and Lithuania find start times close to point w2, some two hours before winter sunrise, struggling to meet the normal 6 am and to find end times closer to a much advanced winter sunset Y. DST regulations still advances human activity in summer and brings the starting point to w3. Finally, a push for permanent summer time in this scenario could also bring the start of the activity in winter too much advanced relative to winter sunrise, even for the standards at $\phi = 60°$.

Irrespective of latitude once human activity gets advanced *in winter* relative to sunrise, summer sunset time puts pressure against seasonal clock changing: as the start of human activity shifts from w to w1, to w2 and to w3, it comes close to the normal 6 am but also to summer sunset (point z, on the other side of the clock), which separates slightly more than twelve hours from w, irrespective of latitude. Indeed, with the start of activity at w3 as in $\phi = 60°$, summer sunset z is only some nine hours earlier. That struggles against human preference for going to bed in darkness. However this setting shows good similarity with previous records from the Age of Enlightenment[38,39] at $\phi = 60°$.

Figure 1 and the preceding discussion sketch the intriguing way by which historically artificial light has impacted human activity at dawn, after having easily impacted human activity at night. The current wave of DST discussion is just showing that a preference for a non-seasonal behavior may be becoming increasingly popular, specifically at high enough latitude, where sunrise ceases to be a lodestar and noon insolation is less intense. Helped by artificial light the starting point of activity can be appropriately set ahead of winter sunrise; thereafter people would just witness the formidable changes in ambient light conditions that happen from winter to summer. The shocking paradox is that both societies in the Tropics and societies at high latitudes could be more willing to share a preference for non-seasonal behavior, albeit for opposite reasons: too little and too large solar seasonal variations.

Conclusion

DST turned out to be the way by which seasonal variability was introduced into non-seasonal mechanical clocks, thus pushing for —but not forcing to— a seasonal behavior in urban, industrialized societies. After decades of practice, it has successfully addressed a three-fold problem: the seasonal variations in the light and dark cycle, the inability of mechanical clocks to track this variability and the appetence for a regular way of life.

In so doing DST has promoted a highly coordinated seasonal adaptation that has matched to its layout: one-hour advance of human activity in summer relative to the winter activity. This is noted in time use surveys by the equal distribution of the labor cycle through seasons as measured local time. The sleep/wake cycle is more prone to seasonal deviations, specially at lower latitudes. Nonetheless these deviations are still linked to solar activity —the advance of sunrise and the delay of sunset, and the changes in the efficiency of the insolation at noon— which reveals that human activity is not misaligned by DST regulations.

Latitude weighs the scores of people pushing for non-seasonal behaviour. A soft divide can be guessed around a latitude equal to $2\varepsilon = 47°$ where the seasonal spread of sunrise/sunset time is a bit smaller than 4h and the efficiency of the insolation at noon ($\cos\theta_s = 92\%$) meets with the value at the Equator. Time use surveys reveal more frequent seasonal deviation below this line, which indicate a coupling with solar activity and a preference for seasonal regulation. Above the line, data reports less frequent seasonal deviations, which suggests a decoupling between social and solar activity and, ultimately, a cue that seasonal regulation of time could be more easily abandoned as latitude increases.

In view of all that the European Commission should be open to consider thoroughly the impact of latitude in summertime arrangements.

Permissions to carry out fieldwork. Time Use Surveys are official surveys carried out by public Institutions. In US it is the Bureau of Labor Statistics and the United States Census Bureau. In UK it is the Office of National Statistics. They are a key tool for sociologists and economists to understand how we share time in a standard day. Any of them is a traceable, well-identified set of data.

Spanish and American Time Use Survey microdata were freely available in the internet at the time of writing this manuscript. A link to these surveys is provided in their corresponding references.

French, British, and Italian Time Use Survey microdata were obtained after a formal request was addressed to the institutions. The microdata were then sent to the author by email, a hard-copy or as a downloadable link. In 2015, these institutions definitely were happy to send their microdata to any researcher who may need them.

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Competing interests
The authors declare no competing interests.

Additional information

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